Investigation of Data Acquisition Approaches for 3D Cadastre with Emphasis on Apartment Units

Firman Ariefiansyah Singagerda

February, 2010

Investigation of Data Acquisition Approaches for 3D Cadastre with Emphasis on Apartment Units

by

Firman Ariefiansyah Singagerda

Thesis submitted to the Faculty of Geo-information Science and Earth Observation University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: Land Administration

Thesis Assessment Board

Chairman	: Prof. Dr. J.A. Zevenbergen
External Examiner	: Dr. Ir. M.J.P.M. Lemmens
First Supervisor	: Dr. A.M. Tuladhar
Second Supervisor	: Dr. Ir. H.T. Uitermark
Third Supervisor	: Dr. M. Gerke

ITC

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
UNIVERISTY OF TWENTE
ENSCHEDE, THE NETHERLANDS

Disclaimer

This document describes work undertaken as part of a programme of study at the Faculty of Geo-information Science and Earth Observation University of Twente. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Abstract

The growth of human population has resulted in the increase of human consumption of earth resources especially land. The limited capacity to provide access to land already reaches its peak, especially in urban areas. This situation has driven people to utilize the available spaces above or below earth surface. This means that the multiple use of space implies the use of a land plot in the three dimensions and led to direct consequences on ownership of used space, bringing the use of 3D cadastre concepts to facilitate better the multiple use of space in the urban area. 3D legal object, as a term that is introduced in this research to describe volumetric space object, basically is the object of registration in a cadastre system which provides components of ‘where’ and ‘how much’ on human-land relation. A provision of information about this object is necessary and should be made available as geographic information. Therefore, an approach to acquire geometric description for 3D legal object is required in order to integrate this object in cadastre dataset.

With the advent of 3D object measurement and reconstruction technology, it is possible to extract 3D geometric representation of an object through various techniques and data sources. From these various techniques available, this research explores two approaches considered as appropriate to be implemented for acquiring one type of 3D legal object which is “apartment units”. Two approaches that being explored in this research are CAD modelling using architectural drawing and Image Based Modelling using pictometry images. Besides exploration of 3D data acquisition approaches, this research also investigates types of 3D legal object and its requirements for registration in cadastre system through desk research.

This research used secondary data which consist of literatures, such journals, articles, and books; architectural drawing, pictometry images, cadastral map, and cadastral database. Semantic model of building and apartment is developed to give better understanding about the object. With this model, components that build the object were segregated and were analyzed with legal specification of 3D legal object to determine information about spatial boundary. Then 3D measurement and reconstruction was performed using architectural drawing and pictometry images. The result of the study show that the two data sources are useful to obtain geometric representation of 3D legal object. This geometric representation can be integrated with current cadastral map, thus information about 2D cadastre parcel and its 3D extension can be accessed by public.

Key words: 3D legal object, 3D object measurement and reconstruction, apartment, legal boundary, architectural drawing, pictometry image, semantic model.

Acknowledgements

I wish to express my gratitude to my supervisors, Dr. A. M. Tuladhar and Dr. Ing. H. T. Uitermark for the guidance and support he showed throughout this research. I specially want to thank Dr. Markus Gerke who showed great interest in my research and also in providing me with technical assistant and data. I also would like to thank Prof. Dr. J. A. Zevenbergen for lending me a book which turns out to be very valuable information for my thesis

I would like to thank people back home: my mother who surely prays for me everyday so I could success with my study and return back home as a new person, my sister for her advices, share of experience in living abroad, and her constant support; my brother for his support, all my colleagues in the office who always keep contact with me and give an strength to finish my study, and my friends from BPN who also study in LA ’08 program (Fajar, Rahmi, Wahyu, and Nia) who always support each others and making fun to each others.

Finally, I would like to thank all my classmates in Land Administration program and all friends in ITC class of 2008 for cheerful and joyful experiences during the study. Without you guys, my life would be a dull and boring in this tinny city.

Table of contents

List of figures

List of tables

List of abbreviations

3D	3 Dimensional
CAD	Computer Aided Design
FME	Feature Manipulation Engine
GIS	Geographic Information System
GML	Geography Mark-up Language
LADM	Land Administration Domain Model
IBM	Image Based Modelling
OGC	Open Geospatial Consortium
RRR	Right, Restriction, and Responsibility
UML	Unified Modelling Language

1. General Introduction

1.1. Background

1.1.1. 3D Cadastre

The growth of human population has resulted in the increase of human consumption of earth's resources especially land. The limited capacity to provide access to land already reaches its peak, especially in urban areas. This situation has driven people to utilize the available spaces above or below earth surface (De Flander and Rovers, 2007). This means that the multiple use of space implies the use of a land plot in the three dimensions. This led to direct consequences on ownership of used space bringing the use of 3D cadastre concepts to facilitate better the multiple use of space in the city.

Basically, the introduction of the 3rd dimension in cadastre already existed centuries ago.
"*Since the Roman law acknowledge principal of "superficies solo cedit", whatever lies above and beneath the surface of the earth, belongs to the owner of the corresponding land-parcel. This concept of ownership was introduced in the Hellenic legislation by the Byzantine-Roman Law Decree (23.02.1835) and recognized by the Civil Code of 1946 (articles 948, 953, 955, 1001, 1057, 1058, 12820)."* (Katerina et al., 2003).

"*Netherlands Civil code (article 5:20 and 5:21) defines ownership of land as ownership of the ground including 'ownership of all space above surface, all earth layers below, all groundwater, and all fixtures'.*" (Van der Molen, 2003).

From above two conceptual perspectives, we see that several countries already realize 3 dimensions (3D) related to the ownership of land and define it in their institution/legal settings. Practically, the concept of 3D cadastre is seen as a means to accommodate human-land relations not only concerning area but by volume of her/his property as well (Stoter et al., 2004b). In most countries, ownership right is unlimited in the vertical dimension. The description of the rights on objects with boundaries in vertical dimension is managed by several regulations, including building right, property in strata, condominium, safety zone for tunnel, and even air right in airport areas.

Up until now, the development of 3D cadastre in real life implementations is still facing major challenges, both institutional and technical. First of all, 3D cadastre is a broad concept and, similar with traditional cadastre, the implementation of the concept itself is varied in every country depending on existing institutions (Van der Molen, 2003). As a result, the definition of 3D legal object exists in many forms according to policy of the country concerned. Secondly, the registration of 3D property in the existing system is still questioned by many legal experts since it would have an impact on the existing policy (Onsrud, 2003). Disagreement also arises regarding to the balance between the benefits against the level of investment in implementing this system (Van der Molen, 2003).

1.1.2. Physical and Legal Object

According to the definition of cadastre by Henssen (1990), and Kaufmann and Steudler (1998), cadastre is a methodically arranged public inventory of data concerning all legal land objects in a certain country or district, based on a survey of their boundaries. One element of this definition is "legal object" which is of main interest for the registration process. Legal object in cadastre can be seen as a unit of land over which homogeneous tenure is established (Henssen, 1990).

Legal object is an abstract notion and it is represented by imaginary lines or boundary lines only for visualisation purposes (principle of speciality of cadastre). Unlike legal object, concept of physical object is easier to understand. According to Tempfli (1998), physical object, or topographic object in his term, is determinate object; because of their visible boundaries they can be distinguished and can be observed. Physical object exists as a natural object or result of human cultural activity. By consequence, a legal object does not necessary coincide with a physical object. Unless there is a declaration from parties who are involved in the transformation of right to land that both physical and legal objects are coincident than it should be represented as such in the cadastre.

The notion of legal object in 3D cadastre reflects similarly with the notion in traditional (2D) cadastre, but it is difficult to determine whether a 3D object is a legal object or only a physical object since it really depends on the existing regulation. If a building is a subject of right superficies then it should be registered in the cadastre, but if it is a part of a property then it is meaningless to register it because it represent the same legal object (Van der Molen, 2003). The previous statement shows one of the situations where land object in form of 3D can take place, but because the ownership of the object is the same as the ownership of the land itself hence it does not necessary represent the object in 3D environment. But what about other situations where the legal object consist of a complex situation (Stoter and Ploeger, 2003), or the concept of strata title as in Indonesia where parties could have full ownership of a unit in a space and share ownership of the common area. Surely registration of these 3D legal objects is a necessity but is it sufficient to represent them in 2D?

1.2. Research Problem

An approach to acquire data about land related objects is one of the essential requirements in establishing a cadastral system. Land related objects as objects of interest will determine 'where' and 'how much' is related to human-land relations as being described in the definition of cadastre. With respect to research in 3D cadastre, many studies already tried to expose the possibility of implementing this concept in cadastre, e.g. Stoter and Ploeger (2003), Billen and Zlatanova (2003), Stoter and Van Oosterom (2005); but all these studies are mainly concerned with how to develop a conceptual model to support the cadastral registration of a 3D property situation. None of these researches gave detailed descriptions about what kind of approaches there are to acquire 3D property data.

As mentioned by Onsurd (2003) and Stoter et al (2004a), one of the requirements in 3D physical object registration is the availability of a construction plan (of a building, bridge, or condominium) or network plan (of a cable, pipeline, or underground tunnel). This kind of data can be considered as base data which can be used to define the spatial dimension of the interest, similar to the use of field sketches in boundary surveys. The real advantage of this approach is that it could give more insight of the inside situation of the object concerned. Delineation between each section of the inside can be seen very clearly using this approach, but this data is very detailed and specific and can only be understood by architects or construction engineers. A simplification or generalization process is needed since not all details are necessary for registration purposes.

The current development of data acquisition using geo-information technology (Geo-IT) has made significant contributions in providing spatial information related to natural and human phenomenon Available approaches, e.g. satellite navigation systems, remote sensing, and geographic information systems (GIS), have provided cheap, easy to use, and fast delivered information associated with the needs of cadastre.

During the recent years a lot of effort was put in developing new approaches for modelling and rendering the real world in three dimensions. This approach, referred to Image Based Modelling (IBM), can be described as a complete and general process of object reconstruction. A study by Remondino and El-Hakim (2006) already reviewed this approach to extract 3D information using photogrammetric technique; and their use in several domains (inspection, visualisation, architect, and even cultural heritage preservation).

Extracting 3D information from the available architectural drawing is seen as a good starting point and as an opportunity to study the relevance for 3D data acquisition with the growing interest for 3D cadastral registration. On the other side, the growing interest in using imaging system (e.g. oblique images and especially Pictometry image) to extract the 3D geo-information also makes it feasible to be implemented for this purpose and might gives additional information for the existing data. An exploration and integration of these two methods may present interesting result and gives better understanding of how to obtain the information about spatial dimension of 3D legal objects.

Although the approaches mentioned above have already proven to be useful in several domains and seems feasible to fulfil the need of 3D cadastre, one has to realize that the object of interest in another GIS is different that are required in cadastre registration. While the first one is concerned with physical attribute to land, the cadastre has interest in recording legal attribute which depends on the institutional setting (including laws) in which it operates. Furthermore, an investigation on what type of legal object that can be acquired using this method and how the integrated approach can be used for 3D cadastre purposes is necessary. One has to realize that the study about the kind of legal objects that exist based on several legal/institutional settings and what the need of registering this object is in the cadastre, is needed before determining the type of data acquisition method.

