



**ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE
DEPARTEMENT OF GEOMATICS ENGINEERING**

**VIRTUAL 3D MULTILAYER CADASTRE WITH PARTICULAR EMPHASIS ON
CONDOMINIUM BY INTEGRATING GEOSPATIAL TOOLS:A CASE OF
MEKELLE CITY, ETHIOPIA**

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Architecture in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Geodesy and Geomatics
Engineering

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Adama,Ethiopia

DECLARATION

I hereby declare that the thesis entitled “**Virtual 3D Multilayer Cadastre with Particular Emphasis on Condominium by Integrating Geospatial Tools:A Case of Mekelle City, Ethiopia**” has been carried out by me under the supervision of As. Mohammed Abdul Athick and , Dr. Hussen Raja Naqvi, Department of Geomatic Engineering , Adama Science and Technology University during the year 2014-2016 as a part of Master of Science program in Geodesy and Geomatics Engineering. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

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CERTIFICATION

This is certified that the thesis entitled “**Virtual 3D Multilayer Cadastre with Particular Emphasis on Condominium by Integrating Geospatial Tools:A Case of Mekelle City, Ethiopia**” is bonafied work carried out by **Weldemariam Weldeabyezgi** under our guidance and supervision. This is the actual work done by **Weldemariam Weldeabyezgi** for the partial fulfillment of the award of the Degree of Master of Science in Geodesy and Geomatics Engineering, Adama Science and Technology University, Adama.

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ABSTRACT

3D property registration has become a vital need in order to optimally reflect all complex cases of the multilayer reality of property rights and restrictions, revealing their vertical component. This paper refers to the potentials and multiple applications of 3D cadastral systems and ability to address ownership rights where limited to the third dimension by identifying the 3D object with necessary information of specific houses from Interlocked and overlapped condominium building located at Mekelle city.

The Arc GIS software has been used for Preparing and processing the pre-Model activities of 3D cadastral data. In order to register and visualize the complex reality in 3D, Esri's City Engine a code based modeling software has been used, which specializes in Computer Generated Architecture (CGA) of 3D urban environments, transforming 2D GIS Data (building footprint) into smart 3D city models have same geographic coordinates but differentiated with respect to surface of the earth. The application and potential of 3D model has been tested by selecting three condominium design types in Mekelle city in which a complex ownership status is established along with approved legal document from Mekelle housing development agency. The 3D model was built using the parameters of spatial object, orientation, attribute, textures and elevation based on input data, derived from Aerial Photographs, cadastral and questionnaire datasets, as well as legal documents and architectural plans. The process resulted in a final 3D model and capable of easy to store, update, search, insert, share, maintain and visualize a single intended 3D property unit by hiding other 3D elements (property units) within the building.

Key Words: 3D Model, Condominiums Building in Mekelle city, 3D Cadastre, 2D Cadastre, Multilayer Cadastre

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BREVIATIONS

CAD – Computer Aided Design

CCDM–Core Cadastral Domain Model

CE – CityEngine

CGA – Computer Generated Architecture

CIS–Cadastral Information System

CSA–Central Statistics Agency

CSV– Comma Separated Values

DXF – Drawing Interchange File Format

EC – Ethiopian Calendar

EMA – Ethiopian Mapping Agency

ERDAS– Earth Resources Data Analysis System

ESRI –Environmental System Research Institute

FIG- Internatinal Federation of Surveyor

GIS – Geographic Information Systems

GDBMS–Geodatabase managment system

GTZ – German Technical Support

ID–Identification

JPEG –Joint Photographic Experts Group (a method used of lossy compression for digital images)

LADM – Land Adminstration Domain Model

NSDI – National Spatial Data Infrastructure

RRR– Right, Ristriction and Responsibility

SHP file – Shape file

SDI/ SII –Spatial Data Infrastructure/ Spatial Information Infrastructure

TIFF –Tagged Image File Format (a computer file format for storing raster graphics images)

UDSS – Urban Development Support Service

UTM–Universal Transverse Mercator

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Contemporary urban environments are distinguished by their structural complexity and the multiple use of space in which a range of different RRRs (Rights, Restrictions and Responsibilities) intersect with the corresponding land parcels. This range of land rights, restrictions and responsibilities requires proper 3D registrations complying with each legal structure, as well as systematic encoding and modeling, fully exploiting technical capabilities of 3D representations (E. Tsiliakou, 27 – 29 November 2013). Cadastre is an official record both in urban and rural land property usually maintained to register location, ownership, land value and attributes of land in a given jurisdiction, state or country (Bekele B. and Amezene R., 2015). 3D cadastral registration system defines with the same longitude and latitude but different owners, titles, size and found at different elevations piled in one parcel area. The formal definition a 3D parcel is defined as the spatial unit against which (one or more) unique and homogeneous rights (e.g. ownership right or land use right), responsibilities or restrictions are associated, as included in a Land Administration system (Peter van oosterom et al, 2011).

In developing countries the application of urban cadaster is very difficult due to the tendency of city (town) official to use land (parcel) for their benefits illegally and lack of awareness of cadaster, improper plan of city or towns, lack of technical manpower, financial and etc. (Bekele Bedada and Amezene Reda, 2015). Ethiopia is one of the developing countries which are being challenged with above state problems. Some works has been started by introducing the 2D boundary parcel registration and it is expected to solve the problem partially in 2D case when it is completed the 2D registration system in Mekelle city and other selected towns (cities).

A properly organized and regularly maintained land registration/cadastral system provide security and clarity with respect to the legal status of land and value of parcel. This security and clarity of property ensured by introducing legal and fiscal cadaster. Legal cadaster is a register identifying the legal owner and precise boundaries of each land parcel. Whereas, Fiscal cadaster is a record of information necessary for levying property taxes, which includes location and frequently, the occupant of the parcel is identified for tax purpose, and no effort is made to determine the legal owner. This eventually leads to the improvement of property, which at the same time contributes to the growth and economic development of the city concerned.

Moreover, well-functioning Cadaster/land information system is useful for effective management of land as well as setting appropriate land related policies, coordination efforts of different agencies, generally for better urban management and development (Daniel Tadesse, 2013).

Digital cadaster and Mekelle city integrated urban land information system (legal cadaster) and properties evaluation and taxation project office (physical cadaster) are projects still underway by Mekelle city. Cadastral registration system in Ethiopia is carried out in accordance with Cadastral Law no. 818/2006. According to this law Mekelle city established two project offices, Mekelle city integrated urban land information system (legal cadaster) and properties evaluation and taxation project office (physical cadaster). The two project offices are carried out research to develop legal and physical cadastral system. Legal and physical cadaster are not yet implemented. Therefore, getting reliable results was not possible. The compatibility of the created database for 2d cadaster for Mekelle city has not been tested yet against the real situation on the ground. Moreover, the contribution of the new cadaster system to the NSDI has not been assessed.

Currently, Mekelle city integrated urban land information system (legal cadaster) is in a preparation of legal documents and proclamation, technical sample 2D cadaster. For the technical 2D cadaster, they are preparing a unique ID according to the Ethiopian standard law No of 05/2007 clause 6. The law states that unique code will be assigned for each region, town (town code) and kebele (kebele code), wereda, sub city, site and building code. Then after, they ensured the ownership rights and any other related rights, there will be prepare the physical cadaster (properties evaluation and taxation project office) in reference to the legal cadaster. In the current cadastral system, buildings are shown on cadastral maps according to the area they occupy on the ground but property units of the buildings and their independent sections cannot be registered on cadaster in this case. The 3D cadaster registration of condominium buildings based on the cadastral system requires land process and to be register with reference to the name of the site, area of the site, number of building within the site, block ID number (building number), house number within the building, floor number of the house and area of the house.

Population is significantly increasing in Ethiopia which results in huge number of land allocating for housing and development activities. To secure this, the government of federal democratic republic of Ethiopia design to develop town vertically as much as the capacity of the city permitted. Due to this policy, condominium houses or buildings are constructing throughout the

towns of the country including the capital city of Addis Ababa. Most condominium houses in Ethiopia are still face with a number of challenges that include inadequate official property records with necessary technological supports. The challenge is how to register overlapping and interlocking constructions and how to register the property situations above and below the surface in cadastral registration as that registered information on 2D parcels (STOTER Jantine et. al., 2004). Lack of instrumental technology in land delivery leads to increases case of corruption, bribery and favoritism by the town and city officials (Bekele B. and Amezene R, 2015).

This research shows the 3D cadastral system is the best solution to overcome the challenges of registration and updating of the interlocking and overlapping property units using Geo- ICT technology especially for Ethiopia condominium property management with study area of Mekelle city, Ethiopia.

1.2 Statement of the Problem

Land is the platform for all economic, political and social activities of mankind. Therefore, knowing the land entirety is very important. In order to study the natural resource and the conditions of these resources, proper surveying and preparation of maps is needed. Whereas, Cadastral system and land registration without cadastral surveying and cadastral mapping will be incomplete. A cadaster and cadastral map unless otherwise constantly updated loses its validity (daniel tadesse, 2013).

The Ethiopian condominium houses are constructed by the budget of the federal government and peoples (users) are expected to deposit money in the commercial bank of Ethiopia side by side which its amount is specified by legislation of housing development agencies office of Ethiopia. These constructed houses will be transferred to whom they deposit money through agreement with commercial bank of Ethiopia for the payment of condominium houses in principle.

When the houses are completed, it would be intended to transfer to the people who deposit money according the agreement with the commercial bank of Ethiopian. However, due to lack of transparency and checking mechanisms using suitable technology (proper registration system), it is suitable to transfer the houses informally to their benefit, relatives, friends and etc. There is missing rooms during transfer because of lack of systematic methodological and technological support.

For example, according to Addis Ababa housing development agency census of each condominium houses from 2-28 March, 2016, it is found, 3231 houses were illegally transferred. Moreover, 127 houses were rented by neighbors (nearby people) and 94 houses were closed i.e. missed to be transferred (Fana Broadcasting, 2016). The same trend for Mekelle city and any other cities which have condominium houses requires a clearly designed and protective technological mechanism that can register for their 3D properties. Although its surface boundary will be intended to delineate in 2D cadaster where the condominium building is situated with the digitally attached of its 3D property units, still the Ethiopian condominium houses are not supported with the true visualization of the registered 3D property units. Whereas only by means of a cadastral system in which ownership rights are accurately designed and guaranteed can prosperity be achieved (I. E. Ayazli, 2008). In case of a building is divided in several apartments, and they belong to different owners adding 3D dimension is necessary (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

The main current problem of the designed urban cadastre in Ethiopia specifically in Mekelle city does not include the 3D registration system of the components of the condominium building and real estate. Even though, no country has developed a spatial and substantial 3D cadastral model, some have resolved key issues concerning 3D registration or representation of 3D cases even in a 2D manner (E. Tsiliakou, 27 – 29 November 2013). So this research targets at establishing up-to-date 3D land and property registration system and digital urban cadastral maps for the condominium houses in Mekelle city to resolve the key issues of condominium houses in the Municipality of Mekelle city. According to (Peter van Oosterom et al, May 2011), the key issues that can be addressed by 3D registration are 3D parcels for infrastructure objects, such as long tunnels, pipelines, and cables and for simple apartments/ condominium buildings with possible related (Subsurface) facilities such as storage or parking. In this research, simple apartments/ condominium buildings are addressed.

1.3 Research Questions

The following research questions are addressed in these research activities.

- How 3D elements (property units) are registered and 3D maps are prepared?
- What are the needs of 3D cadastral system for current Mekelle city?
- How to model the 3D cadastral system that reliably registers the 3D objects?
- How to design, implement and manage the 3D condominium apartment units in the Registration System for querying and editing information, guarantee of ownership and other information for better land and property management system?
- As well as what are contents needs for the 3D urban cadastral system that it will be retrieve, update and link the cadastral information?

1.4 Objective of the Study

1.4.1 General Objectives

The main objective of this study is to develop 3D multilayer CIS by incorporating tabular, spatial and textural data using geospatial tools specification.

1.4.2 Specific Objectives

This study has the following specific objectives:

- To develop a registration system for a 3D objects specifically for buildings.
- To register the parcel of land and its property (3D object) in one database system that representing both spatial and attribute information for better retrieve and storage.
- To model the 3D cadastral maps of the specific house with in the condominium building.
- To prepare a framework of transferring accurately the selected condominium house to the user.

1.5 Significance of the Study

The purpose of this study is used to ensure the guarantee of ownership and security of tenure with in the interlocked and overlapped condominium buildings by integrating the necessary data sets for 3D visualization of each house within the building and its attributes using geospatial tools.

The second purpose is to develop 3D cadaster for proper management and monitor the rooms of condominium houses with the entitled owners which is very important for managers, town planners, owners and government.

1.6 Scope of the Study

This study is focus on to link the ownership, the object to be owned and the extent of the right of the owner by integrating database, city engine and arc GIS for 3D modeling of condominium buildings limited to legal and physical cadaster at Mekelle city.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Overview

There are two models of cadaster to properly manage the land and its property which are called 2D and 3D cadastre. The 2D cadaster registration can apply to the land and its property which has one to one relationship with the owner. The 3D cadastral registration can apply to register one land and many overlapped property owned by different owners. Therefore different countries has been working and set different conferences to share their knowledge and experience about land administration system supporting 3D representation.

In April 2013 Cadaster participated in the World Bank Land and Poverty Conference. During this annual conference world leaders and experts from around the world came together to discuss land administration and its importance in combating poverty. In 2013 Cadaster organized study visits for foreign delegations in order to share knowledge and to offer an opportunity to become acquainted with Cadaster. We welcomed delegations from **Ethiopia**, Bhutan, Cape Verde, Romania and Bangladesh.



Figure 2.1 The Involvement of Ethiopia in the International Cadastre

A decade ago there was no country in the world having an operational Cadaster including the Legislation, 3D survey plans/ mutation plans, 3D Cadastral database, and 3D dissemination. Due to limitation of technological (the spatial DBMS did not yet support 3D volumetric Primitives), legal, organizational and technical i.e. no operational 3D Cadastral system Implementations available. Now, after a decade of more experience with real-world (3D) developments in Israel, other countries also progressing, and an accepted international ISO 19152 standards for Land Administration supporting 3D representations, it is time to realize the 3D Cadaster in Israel. In Israel 3D cadastral system has been applied because the country is relatively small and it has a rapid growing population, the demand on the available land or space is becoming high .So it requires a proper management of land to satisfy the land inadequacy by adapting the available technology which supports 3D cadaster as Proven in some other countries; e.g. China a (Yaron Felus, November 2014)

The development of this LADM country profile is a joint activity involving the Israeli key players: That is, besides the Survey of Israel, also the Land Registry (especially when also considering to register apartments, condominiums in 3D), Israel Land Authority (93% of the land in Israel is in the public domain, and ILA is responsible for managing this land), and the licensed surveyors (creating the new 2D and 3D parcel representations) (Yaron Felus, November 2014).

The four scoping questions rose by the FIG Working group 3D Cadasters have now been answered and indicate where, when, and how to apply 3D Cadaster in Israel:

1. What are the types of 3D cadastral objects? Are these related to (future) constructions (Buildings, pipelines, tunnels, etc.) Or can these be any part of the 3D space, both airspace or subsurface?

Answer: Both a. related to (future) constructions (buildings, pipelines, tunnels, etc.), and

b. any part of 3D space (airspace, subsurface). This in order to make the registration system future proof. Initially not all options may be used and supported in the system, but the model should enable representing all these situations (Peter van oosterom et al, 2011).

2. Use 3D Parcels also for simple apartments/ condominium buildings with possible related (Subsurface) facilities such as storage or parking or use more traditional 2D floor plans for the different levels (Peter van oosterom et al, May 2011)?

Answer: Not in short term (use 2D floor plans), but may be in longer term. As this is a very common case, happening very often this is also an important aspect. Instead of using exact height information, also estimated heights can be used as for example in Spain's 3D Cadastre solution (Peter van oosterom et al, May 2011).

3. Are 3D Parcels for infrastructure objects, such as long tunnels, pipelines, and cables, divided by surface parcels or are these represented by one object?

Answer: Only divided by blocks. So, join sub-parcels within block, which is a slight modification to the original Israeli 3D sub-parcel approach, but joining sub-parcels immediately after creation into larger 3D parcel with its own unique number, will result in a more manageable registration. In order to overcome the last drawback of splitting at block boundaries, especially with infrastructures such as roads or railways, a grouping of these 3D parts is proposed in a kind of "uber parcel". In LADM terms this could be a LA_SpatialUnitGroup with no direct rights attached (in contrast to grouping in LA_BAUnit, which would also have direct rights attached) (Peter van oosterom et al, 2011).

4. For representation of 3D parcel: does a legal space have its own geometry or is it specified by referencing to existing topographic objects?

Answer: Own geometry. This similar with today's practice to 2D parcels, also having their own geometry and makes the solution more robust and not depending on changes in the real world. It may be wise to design a more generic solution, from legal, organizational and technical points of view, of which initially only the most urgent cases will be represented in 3D. However, it is to be expected that in less urgent cases the needs or expectations of society in the future may also change and it is good to anticipate or even stimulate these future uses of 3D registration (e.g. registration of air-space or the registration of apartments in 3D). Another scope/ modeling question are related to the Earth surface (terrain elevation) (Peter van oosterom et al, May 2011).

Orthophotos: Orthophotos combine the advantages of both aerial photos and line maps. Like photos, they show features by their actual images rather than as lines and symbols, thus making them more easily interpreted and understood. Like maps, orthophotos show the features in their true plan metric positions. Therefore true distances, angles, and areas can be scaled directly from them. Orthophotomaps (maps produced from orthophotos) are used for a variety of applications, including planning and engineering design. They have been particularly valuable in cadastral and tax mapping, because the identification of property boundaries is greatly aided through visual interpretation of fence lines, roads, and other evidence. Because they are in digital form, they are also ideal for use as base maps and for analyses in geographic information systems (Wolf, 2012).

Orthophotos can generally be prepared more rapidly and economically than line or symbol plan metric maps. With their many significant advantages, orthophotos have superseded conventional maps for many uses. (Wolf, 2012).

2.2 Definitions and Terminologies of 3D Cadaster

The word condominium is derived from the prefix con meaning “together” and from classical Roman law, dominium meaning “ownership.” In the United States, the term condominium refers to a type of property ownership, where individual units within a multiple-unit building are owned separately (Peter van oosterom et al, May 2011).

3D-Cadastres and models: It is important to realize that for registration, for storage/validation and for dissemination different models (all based on the shared ISO LADM semantics) may be needed and different types of users are involved.” *The formal definition a 3D parcel is defined as the spatial unit against which (one or more) unique and homogeneous rights (e.g. ownership right or land use right), responsibilities or restrictions are associated, as included in a Land Administration system*”. The modeling aspect includes the question of which spatial (esp. height) and temporal information should be used and how different types of users may interact (i.e. produce, archive, edit, analyze, and visualize, edit) with 3D-Cadastre? The 'users' belong to various categories; they range from professionals (which can be further subdivided in notary, real estate brokers, banks, water boards, utility companies, municipalities, cadastral employees, surveyors, etc.) to citizens (with various capabilities of owners/users: from computer illiterates to experienced web surfers/gamers) (Peter van oosterom et al, May 2011).

3D-Cadastres and SII: The registration of legal objects (cadastral parcels and associated rights) and their physical counterparts (e.g. buildings or tunnels) result into two different, but related data sets, which can be very well accessed together via the Spatial Information Infrastructure (SII, sometimes also called SDI). This is already true in 2D, but even more so in 3D. By also showing some physical objects for reference purpose, the location and size of the legal objects will be clearer (Peter van oosterom et al, 2011).

3D-Cadastres and time: A 4D parcel is defined as the spatio-temporal unit against which (one or more) unique and homogeneous rights (e.g. ownership right or land use right), responsibilities or restrictions are associated to the whole entity, as included in a Land Administration system. Homogenous means that the same combination of rights equally apply within the whole 4D spatial temporal unit. Unique means that this is the largest spatio-temporal unit for which this is true. Making the unit any larger (in 3D space or time) would result in the combination of rights not being homogenous. Making the unit smaller (in 3D space or time) would result in at least 2 neighbor 4D parcels with the same combinations of rights (Peter van oosterom et al, 2011).

3D-Cadastres and usability: The graphic user interface (GUI) is an essential aspect when realizing 3D-Cadastres in practice. This includes investigation of interacting with true 3D cadastral data (specific user interfaces: 3D spatial and perhaps temporal aspects via animations or snapshot sliders). The existing quality of successful and popular user interfaces will be the starting point with specific attention for working with the main 3D legal object types (related to underground infrastructure and building/apartment complexes). A true 3D cadastral system with functions should be implemented and applied to demonstrate the possibilities in practice based on 3D visualization. How to distribute the 3D cadastral information (3D parcels and associated rights) to the citizens? How to represent and demonstrate the 3D geographic aspect, on paper (with different viewpoints) or on electronic media (interactive tools based on Adobe Flex or Flash) (Peter van oosterom et al, May 2011).

2.3 Technical Aspect of 3D Data Acquisition and Processing

Cadaster is only one of the application areas which 3D data can be used. Similar to other application areas deal with 3D data, the main technological challenge in maintaining a 3D cadaster is related to collecting, maintaining, editing, analyzing and visualizing the data. Significant developments are taking place in surveying technology and it is not very difficult to add z-values to the x and y-values of a coordinate-set. Horizontal and vertical reference systems are nowadays integrated (e.g. WGS84/ETRS), GPS-based survey provides z-values, and airborne laser-altimetry (e.g. LIDAR) has become very effective in the collection of elevation data for large regions, and terrestrial laser-scanning is a source of 3D data collection ('3D point clouds'). Although there are several techniques that can be used for data collection, it may not be sensible to collect the 3D data for cadastral purposes alone. Hence, sharing and multipurpose use of data are important topics that should be given extra caution (Lemmen and It is important also to examine the state of the art with respect to the relevant software. *"In the 3D application areas, customized software has frequently been used, because the existing Standard geo-DBMS and GIS/CAD software do not cover the 3D aspects sufficiently"* (Biyik, May 2007).