1.3. Research Scope

In this research, not every 3D objects for cadastre are studied in detail. Since this research concentrates on the use of architectural drawing and images to extract 3D legal objects, it is only applicable for certain 3D objects which are erected above ground surface. This research also limits its focus to complex property situations, e.g. apartment units, which are considered suitable for applying this approach. Several previous researches and legal backgrounds from countries will be examined in connection with the research objectives but do not intend to reformat the concept of cadastre itself.

1.4. Research Objectives

The main objective of this research is to investigate a data acquisition method for 3D cadastral legal objects using the available data sources (architectural drawing and imaging system).

Beside the main objective mentioned above, there are secondary objectives:

1. To analyse the requirements of 3D legal object registration.
2. To explore the suitability of 3D data acquisition for 3D legal object registration using architectural drawing data and oblique aerial image data.

1.5. Research Questions

According to the research objectives, some research questions can be formulated in the following table (Table.1.1).

Table 1.1. Research question with its corresponding objectives

No	Research Objectives	Research Questions
1	To analyse the requirement of 3D legal object registration	(1) What are the legal requirements to register a 3D legal object? (2) Is it necessary to represent these types of legal objects in 3D geometric representation?
2	To explore the suitability of 3D data acquisition for 3D legal object registration using construction plan data and image data	(3) What approach can be used to obtain 3D geo-information from the various sources a. Extracting 3D object from architectural drawing b. Extracting 3D object from oblique images (pictometry). (4) What rules can be applied to extract 3D legal object in the propose method? (5) Does the use of oblique images (pictometry) offer improvement for acquiring 3D legal object?

1.6. Research Framework

In order to study the suitability of 3D data acquisition technique for registering 3D legal objects, first we have to analyse the requirements of 3D legal object registration. The varied forms of 3D legal objects which exist according to several institutional/legal bases (The Netherlands, Germany, and Sweden) should be categorized first in order to identify which kind of object can be analysed using this approach. After defining the suitable object, the next step is the analysis of the suitability of extracting 3D geo-information from construction plan and imagery, namely oblique airborne images; to obtain 3D physical object. An additional legal constraint is also introduced in order to extract legal object from the physical object. This research framework can be illustrated in Figure 1.6.1 below.

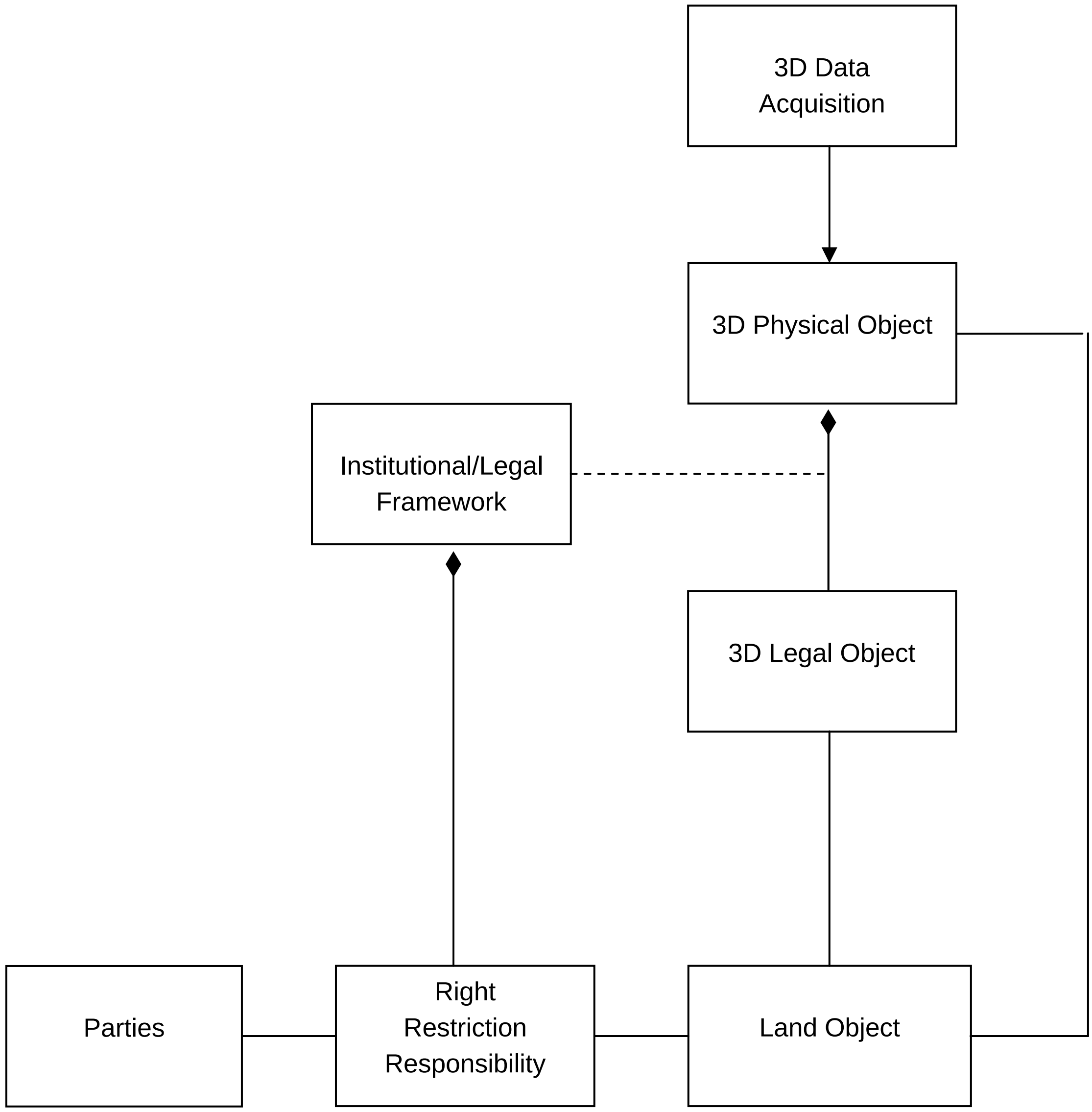


Figure 1.6.1. Research Framework

Figure 1.6.1 shows three main elements of cadastre system. Parties are a representation of people who have interest over land or land related object. Right, restriction, and responsibility are the kind of relation which bound social, economic, and cultural activities of people over certain land object. Cadastral system which operates in country works on the basis of implementation of the institutional and legal setting in the country itself (UN/ECE, 2004). This implies that any type of people-land relationship and the definition of object that being registered only applicable if it is recognized by the law. If we confront the previous statement with the figure illustrated above, we see that the existence of institutional and legal setting, which is translated in real world as law, hold the keys concept not only in determining type of right and other interest to land that are registered but also in defining type of land as object that are recorded in the system.

In general, land object that are recorded in cadastral system is referred to land and in several cases also comprises certain objects that are connected to it, such as building or part of a building (Jansson and Eriksson, 2002; Onsrud, 2003). If we refer to the previous paragraph, object that are recorded and are registered in cadastre only valid if they have legal meaning in the institutional level, therefore land object is classified as legal object.

In countries where land registry and cadastre system are not working properly, problem arises in lack of chances for the people to get legal acknowledgement for their pieces of land (De Soto, 2003). In the meantime countries with properly running cadastre system are facing with other problem. These countries struggle with scarcity of land, especially in urban area. As consequences, people make use the available space to conduct various activities. People fulfil their needs for places of their activities by creating construction that built on top of each other, above or below ground with different use and ownership, in this research term of 3D legal object is introduced to describe this volumetric space with different use and ownership as 3D legal object. To answer this problem, some countries issued regulation by introducing building right and stratified ownership so the association between people, right, and 3D legal object could be established by the institution that has role in this matter.

According to Oxford dictionary, data acquisition is described as automated gathering of data in a form in which it can be processed. In relation with 3D legal object, data acquisition technology is seen as tool to obtain spatial data of 3D legal object. But one has to remember that 3D legal object, similar to parcel in 2D, is an object that only exist in abstract notion. Then how this tool could be implemented to gather an imaginary object? This question is already answered by cadastre system since the establishment of cadastral surveying in Egypt centuries ago. Putting monuments in each corner of the object in the field, measure them to interpolate boundary lines which surrounding the object, and then drawn them in cadastral map are the solution that had been addressed by cadastral survey to make this object visually identifiable.

1.7. Research Approach and Methodologies

1.7.1. Research Approach

The research approach is illustrated as following; and consists of several phases (Figure.1.2)

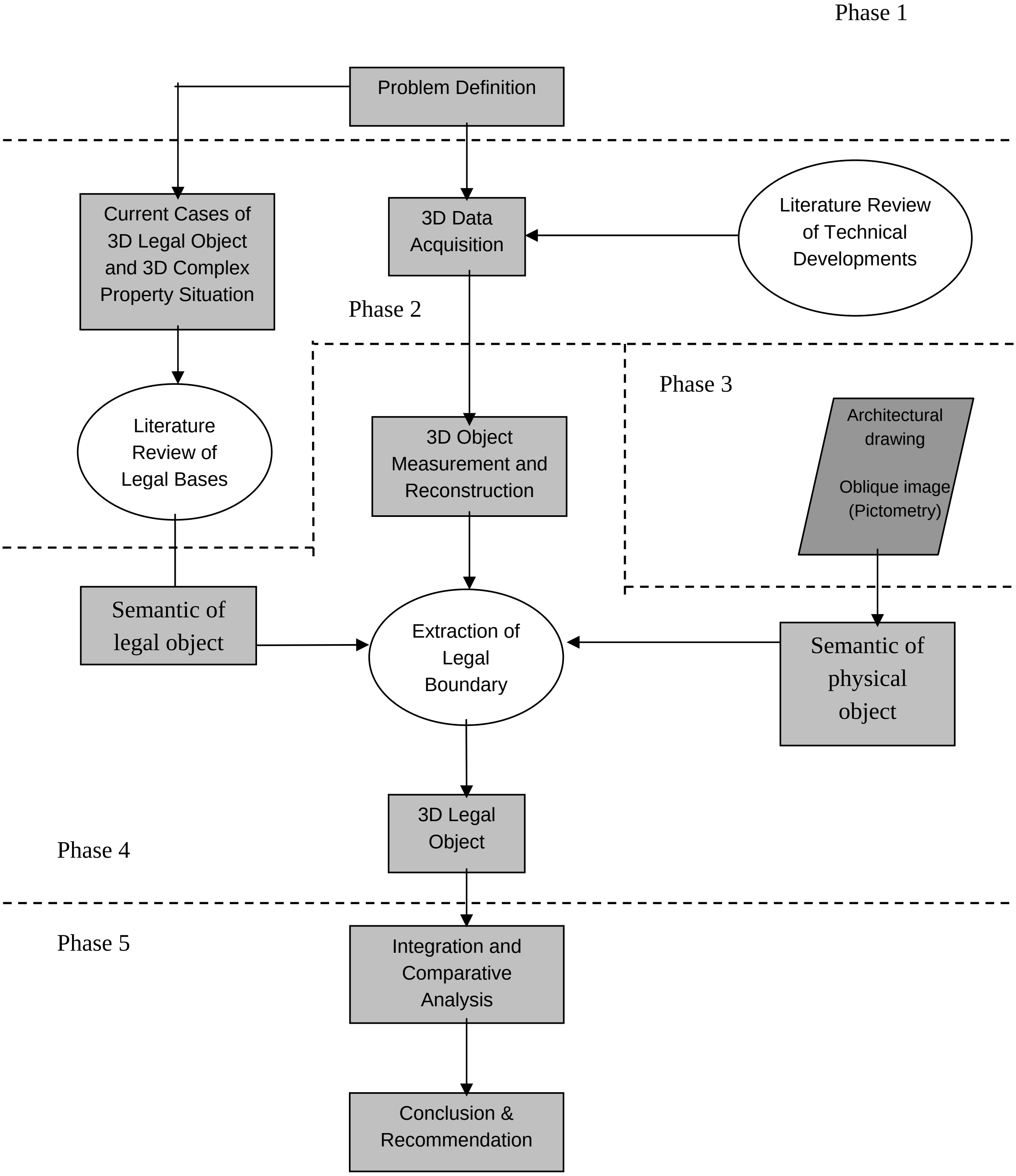


Figure 1.7.1. Research Approach

This research is done in five main phases, namely problem definition, desk research, collecting data, experimental approach in acquiring 3D legal object, and thesis writing.

Phase 1: Problem Definition

In the first phase, background, problems, and objectives of the research are identified base on limited source of information such as scientific journals, conference papers, and books. Afterward, research questions are defined. These questions are outlined in order to achieve research objectives.

Phase 2: Desk Research

This phase involves literature reading and makes an in depth understanding of the concepts and aproaches. There are two topics that become subject of desk research. First topic is about 3D data acquisition and 3D spatial modelling. This topic gives theoretical insight about type of 3D data acquisition and spatial modelling which is implemented in this research. Second topic is about current cases of 3D legal object and experiences of several countries in registering 3D legal object. This topic is reviewed and analyzed in order to identify type of 3D legal object and legal requirements to register 3D legal object. Several countries were chosen in relevance with their experiences in 3D legal object registration.

Phase 3: Collecting Data

In order to carry out this research, a study area is chosen. The study area is an apartment building called “Palazzo Cicero” which is located in Enschede municipality, The Netherlands. Selection of study area is based on several criterions, such as type of ownership and year of building. Secondary data are collected consists of architectural drawings, pictometry image, and cadastre database to perform experiment in the study area.

.

Phase 4: Experimental Approach in Acquiring 3D Legal Object

The fourth phase of this research focuses on data acquisition of 3D legal object using two data source or datasets. Since these datasets have its own characteristic and specification surely processing these data can not be handled by single approach. Therefore, two different approaches are proposed to process each dataset. The result of each dataset are integrated and compared to give better understanding about concept and implementation of 3D data acquisition in cadastre domain.

Beside 3D legal object data acquisition, this phase also introduces the use of semantic information as the preliminary step before processing two datasets. Semantic information can be indicated as generalize knowledge that identifies the meanings of an object or set of object within particular contexts. Use of semantic information is already applied by Kolbe et al. (2005) in developing CityGML, a 3D topographical model of urban setting. An interpretation of this semantic information base on legal and juridical setting of 3D legal object could give valuable input in determining legal boundary and later implement in the process of extracting 3D legal object.

Phase 5: Thesis Writing

Thesis report consists of theoretical background both from technical concept of 3D data acquisition and legal concept of 3D legal object. The report also explained the experimental approach of 3D legal object data acquisition, so there is an understanding of the proposed approach and the finding.

1.7.2. Research Methodologies

The research methodology is in particularly developed for answering all research questions formulated in the previous section within the limited time and resources available. Based on the research questions in the previous section, research methodology can be described in the following table (Table.1.2):

Table 1.2. Research Methodologies and Resources Requirements

<table>
<tr><th>No</th><th>Research Questions</th><th>Methods</th><th>Resources</th></tr>
<tr><td>1</td><td>What are the legal requirements to register 3D legal object?</td><td rowspan="2"><u>Desk Research:</u>
Investigating the current 3D cadastre legal bases and practices from several countries (Germany, The Netherlands, and Sweden)</td><td rowspan="3">Scientific articles
Books</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Is it necessary to represent these types of legal object in 3D geometric representation related to the need of cadastre?</td></tr>
<tr><td><u>Desk Research:</u>
Analysis of the current development of 3D data acquisition and modelling</td></tr>
<tr><td>3</td><td>How to obtain 3D geo-information from the various data source
o Extracting 3D object from construction plan
o Extracting 3D object from oblique image</td><td>Collecting data, i.e. architectural drawings, oblique imagery (pictometry)
Cadastral database

3D object reconstruction processing</td><td><u>Data:</u>
Architectural drawings
Oblique images (pictometry)
<u>Software:</u>
Autodesk Image Modeller
Autodesk AutoCAD Map 3D
Feature Manipulation Engine (FME)
Aristotles</td></tr>
<tr><td>4</td><td>What rules can be applied to extract 3D legal object in the proposed experimental approach</td><td>Determining 3D legal boundary</td><td>Semantic of 3D physical object
Semantic of 3D legal object</td></tr>
<tr><td>5</td><td>Does the use of oblique image offer improvement for acquiring 3D legal object?</td><td>Integration and comparative analysis of the results</td><td>Results of experiment</td></tr>
</table>

1.8. Resource Requirements

This research requires additional resources which can describe in the following:
Software: Autodesk Image Modeller, Autodesk AutoCAD Map 3D, FME, Aristotles
Data:

- Cadastral Map and Cadastral databases from The Netherlands KADASTRE
- Oblique Images (Pictometry) which can be acquired from BLOM Aerofilm
- Architectural Drawings from Enschede municipality

1.9. Thesis Structure

Chapter 1: General Introduction

This chapter provides the introduction to the study, the research background and discusses the research problem. The chapter present the theoretical background which becomes the basis on defining research objectives and research questions. The chapter also discusses the research method used in the study

Chapter 2: Theoretical Concept for 3D Geo-Information/Data Acquisition and Modelling

This chapter explains the theoretical concept of 3D geo-information, 3D data acquisition, and 3D modelling which becomes the technical foundation of the study, by reviewing and evaluating the literatures.

Chapter 3: 3D Legal Object: Cases Experiences and Lessons Learned

This chapter present the current cases and lessons learned from several countries practices and experiences in handling 3D legal objects. From cases and lessons learned we identified definition of 3D legal object, types of 3D legal object, and features of 3D legal object. We also evaluate cadastre registration of 3D legal object which was already applied in countries, i.e. The Netherlands, Germany, and Sweden, to find out the legal requirement and specification in registering 3D legal object.

Chapter 4: Data Acquisition Techniques for 3D Legal Object

This chapter describes methodologies used for this study. Firstly, we identified semantic of the study area from topographical domain and cadastre domain and then developed semantic model based on these two domains. These semantic models were analyzed to determine how the legal boundary can be delineated. Secondly, this chapter explain the experimental approach to acquire 3D legal object. There are two approaches that we use in this study. First approach is 3D object measurement and reconstruction using architectural drawing. Second approach is 3D object measurement and reconstruction using Image Based Modelling.

Chapter 5: Experimental Results

This chapter explains the implementation of experimental approach and discusses the findings of the results.

Chapter 6: Conclusions and Recommendations

This chapter draws conclusions on the 3D geo-information extraction approach for cadastre purposes and recommendations for further research.

2. Theoritical Concepts for 3D Geo-information/ Data Acquisition and Modelling

2.1. Introduction

This chapter is aimed to answer research question (3) which is defined in Table 1.1 and to present the current development of 3D spatial data acquisition and 3D modelling approach that supports this research. 3D spatial data becomes major interest in many applications, such as historical monument preservation and documentation (Gruen et al., 2005), urban planning and management (De Flander and Rovers, 2007), studies on pollution (Stoter et al., 2008), natural hazard response (Kolbe et al., 2008), cadastre and real property registration (Stoter and Van Oosterom, 2006), and property valuation (Yu et al., 2007). Section 2.2 gives explanation about 3D spatial object definition. Approaches on collecting 3D spatial data are outlined in section 2.3. Overview about 3D spatial modelling is discussed in section 2.4. The modelling approach of 3D data in standard domain model and exchanging mechanism using GML are overview in section 2.5. Finally section 2.6 presents discussion and critical evaluation of this chapter.

2.2. Definition of 3D Spatial Object

Oxford dictionary defines spatial as having extension in space; occupying or taking up space; consisting of or characterized by space. In geo-information science, definition of 3D spatial object is given by Molenaar (1992). 3D spatial object is none other than object which is defined in 3D space with volume and surface as it spatial extension. Based on Molenaar definition, 3D spatial object is bounded by surface built by faces which may consist of unconnected part, such as hole. These bounded surfaces form the shape of body of 3D spatial object. Another definition of 3D spatial object is defined by Stoter and Van Oosterom (2006). According to them, 3D spatial object refers to spatial object which having, or appearing to have three dimensions (width, length, and depth). It has to be clearly distinguished between spatial object which consist of only one z value as an attributes of a 2 dimensional point, line, or polygon and spatial objects which allowed multiple z value for the same x-y position. The first case is more suitable to be called as 2.5 D situation while the later is a full 3D object.

2.3. Data Acquisition for 3D Spatial Object

3D modelling can be seen as the complete process of capture, modelling, and ends with 3D visual interactive model virtually represented (Remondino and El-Hakim, 2006). It is also important to be underlined that this 3D modelling approach is intended to model the reality and not concerning on building an artificial world, such as in gaming industry or movies. Examples of these augmented 3d reality modelling are Virtual Environment Planning System (VEPS), and CityGML. VEPS is a web based 3D application design. The aim of this project is to analyse large various datasets for use within virtual reality visualisation software and its distribution via the Internet (Song et al., 2009). CityGML is a profile of GML3 which has been developed by working group lead by Prof. Kolbe and Dr. Groger. CityGML covers the geometrical, topological and semantic aspect of 3D city models. This will be discussed in section 2.5.3.

The most general classification of 3D spatial object measurement and reconstruction techniques can be divided into (a) *contact methods* and (b) *non-contact methods* (Remondino and El-Hakim, 2006). While (El-Hakim and Beraldin, 2008) subdivided this classification into four categories.

- Geometric modelling by CAD data based on surveying data;
- Geometric modelling base on existing architectural drawing such as floor plans;
- Image based modelling based on photogrammetry images, including vertical, oblique, and terrestrial images;
- 3D or range capture with laser scanners.