However, significant progress has been made in the recent years. For example, the DBMSs Oracle Spatial, IBM Informix Dynamic Server (IDS) and IBM DB2 Spatial Extender, can all store the third dimension within their point, line and polygon spatial data-types. However, the geometric functions (area, overlap, buffer, etc.) are still limited to two dimensions, true 3D volume primitives are not available and there is no 3D standard available like the Open GIS Simple Feature Specification for 2D data types. *"The geo-DBMS can be considered as the back-end of geo-information processing."* The front-end can either be 'traditional' GIS software (strong in analysis) or CAD software (strong in data editing). In general GIS packages support (2D) editing, analysis and visualization, and in many systems 2.5D functionality is added. However, functional support in true 3D is still very limited. *"CAD packages on the other hand have supported true3D editing and visualization for many years, but are limited with respect to analysis of information at geographical scales of measurement"* (Biyik, May 2007).

"In practice, and in spite of the many possible applications, true 3D geo-information processing has not yet made any great breakthrough, because of limited availability of 3D data and

standard 3D software”. However, on both fronts the situation is improving rapidly. Some of available software packages (ArcGIS 3D Analyst, ESRI; Imagine Virtual GIS, ERDAS; GeoMedia Terrain, Integraph.Inc etc.) that attempt to provide solution for 3D representation and analysis were evaluated. *“This paper concludes that most of these packages can efficiently handle 3D data in the 3D visualization aspect but further progress is still needed for true GIS functionality such as 3D structuring, 3D manipulation and 3D analysis”*. Consequently, major development has been seen in 3D visualization and editing thanks to advanced computer hardware and graphics achievements. However, 3D functionality is still lacking such as generating and handling (querying) 3D geo-objects, 3D structuring, 3D manipulation and 3D analyses (3D overlay, 3D buffering, 3D shortest route). This is caused by the specific character of 3D data compare to 2D. Bottlenecks are still the 3D object reconstruction, the representation and navigation through large 3D models, editing and organization of the data (Biyik, May 2007).

2.4 Registration of 3D Parcels in the Cadastral Database

3D parcels as such do not exist in any cadastral registration. The description of the 3D space will be found in the survey plans or in the legal documents. *“The standard seems to be that “floorplans” that the boundaries per floor are listed in the title deed or the appropriate public records (Land Book, Land Registry, public records) or survey plans but not in the cadastral database (map)”*. It may be possibly a make a reference to the 3D parcel in the cadastral map in the form of a 2D polygon in a single layer as in the case of Australia, Cyprus (see Figure 2.2), Croatia (where is spoken of a “2.5D representation”) , Norway and Sweden (Peter van oosterom et al, May 2011).

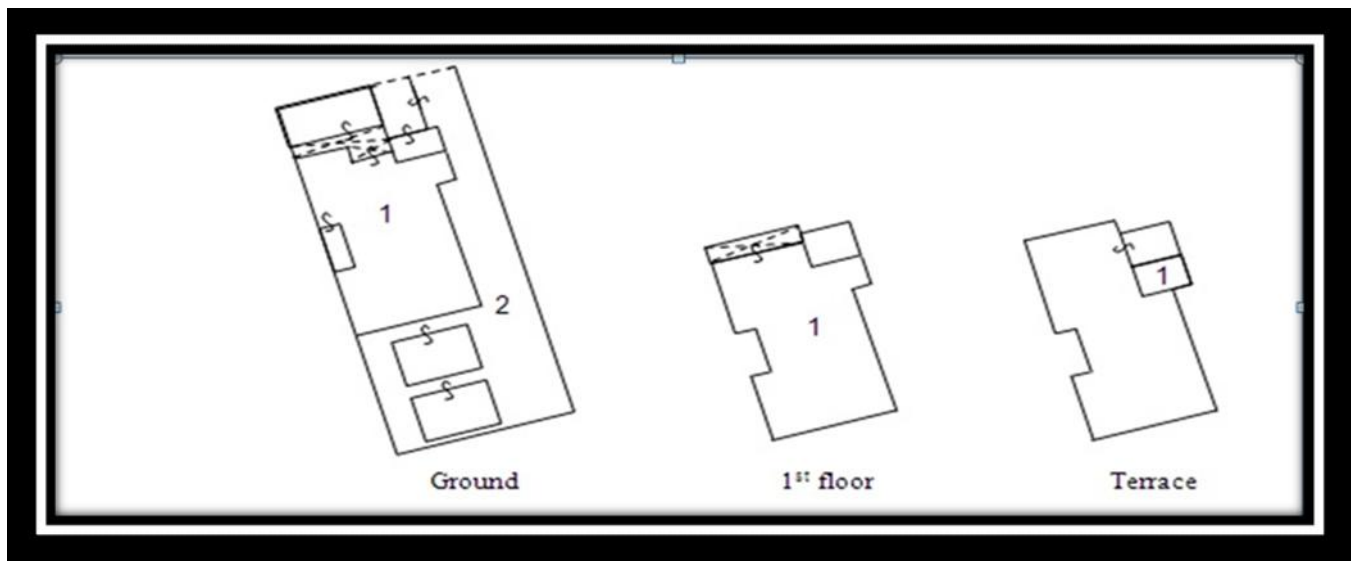


Figure 2.2 Example from Cyprus: Floor Plans from two Cadastral Objects at Ground 1st, and 2nd Floor (Terrace) (Peter van oosterom et al, 2011)

In Italy 3D Cadaster in Italy is represented by the Cadaster of Buildings that exists next to the “Land Cadaster”. This holds a register of every building. A very interesting system of 3D registration exists in Spain. *“Here on the cadastral map a 3D model of the buildings can be shown, including the boundaries of rights inside the buildings”*. But this is not a 3D representation of the actual height of the units. In fact the representation is based on a standard height of 3 meters from floor-to-floor. *“Although this is a limitation, this solution does offer a more or less a realistic view of the buildings and property rights within buildings in urban areas”*, see Figure 2.3.

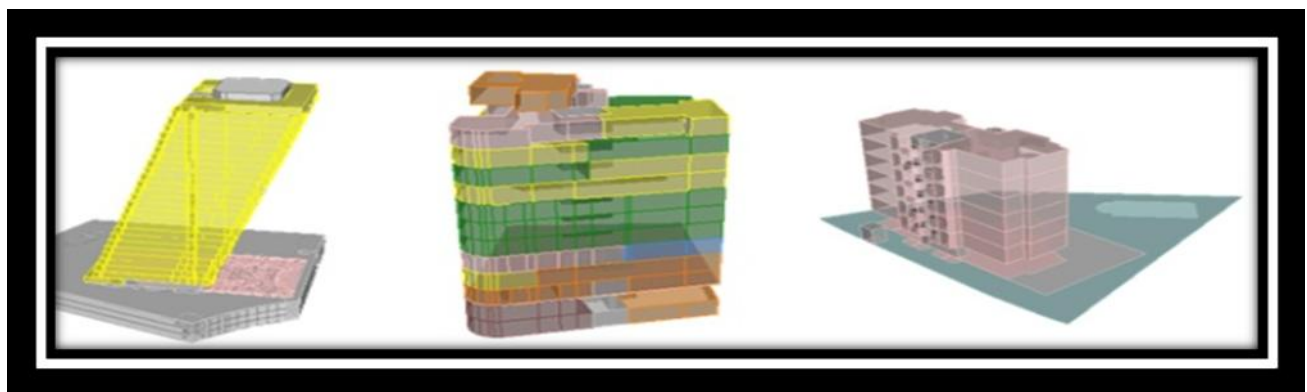


Figure 2.3 3D Visualization of Buildings in the Spanish Cadaster (Based on a Standard Floor-to-Floor Height of 3 Meter) (Peter van oosterom et al, 2011)

The principal objectives of the research are to find a cadastral geodetic solution for utilizing above and below surface space and for defining the characteristics of the future analytical, three-dimensional and multilayer cadaster that will replace the existing two-dimensional graphical surface cadaster in Israel (Peter van oosterom et al, 2011)

The increasing complexity of infrastructures and densely built-up areas requires a proper registration of the legal status (private and public), which only can be provided to a limited extent by the existing 2D cadastral registrations. *“Despite all research and progress in practice, no country in the world has a true 3D-Cadastre, the functionality is always limited in some manner”*; e.g. only registering of volumetric parcels in the public registers, but not included in a 3D cadastral map, or limited to a specific type of object with ad hoc semi-3D solutions; e.g. for buildings or infrastructure. The registration of the legal status in complex 3D situations will be investigated under the header of 3D-Cadastrals with Starting point of the working group is the observation that increasingly information is required on rights, use and value in complex spatial and/or legal situations. *“A 3D parcel is defined as the spatial unit against which (one or more) unique and homogeneous rights (e.g. ownership right or land use right), responsibilities or restrictions (RRRs) are associated to the whole entity, as included in a Land Administration system”* (Peter van oosterom et al, 2011).

Using 3D data in applications, to register properties, property rights of objects in geometrically and legal situation, parcel based 3D information systems should be supported with third dimension, information and 3D data. Today, urban concept has different meaning with the new technologies. About virtual urban, virtual urban management are mentioned. Therefore urban planning, design and imagination become more important. *“Seeing the world in three dimensions, having the powerful, superiority and easy-to-use technology, the rapid change of user needs are the main reasons for human being to bring and built the 3D technology and systems in computer environment”*. 3D geographical information systems used for modeling urban areas in 3D and GIS also used as a main base for these studies in last years. In addition, 3D virtual scenarios have been put in practice (C. Coşkun Aydın, May 22-27, 2004).

2.5 Registering Multilevel and Multilayer Construction by Employing Existing Tools

This research was not intended to deal with the judicial aspect of the multilayer cadaster. However, since a dependency exists between the geodetic and cadastral solution and the judicial solution, we relate within the framework of formulating alternatives for solving the research issues, to the possible solutions within the current judicial framework, where under the Israel Land Law (of 1969), the property right in a land parcel extends heavenward from the center of the earth. Example for registering multilayer construction according to the existing registration method is as follows (Yaron Felus et al, 2014).

Registration of Condominiums:

The word condominium is derived from the prefix con meaning “together” and from classical Roman law, dominium meaning “ownership.” In the United States, the term condominium refers to a type of property ownership, where individual units within a multiple-unit building are owned separately. Every unit owner receives a deed describing their property and is able to buy, mortgage, or sell their unit independent of the other owners. Thus, legal descriptions based on surveys are required. The condominium concept of ownership is relatively new in the United States, as compared with other countries. They have been present in Europe since the Middle Ages and appeared in this country in the later part of the 19th century (Yaron Felus et al, 2014; and Uri shoshani et al, 2004).

The number of condominiums in the United States has been growing rapidly as more families discover the many benefits this type of living offers. *“Condominium ownership has tax advantages, investment benefits, and most of all, eliminates rent increases. This form of ownership can be an economical solution to rising land values, building costs, and maintenance expenses. It can also provide shared recreational facilities and other amenities that might otherwise be unaffordable”* (Wolf, 2012).

Although condominium ownership often applies to multistory residential buildings, it is also used in commercial and industrial situations. The condominium concept has been applied to mobile home lots, travel trailer and camper sites, boat slips and docks, horse stables, shopping centers, and other types of properties. Special types of condominiums include: timeshare, in

which the owner purchases an interest in a unit for a specified time period each year; mixed-use, includes both residential and commercial units; and multiple condominium community, which is a development containing several separate condominiums that share a single common recreation area. Condominium surveys differ from ordinary land surveys in several ways. *“Preparation of the required materials for a condominium project is a joint effort, which typically includes an architect, engineer, attorney, and surveyor”*. The architect prepares the building plans and specifications; the engineer designs the construction plans; and the legal representative creates the legal documentation for the condominium and the association. The surveyor assembles necessary information; prepares the required condominium plat, graphic plans, and descriptions; and performs the surveys needed for describing the parcel boundary and for locating the “as-built” improvements. It is important for the information shown on the graphic plans to agree with the provisions described in the Declaration. (Wolf, 2012)

Since most condominiums consist of several apartments build on top of each other, it is possible in any case to relate to condominium as a vertical parcelation, change in ownership in the parcel's space and multiplicity of owners and properties on the same parcel. *“The Registration of Condominiums Law governs the status of the rights of the several property owners at the same land site, and provides a judicial solution of separate ownership on levels. An apartment in a condominium is a separate issue regarding ownership, rights and transactions”*. Application of this solution to the complex future multilayer reality is not optimal, since the method of registering condominiums refers only to the specific case of "orderly" vertical construction in apartment buildings (Yaron Felus et al, 2014; and Uri shoshani et al, 2004).

The most common way to divide the use of building complexes over multiple owners in the Netherlands is to split the complex into apartment rights (condominium rights). According to Dutch law the entire complex (land and building(s) is in joint ownership. Therefore an apartment right is a share in this joint ownership, while it also provides each apartment owner an exclusive right to use his apartment unit. Furthermore, each apartment owner is compulsory member of the Homeowners Association (Verenigingvan Eigenaren). In practice this membership might be an obstacle for selling individual units as well as for their funding. In addition, foreign investors do not always accept the legal concept of joint ownership (Ploeger, 2012)

A right of superficies (opstal) is a right to construct buildings or other constructions above, on or in land owned by another person. Interesting is to note that the holder of the limited right of superficies is also the legal owner of the building or construction he is allowed to have on this land. The right of superficies therefore separates the ownership of physical objects or constructions from the land itself. Although in most cases the use applies to the entire property (land with buildings), the right may also be limited in space. Therefore it is a property right with a clear 3D characteristic. (Ploeger, 2012).

An easement is a burden on the serving parcel in favour of a (usually neighbouring) parcel of another owner (the ruling parcel). Common examples include the right of way, the right to extend a building over the serving parcel or the right to have a pipeline in the serving parcel. But it is also possible that the burden guarantees a free view or prohibits the construction of new buildings (Ploeger, 2012).

2.6 Prototype Implementation

To describe the rights concerning complex situations in 3D we will introduce table (3D right-table) that contains for every parcel the different height-levels of ownership (z-list). The z-list contains n z-values corresponding to $n-1$ consecutive ranges associated with the parcel. Redundancy is avoided since only the z-levels are stored in addition to the currently stored data (boundary of parcels). This information is sufficient to generate the representation of 3D right-objects based on the geometry of parcel boundaries. The 3D right-objects are identified by unique numbers that are based on the parcel number concerned (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

Holders of a 3D right-object can be obtained by the right to which the 3D right object is associated (e.g. a right of superficies). The right-owner of this right (subject) is the holder of the 3D right-object (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

The height-levels are invariant for every 3D right-object, which means that the upper and lower boundaries of 3D right-objects are defined by horizontal planes. We have considered defining the lower and upper limits in more detail, however the horizontal boundary. More detail registered at

the Cadaster makes the Cadaster responsible for the consequences of this information (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

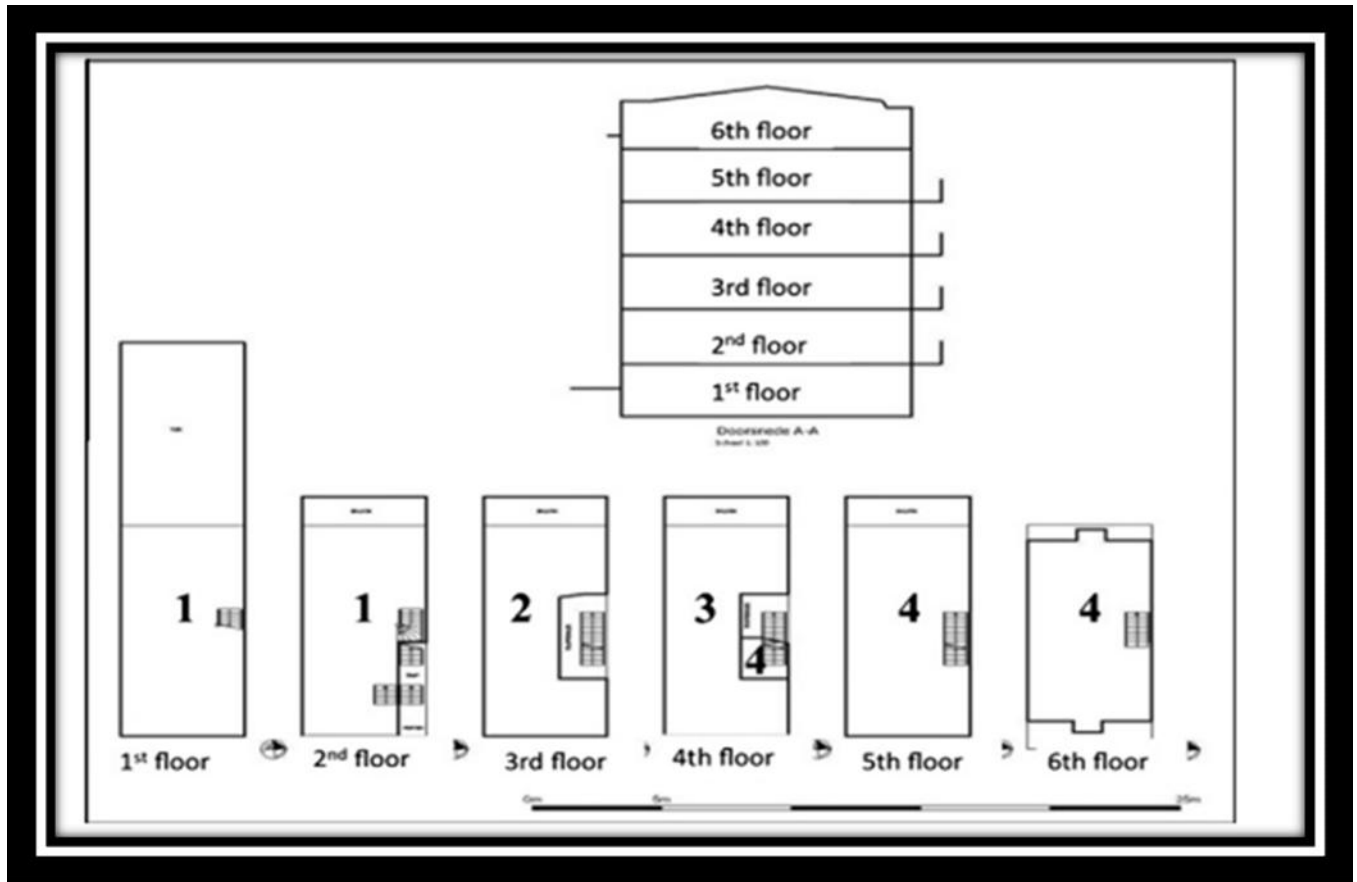


Figure 2.4 Floor Plan of the Multilayer Buildings (Peter VAN OOSTEROM et al, May 2011)

In practice both sketches and more detailed drawings can be registered in the land registers to show the 3D extent of the limited rights or restrictions. The land register accepts detail 3D representation for the better reflection of the legal situation but (s) he cannot demand this. The format of 3D representation can be horizontal and or vertical cross section(s) bet also a digital 3D Pdf since this fits within the currently used electronic conveyance system. The Netherlands was the first country in the world supporting 100% electronic conveyance with this system.

Despite the possibility to register a 3D representation in practice in reference to a demarcated area at location is sufficient. This of course has its risks because the real world at this location

can change. In case the deed provides no description of the boundaries at all, the land registration of the deed (Peter van oosterom et al, May 2011).

Because of reliable and observable reference points often missing, in practice the intension of the involved parties are only verbally described in the deed 3D representations added to the deed often acts as a sketch no legal meaning with respect to the exact locations of the boundary. In theory, the deed can include a representation of boundaries, which are considered legally binding if the parties declare that the boundaries exactly reflect their intentions. In practice this rarely happens, although it is obvious that it would be helpful for both the submitting and the receiving parties if some voluntary best practice based guidelines would exist; e.g. to clarify the situation in the form of 3D representation (Peter van oosterom et al, May 2011).

2.7 Why CAD Models Do not Comply a 3D Cadaster

3D data is needed to represent 3D objects in the 3D cadaster. Since 3D data is available with designers, mostly as CAD models, it is a relevant question how this information can be used. Municipalities, the Ministry of Transport and Public Works, and designers were visited in the search for usable CAD models. Based on this research the conclusion can be drawn that CAD models suitable for the 3D cadaster cannot or hardly be found. *“The first reason for this is that newly planned objects are mostly still designed in 2D by using linear profiles and cross-sections”*. Contractors and builders are used to the 2D drawings: understanding 3D drawings would require special skills. The 2D models could be used to construct 3D models that are relevant for the 3D cadaster (as this is the most original source). In this process attention has to be paid to the conversion of local coordinates of the CAD files to absolute coordinates in the national coordinate frame (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

In the design and building process, 3D CAD models are generated from the designs for visualization purposes. Also those models cannot directly be used for the 3D cadaster. Since CAD models contain much more details than is needed in the 3D cadaster it has to be studied what selections and generalizations are needed to obtain the relevant information such as the outer boundary of objects? When the Cadaster would register the detailed information that is available in CAD models, it would make the Cadaster responsible for this information, which they obviously want to avoid. Furthermore, 3D CAD files can get unworkable large, since

mostly they are not made for interactive purposes but to generate movies out of them. Furthermore the relevant objects can hardly be recognized in the “**file-based models**” and finally 3D spatial data in CAD files contain complex geometries and are sometimes parametrically described. At the moment these data cannot automatically be converted to the primitives that are available in the spatial DBMS, which is used for the 3D cadaster (point, lines, polygons, polyhedrons). Also once the 3D CAD objects will be available as geometries in the DBMS, 3D generalization and simplification is needed to obtain the appropriate information. Although the use of CAD models (2D and 3D) still seems to offer a lot of potentials for the 3D cadaster (information on the third dimension is available in those models), generating relevant information out of these models requires further study. The main reason for this is that experiences have shown that it is a complex process to obtain the needed information (property boundaries in 3D) out of these models. For simple “**buildings it might still be straightforward**”, but for more complex situations (e.g. tunnels) it requires study on basic fundamentals in GIS science (generalization; converting parametrically described geometry to geometry primitives).borate on this solution. A future solution may define a 3D right-object in more detail (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

At a first glance it seems that there are four owners, thevereniging van eigenaren (association of owners) and the holders of each of the three apartments. But this conclusion is not correct. The parcel 5238 G0 refers to the ground parcel. This parcel, with the apartment complex erected on it, is co-owned by all the holders of apartment’s rights. In practice the Cadaster names thevereniging van eigenaren(the association of owners) as owner. From a legal point of view this is not correct. The complex is co-owned by all the apartment owners, not by the association. In Dutch law this association of co-owners is merely a legal body intrusted with the day-today administration and management of the complex. All the co-owners of the complex are compulsory members of this association (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

Apart from the (co-owned) ground parcel, we find the individual apartments, each indicated by a unique number (6408 A1, 6408 A2, and 6408 A3). The suffix A shows this number refers to an apartment right. The last digit is the same as the apartment number in the deed of division (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

It is most important to realize that the individual apartments, the areas of exclusive use, cannot be found on the cadastral map. The Public Registers have to be queried to find the plan of division. Another disadvantage of this way of registration is that the plans in the notarial deed are drawn in a local coordinate system (in 2D layers). When coordinates were defined in the national reference system they could be combined with the cadastral map or other geo data (e.g. topographic data). However, the addition of 3D information on the individual apartments in the cadastral system itself would especially enhance (Jantien E. Stoter and Hendrik D. Ploeger, 2003).