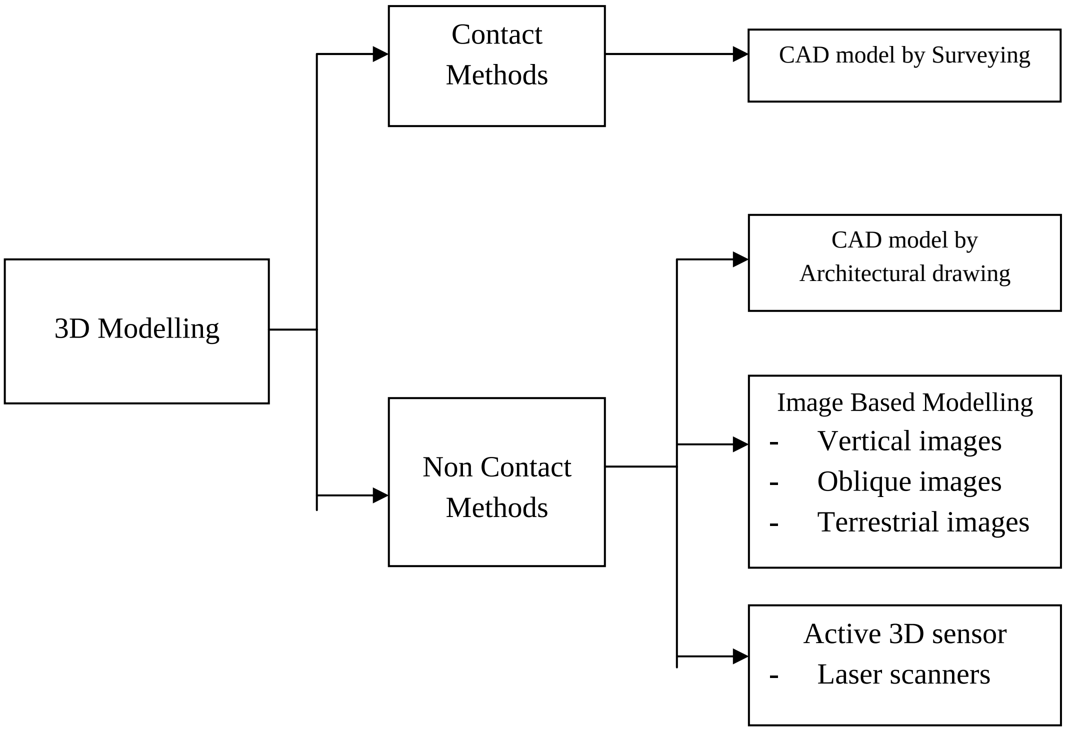


Figure 2.3.1. Classification of 3D data capture

The figure above is drawn based on the two classification mention in previous paragraph and being used to describe the following section.

2.3.1. Surveying

Conventional surveying equipments, which are available widely with relatively low cost, can be used to measure 3D objects. One of these instruments is “Total Station”, an integrated electronic theodolite and automatic distance measurement, which is capable to measure distances and angles of an object from its reference station. To measure a 3D object, such as building, an angular and distance values are observed and then the observed values are used for computation to derive set of 3D coordinates of each corner of an object with few millimetre accuracy (Mitchell, 2008).

The establishment of satellite positioning system also gives mean of surveying of 3D object directly in field. With the current satellite configuration available nowadays, it is possible to obtain 3D coordinates of a point in earth surface by triangulating satellite's signal which is collected by satellite receiver. Surveyor is able to measure each corner point of a building by positioned satellite receiver on the respective point.

The choice to use direct field measurement to obtain 3D geo-information should be considers carefully since it requires considerable amount of time to measure several 3D object although it could achieve higher accuracy compare to remotely sensing methods. One has to realize that to have a obtain whole model of a building it requires to record all corner points of building which means reflector or receiver has to be moved each time corner point want to be measured and moving reflector from one point to another requires physical energy and time.

2.3.2. Architectural Drawing

In architectural and civil engineering, CAD system is commonly used to create 3D model of an object. CAD system mainly is being utilized in designing a building or other structural object. CAD model use in this work field contains very detail and rich of structural information of a building and usually available before building construction process begins.

There are two possibilities in creating 3D models from 2D drawing data. First, if CAD data already exist in digital form then it is important to develop a automation procedure to aggregate the information which is stored in various layer in CAD model (El-Hakim and Beraldin, 2008). Secondly, if drawing only exists in paper then it is wise to convert it into digital form and digitizing the drawing, either by manual digitizing or automatic process.

Choosing proper digitizing method, manual or automatic, mainly depends on the quality, complexity, and content of the input image. If the input contain complex, full of detail and symbol, in this case architecture drawing; one may consider applying manual digitizing. Some rules also should be decided in order to extract only necessary information, e.g. does the outer wall should be digitized or only the median wall, do we have to separate all the opening such as doors and windows or we can treat them as a part of the wall.

Although creating 3D model from existing drawing seems practicable to be implemented in geo-spatial environment, one still have to realize that this approach is undoubtedly time consuming and not showing proper result for large or complex objects. A technique was developed by (Kernighan and Van Wyk, 1996) to extract only the necessary detail from digitize floor-plan and remove those which are not needed.

2.3.3. Image Based Modelling

Image based modelling (IBM) is a method to reconstruct geometric surface of 3D spatial object using 2D image measurement through a mathematical model, including photogrammetry. Multiple images use in IBM approach is obtained from passive sensor, such as camera, which can be based on aerial (vertical images and oblique images) or from terrestrial camera. 3D modelling process base on IBM approach consist of several steps:

- Sensor and network geometry design
- 3D measurement of point clouds and lines
- Structuring and modelling
- Texturing and visualisation

Next section will describe more detail about IBM method using vertical aerial images (section 2.3.3.1), oblique aerial images (section 2.3.3.2), pictometry images (section 2.3.3.4) and terrestrial images (section 2.3.3.5)

2.3.3.1. Vertical Aerial Image

Acquiring 3D data from aerial images is conventionally performed by using stereo images pairs. Images in aerial vertical photogrammetry are mainly being obtained using metric camera. This mean that configuration of camera already been fixed, such as dimension and focal length. The camera also consists of several parts that have specific purposes, such as fiducial marks in the focal plane for calibration purposes, forward motion compensator and vacuum instrument to stabilize the negative of the photo. The focal length is approx. between 60 and 300 mm depends on the angle that is going to be used. The result of vertical is images which have approximately constant scale throughout the image with resolution between 2 – 5 microns with image size of 23x23 cm. The use of overlapped images is the primary approach for 3D mapping and object reconstruction (Figure.2.3.2).

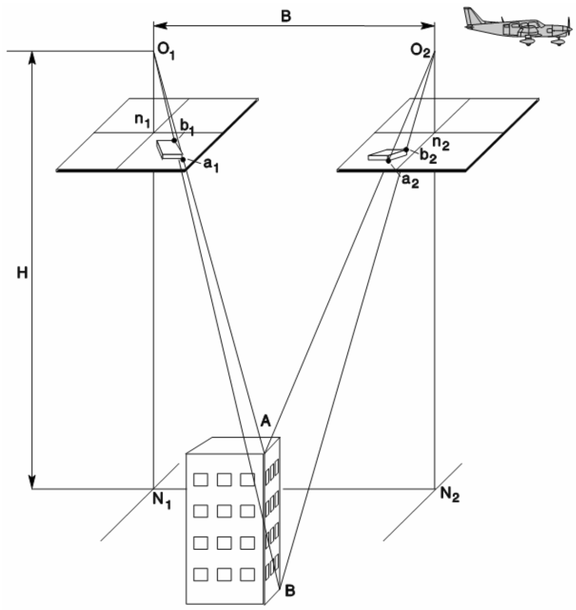


Figure 2.3.2. Measuring height of building using stereo image
(Courtesy of Dr. Ir. M.J.P.M. Lemmens, TU Delft)

The following steps describe process of obtaining 3D data using aerial vertical images and its quality aspect.

Camera calibration

Camera calibration in aerial images using metric camera is done in laboratory which result in calibration report. This report describes several camera parameters, such as position of focal point, length of principal distance, position of fiducial marks, and angular distortion of the lens. All of these parameters are used in calculating interior orientation parameter of the images.

Interior orientation parameter

Calculating interior orientation parameter is a process of reconstructing camera coordinate plane from image coordinate plane. This process is done by make use of camera parameters which are provided by calibration report. The process mainly involves coordinates transformation where fiducial marks in the images are observed and are calculated to obtain transformation parameters. Then these parameters are used to transform the image coordinates into camera coordinates.

Exterior orientation parameters

The main principle in the process of exterior orientation parameter calculation is to reconstruct images in coordinate space (3D) from camera coordinates plane (2D). We need to know six orientation parameters to derive 3D space coordinates from 2D plane coordinates. These parameters consist of three parameters from centre coordinates of the image (XYZ) and three parameters from rotation of image (omega, phi, and kappa). There are many ways to determine these parameters. First by performing bundle adjustment or self calibration which mainly involves calculation of ground control points which are distributed evenly throughout images. Secondly, direct measurement using integrated navigation system during data capture process also can be used to determine these parameters.

3D measurement from stereo images

Measuring 3D coordinates of points on an object from 2D image is determined by measurements made in two or more overlap images taken from different position or stereo-image. This stereo-image could give 3D perception to the observant, hence not only he or she could do an observation in X and Y axes but also could make an observation on depth or height (Z axes) of points on an object. Extraction of 3D object such as building is performed by measuring each corner point located in footprint and roof of the building in stereo-image.

Quality Aspect

Although the use of stereo of aerial images is already well known for capturing 3D spatial data, it is still not sufficient enough to produce large amount of data. Capturing and processing data using photogrammetry technique requires time and lot of human intervention. Start with data acquisition which requires very well planning and produce an abundant number of images, and ends in laboratory work which also requires high skill and well trained human resources. Another factor that should be considers is the fact that not all information about the ground condition of an object can be identified in the image, i.e. obstruction of the roof or shadow.

While the long process in capturing the aerial data can be solved by introducing digital imaging system (digital camera) and integrated navigation system (satellite positioning system and Inertial Measurement Unit), the process of interpreting aerial images to extract 3D spatial information still need lot of human intervention (Mayer, 1999). To minimize this problem and cut down the required time of processing, many scientists focused their research on increasing the level of automation in processing and extracting 3D spatial information from aerial images.

Suveg and Vosselman (2004) developed a method to acquire 3D data from aerial images and integrate it with 2D information from GIS and knowledge based information. Their result shows an appropriate 3D model with considerable accuracy although some minor problems still can be found due to the partitioning of building and the difficulty in generating primitives of small objects.

2.3.3.2. Oblique Aerial Images

The use of oblique aerial image has also been matured to the level where cameras or digital cameras can be used to capture images of objects, e.g. buildings, and reconstruct them using the similar approach as in vertical photogrammetry (Tao, 2004). Oblique imaging can be considered as an approach which provide alternatives solution in photogrammetry, although the process is similar to vertical photogrammetry but it uses different technique in data capture. Technically, procedures to reconstruct 3D spatial object using oblique aerial images are camera calibration, establishing correspondences features, building and refining model, and texturing.