Table 2.1 The Right, Apartama Parcel and Kind of Right

PARCEL	KIND OF RIGHT	OWNER OF RIGHT
6408 G0	VE	VERENIGING VAN EIGNAREN
6408 A3	VE	VERENIGING VAN EIGNAREN
6408 A2	VE	BARRELING
6408 A1	VE	STOTER

2.8 Cadestre in Ethiopia

Emperore Menilek II, who was signed the country's first Proclamation related to urban lands at the end of 1907, which was started by a French company in Addis Ababa. The land owner was to be provided a certificate referred to as "yerist waraqet" or "rist" paper to be written in Amharic and French, with a map showing the boundaries of the land. But it remained without maintenance for more than 80 years. The Addis Ababa city Administration around 2002E.C decided to launch a cadastral project initially intended to register all property owners liable for property taxation and collect data that would enable the city administration to assess a value of a property more realistically. As it has been already stated cadaster as a system is non-existent for most cities in developing countries. This is true for Ethiopian towns and cities. By considering this reality the UDSS/GTZ took an initiative on four selected regional towns to establish their own cadastral system. These include the study area (Mekelle city), Adama, Awassa, and Bahir Dar which are selected from the four major Regional States in Ethiopia. Despite UDSS/GTZ played the leading role in promoting cadaster in the four mentioned towns until now it was not possible to replicate the system to other urban centers in the country, since the project is still going on for more than 8 years. Even from the four selected towns as shown in an inception report DHV Consultants (2013), currently the project is still operational in one of the towns and

paused due to various reasons in three of the towns including the study area. The following table from the same report summarizes the status of the project (daniel tadesse, 2013).

Table 2.2 The Status of Cadaster in the Four Towns of Ethiopia since 2013

City	Start Date (E.C)	%Complete	#Parcel	Status	Remark
Adama	1999	95%		On going due for completion early 2013	Original survey stalled now bieng completed by a private contractor
Bahir Dar	1998	75%		Paused, HR and financial constraints	Some updating with lease subdivisions
Hawassa	1998	50%	20,000	Paused; pending reorganization	New project proposal prepared
Mekelle	1996	90%(Spatial) 5%(Aspatial)	35,000	Paused,pending new contrat	New lease subdivision bing added

(Daniel Tadesse, 2013)

Addis Ababa, capital of Ethiopia has witnessed rapid urban expansion over last 20 years. This has pressure on the city's land resource to increase of slum settlement .the Addis Ababa city government has recently integrated program for the development of slum settlement and the development of new house areas both of which requires reliable and consistent systems of real property registration and ownership. To this end Addis Ababa city administration is committed

to securing and clarifying land and property right and promoting land transaction process through registration. Those aims primarily are achieved with up-to-date city cadastral map data and robust geo-database system (zien, 2012). The system developed was treated as pilot solution which could be ported to all Ethiopia. Such a system could potentially include an automated city administration system, in a essence an e administration and core of national spatial infrastructure. All cadastral attempts in Ethiopia are depending on 2D Cadaster. No official effort and proposal is suggested to apply 3D cadastre in Ethiopia

2.9 The gabs of the Previous 3D Cadastral Researches

According (Yaron Felus et al, 2014). puts the 3D cadastral problems to be solved from the scientific and technological standpoint, the principal challenge in developing a three-dimensional multi-layer cadastre lies in gathering, processing and managing the three-dimensional data. The third dimension, which does not appear in the current two-dimensional cadastre, necessitates development of new spatial models for managing the subsurface information and linking it to the surface information. The main tasks in the process of defining and establishing the 3DCAD are: Developing three-dimensional models in respect to the cadastre; Study and understanding of the special character of the subsurface cadastre; and, Creating links between the subsurface cadastre and the surface cadastre. According to (Yaron Felus et al, 2014), Due to limitation of technological (the spatial DBMS did not yet support 3D volumetric Primitives), legal, organizational and technical i.e. no operational 3D Cadastral system Implementations available. Nowadays *“In the 3D application areas, customized software has frequently been used, because the existing Standard geo-DBMS and GIS/CAD software do not cover the 3D aspects sufficiently”* (Biyik, May 2007). *“CAD packages on the other hand have supported true 3D editing and visualization for many years, but are limited with respect to analysis of information at geographical scales of measurement”* (Biyik, May 2007). So in this research it will use the City engine as customized software. This paper concludes that most of these packages can efficiently handle 3D data in the 3D visualization aspect but further progress is still needed for true GIS functionality such as 3D structuring, 3D manipulation and 3D analysis. *“The Registration of Condominiums Law governs the status of the rights of the several property owners at the same land site, and provides a judicial solution of separate ownership on levels. An apartment in a condominium is a separate issue regarding ownership, rights and*

transactions". In ethiopia, there is a designed 2D cadastral system that can register and store the spatial and its attached rights ,restrictions and responsibilities even for the condominium houses digitally.However, the registration system cannot support visualization of its 3D object. So, this paper will contribute the 3D visulization to the existing 2D cadaster.

CHAPTER THREE

STUDY AREA

3.1 Introduction

This chapter discusses about description of the study area, the activities of cadastral experience in the study area specifically in the condominium registration system. The development of the conceptual data model, the available softwares used to develop the 3D cadastral data model and the available data sets, their source and the unique ID development will be explored in this chapter.

3.2 Description of the Study Area

Mekelle which was founded as a national capital during Emperor Atse Yohannes the 4th era in the nineteenth century and subsequent years, as a regional city of Tigray has been developed as political, economic, and cultural center characterized by its spontaneous growth. Mekelle is one of rapidly growing cities in terms of human settlement, industrial and institutional establishment and at present the city has a built-up area. Mekelle is located in the northern Ethiopia highlands at 777 km drive north of national capital city, Addis Ababa. Geographically it is located between 13° 24' 30" to 13° 36' 52" Latitude and 39° 25' 30" to 39° 38' 33" Longitude (Fig. 3.1). It has an average altitude of 2200 meters above sea level with a mean minimum, mean maximum and mean average monthly temperatures of 8.7, 26.8 and 17.6°C, respectively (Kibrom, 2005). Amount of rainfall is variable in Mekelle; on average about 600 mm, and more than 70% of it falls between July and August, followed by a long dry season (Kibrom, 2005). Mekelle has projected

population of 323,700 according to the census of 2007 (CSA, 2015).

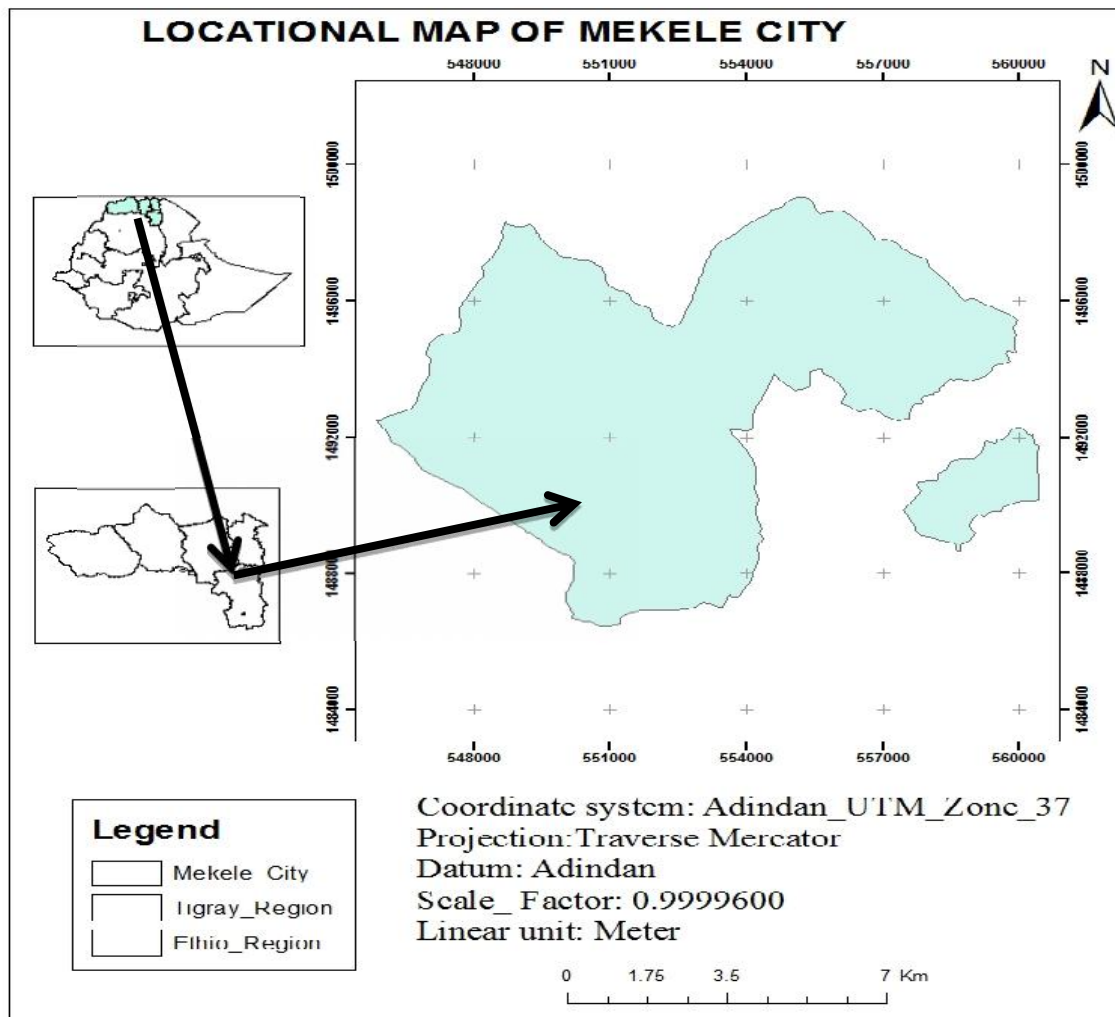


Figure 3.1 Map of the Study Area

The sample of developed 2D spatial object and corresponding unique numbers attached to the spatial object in the study area (Figure ,3.2).

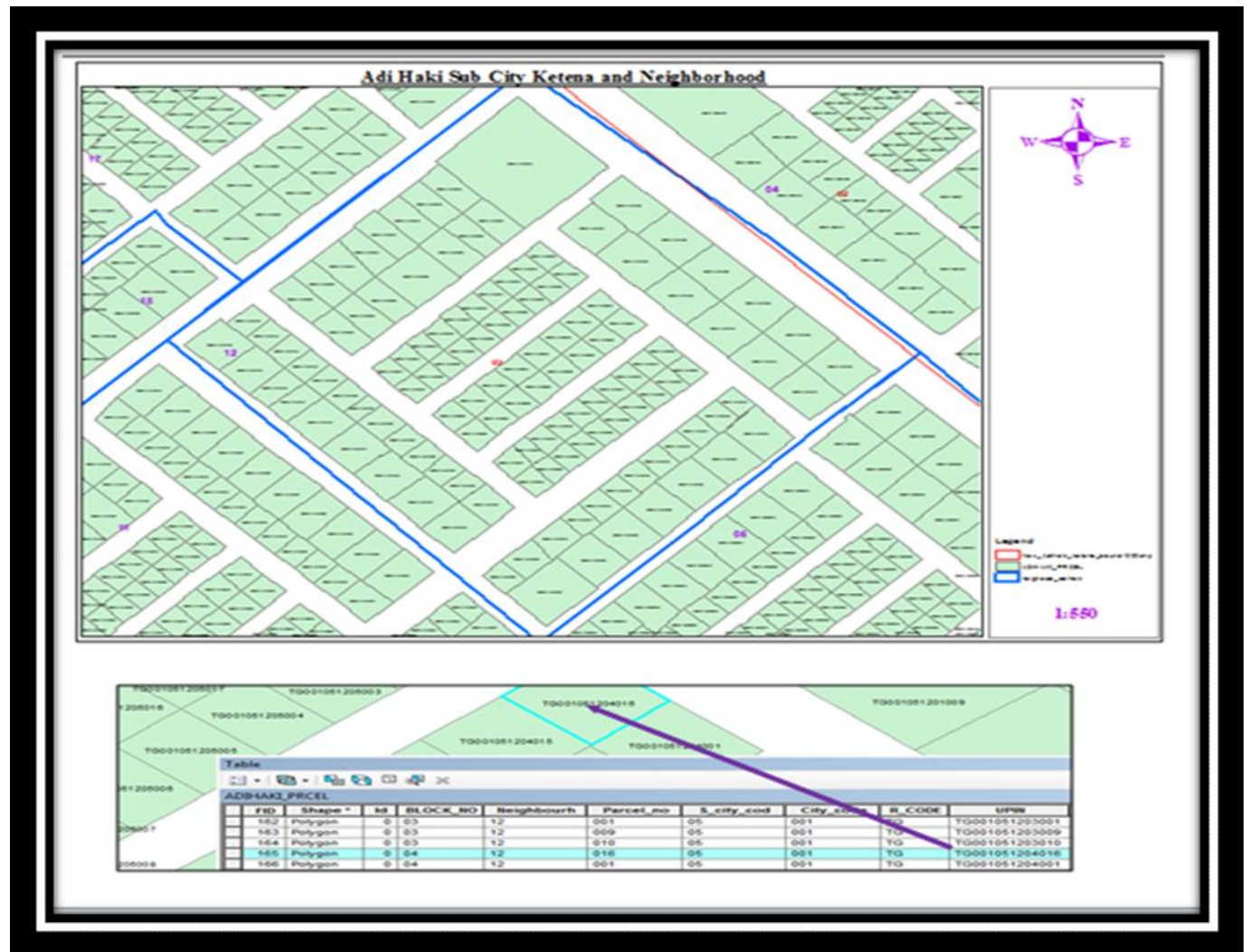


Figure 3.2 Sample Existing 2D Cadaster of Mekelle City, Ethiopia(Legal Cadaster)

3.2.2 Description of the Selected Condominium Sites in Mekelle city

“The word condominium is derived from the prefix con meaning “together” and from classical Roman law, dominium meaning “ownership.” In the United States, the term condominium refers to a type of property ownership, where individual units within a multiple-unit building are owned separately” (WOLF, 2012).

Because of the growing needs for residential houses the federal democratic of Ethiopia has set different packages to address the national demands. One package focuses on the building condominium houses at different regions of the country. To achieve this goal, housing development has been established in different regions of the country and Tigray housing development is one of them. Tigray housing development agency is a governmental non-profitable organization which has been established by the proclamation No 109/1998 with the mission to build affordable and quality houses for the people who have the interest and capacity to pay as well as encourage the construction industry of the region.

Mekelle housing development agency is one of the branches in Tigray housing development agencies which were established in 2006 E.C to achieve these missions. In Mekelle city, the agency constructed 122 condominium blocks and 3287 housing units in 19 sites from which 10% are used for commercial purpose. Initially there were 11 types of condominium designs in Tigray such as B-L, B-2, C-2, C-4, M-1, M-2, T-3, T-4, T-9, T-16 and T-18. However, different housing development agency offices made an arrangement of design for their convenience by an agreement among the ministry of construction and urban development, the regional housing development and the consultants. For this reason, the Mekelle city housing development agency reduced the designs to seven types of design type (B2, C-2, M-1, M-2, T-3, T-4, and T-9) (Mekelle Housing Development Agency, 2013).

For this study, three types of design types have been selected from three sites. The selected design types are B2, C-2 and T-4. The selection of the designs was based on evaluating the complexity of the shapes. Designs having sample geometry have been selected. The rest design types were represented by the selected design types (Figure 3.3, 3.4 and 3.5) and used for evaluating the developed cadastral registration systems (Mekelle Housing Development Agency, 2013). The selection was taken by advising experts and the author's professional judgments.

The selected sites, the site descriptions and the building footprint of the selected building design type on the aerial photograph are listed below:

Site one: 03 water and mine bureau condominium site

03 water and mine bureau condominium site is located in Mekelle city at sub city of Ayder in kebele 03. In this site the following condominium building types are available (Figure, 3.3) and (Table, 3.1).

Table 3.1 Types of building and the Selected Building Type C2 (Mekelle Housing Development Agency, 2013)

Project year	Types of building	Building height	Number of blocks
1999E.C	M1	G+3	1
	B2	G+4	2
	C2	G+4	2

From those buildings C2 is selected as sample to evaluate the developed 3D cadastral registration system (Figure ,3.3) (Mekelle Housing Development Agency, 2013).

Site two:Endamaryam Adihawsi condominium site

Endamariam Adihawsi site is found in Mekelle kebele 18. In this site the following types of buildings are available. This site has four blocks which contains many houses inside those buildings and the following types of building are available (Figure,3.4) and (Table,3.2) (Mekelle Housing Development Agency, 2013). From this site, one condominium building is selected to test the 3D cadastral registration system that is T4 building.

Table 3.2. Condominium building at site two and the Selected Building Type T4 (Mekelle Housing Development Agency, 2013).

Year of construction	Types of building	Building height	Number of blocks
1999 E.C	T4	G+3	1
	T9	G+3	1
	M1	G+4	1
	M2	G+4	1

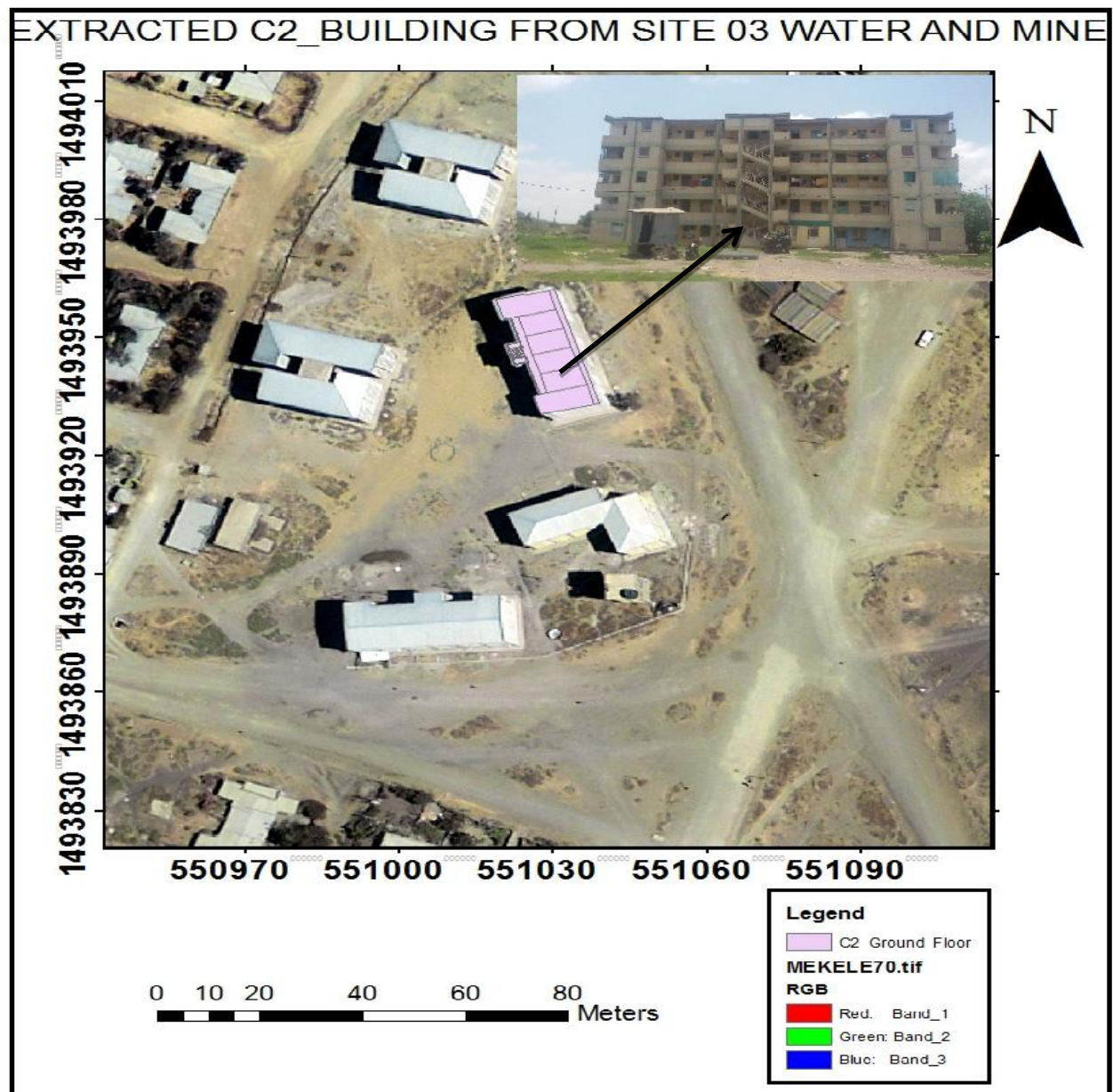


Figure 3.3 The Condominium Site of 03 Water and Mine Bureau and the Selected Building C2