Camera calibration

Similar to vertical aerial image, camera calibration for oblique aerial image is performed to calculate camera distortion parameters which will be use to determine image orientation. Likewise vertical image case, there two possibilities to determine these parameters either by using direct approach by means of INS instrument or using indirect approach by means of self calibration. According to Gerke and Nyaruhuma (2009) the latest approach is indispensable since most of data capture technique for oblique aerial image use non metric camera therefore it is lack of calibration information, while the first approach is not widely implemented since the high cost consideration of the instrument.

Establishing correspondences features

Establishing correspondences features is a process where coordinates of an object is observed by means of triangulation from multiple images. It is a prerequisite to have at least two oblique images that cover the same object from different point of view. Number of images with different point of view that available will determine the geometric strength of the point. Other prerequisite is the availability of accurate camera calibration parameters since these parameters are also considered in calculating the triangulation (Hohle, 2008). Figures below (Figure 2.3.3 and Figure 2.3.4) illustrated how 3D coordinates of a point can be determined from 2 different oblique images)

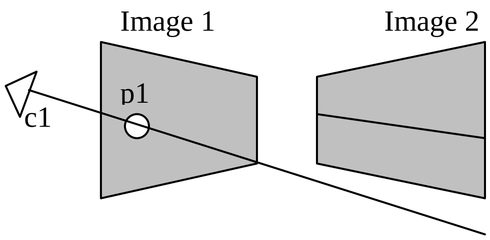


Figure 2.3.3. Object only measured in single oblique image

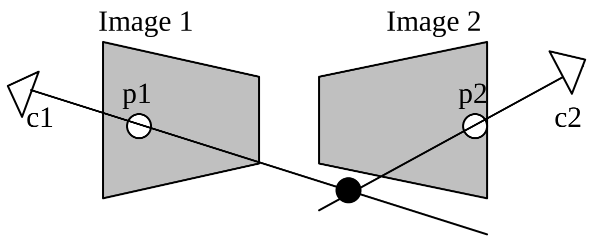


Figure 2.3.4. Object measured in two oblique images

Figure 2.3.3 illustrates that if an object, in this case point p1, is only observed from image1 then the array which connecting the principal point of camera (c1) and the object from image 1 will be projected as straight line in image 2, in other word position of p1 still can not be resolved. Figure 2.3.4 shows that if the same object, namely p2 is observed from image 2 then the array from principal point camera (c2) and p2 will intersect with array from image1. The intersection of these arrays will solve the triangulation and as a result position of the object is defined in coordinate space (3D).

Building and refining model

Choosing and adjusting 3D geometric model into the building are the next procedure to perform. There are two factors one has to consider in performing this step. First factor is geometric constrain which involves level of detail of the modelled object. Model with high detail means that object, e.g. building, is modelled with structural details such detailed wall, roofs, balconies, and even interior structures likes doors, windows, and furniture. While low detail model consists of basic exterior structure such as walls, roof, and floor. Object that is modelled with high level of detail requires quite numerous geometric models which have to be fitted and merged compare to low level of detail. Second factor is numbers of topologic constrains that can be applied into the object. Several topologic constrains that can be imposed into the object consist of parallel, coplanar, and orthogonal constrain of facades of building.

Stepwise, this procedure starts with selection of 3D geometric model. Types of 3D geometric model are described in section 2.4. The selected geometric model is re-projected back and fitted into the image with considering all the possible constrains. Other operation also can be performed to enhance the model, such as splitting the face, moving edge and face, or face extrusion.

Texturing

The purpose of texturing is to make the model more realistic with real texture. Basic operation in this procedure is pasting texture from image onto 3D model by using 2D projective transformation. Although this procedure is considered as a general workflow in IBM method, this research does not include texturing procedure since it focuses on applying 3D geometric model in specific domain.

Quality Aspect

Oblique images have advantage in providing vertical information of an object explicitly to the users. Height of a building can be easily determined since the image provides side view of a building façade. However, the characteristic of oblique image cause difficulties in processing this kind of data. Unlike in vertical images, a single oblique image may contain various scale differences across the image. Normally, the scale is smaller in the area at the far edge of the direction of the camera, and it is bigger in near edge. Other negative characteristic of oblique image is the presence of occlusions. Objects in the foreground (e.g. high rises building) can obstruct the view of objects behind them and creating dead zone, an area where there are no spectral information at all (Gerke, 2009). They can also be difficult to integrate in a GIS, as most GIS application feature a "top-down" perspective when visualize the data. For photogrammetric applications, it also isn't very practical to work with high oblique images in stereo.

2.3.3.3. Pictometry

The advent of digital airborne camera has led to the use of multiple arrays, multiple lenses or multiple cameras to acquire enormous numbers of images format. One of the imaging systems which apply this is Pictometry. The unique difference of this system compared to other aerial imaging systems, both vertical and oblique, is the configuration of the camera. The on board configuration or “Maltese Cross Configuration” (Petrie, 2009) camera consist of one vertical camera being situated in centre and four cameras can capture oblique images from four direction simultaneously (Figure 2.3.5). The imaging system is also equipped with GPS and IMU to provide accurate orientation parameters of the camera, thus the result is a directly geo-referenced image (Wang et al., 2008).

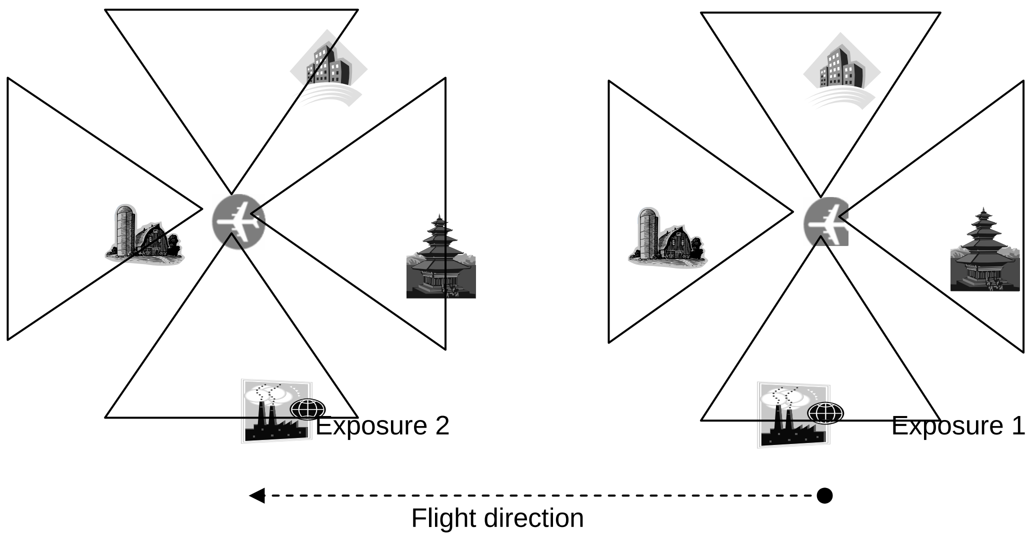


Figure 2.3.5. Illustration of pictometry covering four directions in two consecutive exposure times

Basically, oblique image which is produced by pictometry system is similar to other oblique image. The only difference compares to ordinary oblique image are the use of multiple lenses, thus multiple images can be captured in single exposure. Therefore, processing and measuring object from pictometry image can be treat similarly to oblique image (see section 2.3.3.2).

The establishment of pictometry imaging system opens a wide range of applications. Since it could cover multiple oblique views of built up area at fairly high vertical angles, this system could be aimed at the provision of information about characteristics of buildings and other structures (Petrie, 2009). Wang et al. (2008) discuss the application of pictometry images for 3D city modelling. They summarize that vertical images from this system could be used to generate large scale digital orthophotos and refining building model from laser scanning while oblique images can be utilized to generate 3D city modelling. Lemmens et al. (2007) also discuss the potential use of this system for broader application, in this case land administration purposes. Their research emphasizes the use of pictometry images as an aiding tool in process of splitting and object formation by preliminary boundary determination.

The characteristic of oblique cameras configuration in pictometry system is very suitable to generate 3D model since:

- It can provide multiple views of an object from different directions from single exposure, hence object occlusion can be minimized (Petrie, 2009);
- It can cover a vast area within a single exposure (Petrie, 2009);
- Images from oblique camera also can be used for texturing 3D model (Wang et al., 2008);
- Non professional can carry out the interpretation of the resulting oblique images more easily (Lemmens et al., 2007; Petrie, 2009).

To support the above motivation on using Pictometry image, we compared and evaluated several data sources and its characteristics which are possible to be used with IBM method. Table 2.1 shows the result of this comparison.

Table 2.1. Image Characteristics for IBM Method

Aerial Vertical Image	Aerial Oblique Image	Terrestrial Image
Mostly from calibrated camera	Mostly from calibrated camera and pose camera	Mostly un-calibrated camera
Roofs are not occluded	Roofs are mostly not occluded	Roofs are mostly occluded
Object facades only appear because relief displacement in built up object	Oblique view is necessary for object façades	Object façades are more visible

From Table 2.1 we see that characteristic of oblique aerial images and terrestrial images are potential to be used with IBM method since they could provide information of object façades. Hence Pictometry imagery, which is one of oblique imaging system with systematic configuration, is also possible to extract geometric of spatial object.

2.3.3.4. Terrestrial Image

Use of terrestrial images has been applied in architectural field to reconstruct historical building and monument for documentation and preservation. Terrestrial image can be produced only using consumer camera, either professional or semi-professional, and with well manage planning process (to design data capture network) it can produce a very high resolution of 3D model of an object compare to oblique images (Remondino and El-Hakim, 2006) (Figure 2.3.4). It also can be applied for in-door situation whereas aerial system only can capture 3D spatial data from the outside. Basically, principle use in capturing terrestrial image is similar with aerial, vertical and oblique, photogrammetry (Monaghan, 1967). Therefore, processing terrestrial image can be treated similarly with aerial image.

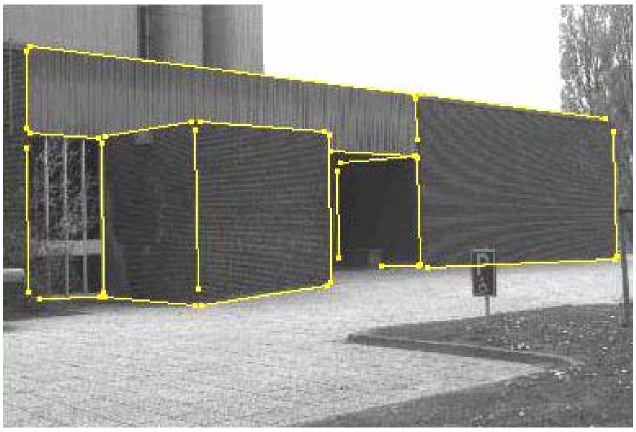


Figure 2.3.6. Measurement of building using terrestrial image

(Courtesy of Dr. Ir. M.J.P.M. Lemmens, TU Delft)

Quality Aspect

From its quality aspect, 3D spatial object created from terrestrial image appears more realistic, in terms of level of detail and texture, than those as compared to aerial image. Terrestrial image is captured from the close range devices hence it has better resolution; although it is relied on type of camera that being used and base to depth ratio. On the contrary, there are several factors one has to consider to create 3D model from this method. First, certain object like roof or other object on top of it can be modelled perfectly since data capture is performed on the ground. Secondly, numbers of image are required just to model one object, hence it is time consuming process to model several object.