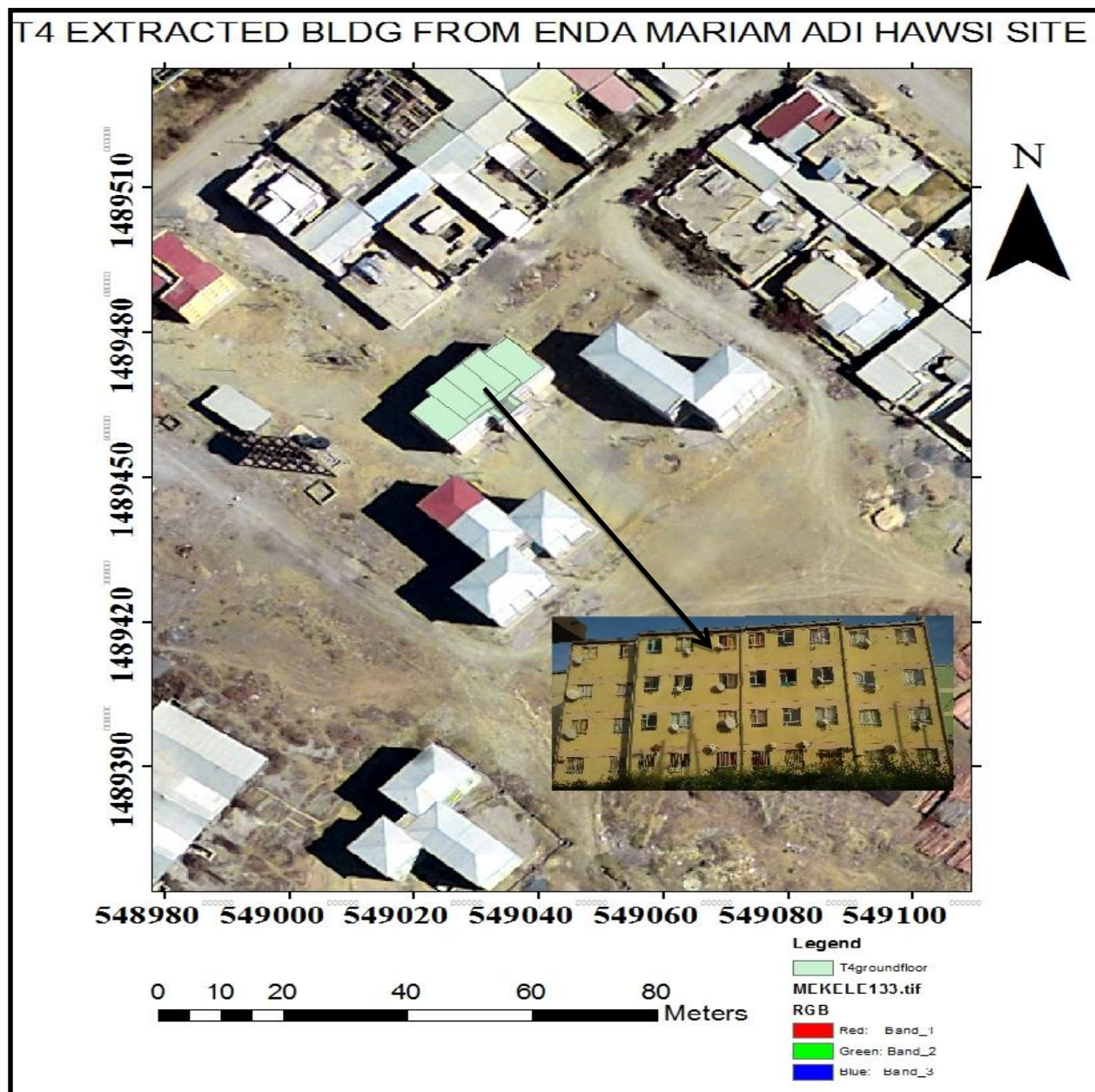


Figure 3.4 Endamariam Adihawsi Condominium Site and T4building

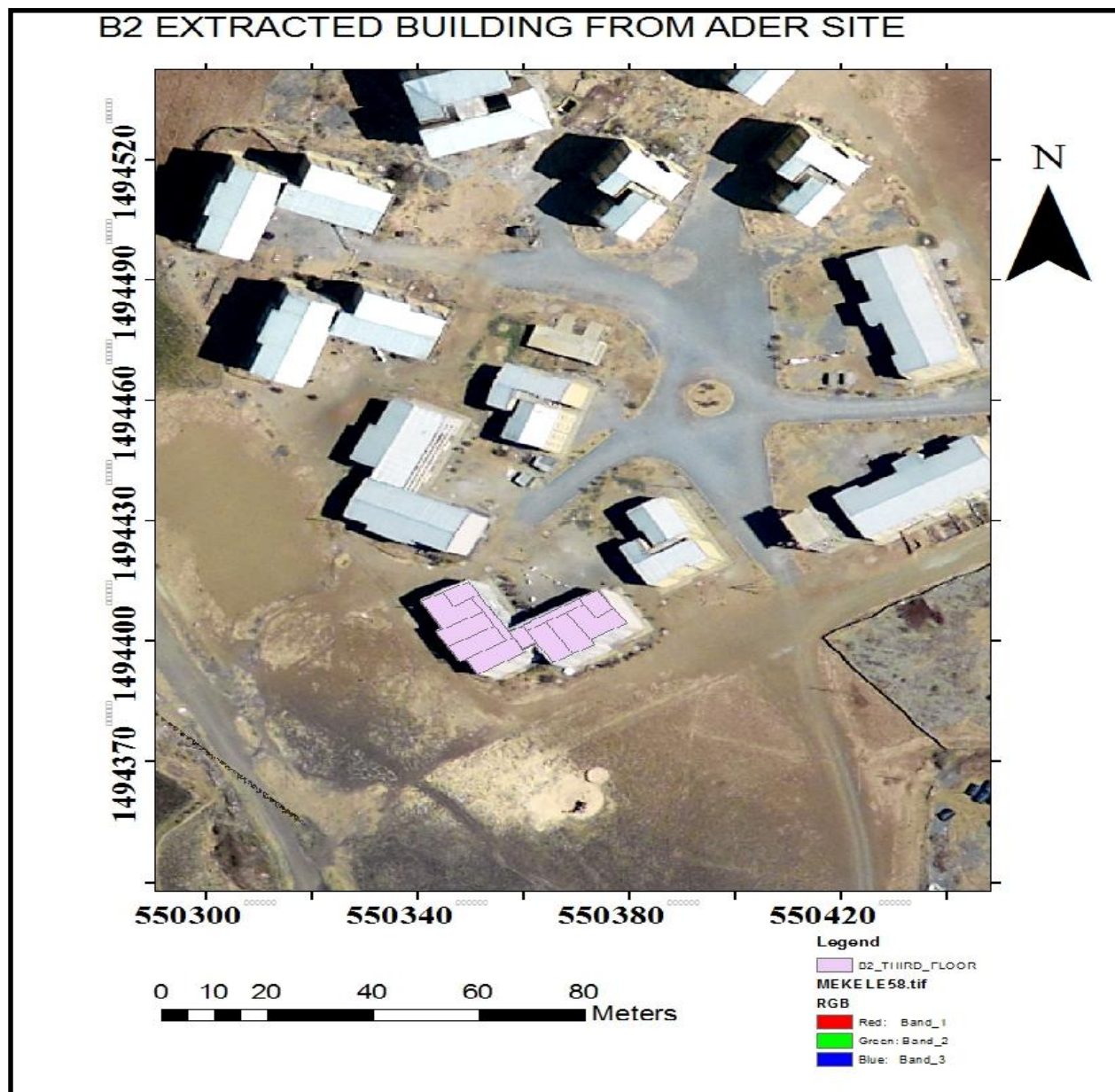


Figure 3.5 The Condominium Site of Ayder and the Extracted Building of B2

Here in the ayder site, there are eight condominium buildings are constructed. From this site B2 building is selected to evaluate the developed 3D cadastral registration system(Figure, 3.5).

CHAPTER FOUR

MATERIAL AND METHODS

4.1 Introduction

In order to develop a registration system and model for 3D cadastral maps within the integrated platform, different parameters have been derived from cadastral and urban planning datasets, as well as legal documents and architectural plans. Specifically Mekelle housing development agency and Tigray cadastral office provided me with a number of datasets (in the form of CAD files), a structural map of the city, geo-referenced in the Adindan UTM Zone 37 Geodetic Reference System, architectural plans of the existing and future condominium buildings also geo-referenced, as well as, floor plans, views and sections of Mekelle city condominium buildings. For the selected condominium sites and buildings socio-economic data was collected through questionnaires provided with information on the number of floors, year of construction, and finally a cadastral diagram also geo-referenced with related legal documents that describe the ownership status. The Mekelle city integrated urban land Cadastral information system project office provided me with the necessary aerial photo which served as a basis to the modeling approach.

4.2 Materials

The data and their sources used to generate cadastral model and cadastral registration systems of multilayer condominium buildings in Mekelle city are reported in (Table, 3.3).

Table 4.1 Data and their sources

Layers(data)	Format	Scale/ Resolution	Data source	Purpose of the layer
Aerial photo	Raster	15cm*15cm	Ethiopian Information Network Agency(INSa)	To develop the basic cadastral shape via digitization and to keep the position via georeferenced
AutoCAD	DXF	1:50 and 1:100	Tigray housing development agency	To develop the shape and size of the parcel to be digitized
Elevation	Structural plan	1:50	Tigray housing development agency	To develop the 3D building
Socioeconomic	CSV	personnal interview	Questionnaire from the site	To understand rights, restriction and responsibility of the cadaster
Photographs	Jpeg	3.264cm*1.836cm	Directly taken from the site by digital camera	To develop the texture and physical appearance of buildings

4.3 Aerial Photograph

The aerial photography was acquired in order to fix the 2D boundaries and develop the 3D cadastral object by taking the surface of the earth as initial elevation. One hundred sixty seven (167) digital aerial photography was acquired from Municipality of Mekelle city which are captured by INSA in 2012 with an average accuracy of 15cm. These aerial imagery are mosaicking to combine the individual photographs using ERDAS imagine software. After data capture the data was input in ESRI ArcGIS and processed so as to generate closed polygons, to assign unique identification numbers and to merge existing attribute data to new polygons. The acquired aerial photography has been given me with the following map information (pixel) as shown in Table 3.4 and projection informations. This aerial photograph is used to extract two dimensional geospatial data depending on the size and shape of the Ato CAD data.

Table 4.2 Map Information (INSA, 2012)

Unit	Pixel size x	Pixel size y	Upper left x	Upper left y	Lower right x	Lower right y
Meter	0.15	0.15	546453.824999	1501126.125	561213.825	1486808.9249999

The projection information of this aerial photography is UTM Zone 37 Adindan and the spheroid is clark 1880 RGS.

Figure 4.1 shows the flight line which cover the entire town of Mekelle city with 15cm ground resolution aerial imagery (INSA, 2012)).

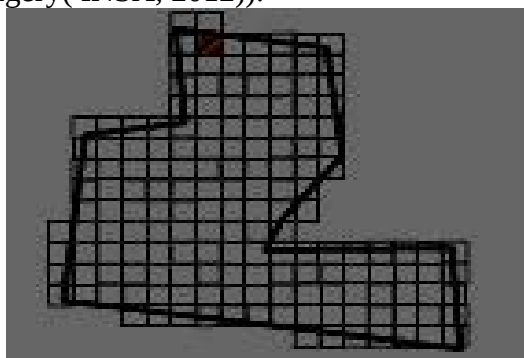


Figure 4.1 Flight Lines Covering Entire Mekelle City (INSA, 2012)

4.4 Elevation

The elevation source of this research is the structural plan of a repetitive condominium buildings. After digitizing and validating the extracted two dimensional buildings, it can develop into 3D cadastral object by adding the elevation data. The source of the elevation can be found in different mechanisms, such as through ground surveying, DEM, topographic maps and structural plan etc. So the source of elevation to develop the 3D cadaster is structural plan as shown in Figure 4.2.

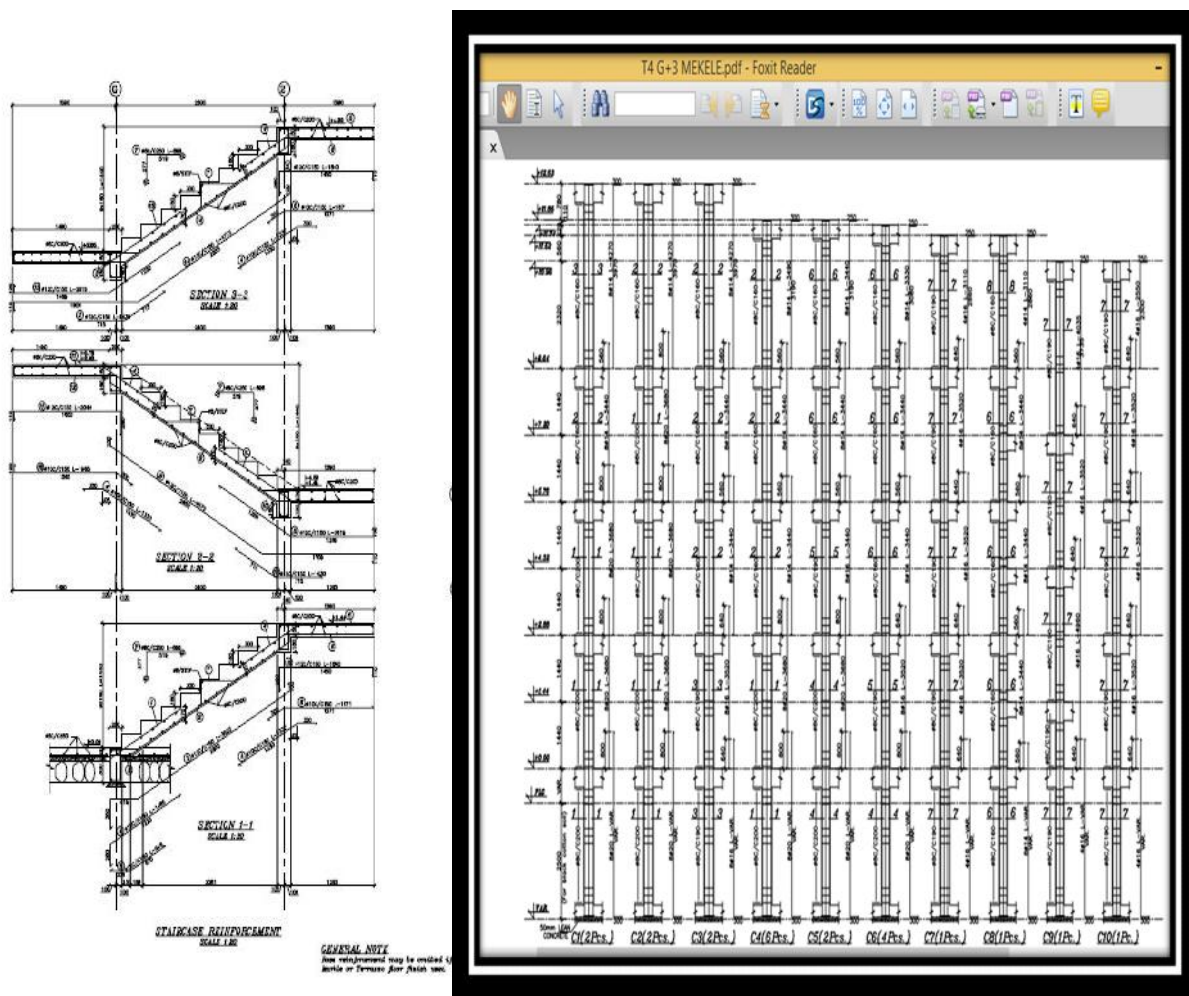


Figure 4.2 The Section Plan Containing Elevation Data of Parcels

4.5 Softwares

Softwares used in this study were selected based on their capability to work on the existing problems for achieving the predetermined objectives. Hence, following software packages were used as mentioned below:

ERDAS 2014 :

Used for image process of satellite images for the preparation of mosaicking of the aerial photos.

ArcGIS10.2.2:

The integration of attribute data collected through questionnaire and extracting of the foot print of a building from the aerial photo, the factors that are input to the development of 3D cadastral maps of the individual houses within the condominium building. Cadastral system should be preprocessed in accordance to the criteria set to develop the registration system of 3D cadastral models. So using the shape and size of the AutoCAD, some relevant GIS analyses were undertaken to convert the collected file geo database. ArcScene was used to develop the physical appearance for visualization of shaded 3D objects and used to combine the basic shape and the elevation data.

CITY ENGINE 2014:

In order to register and visualize the complex reality in 3D, Esri's City Engine 2014 modeling software has been used, which is specialized in the generation of 3D urban environments, transforming 2D GIS Data into Smart 3D City Models (E. Tsiliakou, 27 – 29 November 2013). City engine for the selected and organized database has been used to develop the system and proto type implementation of the 3D cadaster. In city engine the prototype and the implementation of the 3Dcadaster has been developed based on the 3D procedural modeling (CGA rule file). The 3D procedural modeling achieved through the arrangement of geometry, attributes and rules or algorithms.

4.6 Methods

A standardized core cadastral domain model (CCDM), covering land registration and cadaster in a broad sense (multipurpose cadaster), will serve at least two important goals:

1. Avoid reinventing and re-implementing the same functionality over and over again, but provide an extensible basis for efficient and effective cadastral system development based on a model driven architecture, and
2. Enable involved parties, both within one country and between different countries, to communicate based on the shared ontology implied by the model. All systems are in principle mainly the same in which they are working based on the relationships between persons and land, via (property) rights and are in most countries influenced by developments in the Information and Communication Technology (ICT) (Christiaanlemmen et al, 2003).

The approach adopted in this study in order to reach to the objectives of the study is to extract data from aerialphoto to create the 2D geometry, join the separate attributes to the extracted geo database has been undertaken in ArcMap 10.2.2 software package. The extraction of 3D geometry, prepare 3D cadastral system, and 3D cadastral maps with the integration of questionnaire data was developed in ArcScene 10.2.2 software package. However, the development of 3D data or buildings in these software packages was not sufficient to show the complete 3D cadaster with its texture and roofs. In the 3D application areas, customized software has frequently been used, because the existing Standard Geo-DBMS and GIS/CAD software do not cover the 3D aspects sufficiently (Biyik, May 2007).So, Esri's City Engine modeling software has been used, which is specialized in the generation of 3D urban environments, transforming 2D GIS Data into Smart 3D City Models with necessary tools to fill the gaps of GIS/CAD software packages. The elements that are participating to develop 3D cadastral model should be preprocessed in accordance to the criteria set to develop 3D multi layer cadaster. So the rules or algorithms could be worked out using advanced Esri city engine 2014 software to get the rule derived modification and replacement of shape. The rules in Esri city engine can be developed based on CGA (computer generated architecture). Esri city engine software is used to provide rule defined value to produce rule dependent 3D cadastral system. The input datasets are organized in personal geo-database and then processed to the suitable format, extracting,

Mosaicking and validating. The resulted 3D physical object (building) is created by extruding the elevations starting from each floor up to the next floors of the building situated in different level of elevation and produce 3D multilayer cadaster. 3D cadaster of the city was developed from the following general standards of 3D core cadastral domain model (3DCCDM) (A. Aien et al. , 2012; and Paul van der Molen,et. al., 2004).

4.6.1 Diagram of 3D Cadastral Procedural Modeling

Models are the apparatus, translating the real world into a digital substance, providing their own interpretation of the existing data according to the users and the purposefulness of the system (E. Tsiliakou, 27 – 29 November 2013). In GIS, a data model is the structure used to identify and represent objects referenced by space relative to the earth surface (Stoter Jantine et. al., 2004). The classification of the the flow chart in (Figure 3.6) describes as follows:

- The yellow colour in (Figure 3.6) indicats, features that have been enriched with specific 3D cadastral attributes, owners and geometries to meet the relationship of 3D cadastral data content.
- The blue colour in (Figure 3.6) indicated the framework developed as 3D Building
- The green colour in (Figure 3.6) indicated subclasses of a Building model

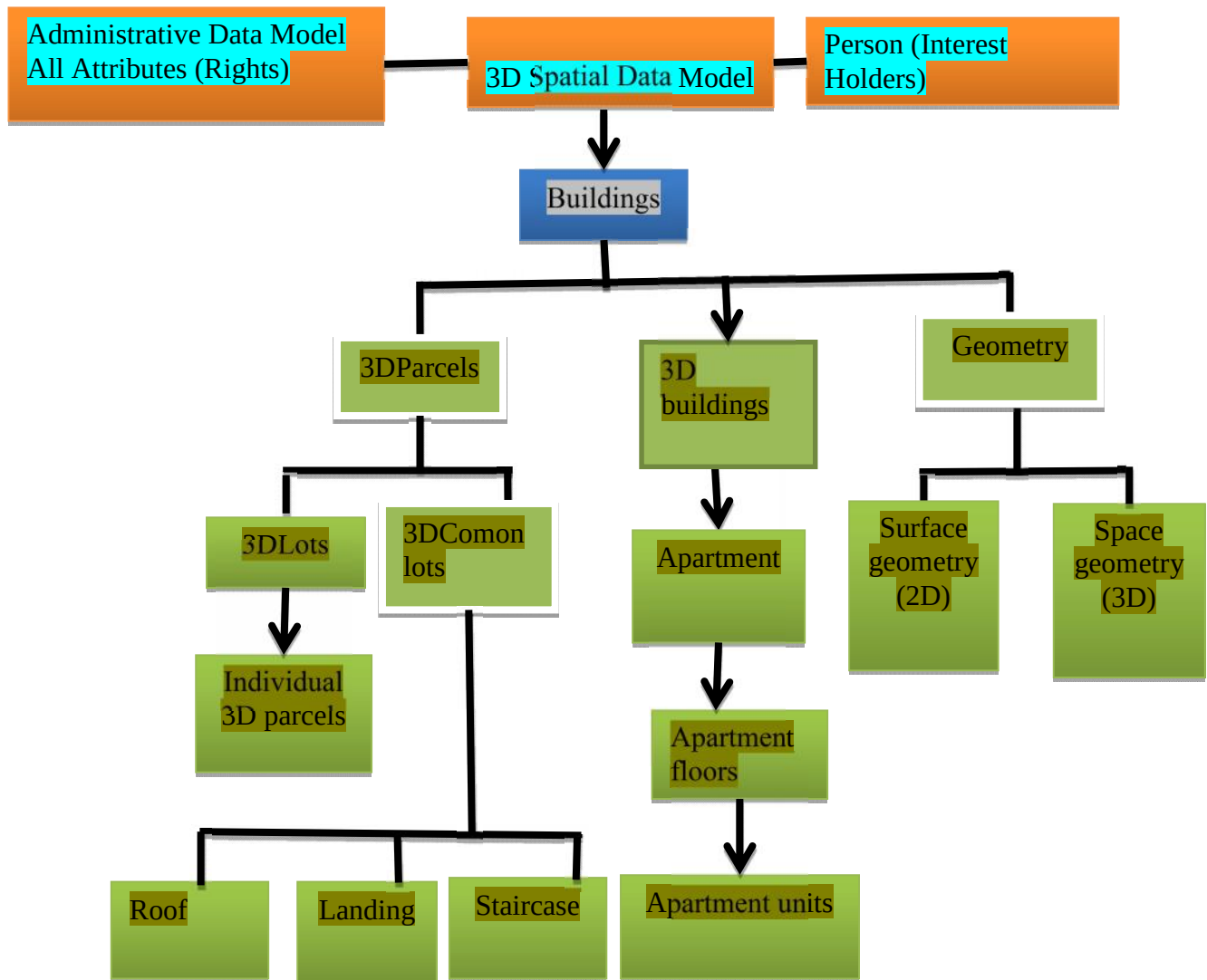


Figure 4.3 The Conceptual Model Adopted from CCDM (Christiaanlemmen et al, 2003)

4.6.2 3D Spatial Data Model

The 3D description of 3D objects initially starts with parcel boundaries in 2D. Parcel boundaries are extended into the vertical dimension using the upper and lower limits of rights. This spatial definition of 3D objects results in 3D property unit features bounded with flat faces. The height-levels are initially invariant for every 3D object (upper and lower boundaries of 3D objects are defined by horizontal planes). The representation of one elevation per upper or lower boundary is restrictive (Stoter Jantine et. al., 2004). To implement the 3D spatial data model of this research, a table was introduced that contains for every parcel on which different height-levels of properties superimposed on one parcel of land. The table contains n z-values (elevation) corresponding to relative to earth surface for every floor of parcel. In this paper, relative z-values and surface of the earth were used to develop the complete 3D cadastral models. There are three parcelation systems below the surface of the earth, on the surface of the earth and above the surface of the earth. To develop the parcel on the surface of the earth making sub division of the earth's surface into property units using 2D boundaries. To develop the parcel above or below the surface of the earth with reference to the surface of the earth using positive elevation for the above surface parcel and negative parcel elevation for below surface is necessary. So, to develop the 3D spatial cadastral data model only positive 3D objects could be registered. In this case, the space to which the owner is entitled in the second floor at elevation of 6 meter from ground floor i.e surface of the ground where the building situated can be found by adding all positive elevations that have been registered above the parcel of the ground floor. It is possible that the space that is left for the owner may also include space between two 3D objects.