2.3.4. Active 3D Sensor

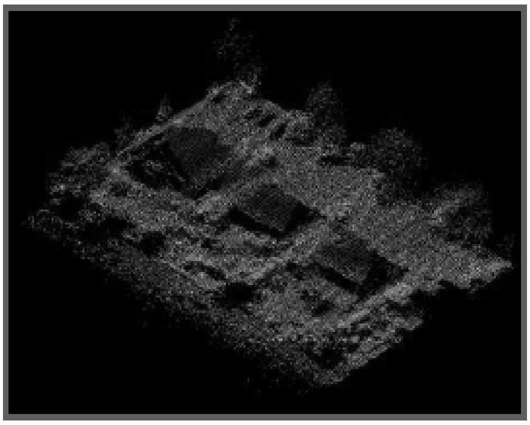


Figure 2.3.7. Example 3D spatial object from laser scanning (Vosselman, 2008)

The development of *light amplification by stimulated emission of radiation* (laser) in 1960s has great impact on the approach of acquiring 3D spatial objects. Nowadays it is possible to capture directly 3D geo-information of an object using active sensors based on the laser ranging mechanism. This type of sensor also refers to laser scanning, first being developed for forest mapping application and later being implemented in the generation of high resolution Digital Elevation Model for various purposes; namely topographic mapping, natural hazard studies, water resources management, and geological application. Example of 3D spatial object obtained by laser scanning is shown in Figure 2.3.7.

Laser scanning technology can be operated either using airborne platform (airplane and helicopter) or terrestrial platform. In airborne platform, laser scanning instrument can be integrated with other navigation system such as GPS and IMU to derive position and attitude information in real time within centimetres level for height accuracy (Kerle et al., 2004). Terrestrial laser scanner (TLS) is mainly operated from a stationary base using tripod or it can be mounted on top of a vehicle (Frueh et al., 2005) in order to increase the time of acquiring the data for urban application. This type of instrument may have accuracy of 2 – 6 mm (Kerle et al., 2004).

Although laser scanning can provide high resolution of 3D spatial objects and the result can be use to produce a 3D city model, there are still some disadvantages in implementing this system. Remondino and El-Hakim (2006) identifies two factors which one have to consider to implement this system. First, laser scanning instrument is still expensive. Secondly, operating this system requires expertise and knowledge.

2.4. 3D Spatial Modelling

In sub chapter 2.2, the development of various type 3D data acquisition already been discussed. The important improvement from this technology makes it possible to produce accurate and highly detail model of 3D spatial object. In the following section, topic about spatial modelling of 3D object will be discussed further. Section 2.4.1 will discuss about semantic model 3D spatial object. Section 2.4.2 will explain about geometric model representation of 3D spatial object. Section 2.4.3 will discuss topological model for 3D spatial object.

2.4.1. Semantic Model for 3D Spatial Object

Spatial object, as an object of interest in geo-information, consists of geometric and thematic characteristics. Geometric aspect of spatial object, which determine the shape and dimension of the object, can be represented either by using raster or vector approach. Thematic aspect, which describe the characteristics or meaning of the object, can be organized in attribute structure depends on specific application context or object classes (Molenaar and van Oosterom, 2009), e.g. definition of an object in topographic survey mainly focused on real object along with its all physical characteristics, while cadastre only have interest on an object which is defined by its legal attributes.

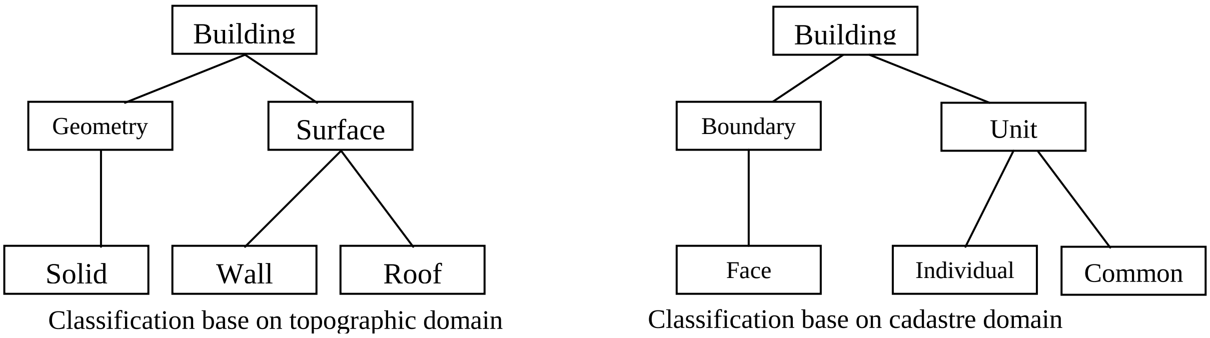


Figure 2.4.1. Classification hierarchy of a building base on two different domains

Semantic model of an object is based on Molenaar and van Oosterom (2009) that defines thematic characteristics as an hierarchy of classes which consist of classification, aggregation, and association. Classification hierarchy has top down approach where classes are collection of object with same attribute structure. In this hierarchy, object in higher level or super class can inherit its attributes to object in lower level. Relation between higher level and lower level also strictly define as 1: m relation, where super class can have many lower level classes (Figure 2.4.1).

Aggregation hierarchy describes how the object is constructed from several objects from lower level based on construction rules. An aggregated object can be seen as a container which is composed from several elementary objects, although these elementary objects can be formed from different classification classes (Figure 2.4.2). Object association is another way to organize spatial object. An association represent relation or link between objects base on common aspects.

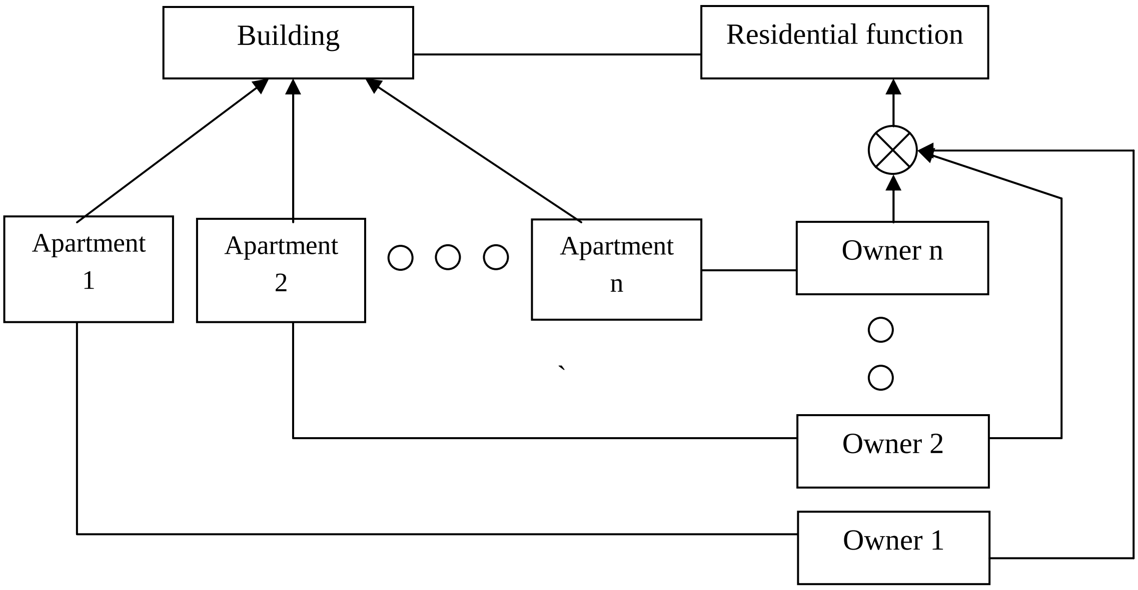


Figure 2.4.2. Aggregation hierarchy of building base on cadastre domain

Discussing semantic of 3D spatial object mainly depends from which specific domain of application that the object will be described. For instance, Tempfli (1998) stated that the interest in 3D spatial object and its representation not only relates to its geometric properties but also to its surface related information. 3D spatial object such as building should not only be determined geometrically but also should be categorized on the basis of its function, names, owner, or value in order to give the meaning of the object. Another study by Fuchs (1996) concludes that the object of interest in 3D city model studies are mainly focuses on real object, such as building, vegetation, and traffic network. This perspective is clearly based from topographical point of view, where representing a building as 3D object is seems normal (because this is the reality).

While from other perspective such urban planning, more specifically cadastre; the interest goes far beyond real object (Billen and Zlatanova, 2003; Stoter, 2004), such as property boundary and legal status of real estate where they exist in more abstract sense. Hence Billen and Zlatanova (2003) proposed criterions based on geometric characteristic to distinguish semantic of spatial object; (1) objects with non-complete geometric characteristic, (2) objects with complete geometric and existence in the real world, (3) complete geometric and fictive existence, and (4) without geometric.

2.4.2. Geometric Model for 3D Spatial Object

Geometric modelling can be describe as a method to describe, process, and store geometric properties of spatial object based on analytical and approximation methods. Geometric modelling can be classified in four categories.

- Unstructured set or point cloud

  Unstructured set is set of independent vertices that represent visible surface of an object. These points are not connected each other. They also can not be used directly to generate a model and need to be converted into another form such polygonal mesh.
- Surface modelling

  Surface modelling is a modelling concept where each point in plane (x,y) have exactly one elevation value (z). Examples from this modelling are Triangular Irregular Network (TIN), meshes, and 2.5 D representation of a surface.
- Wireframe modelling

  Wireframe model is a visual representation of an object by connecting each vertices using straight line without any spatial relation defined between each element.
- Solid modelling

  Solid modelling is one of geometric modelling methods which focus in 3D solid object. One characteristic of this method is the ability to differentiate whether an element is located in inside or outside the object (Rottensteiner, 2002).

From all concept mention above, only solid modelling that suite to represent man made 3D object. According to (Rottensteiner, 2002) there are several concepts to represent 3D object in solid modelling.

- *Constructive solid geometry (CSG).* CSG is a modelling approach of 3D object using solid model. CSG consist of simple object as primitives such spheres, cubes, cylinders, tetrahedrons, and quadratic pyramids. This type of simple object can be combined using Boolean operators, such as intersection, union, and differences (Figure 2.4.3). This is the reason why CSG representation is commonly used in CAD model for AEC and industrial CAD model. For real world modelling in GIS environment, it is still difficult to implement this concept since the object and their relationship is very complex (Stoter and Zlatanova, 2003).