4.6.3 Development of Unique Identification for 3D Parcel

According to (Jantien E. Stoter and Hendrik D. Ploeger, 2003) the 3D right-objects are identified by unique numbers that are based on the parcel number concerned. To locate a parcel in the official record (cadastral map) it is necessary to link the parcel number with the geometry of the cadastral map. The research has been used the hansa luftbid (Germany Company Addis Ababa city cadaster contractor) which adopted the unique ID to Addis Ababa city administration, according to the Ethiopian standard law No of 05/2007 and internationally (Jantien E. Stoter and Hendrik D. Ploeger, 2003) for 2D cadaster and it has been derived for 3D cadaster.

For example **TG00118CS00317G00342/2** in (Table,3.4)

rrccccscscbbAAAUUU/r

rr Region code number (TG fo Tigray region)

ccc City code number(001 for Mekelle town)

ss Sub city code number/kebele(18 for kebele or sub city code)

cscsc Condominium site code in alpha numeric(CS003 for site code)

bb Block or building code(17 for block number NQ17)

AAA Apartama or floor code per room number with in the floor(G00 code for ground floor)

UUU/r Building unit code per partition room number with in the unit(342/2 door code number)

For example the above code describes the block found at Tigray region(TG),Mekelle city(001),kebele18(18), in condominium site of endamariam adahawsi(CS003),at ground floor(G00) and house number of (342/2).

4.6.4 Socio economic Questionnaire Survey

The questionnaire survey was carried out to collect the rights (ownership rights,land use rights etc.),restrictions and responsibilities(RRR) that could be attached to the corresponding 3D parcels to provide the comprehensive 3D cadastral registration system in Mekelle city. In Mekelle city the total 122 condominium blocks were constructed in which 3287 housing units in 19 sites (Mekelle Housing Development Agency, 2013). From this total buildings 3 sample buildings were selected from 3 sites to collect about the owner type, location and owner name, land acquisition type,land use type and tax record for the development of complete spatial and non spatial 3d cadaster. Questionnaires were used as a main instrument to collect primary data from the selected sample 50 house owners who are represents total population of Mekelle city living in condominium house units. The RRR random sample systematic questionnaire survey is conducted to collect the socio economic data of the people who are living in the condominium to evaluate the capability of the 3D cadastral registration system as include the spatial and non

spatial representation, through the semi-structured questionnaire means that the data is collected in the close-ended method (appendix B).

The questionnaire is adapted in Tigrigna and Amharic language and also translated into English language to check the possibility of changing the meaning of the questionnaire. The data collection unit was every person who has a house unit in the condominium buildings among the sample.

Table 4.3 Example of the Developed Unique ID

TG	Region code number (rr)	Tigray
001	City code number(ccc)	Mekelle
18	Sub city code number/kebele	Adihawsi or Kebele 18
CS003	Condominium site code in alpha numeric(cscsc)	EndamariamAdihawsi condominium site
17	Block or building code (bb)	From Endamariam Con.Site Block NQ17
G00	floor code per room number with in the floor	From Block NQ17 at Ground Floor
342/2	building unit code per partition room number with in the unit (UUU/r)	From Block NQ17 house number 342 at that house there have two partition rooms

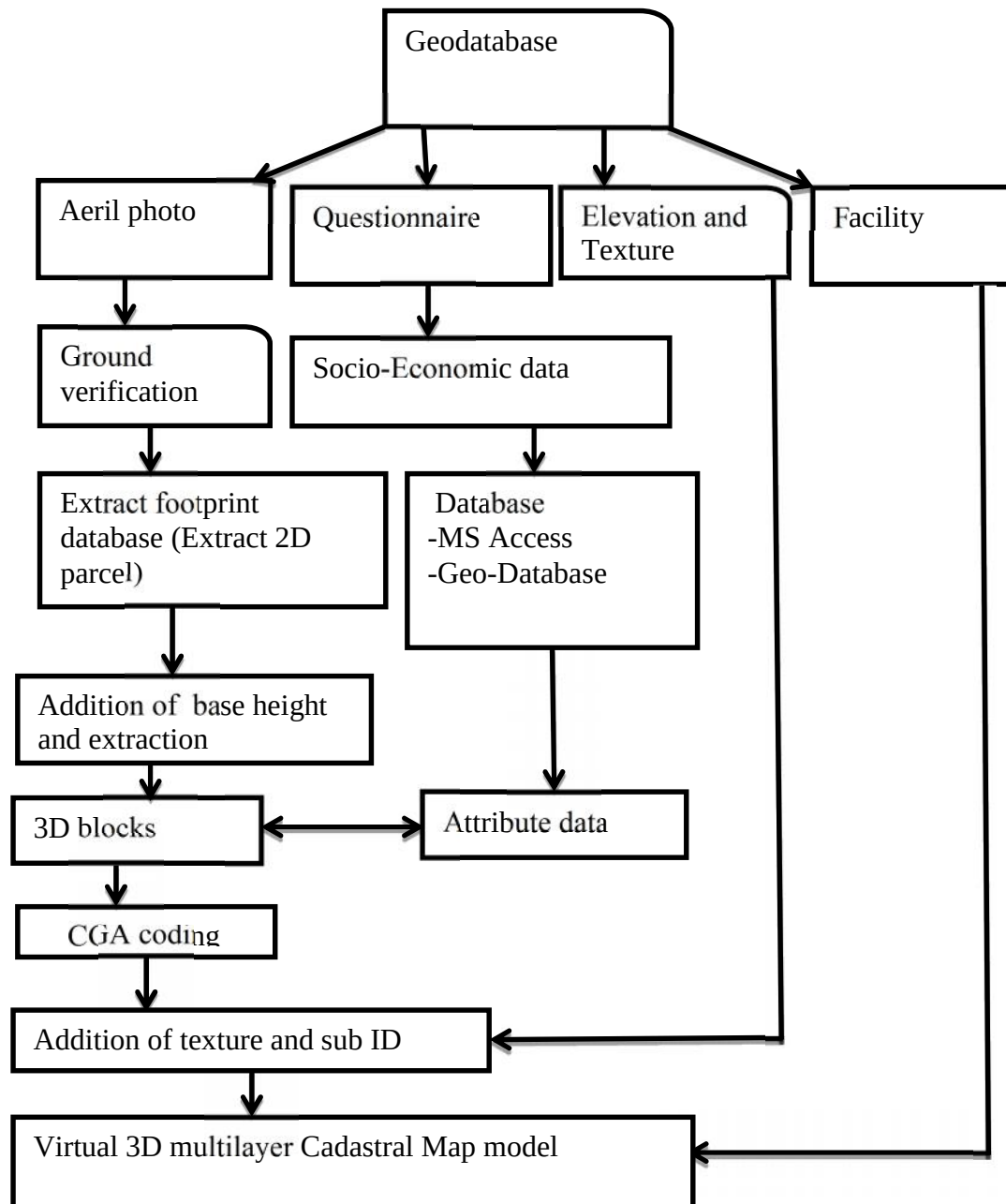


Figure 4.4 Methodological Approach Developed for the Implementation of 3D Cadastre in GIS and City Engine

CHAPTER FIVE

DATA PROCESSING, RESULT AND DISCUSSION

5.1 Development of Geodatabase

The geographic database (geodatabase) is a core geographic information model to organize a spatial data in to spatial representations. Two types of geodatabase architectures are available under ESRI's ArcGIS package: Personal Geodatabase and File Geodatabase. In this study, File Geodatabase was generated in Arc Catalog to include all the input datasets, its analysis and the final 3D registration system and 3D cadastral model with the integration of the attribute and spatial characteristics. In addition to these, a file geo-database is used to protect the data from lost and easy access in the Arc GIS tool. Thus, the extracted building footprint files were imported to the corresponding feature data sets to develop the layers of the rest building floors by changing the lower limit of the elevation i.e the surface of the earth and the raster files were exported as individual raster datasets in the file geodatabase Figure. 5.1. The coordinate system selected to be used for analysis was projected to UTM coordinate system. Thus, the geodatabase was set to this spatial reference and all extracted building footprints were projected to it while exporting/importing to the geodatabase.

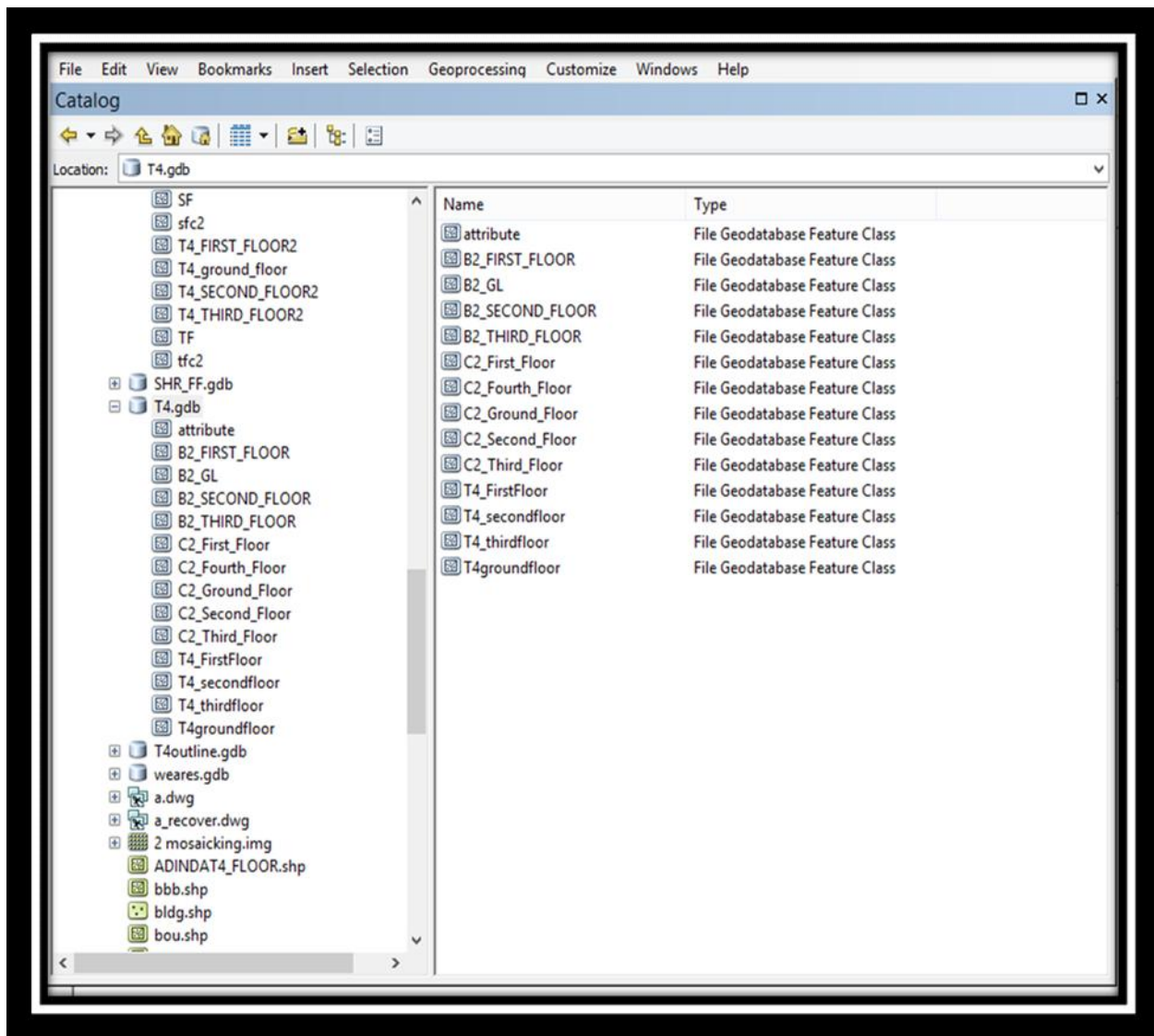


Figure 5.1 Built Geodatabase for 3D Cadastral Modeling and Registration System

5.2 Extraction of Useful Information for 3D Cadastre from Aerialphoto and CAD Design

The registration of cadastral physical object in a 3D starts with parcel boundaries in 2D. Parcel boundaries are extracted from the aerialphoto and CAD floor plans by digitizing in the ArcMap 10.2.2. Depending on the size and shape of the CAD plan the building footprint was extracted from the aerial photograph by considering the snapping issues to create 2D cadaster Figure,5.2 (a,b). Snapping issues can ensure the connectivity of objects or polygons in a vertex, edges and other end point of the two or more interconnected objects. 2D floor plans can ended be combined with section plans or with floor height information to define the 3D cadaster corresponding to 3D properties (Benoit Frédéricque , 2011). The height-levels are initially

invariant for every 3D right-volume (upper and lower boundaries of 3D right-volumes (E. Tsiliakou, 27 – 29 November 2013) are defined by horizontal planes). The representation of one elevation per upper or lower boundary is restrictive; especially when the terrain itself has relief (STOTER Jantine et. al., 2004).

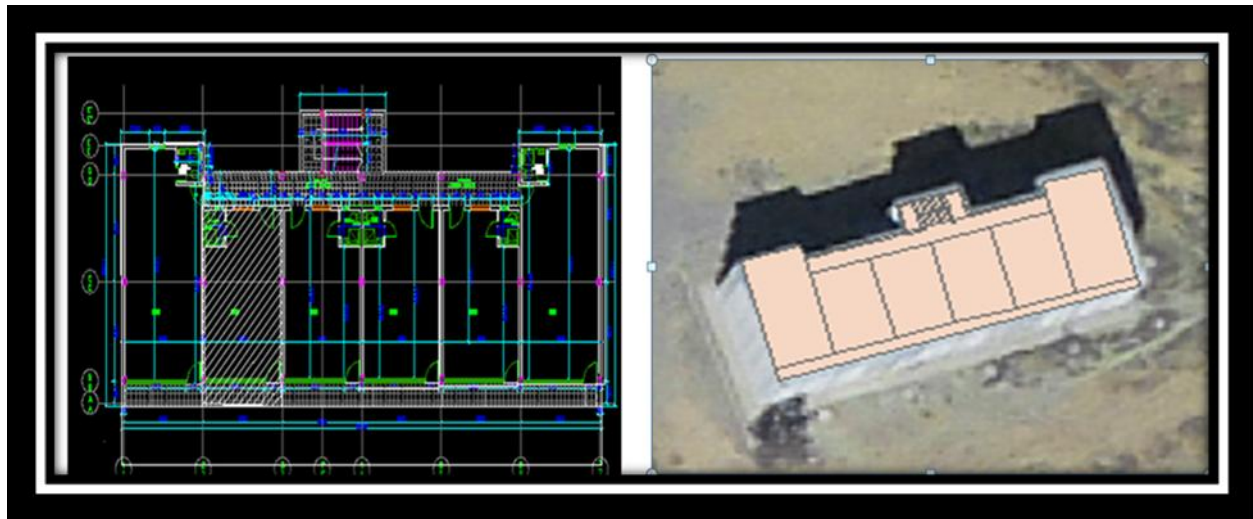


Figure 5.2 (a) Example of an Illustrative Map Cad floor with Common Areas (b) Aerialphotograph

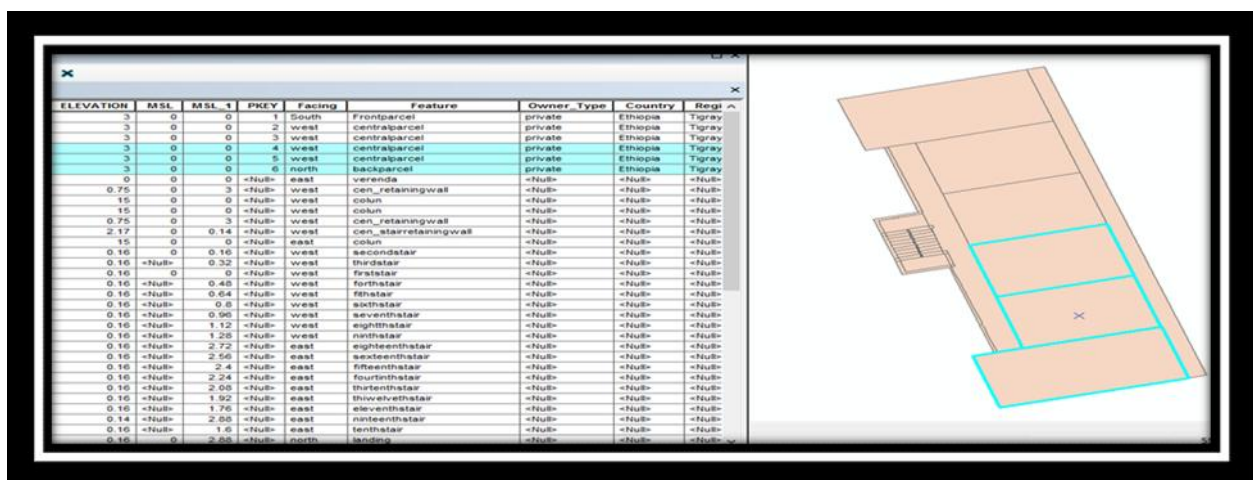


Figure 5.3 Example of the Extracted Building Foot Print with Integrated Geodatabase

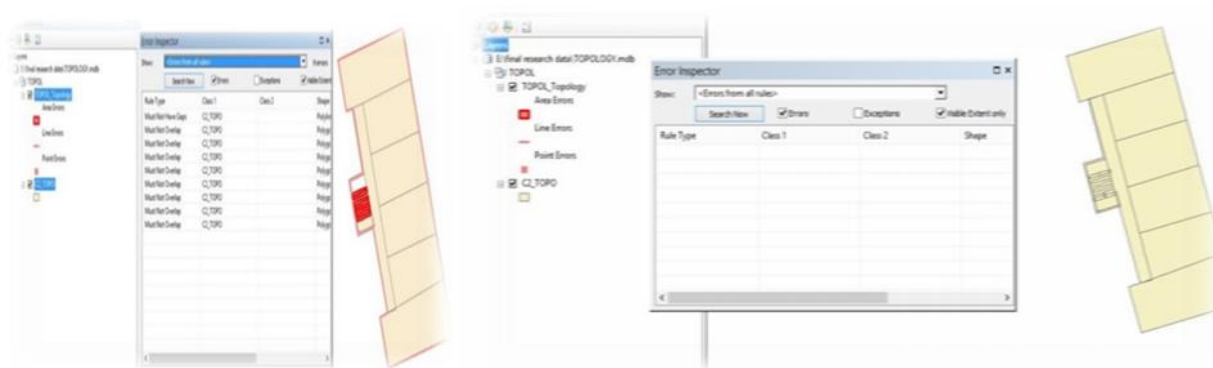
5.3 Data Validation

5.3.1 Topology Checking

A spatial object is the representation of a real-world object having spatial (topology, size and shape, position and orientation) and thematic characteristics. Topological relationships describe the connectivity, containment and adjacency relationships among spatial objects. These relationships are invariant under topological transformation, such as translation, scaling and rotation (STOTER Jantine et. al., 2004).

There are mentioned and explained issues which should be taken into account when modeling the buildings, for example, overlap (occlusion), gaps and snapping. It is important that the spatial data is checked (validated) when it is inserted in the GDBMS or when it is updated. Valid objects are necessary to make sure that the objects can be manipulated in a correct way, e.g. it is impossible to compute the volume of a cube when the top face is omitted; this would be an open box without a volume. Validating may seem quite easy for humans, but a computer needs an explicit set of rules to check the spatial data. So in this research the following rules were applied to validate features (Figure 5.4):

1. Area must not overlap another area from same layer.
2. Must not have gap; a void can't exist between areas on same layer.



**Figure 5.4 (a)The Parcel Before Topological (b)Parcels After Topological
Validation Validation**

5.3.2 Tolerance

The validation function and some of the 3D functions have a tolerance value as input Parameter. The points that make up the polygon can be slightly out of the flat plane, because of the geodetic measuring methods the finite representation of coordinates in a digital computer. To solve this problem a tolerance value has been introduced. The cluster tolerance is a distance range in which all vertex and boundaries are considered identical or coincident. This tolerance value should not be too large; otherwise invalid objects will be accepted as valid. A good value for the tolerance is the standard deviation of the geodetic measurements. So the cluster tolerance value used in this research is 0.001 meter which the default value of x y tolerance value Figure 5.5. The maximum allowable error for cadastral operation given by Ethiopian Map Agency (EMA) is 0.2- 0.25 meter. So, the cluster tolerance value used for this research is below the standard which is 1mm and it is accepted as operational parameter.