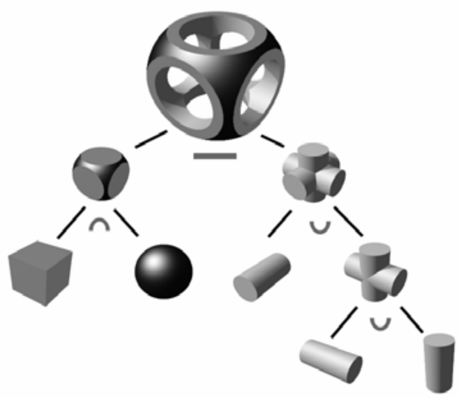
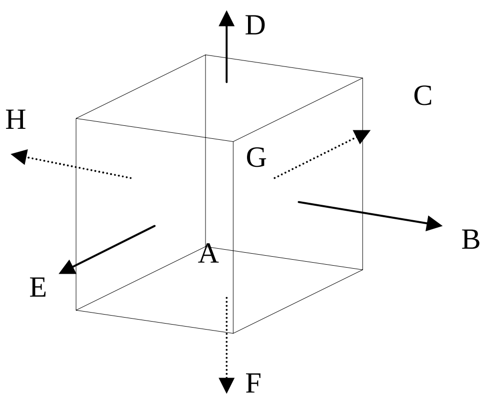


Figure 2.4.3. Boolean operation in CSG
(http://en.wikipedia.org/wiki/File:Csg_tree.png)

- *Spatial occupancy enumeration.* Spatial occupancy enumeration is an approach where 3D object is being represented by set of evenly distributed 3D volumetric pixel element (voxel), similar concept with pixel in 2D image. Each voxel can contain certain value (real or Boolean value). The disadvantage of voxel are the required large space to store an object since it might consist of highly redundant information (Rottensteiner, 2002), and the rough appearance of irregular object (Stoter and Zlatanova, 2003).
- *Sweep methods.* In sweeping methods, 2D area is being swept out along a path perpendicular to the plane. It is possible to sweep the feature in translational or rotational direction. This method only appropriate for symmetrical object (Rottensteiner, 2002).
- *Boundary representation (B-Rep).* In boundary representation, an object is represented by its bounding faces. This bounding faces consists of a set of composition of much lower elements (vertices, edges, lines, and polygons or faces). The advantage of this concept is the fact that it can preserve topological relationship between its elements according to the data structure (Figure 2.4.4) (Rottensteiner, 2002).



Vertices/nodes	lines/arcs	Oriented Faces
A (0,0,0)	AB	ABFE
B (1,0,0)	BC	BCGF
C (1,1,0)	CD	GHEF
D (0,1,0)	DA	HDAE
E (0,0,1)	EF	DCBA
F (1,0,1)	FG	GCDH
G (1,1,1)	GH	
H (0,1,1)	HE	
	AE	
	BF	
	CG	
	DH	

Figure 2.4.4. Example of B-rep with its data structure
(http://www.cs.mtu.edu/~shene/COURSES/cs3621/NOTES/model/b-rep.html)

2.4.3. Topologic Model for 3D Spatial Object

Concept of topology in spatial environment is needed to maintain the consistency and provide an effective analysis of data. Topological model of spatial data can be distinguished as internal topology and external topology. In internal topology, relation between low dimension primitives which constructs an object is defined in the data structure, e.g. a line is stored as a sequence of points, 2D polygon is defined by one exterior boundary and zero or more interior boundary, and exterior boundary of a polygon consist of a set of close linear segment. External topology in 2D space sets up the rule where space (2D) is completely subdivided into object, thus no existence of overlaps and gaps between object in space.

Contrast to 2D spatial data, topological model for 3D data is still being researched. A review by Stoter and Zlatanova (2003) states that the lack of topological model for 3D data has made 3D GIS only as a mere visualization tools, and more effort in implementing 3D topology should be put in order to show the full potential of 3D GIS. Another research by Billen and Zlatanova (2003) also mention the importance of topology relationship to solve spatial query in cadastre domain. Their research explain the importance of this model by presenting two examples where (i) one want to know distance between an object situated above or under a cadastral unit and (ii) the concept of cadastral space partition (Figure 2.4.5).

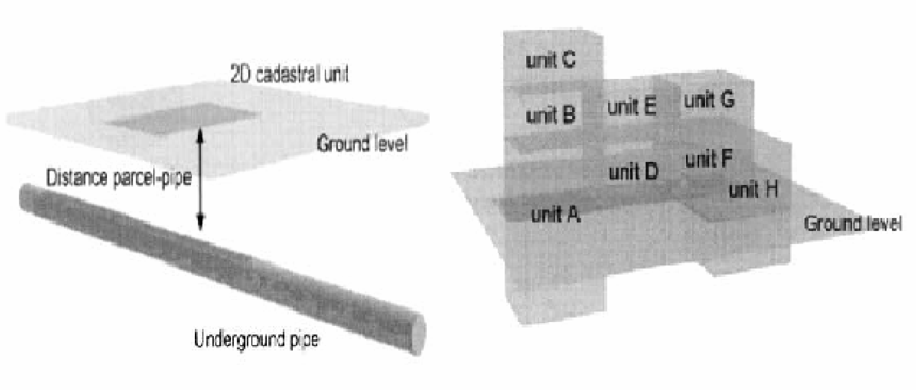


Figure 2.4.5. The need of topological model in 3D Cadastre
(Billen and Zlatanova, 2003)

Although many research already developed such model to accommodate 3D data, but the question whether it is possible to have one 3D topological model for all type of application still can not be answered (Zlatanova et al., 2004).

2.5. Representation and Exchanging 3D Spatial Data

Advances in data acquisition technology have made individual producers and organization to collect spatial data for their own use. The need of exchanging and representing these data become crucial since producers and users stores their data in various forms which reflecting their purposes of the data. To overcome the interoperability issues, ones have to consider a standardization mechanism. One possibility to achieve standardization is by developing standardized data model. In this section, an overview about one means of how a specific domain stores, describe and structures 3D spatial data using standardized data model, i.e. Land Administration Domain Model will be discussed (section 2.4.1), means of exchanging and visualizing 3D spatial data by GML technology will be discussed in section 2.4.2, and section 2.4.3 will give overview about CityGML, an application schema of GML which being developed to handle 3D topographical data, and will be discussed as a reference to develop the semantic model in this research.

2.5.1. Land Administration Domain Model

Oldfield(2002) defines domain model as a model of the area within which an enterprise conduct its business. Therefore, Land Administration Domain Model (LADM, (ISO/TC 211, 2009)) can be seen as a model that describes various entities which involved in land administration domain and their relationships. LADM uses Unified Modelling Language (UML) class diagrams to express object classes and their relationship.

LADM provides abstract conceptual schema which consists of five packages according to ISO/TC 211, namely Party Package, Administrative Package, Spatial Unit Package, Surveying Package, Spatial Description Package. The decomposition of class into several packages is to present LADM in comprehensive part yet maintain and developed each package independently (Ary Sucaya, 2009). Explanation about packages in LADM is presented in following paragraphs.

Party package

Party package contains LA_Party, LA_GroupParty, and LA_PartyMember. LA_Party is the main class in this package, while LA_GroupParty is the specialization of LA_Party. LA_PartyMember is an optional association class. Party package comprises basic components about party that have interest over certain legal object. Party is natural person or non natural persons that compose an identifiable single legal entity (ISO/TC 211, 2009). Single legal entity means that party only can be accommodated in the package if they are recognized by external registration, such resident registration or companies' registration office. Party package gives solution to parties that are not acknowledged in external registration as a single entity, such as family, tribe, and community; by introducing LA_GroupParty.

Administrative package

Administrative package contains LA_RRR as the main package; LA_Right, LA_Restriction, and LA_Responsibility as specialization class of LA_RRR. Other important classes in this package are LA_LAUnit, LA_SourceDocument, and LA_Mortgage class. According to (ISO/TC 211, 2009), right is formal or informal entitlement to own, or to do something; responsibility is formal or informal obligation to do something; restriction is formal or informal entitlement to refrain from doing something. Therefore, LA_RRR acts as an abstract class that covers information about types of interest which can be entitled to certain legal object.

LA_Mortgage is class which deal with component about conditional conveyance of right as security for repayment of loan. LA_SourceDocument is a class to maintain administrative document providing facts concerning to registration (ISO/TC 211, 2009). In principle, all rights, restrictions and responsibilities in LA_RRR has to reflect from document in LA_SourceDocument.

LA_LAUnit is an administrative entity with unique and homogenous tenure is associated to the whole entity (ISO/TC 211, 2009). Base on LADM description, LA_LAUnit does not contain spatial description which means that person still could held right with no association to a certain location. On the contrary, LA_LAUnit could relate to many locations so it is allowing an association of one right to several of location, e.g. house and parking space.

Spatial unit package

Spatial unit package maintains basic components of legal object which can be defined spatially (Figure 2.5.1). The main class of this package is LA_SpatialUnit. LA_SpatialUnit is an abstract class and has three specialization classes (ISO/TC 211, 2009):