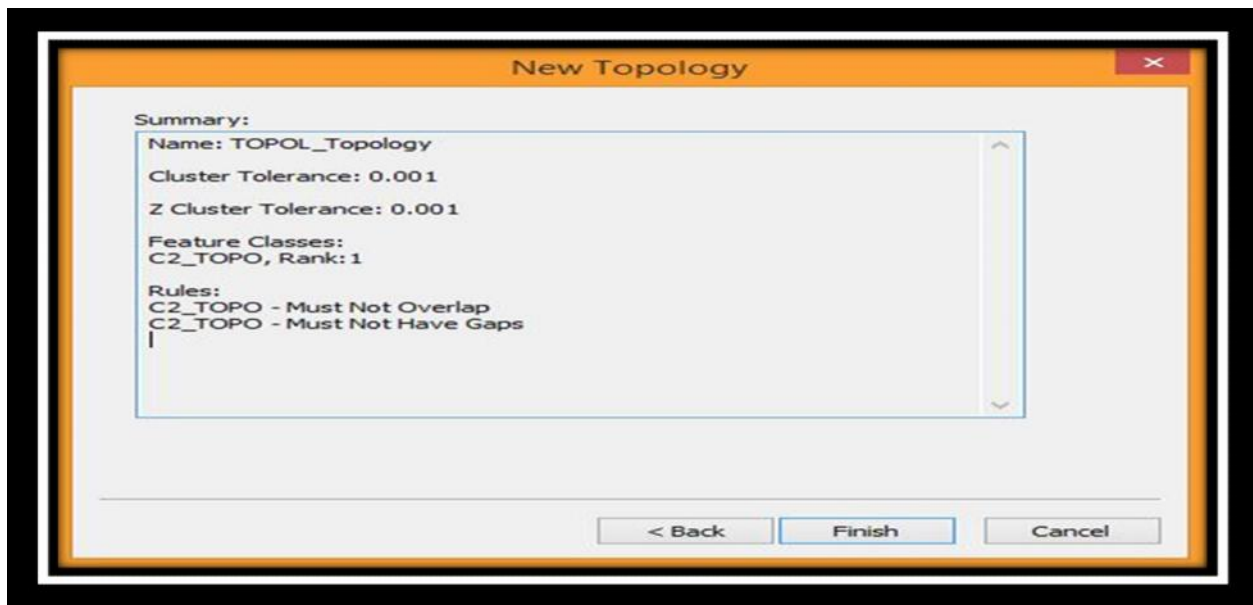


Figure 5.5 The Summery Shows the Topological Rule,Tolerance Value and Rank on the Feature

Table 5.1 Tabular Data Collected from Corresponding 3D Parcels

Owner	Ethio	Region	Zone	City	Subcity	Keb	CON	Condo	Bloc	apart	PK	House	Parcel_ID_ROOM	Owner_Name	Sex	Living	Profes	Telephon	Fam	Ma	Fem	Lease	Inddy	LandY	Annual	Paid	Sty	Con	Building_USE	
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	G00101	1	342/2	TG0018C3003017G00101342/2	Abraham Ababa	M	Mekelle	Marchant		5	2	3	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	G00102	2	343/1	TG0018C3003017G00102343/1	Alenegegn Arega	M	Mekelle	Driver	914721542	7	5	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	G00103	3	344/1	TG0018C3003017G00103344/1	Alentschay Yibelu	F	Mekelle	Self	914745717	4	2	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	G00104	4	345/1	TG0018C3003017G00104345/1	Asaw Haders	M	Mekelle	Marchant	914425301	8	5	3	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	G00105	5	346/2	TG0018C3003017G00105346/2	Tesfay Gihor	M	Mekelle	Account	914031822	5	2	3	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AM101	6	347/2	TG0018C3003017AM101347/2	Yodit Eirhane	F	Mekelle		094645072	3	2	1	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AM102	7	348/1	TG0018C3003017AM102348/1	Arayne kibede	M	Mekelle	Airporter mekelle	0913	4	2	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AM103	8	349/1	TG0018C3003017AM103349/1	Gihor Gmichea	M	Mekelle			3	1	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AM104	9	350/1	TG0018C3003017AM104350/1	Amanuel Gebre	M	Mekelle	Camera	914704556	5	3	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AM105	10	351/2	TG0018C3003017AM105351/2	Ababa Falekagi	M	Mekelle	Teacher	914734866	3	1	2	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ2101	11	352/2	TG0018C3003017AQ2101352/2	Pam Tesfay	F	Mekelle			3	2	1	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ2102	12	353/1	TG0018C3003017AQ2102353/1	Gargis Gebreselassie	M	Mekelle	Self Em	931104615	5	3	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ2103	13	354/1	TG0018C3003017AQ2103354/1	Ataklti Gebre	M	Mekelle	Nurse		4	1	3	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ2104	14	355/1	TG0018C3003017AQ2104355/1	Birhan Debakew	M	Mekelle	Tiretogi	920430741	5	2	3	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ2105	15	356/2	TG0018C3003017AQ2105356/2	Ababa nokoner	F	Mekelle	Nurse	914700150	4	2	2	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ3101	16	357/2	TG0018C3003017AQ3101357/2	Janet G/medhir	F	Mekelle	Self Em	929327248	3	1	2	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ3102	17	358/1	TG0018C3003017AQ3102358/1	zelegabriel Girmay	M	Mekelle	Marchant	914483408	5	3	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ3103	18	359/1	TG0018C3003017AQ3103359/1	zelegabriel Tekle	M	Mekelle	Contract	914747341	5	3	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ3104	19	360/1	TG0018C3003017AQ3104360/1	Tasaw Gebre	M	Mekelle			4	2	2	Lease	14	Fesiden	0.65	17.25	2002	T4	1993	residential
Private	Ethio	Tigray	Mekelle	Mekelle	Adiraki	18	C3003	Endamu	17	AQ3105	20	361/2	TG0018C3003017AQ3105361/2	Girce aregawi	M	Mekelle	Marchant	914703417	6	3	3	Lease	14	Fesiden	0.65	24.71	2002	T4	1993	residential

5.4 Incorporating the Socio-economic Data with Building Footprints

The 3D cadastral data model should not only accommodate 3D RRRs and their association with physical objects. The data model should also represent the spatial extent of 3D RRR. However, visualizing 3D RRRs alone would not adequately assist management of 3D RRRs (Ali AIEN, November 2011). A complete model consists of spatial objects as well as non-spatial attributes integrated within a system, supplying the users with a conceptual analysis of the data and explanation of real phenomena (E. Tsiliakou, 27 – 29 November 2013). The socio economic (non-spatial attributes) were collected from three sites; three different building types (design types) and each have different shapes and sizes. After the non spatial data has been collected and organized, it could be stored in the excel in the format of comma delimited (CSV) to be accepted in the Arc map Table 5.1. In this research, to see a comprehensive 3D cadastral data model, it needs an integration of the extracted footprint of every floors of the building in relation to the socio economic data which are collected from the selected condominium buildings (design types) of Mekelle city through questionnaires by providing the same primary key to the MS Access and Geodatabases. In Figure 5.6, for example the primary key of 1 in the excel is ready to incorporate with the primary key of 1 in the geodatabase in order to express the full integration of spatial and non-spatial characteristic of the specific parcel within the condominium building of Ayder site.

In Figure 5.7, there shown an integrated system of the spatial object and its characteristics i.e. non spatial attribute within one system where we collected from the corresponding individual rooms of the selected building design types within the condominium through the questionnaires. So in both tables there have a common field used to integrate the two tables in one geodatabase.

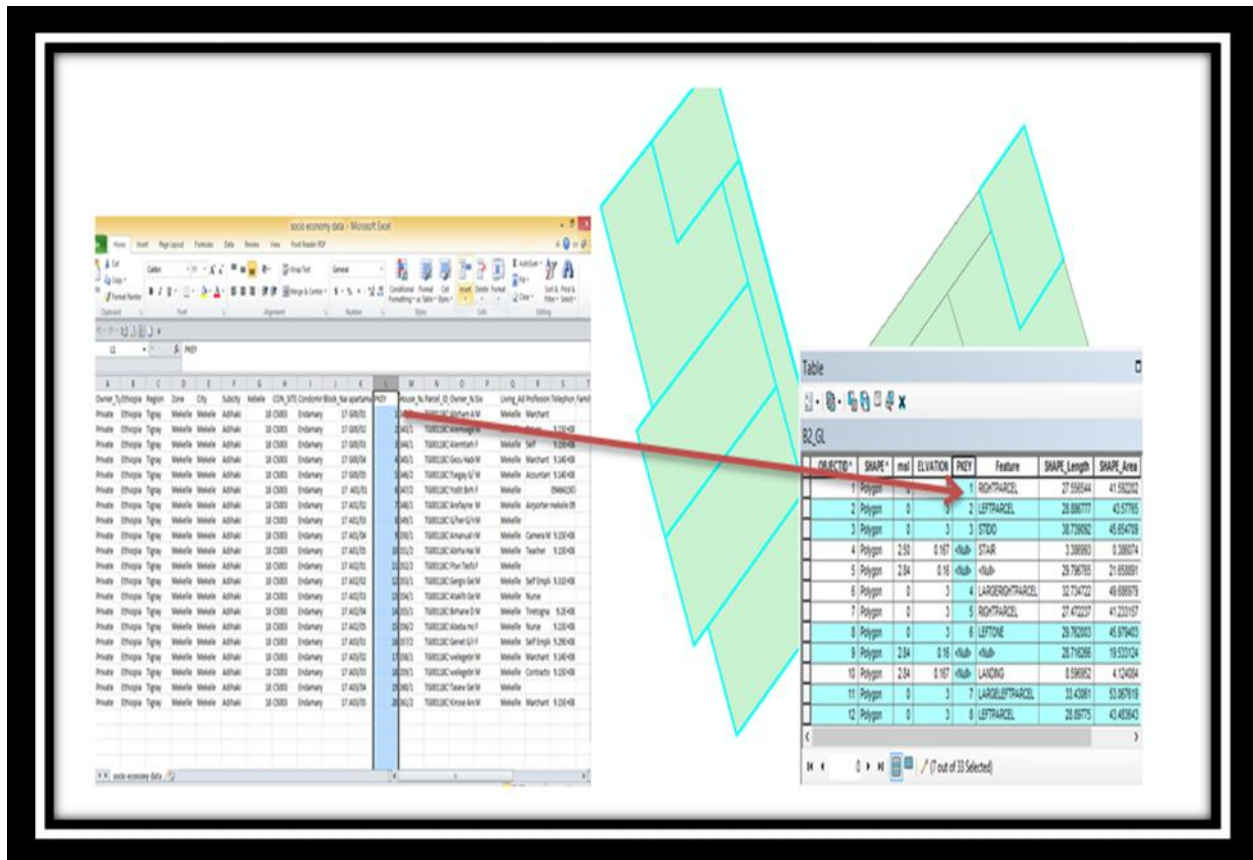


Figure 5.6 Overview of 2D Non-spatial and Spatial before Incorporated

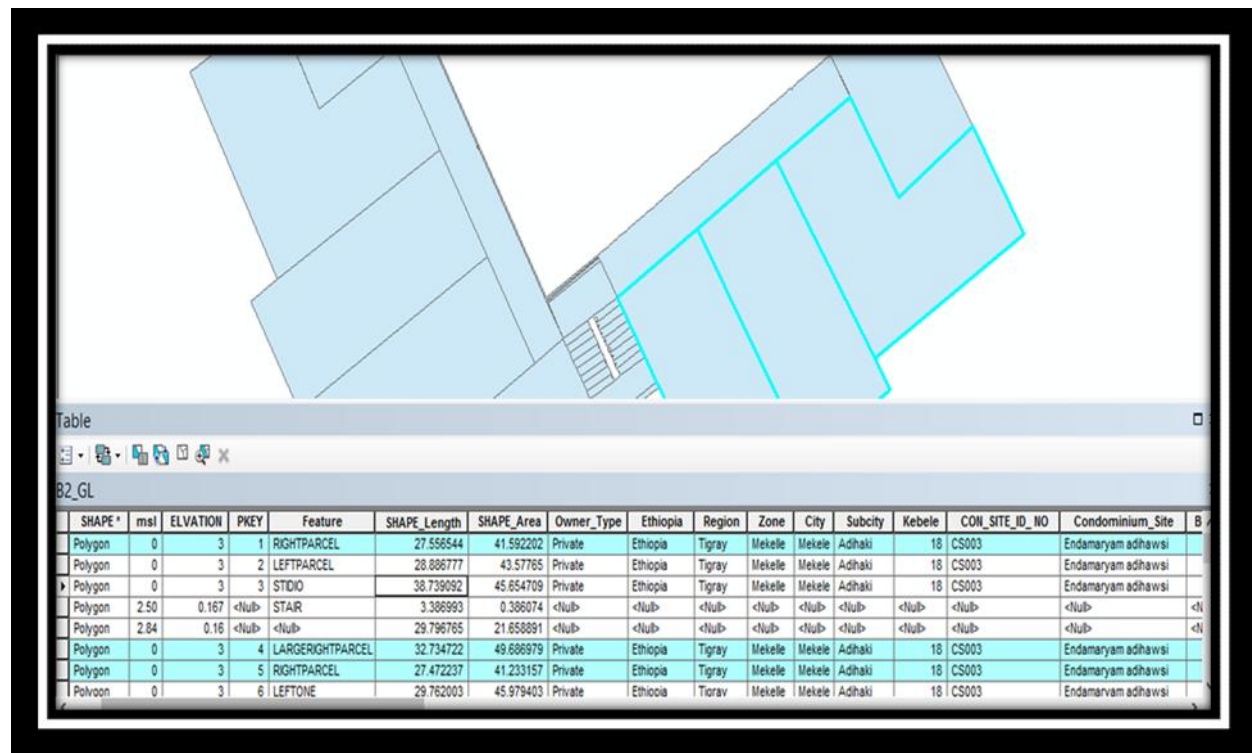


Figure 5.7 Overview of the Incorporated 2D Spatial and Non-spatial Data

5.5 Extruding building floor plans with respect to the earth's surface

For every parcel on which limited real rights or apartment rights are registered, a z-list is generated, that defines the upper and lower limits of (limited) rights (and apartment rights) established on the specific parcel (Stoter, 2004). So, for this research, two types column list are prepared in z-list table to define the lower limit used as an initial elevation which is represented as surface of the earth in this table and the elevation which defines the extent (the range b/n the consecutive elevation) of the right from the initial surface of the earth to the upper right of the owner for each parcel as shown in Figure 5.9.

The elevation data are derived from the section plan of the condominium design of that specified building which is found from the housing development agency of Mekelle city as shown in the Figure 5.8.



—

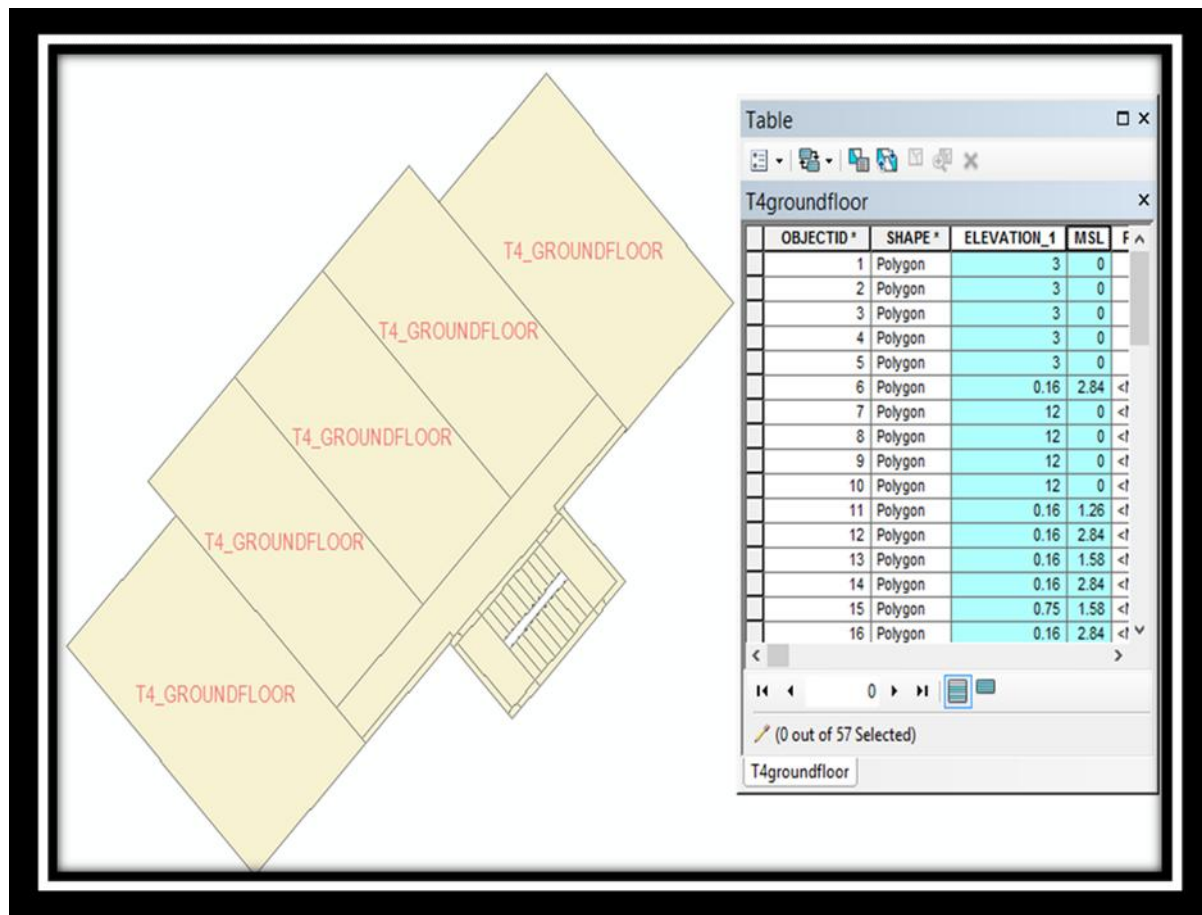


Figure 5.9 Addition of Elevation to the Building Footprint

To add another layer a first floor in this case, it should be added 3 meter height to the earth's surface of the ground floor as shown in (Figure 5.10) to create the first floor. The black arrow indicating the addition of elevation to the foot prints to create the next layer (floor) of the building. The two red arrows indicate the extrusion of footprints using the parameters of initial elevation and elevation.

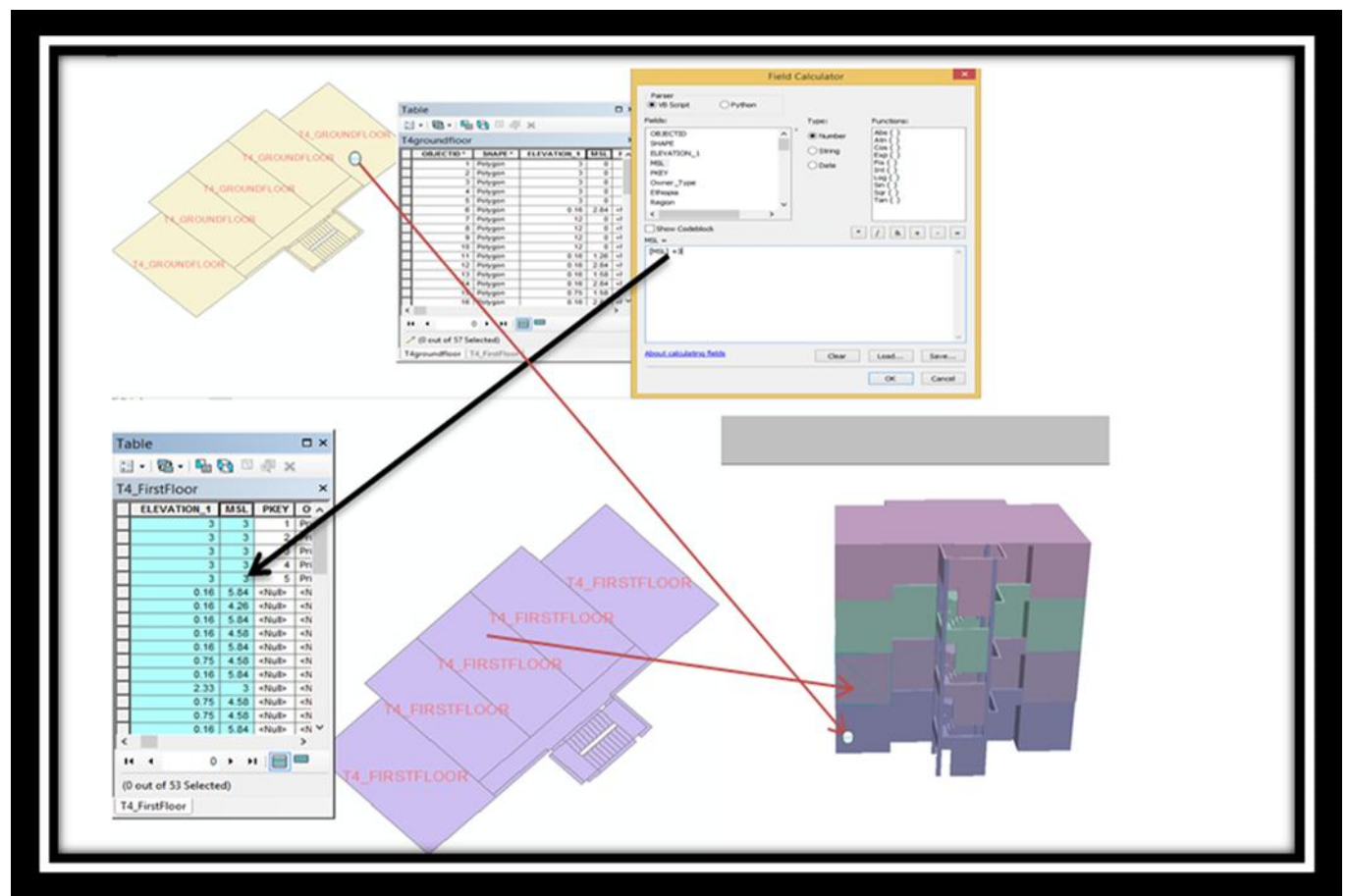


Figure 5.10 Procedural Preparation of 3D Data in Arc GIS

Finally the layer of the first floor as shown in the (Figure 5.10) was extruded from ground floor and so on for any more floors to prepare the 3D cadastral data that are digitized from the aerial photograph. This developed 3D graphical model is not enough to manage the condominium building of Mekelle city because it is merely shown 3D physical objects. So it needs further modeling parameters and procedures to find the efficient 3D cadastral model in more realistic manner. For this reason, Esri city engine has been used to construct a complete 3D cadastral data models and registration system that can handle the spatial and non-spatial data integratly. Generally, GIS is used to prepare data that are used for the pre-model 3D data which will use as an input for city engine software.

5.6 Esri City Engine Software as a Tool for Procedural Modeling

The best method for need to create a large size 3D city model in a short time and with low expenses is procedural modeling, which are a 3D model creation using rules and algorithms. It is a cost-effective solution for generating 3D urban contents (Watson et al, 2008).

Procedural modeling in the software Esri City Engine has been mainly used for creating a 3D model of urban areas. The modeling is based on CGA (Computer Generated Architecture) rules. CGA is a scripting language quite appropriate for generating architectural 3D content (Parish, Y.I.H. & Müller, 2001).

3D modeling is an Image-Based modeling which can model objects with different sizes and shapes and get the information of building elements and texture at the same time. There are several researches in the field of procedural modeling for cities and buildings already made. For example, research by (Parish, Y.I.H. & Müller, 2001) in which they introduce the system “City Engine” which is appropriate for modeling the whole city using comparatively small set of statistical and geographical input data. A detailed description about the creation Process of lots of buildings is using the shape grammar (CGA shape). CGA shape is a shape grammar used for procedural modeling of CGA to produce building shells including high visual quality and geometric details. It is based on production rules to develop a design by creating more and more details of the shapes which consist of symbol, geometry (geometric attributes) and numeric attributes. Geometric attributes such as the position P, the coordinate system describing orthogonal vectors X, Y, Z and the size define an oriented bounding box called scope (Figure 4.11). Scopes are used in the rules to make modifications, for example, a rotation of the shapes.

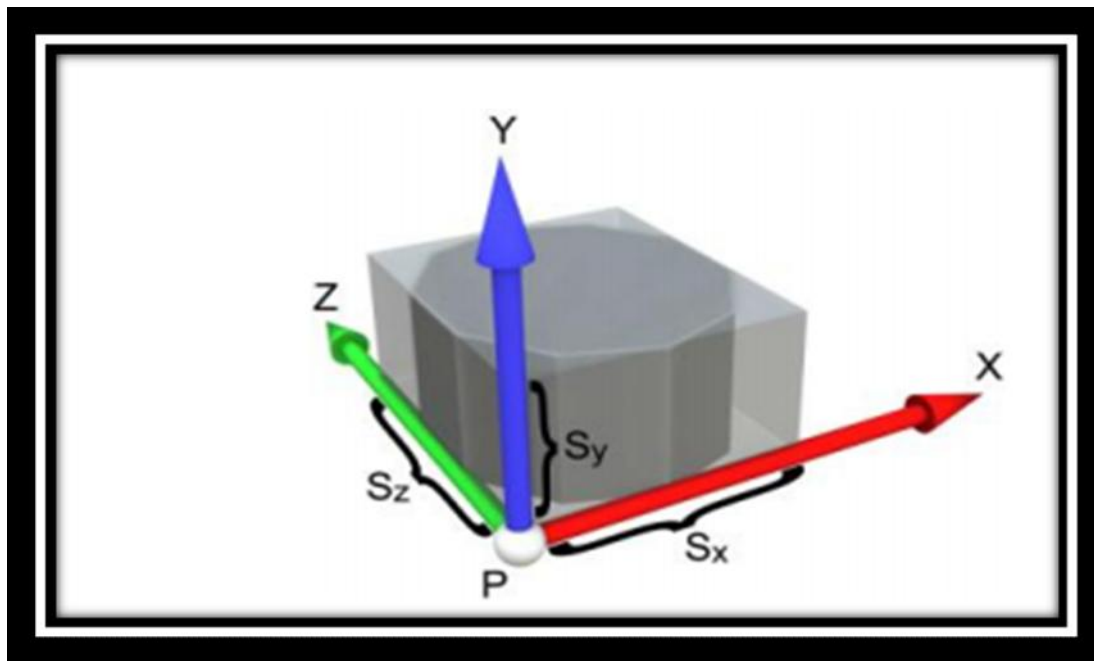


Figure 5.11 The Scope of the Shape (Müller et. al., 2006)

Example of code generated in this project

```
case Feature == "B2_Cen_parcel1": B2_Cen_parcel1
B2_Cen_parcel1-->
extrude(3)
comp(f){back:S_otherside_ent|left:wall|right:wall|front:cen_1|top:Top|bottom:
Bottom}
S_otherside_ent-->
split(y){2.7:osS_base|0.3:beam}
osS_base-->
split(x){1:wall|1.5:T4_G_B_win|1:wall|1.5:T4_G_B_win|1:wall|1.5:T4_G_B_win|~1
:wall}
setupProjection(0, scope.xz, scope.sx, scope.sz)
setupProjection(0, scope.xy, 2.5, 2.5)
```

3D models created in the City Engine have different applications, for example, in a cultural heritage, urban planning and in a movie industry. Procedural modeling can be applied in the 3D urban content creation for video games as well (Watson et al, 2008). The software City Engine, Procedural modeling principle (Figure 5.12) is based on shape grammars with production rules to generate detailed 3D objects from a simple initial geometric features. It starts with the extrusion of the initial shape to a block model which is later divided into shapes, for example, front face ,side view and a roof. To create a high level detailed model, created shapes are split into elements, for example, windows and doors, and textures or colors are added to these elements.

5.7 Data Import into City Engine

After the pre-processing in Arc GIS 10.2.2 are completed, import the data into software City Engine can be started. It starts with a creation of a new scene and setting a coordinate system of it. For this project, Adindan UTM zone 37 transverse Mercator was chosen. There were different types of data imported, for example, the selected condominium building footprints of Mekelle city and the locations of vegetation were imported as file geo database and the height map were imported by masking the surrounding of the selected building from the aerialphoto of the study area to take the relative height as file of TIFF format.

5.8 Steps of Procedural Modeling Using City Engine

Creation of the 3D model using procedural modeling was done with the software Esri City Engine 2014. Procedural modeling process in City Engine software starts with a rule file creation. “A rule file is a collection of attributes, functions and rules”. Rule files can be created as scripts (**Appendix A**) or graphically (Figure 5.13).

At the beginning user has to define all the attributes, constants, functions and textures which will be necessary for further modeling process. Attributes, functions and constants are used to control the operations defined in the file and they work as parameters to the operations used for modeling. Parameter values can be set or changed by user as well in the Inspector window. It gives user more control over modeling process. When starting to write the rule, the initial shape from which the generation process begins should be defined. It can be created with City Engine tools or created in other software and imported into City Engine. The final 3D result is a result of a sequence of transforming operations (for example, extrusions, rotations, etc.) applied on the initial shape. When the rule file has been created, it is applied to the initial shapes and the 3D content is generated.

5.9 Development of CGA rule file

The scripting language CGA (Computer Generated Architecture) which defines the rules or procedures to create a 3D content is the core of this software. City Engine can be used for the whole procedural modeling development cycle because it includes tools for setting up the scene with pre-existing data, modeling street and lot geometries, writing and analyzing the CGA script files, applying the CGA files to create 3D models and exporting the created models for further processing (Viinikka, 2014).

Two primary attributes which connect the initial shape (Building Footprint) to the procedural generation process are “Rule file” which defines the CGA rule file assigned to the initial shape and “Start rule” which defines the production rule from which the creation process begins. Other attributes which describe the initial shape (for example, buildings heights, number of floors, roof shapes, etc.) can be used as parameters in the CGA production rules (Viinikka, 2014).

This research has prepared 2D data in GIS and the CGA rule file in city engine to produce a 3D cadastral registration system that manage the condominium of Mekelle city. The registration system contains the high quality 2D geometry and the attribute data with the procedurally defined rules. The rule file also developed to provide texture data which is taken from the photograph collected in the site during ground verification. Figure 4.12 shows the example of 2D data for Mekelle City condominium building which consists of building footprints and texture data (photographs).

Figure 5.13 shows the graphical representation of the rule file developed for the selected condominium building of Mekelle city in the City Engine software. It consists of the attributes, the constants and the textures defined and the rule.

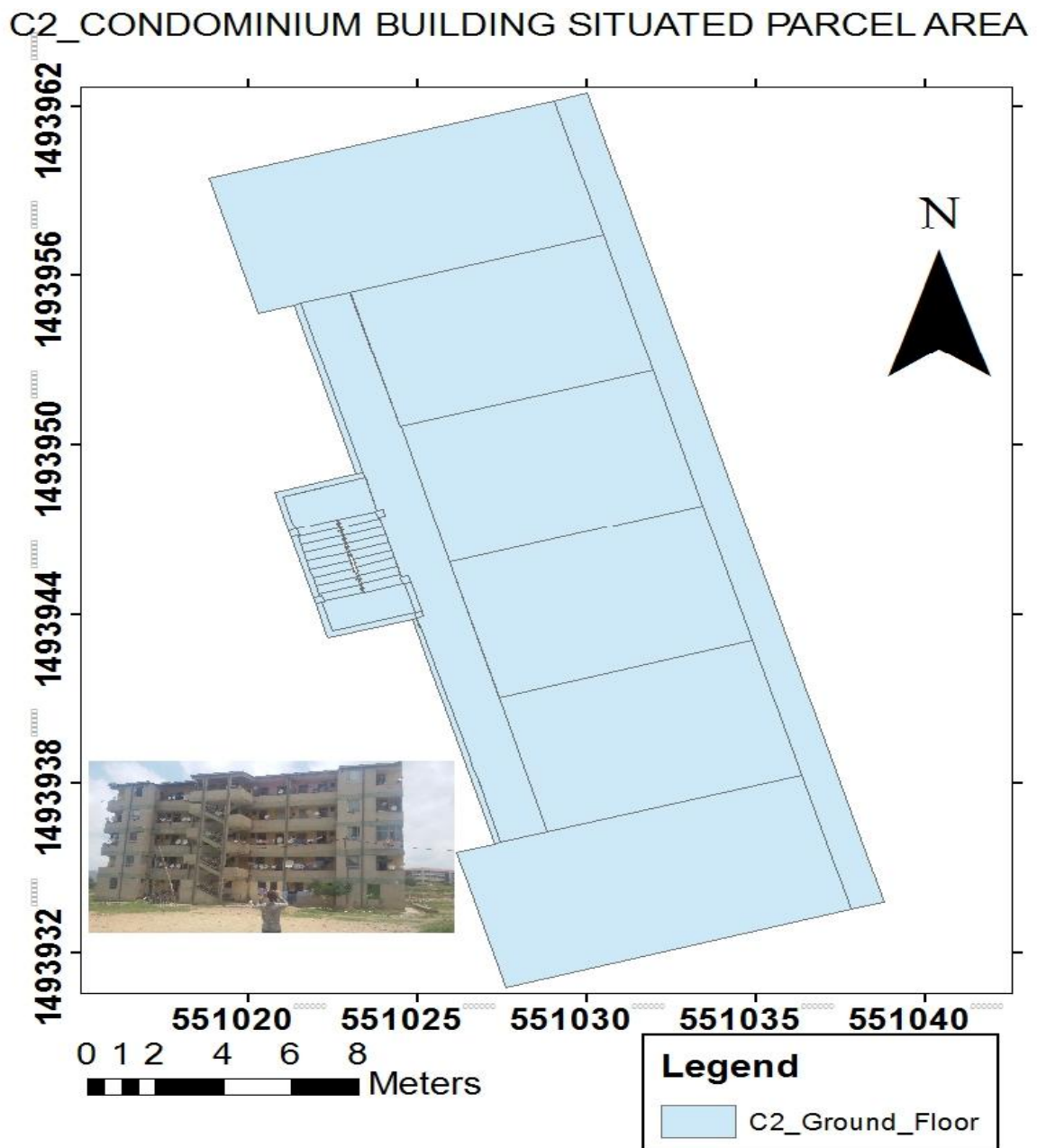


Figure 5.12 2D Foot Print and Texture of C2_Condominium Building



d



5.10 Esri City Engine as a 3D Cadastral Registration System

According to (Watson et al, 2008), Esri City Engine is one of the most mature procedural modeling tools which are available. It is stand-alone software which transforms 2D GIS data into smart 3D City models. It improves urban planning, architecture and design. City Engine combines procedural modeling methods with shape and split grammars to generate a 3D content. Shape grammars perform recognition of a particular shape and its possible replacement. The shapes which will be replaced and the manner in which it will be done are specified by using rules. Split grammars split a 3D object into its components, for example, faces, edges or vertices. For a successful use of shape and split grammars in the modeling process two following steps should be taken into account and completed. The first step is the acquisition of a good understanding of basic building elements such as windows, doors, columns, walls and others. The next step is the creation of grammar rules to combine these basic elements (Watson et al, 2008).

The user interface of City Engine consists of several windows. A typical modeling session includes (Figure 5.16):

- 1 “Scene Editor” window where the user can manage the scene, it is organized in layers.
- 2 “Rule Editor” window where the CGA scripts are generated. “Rule Editor” can have a text and a graphical view.
- 3 “Viewport” windows where the generated 3D content is displayed.
- 4 “Inspector” windows which gives a detailed view editing possibilities of selected objects. Within this window there are object attributes which are spatial and non-spatial descriptions
- 5 “vertex” windows show the X, Y, Z records. They are classified as information orthogonal coordinate system of the selected object.

- 1 “Navigator” window where all the files are stored. In this section user can manage and preview files in the workspace as shown (Figure 5.17).

5.11 3D Data Validation

During the modeling process different errors may be created while generating buildings. For example, too many vertices were created for one building and on the wrong positions, buildings elements were mismatched with the imported windows and/ or doors were created at the wrong position due to unnecessary vertex created during digitization of the Buildings footprints, and problems occurred with creating roof overhangs. Further, these problems and their solutions are described in Figure 4.15a,b,c and d.

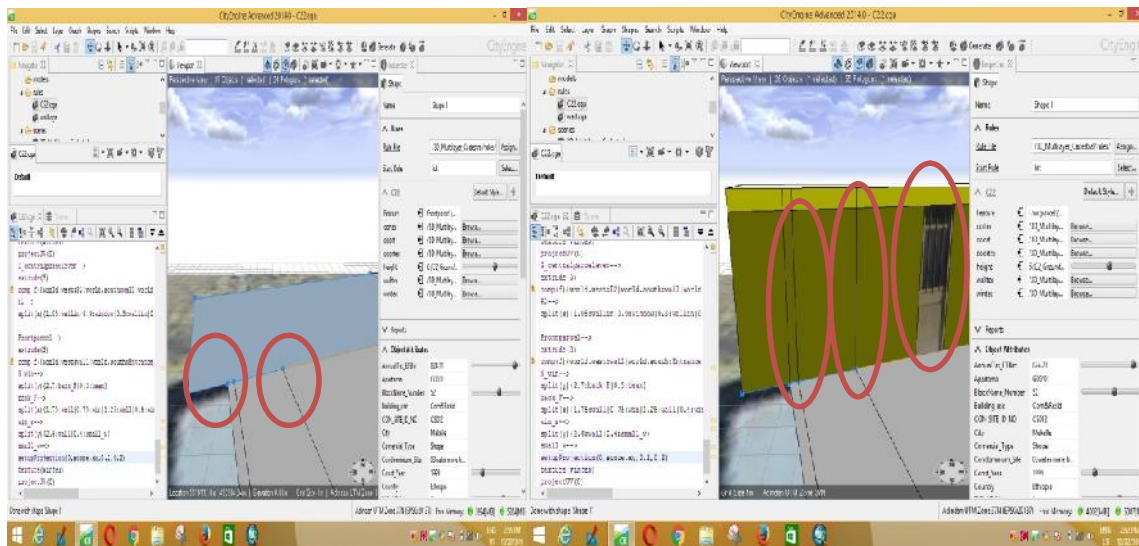
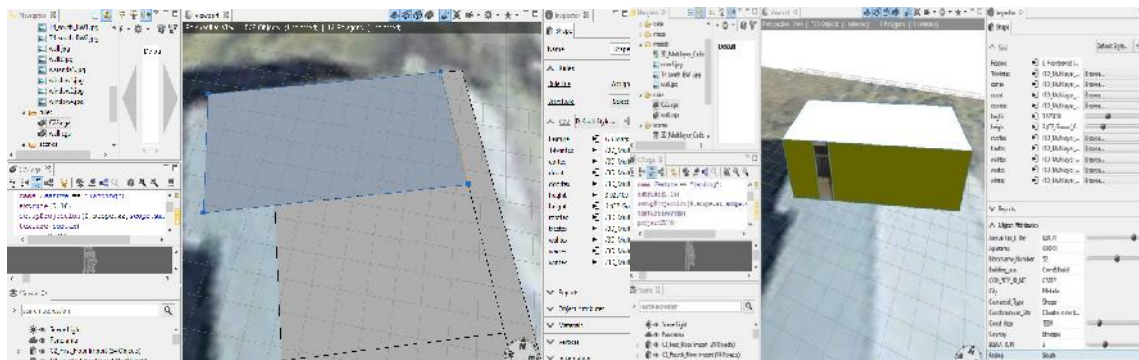


Figure 5.15 (a) 2D FootPrint Vertex Error Creates (b) Wrong Position of 2D Vertex Resulted in Wrong 3D Position



(c) After Removing Vertex Error of 2D FootPrint (d) Validated 3D Object with Correct Position of Door

The extra vertex creates unnecessary lines and puts the door in a wrong position on the 3D cadastral objects. After the extra vertex is removed the door becomes to the correct position according to the rule and algorithms developed in the registration system in city engine software. Finally, the parcel remains with four vertex which represents the four corners of the footprint of the 3D objects. In this case, it was done manually, looking through the whole model. The manual mechanism is by selecting and deleting the extra vertex to be remain in four vertex for the rectangular building footprints.

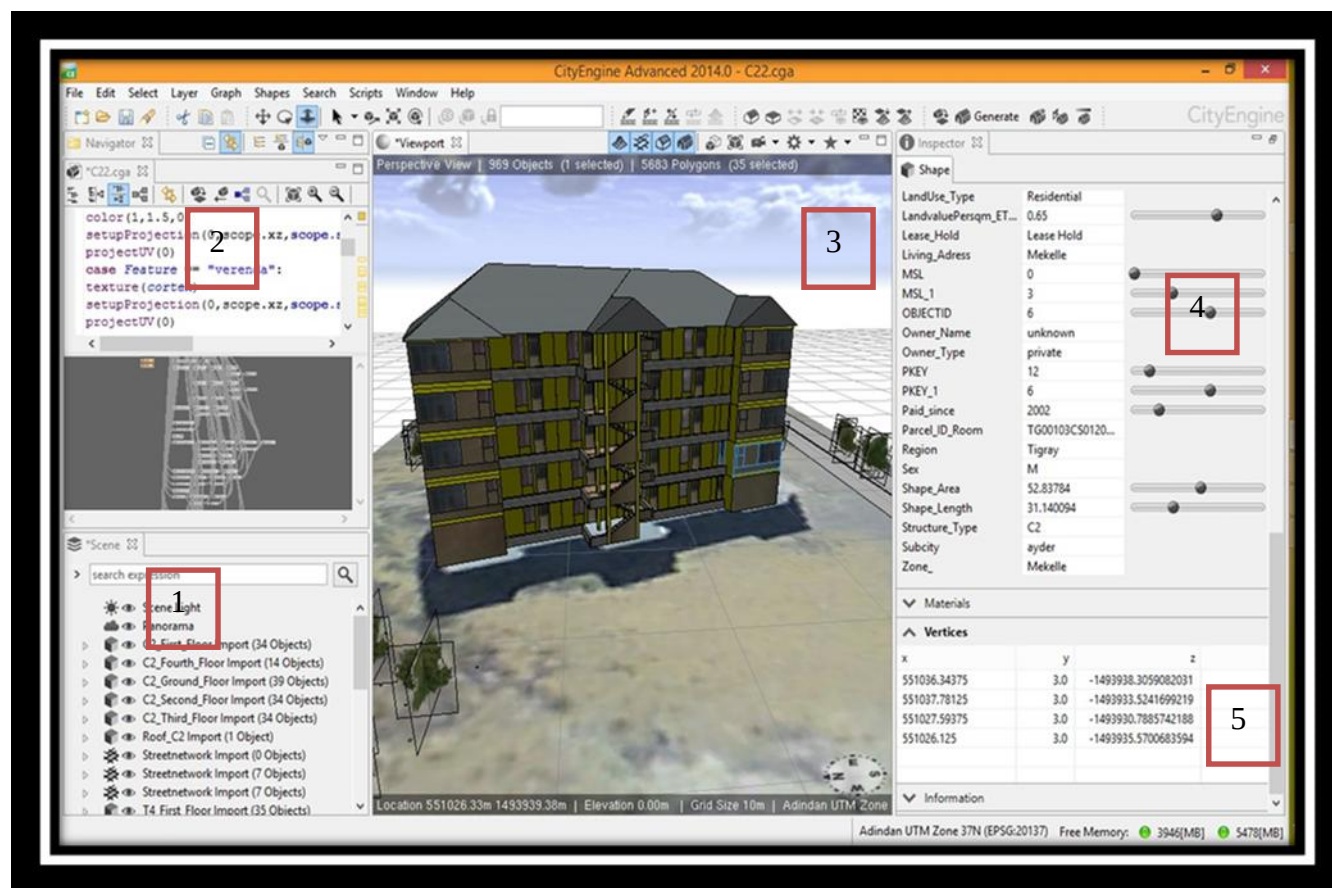


Figure 5.16 The 3D Cadastral Registration System

As shown in Figure 5.16 the developed physical object which is represented by number 3 for the condominium building in Mekelle city in ayder subcity and at the site of 03 water mine bureau. Within this condominium building, there are 30 owners. This condominium building is G+4 building i.e it has a height of 15 meter and the upper limit of one owner is 3 meter. So that, there are 5 owners living in the same latitude and longitude and which are separated only by elevation, so this system has a capable to register the individual owners by providing the

orthogonal coordinate system i.e X,Y,Z as shown in Figures 5.15 and 5.16 and represented by number 5 and 6 respectively. The difference of the two owners (objects) is the elevation of 3m and 6m. The coordinate and the attribute shown in the window inspector (represented by numbers 4 and 5 in Figure 5.16 represents the highlighted object in the registration system.

This developed registration system allows the user to interact with the following data base management operations:

- Insert: add new data to the database e.g insert the owner name of the house
- Retrieve: make a whole data set available to the user;
- Delete: remove data from the database;
- Update: change existing data
- store and selection

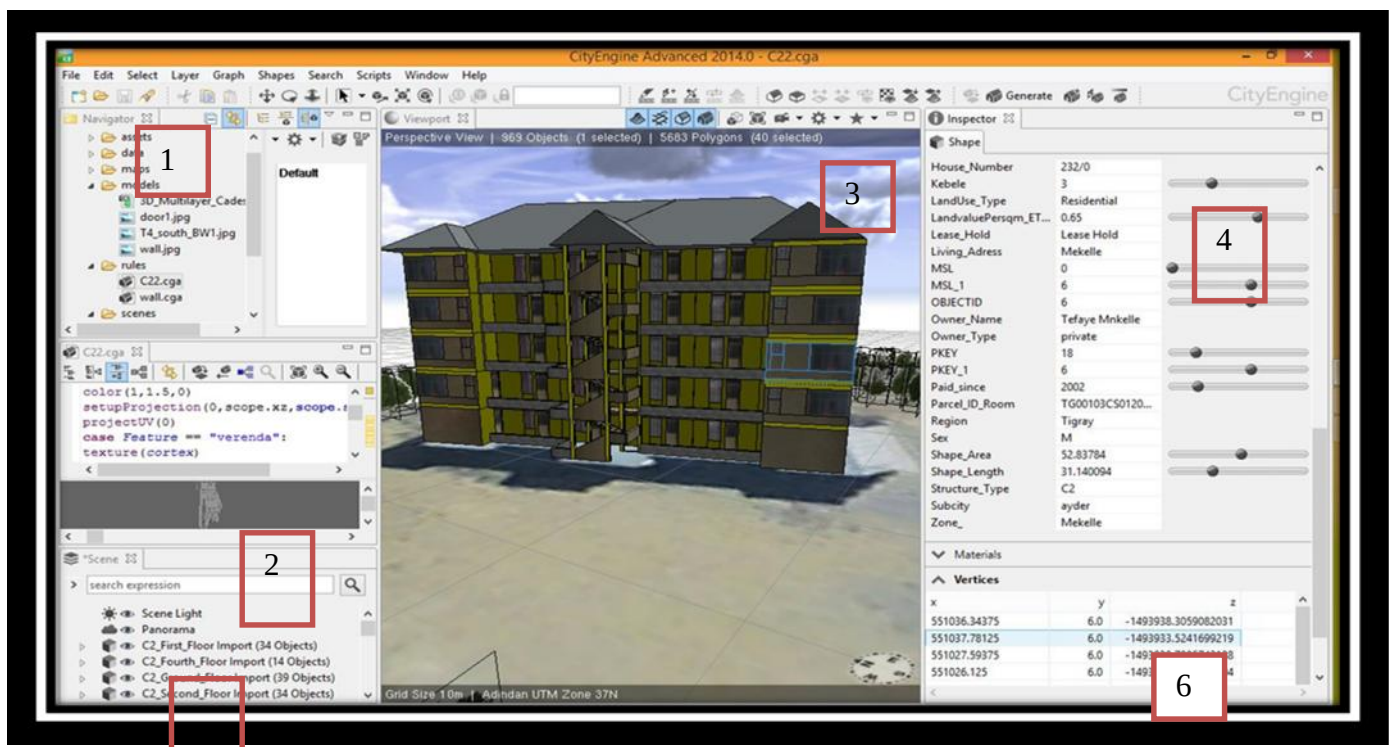


Figure 5.17 The 3D Cadastral Registration System

The 3D cadastral registration systems represented in Figure 5.16 and 5.17, only difference in elevation, in case of positional orientation of the highlighted objects in the system. The latitude and the longitude of the two highlighted object are the same but their elevation are 3 and 6 meter

one piled on the other as shown in Figure 5.16 being represented by number 5, and in Figure 5.17 being represented by number 6. The two highlighted 3D objects are entitled to two different owners and they have different attributes.

The registration system has two options:

- The registration system which is allowed to the authorised body can be editable. During legal transferring of the houses to the user the expert can insert the name and other necessary information or delete the unnecessary information to/from the associated database.
- The registration system which is allowed for the user can be uneditable but it can query, visualize, retrieve and print. This can be viewed through esri web scene.

5.12 Retrieving a Model of 3D Cadastral Maps of the Single Houses from the Condominium Building

According to (Benoît Frédéricque , 2011; A. Aien et .al. , 2012), 3D cadaster should be capable of storing, manipulating, querying, analysis, updating and supporting the visualization of 3D property rights, restrictions and responsibilities. A 3D aspect should exist in any modern system. According to this principle, this research is designed to fulfill the above principle in Mekelle city and tested using three condominium buildings. There are 82 owners (30 owners in C2 building, 20 owners in T4 building and 32 houses in B2 building). Within the condominium buildings 50 owners are registered associated to their 3D physical object with its full administrative descriptions and model of 32 house units are developed and ready to be transferred to the user. The system will register the ownership rights after transferred from government to the respective owners. The registration system assigned unique identifier to enable reliable transfer allocation based on ID.

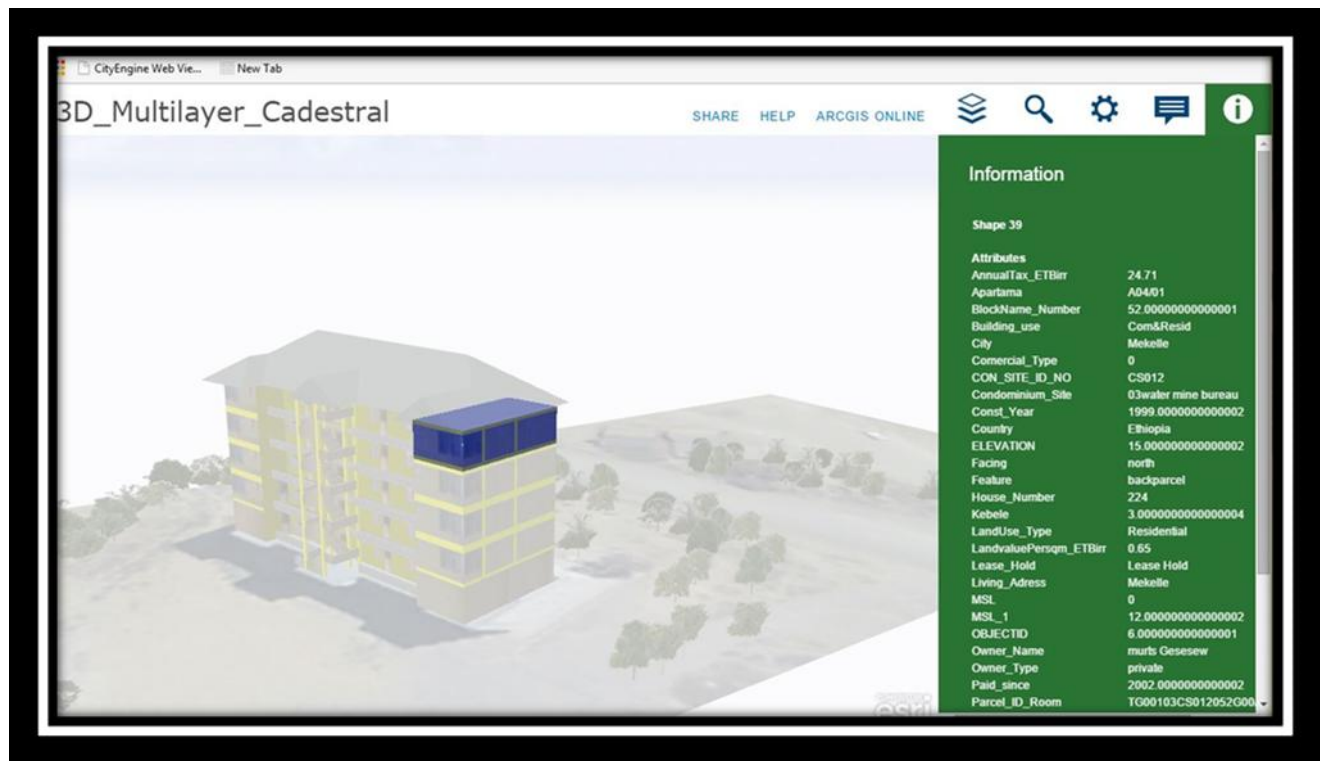


Figure 5.18 Spatial and Attributes Information of Single Houses from the Building



Figure 5.19 Many 3D Parcels Held by one Person

This system is used to display or retrieve a complete information of all the three dimensional(3D) objects that are registered on his or her name when it is searched using the owner name of 3D objects. For example, as shown in Figure 5.19 the owner of the 3D objects of Arefyine kebede owns four condominium houses in different site and buildings within the city. In this case arefayine has one condominium house from o3water and mine bureau site in the building type C2 as shown in Figure 5.19 and at block number 52, and the three houses as shown in Figure 5.20 are in the site of endamariam addihawsi from building type T4 at block number 17. When it is searched using the owner name as a search type, the registered objects on his name are retrieved as shown in Figure 4.19 and displayed as follows: On Figure 5.20 and 5.21.

Search

arefayin kebede

4 results found

Shape 125

Owner_Name is Arefayne Kebede

In layer C2_Third_Floor Import

• **Shape 156**

Owner_Name is Arefayne Kebede,

In layer T4_First_Floor Import

• **Shape 231**

Owner_Name is Arefayne Kebede

In layer T4_Second_Floor Import

• **Shape 266**

Owner_Name is Arefayne KebedeIn layer

T4_Third_Floor Import

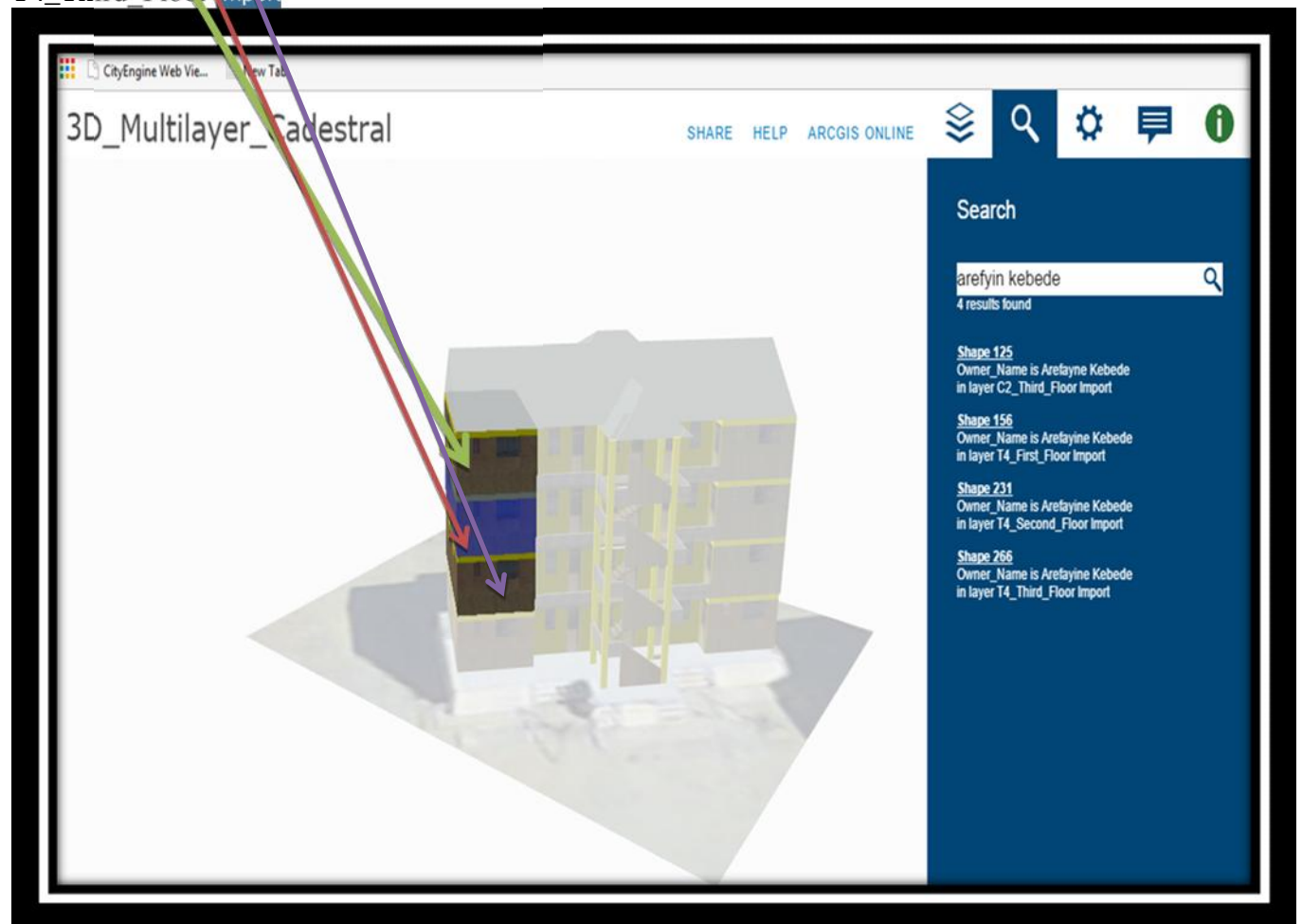


Figure 5.20 The Visible 3D Objects Belongs to one Owner Represented by Shape Number

-

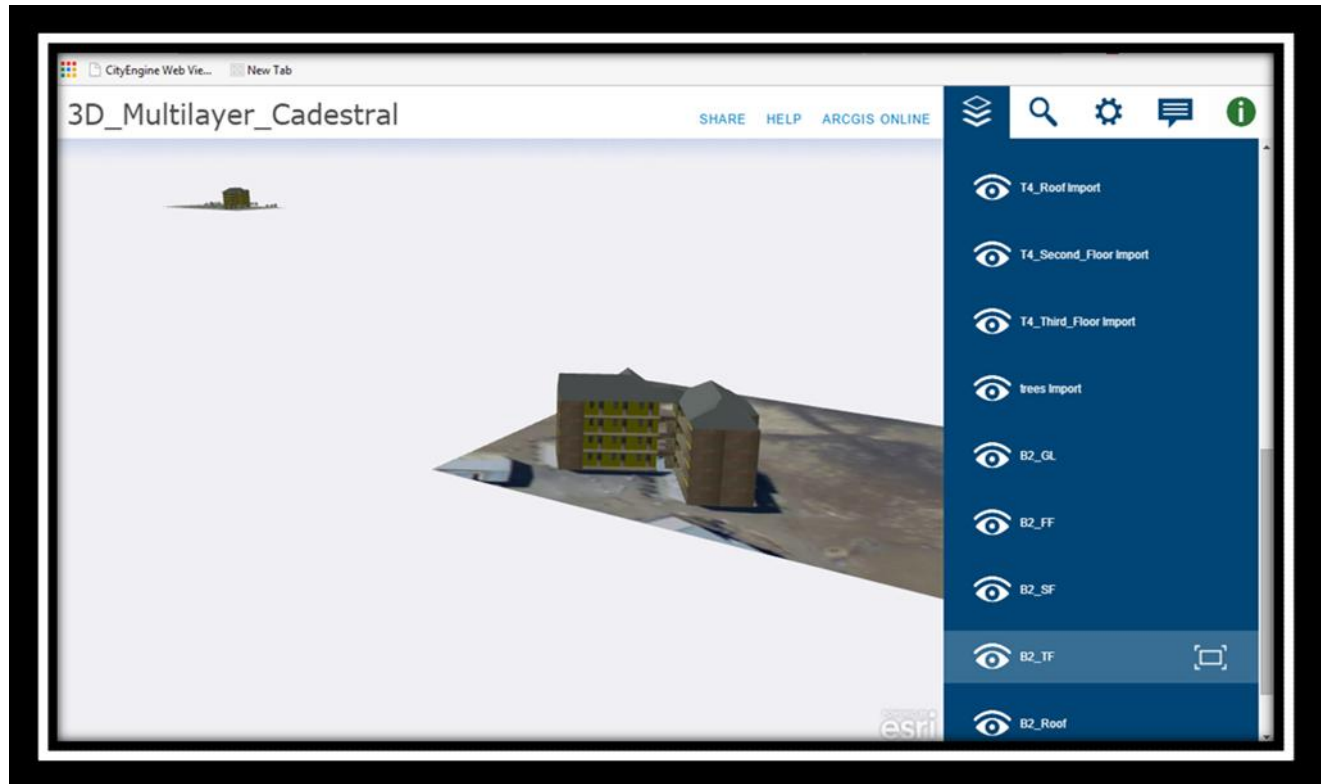


Figure 5.21 3D Parce Cadastral Registered System

The final result of the process is exporting of the created 3D model to another 3D application which the 3D content can be viewed and shared online using Esri Web Scene.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion the creation of new geospatial software packages and their interoperability with the current standard of geodatabase and ICT technology was leading to develop a new 3D cadastral registration system. In this case, procedural based, Computer Generated Architecture is employed through Esri's City Engine to create 3D multilayer cadaster and 3D models with easy to maintain and store the 3D reality with its appropriate geodatabase. Moreover, it is maintained using rules and algorithms. This fully functioning system is used to support many services and able to guarantee a legal ownership of 3D property rights. The 3D cadastral registration system is developed with standard specification ISO 19152 3D supported land administration system and core cadastral domain model (CCDM).

As can be seen from the results achieved procedural modelling in the software city engine can be applied for modelling a 3D content of a condominium building in Mekelle city. After data capture the data was input in ESRI ArcGIS and processed so as to generate closed polygons, to assign unique identification numbers and to merge existing attribute data to new polygons. This developed 3D cadastral registration system provides a highlight for managers of cadastral project offices in Mekelle city, to think further than 2D cadastral systems. Managers and decision makers should make use of the information from this models, as a decision support for a better management of condominium buildings and real estate that are found in the city.

6.2 Recommendation

The Mekelle city integrated land registration system(legal cadaster) project office should include the 3D cadastral registration system in order to register the key issues in the city such as condominium buildings.

The CGA code created for the selected three condominium buildings can be applied to generate a realistic 3D model of other similar Condominium buildings.

The federal and regional housing development agencies should use server based license;so that managing and monitoring all condominium informations of their repective offices in one system and /or the whole condominium of the country(Ethiopia) in one system.

There are three types of spatial parcelation(on the surface(2D), above the surface(3D) and below the surface(3D)) (Agency, 2012)and the author developed the integration of the above surface parcel and on the surface parcel.The next researcher can study the integration of the three spatial parcelations.

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APPENDIX

Appendix A: Rule File for Buildings

```
/**
 * File:      C22.cga
 * Created:   13 Oct 2016 23:58:23 GMT
 * Author:    WELDEMA
 */

version "2014.0"
attr height = 0
attr Feature = ""
attr cortex = fileRandom("assets/wall/wall*.jpg")
attr walltex = fileRandom("assets/floor/floor*.jpg")
attr doortex = fileRandom("assets/door/door2.jpg")
.
.
.

.
attr heghit = rand(3, 5)

lot-->
case Feature == "corrider" :
extrude(0.16)
setupProjection(0, scope.xz, scope.sx, scope.sz)
texture(cortex)
projectUV(0).
.
.
.
.
case Feature=="Roof_C2":roofGable(35)
setupProjection(2, scope.xy, scope.sx, scope.sz)
texture(rooftex)
projectUV(0)
case Feature == "G_Frontparcel":G_Frontparcel
case Feature == "G_backparcel":G_backparcel
case Feature == "G_centralparcelodd":G_centralparcelodd
case Feature == "G_centralparceleven":G_centralparceleven
.
.
.
.
case Feature == "LEFTONE_TF":leftoneTF
else:
NIL
comp(f){world.west:wall|world.south:Entrance|world.east:door|world.north:wall
|top:Top|bottom:Bottom}
glass-->
texture(doortex)
setupProjection(0, scope.xy, 2.5, 2.5)
projectUV(0)
door-->
split(x){0.3:beam|4.4:b|0.3:beam}
```

```
b-->
split(y){0.3:beam|2.4:glass|0.3:beam}
beam-->
color(2,2,0)
Entrance-->
split(y){3:ent}
ent-->
split(x){1.8:wallin|0.9:door1|8:wallin}
wallin-->
setupProjection(0, scope.xy, 5, 5)
color (0.6, 0.6, 0)
projectUV(0)

wall-->
.
.
.
.
//T4
T4_G_backparcel-->
extrude(3)
comp(f){back:T4_G_B_west|left:T4_G_B_south|right:back_t4_G|front:T4_Entrance|
top:Top|bottom:Bottom}
t4_G|back:T4_G_B_south}
.
.
.
.
//B2

leftone-->
extrude(3)
comp(f){back:otherside_ent|left:one_win|right:back_t4_G|front:T4_Entrance|top
:Top|bottom:Bottom}
one_win-->
split(y){2.7:side|0.3:beam}
side-->
split(x){1:wall|0.5:T4_G_B_S_win|~1:wall}
comp(f){back:wall|left:S_otherside_ent|right:cen_1|front:wall|top:Top|bottom:
Bottom.
.
.
.
leftoneTF-->
extrude(3)
//back_t4_G
```

Appendix B: Questionnaire Data

Adama Science and Technology University

Department of Geomatics Engineering

Land/property registration form (door-door socio-economic data collection form)

1. Owner type: government public institution private unknown/information not available

2. Location: Country Region Zone City
Kebel Street name Subdivision name Blockname/number

Lot number Parcel ID House number Parcel area surveyed

3. Owner name: Living address Profession

Company name _____ work place _____

Tel.no P.o. box Email Personal ID no/passport

No Family size _____ Male _____ Female _____

3.1 Owner representative (if any): Living address civil status/profession

Company name/work place Tel.no. P.o. box Email

Personal ID no/passport no.

4. Tenant name (if any): Living address civil status/profession _____ Company name/work place Tel.no. P.o. box Email Personal ID no/passport no.

5. Land acquisition type: Free hold Lease hold (long term) illegal/not registration end of contract (if lease). Date of acquisition _____

6. Land use type: land value/m2 land grade (1st level 2nd level. etc) .

7. Tax record: Amount of annual tax _____ paid Since _____
not paid information not available if not paid,

8. Building information: Type of structure _____ Year of construction _____ No of room _____ Use of building _____

9. Encumbrance (charge or claim on the property; like: mortgage, or if any)

10. Boundary conflict: Yes No If yes with which parcel and why?

11. Infrastructure: Access road Water supply Telephone Electricity/power supply

Certification of the surveyor or the assessor

Name _____ Signature _____ Date _____