- LA_Parcel or LA_SubParcel
- LA_Building or LA_BuildingUnit

- LA_Networks

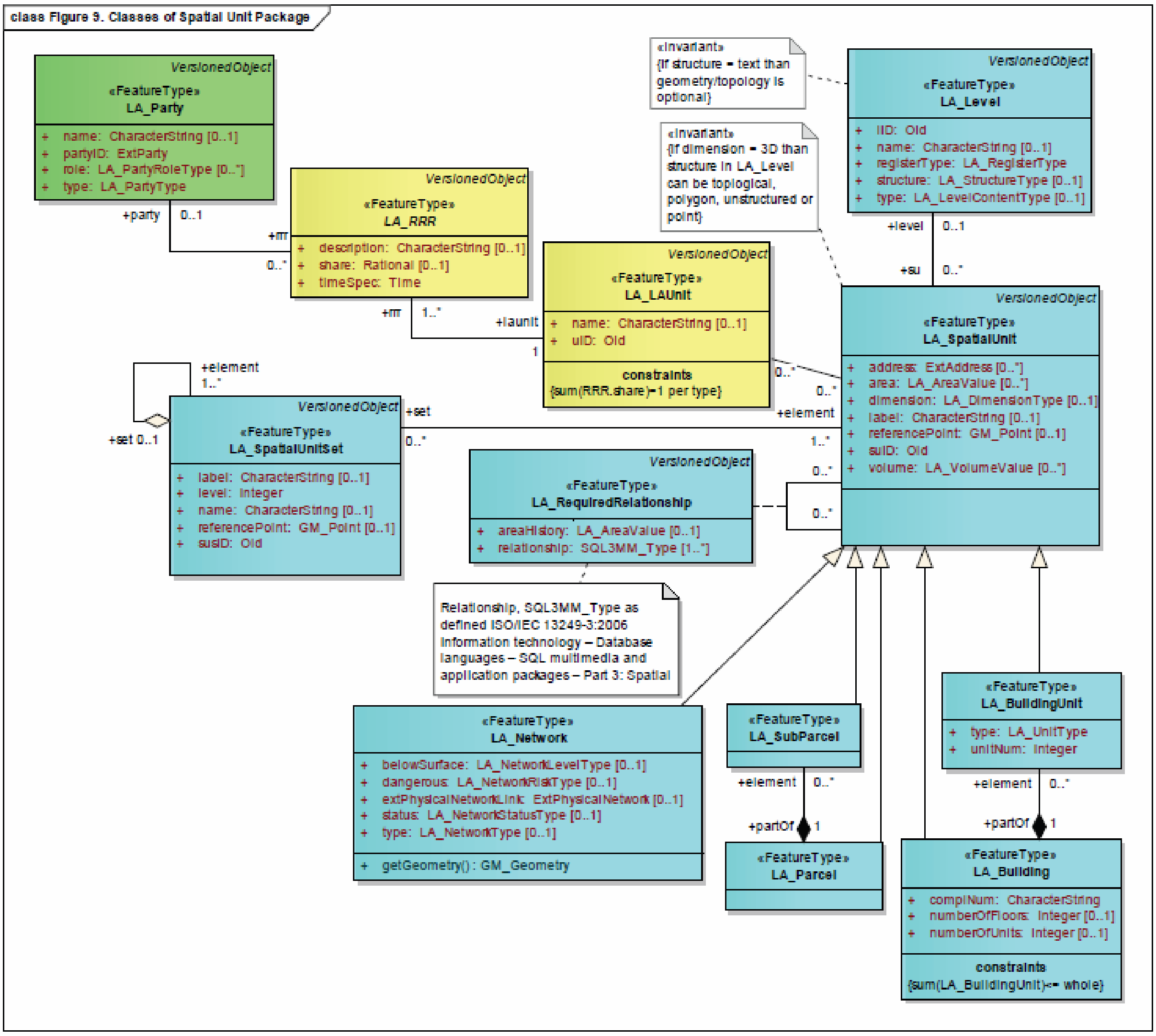


Figure 2.5.1. LADM classes of spatial unit package

(ISO/TC 211, 2009)

A parcel (2D or 3D) is an instance of LA_Parcel subclass and may holds no attribute. LADM defines a building from legal entity description (LA_Building) and not the physical entity. It is composed out of several building unit (LA_BuildingUnit). Building unit can be expressed as common area, commercial purposes or individual property (condominium). LA_Network hold description of legal, recorded or informal space of a utility network (ISO/TC 211, 2009).

Surveying package

Surveying package consists of two classes, LA_SpatialSourceDocument and LA_SourcePoint. Basic information in surveying package is related to cadastre survey document (ISO/TC 211, 2009). LA_SpatialSourceDocument gives description about data acquisition method for determining boundary, and set of measurement value of legal object. This class accommodate both digital and paper document which may be scanned. LA_SourcePoint sustains information about boundary point of legal object as a result of single survey document and contain geometric description of the point. Therefore LA_SourcePoint has to be associated with LA_SpatialSourceDocument.

Spatial description package

The two classes of this package are LA_FaceString and LA_Face. Spatial description package gives geometric description of legal object (2D or 3D). 2D or 3D geometric description of a spatial unit uses facestring and face as key concepts (Figure 2.5.2). The term facestring is derived from face and line string and it is intended to model 2D and 3D situation uniformly, while face is introduced if there is 3D situation where facestring is not sufficient (Lemmen et al., 2009). LA_FaceString and LA_Face are result of interpolation of boundary point. Coordinates of the point are held in LA_SourcePoint. Concept of face string means that boundary of legal object (2D) is a line-string and it could be projected vertically up and down if 3D description is required. Face is a concept to define boundary of 3D legal object as surface and create horizontal partition for condominium registration.

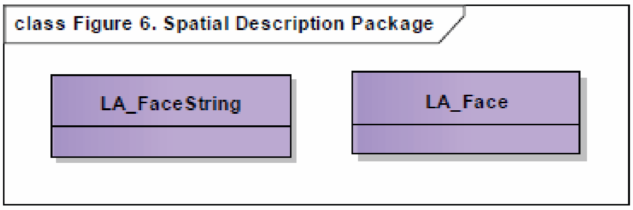


Figure 2.5.2. LADM classes of spatial unit description package
(ISO/TC 211, 2009)

2.5.2. Geography Markup Language

In current situation, there are various format of data that provide by data provider depends on their purposes and needs. This situation creates interoperability issue among various users who want to use data. Interoperability issue in sharing data is a challenge that must be overcome in order to share and exchange geo-information. In order to solve this problem, Open Geospatial Consortium (OGC) publish Geography Markup Language, an independent format which claimed to be standard format to share and exchange spatial data. Geography Markup Language (GML) is an Extensible Markup Language (XML) encoding to store and exchange spatial information (Open Geospatial Consortium, 2007). It can accommodate both spatial and non spatial properties of spatial object. In GML, spatial object is defined as a feature type and feature property. A feature type is comparable to a class in object modelling, while property corresponds to its attribute or association. Since GML document is a conceptual model, which is based on OGC Abstract Specification, ones need to transform conceptual schema into application schema to declare the actual feature types and properties according to the corresponding application domain. Hence, designer of GML may extend or limit the types defined in base schema according to its own types of application.

The previous version up until version 2.x, GML only implements simple features specification to describe real world phenomena correspond to spatial object. This means GML only can handle 2D representation, such as point, line string, and area or polygon. The current version of GML, i.e. GML 3 (Figure 2.5.3), already addresses some following needs that were not addressed met by the previous version (Cox et al., 2004):

- Able to represent spatial object with complex, non linear, 3D geometry, features with 2D topology, temporal properties, dynamic, coverage, and observation
- Provide more explicit support for properties of features and other objects whose values is complex

- Represent spatial and temporal reference systems, units of measure and standard information
- Represent default styles for feature and coverage visualization
- Conform with standards from the ISO 191xx series

With this current version, GML able to exchange and store spatial data which has 3D geometry, although it still can not support 3D topology which define the relationship between spatial object.

The design of GML is intended to support interoperability through a common data model (feature and properties), a mechanism to create and share application schema, and in some case through the use of a profile. The next section will describe one of GML profile which is being developed to accommodate 3D spatial object as 3D city model for broad range application.


```
<?xml version="1.0" encoding="UTF-8"?>
<gml:FeatureCollection xmlns:gml="http://www.opengis.net/gml" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="
http://www.w3.org/2001/XMLSchema-instance" xmlns:fme="http://www.safe.com/gml/fme" xsi:schemaLocation="
http://www.safe.com/gml/fme ciceroAEC.xsd">
  <gml:boundedBy>
    <gml:Envelope srsName="EPSG:28992" srsDimension="3">
      <gml:lowerCorner>258518.373930736 471137.876141497 -0.000163674073862</gml:lowerCorner>
      <gml:upperCorner>258551.222724574 471154.821210691 15.5</gml:upperCorner>
    </gml:Envelope>
  </gml:boundedBy>
  <gml:featureMember>
    <fme:public_la_building_unit gml:id="idb0863a90-73e1-401c-83e7-3255fecf5b88">
      <fme:unitid>l</fme:unitid>
      <fme:floorid>2</fme:floorid>
      <fme:type>individual</fme:type>
      <fme:gid>1</fme:gid>
      <gml:multiSurfaceProperty>
        <gml:MultiSurface srsName="EPSG:28992" srsDimension="3">
          <gml:surfaceMember>
            <gml:Surface>
              <gml:patches>
                <gml:PolygonPatch>
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:posList>258534.91256542 471138.049417328 5.6 258534.912565592
471138.049401073 8.4 258529.497945457 471137.991957638 8.4 258529.497945285 471137.991973894 5.6
258534.91256542 471138.049417328 5.6</gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:PolygonPatch>
              </gml:patches>
            </gml:Surface>
          </gml:surfaceMember>
          <gml:surfaceMember>
            <gml:Surface>
              <gml:patches>
                <gml:PolygonPatch>
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:posList>258534.804575917 471148.229240628 8.4 258534.804575917
471148.229240628 5.6 258534.91256542 471138.049417328 5.6 258534.912565592 471138.049401073 8.4
258534.804575917 471148.229240628 8.4</gml:posList>
```


Figure 2.5.3. Example of GML 3

2.5.3. CityGML

CityGML is a profile of GML3 which provide an interoperable, multi purposes, multi scale and semantic of 3D city model (Kolbe et al., 2005). It has become subject of development of working group lead by Prof. Kolbe and Dr. Groger. CityGML is intended to accommodate geometric, topological, and semantic aspects of 3D city model.

Kolbe et al. (2005) describe several concepts of CityGML as follows:

- *Levels of details (LoD)*

CityGML consist of five level of detail. The lowest level, LoD0, is a two and a half dimension which represents Digital Terrain Model (DTM). In LoD1, building models start to be represented as block without ant roof representation. In addition, roof structure can be differentiated in LoD2. More architectural details and wall textures allowed to be applied in LoD3. Finally, LoD4 allows interior structure and detail ornaments to be modelled to complete the city model

- *Geometric-topological modelling*
  Geometric properties of an object are represented using boundary representation (B-rep). With B-rep, it is allowed to store the geometric-topological primitives where each solid object is bounded by its lower dimension elements, i.e. solid bounded by faces, face bounded edges, and an edge by nodes.
- *Coherent semantic and geometric modelling*
  CityGML consists of two hierarchies, the semantics and the geometric-topological. Semantics of an entity are addressed to attributes, relation, and aggregation hierarchies between object; while the geometric/topological objects are assigned to semantic object as a spatial properties.
- *References to object in external data set*
  One features of CityGML is the ability to link to external dataset. A reference between members of CityGML with corresponding object in other dataset can be established, hence it able to receive from or supply of information to external database or dataset. This link mechanism is applied using *Uniform Resource Identifier (URI)*.
- *Dictionary and code lists for attributes*
  CityGML provides dictionary and code list to assure value of an attributes have the same notion according to its class object. This also facilitates the translation of attribute values into other language.

In conjunction with cadastre, CityGML will provide methods and workflows for municipalities in generating and maintaining 3D city model in LoD1 and LoD2.

2.6. Discussion and Critical Evaluation

In this chapter, we have reviewed theoretical bases for 3D geo-information. 3D modelling is a concept start with data collection and ends up with visual representation of 3D object. The task of designing and executing 3D data collection requires clear understanding of the performance of the approach and instrument that will be used. Selection of technique should be taken under some consideration depend on several parameters, such as:

- Accuracy requirement;
- Level of detail;
- Level of automation;
- Visual quality;
- Cost and time of acquisition.

While a single approach or technique might not give an absolute result, one might need to consider integrating multiple dataset from various sources to give appropriate result.

One approach that might give effective result in obtaining 3D spatial object in dense built up area is by using systematic oblique aerial photogrammetry which uses multiple frame cameras. One of aerial system that uses this special kind of approach is Pictometry imaging system. With systematic configuration of multiple frame cameras, Pictometry provides multiple oblique views of urban areas with high vertical angles. With such specification, Pictometry images can overcome the difficulty in obtaining information about building and other structure with near vertical photos (Petrie, 2009) and it is more effective compare to single frame oblique photogrammetry since it can provide more coverage of an area with its multiple frame camera. Petrie (2009) also claimed that the interpretation of oblique image with high vertical angle is more easily carried out by non-professional users and this has led to the widespread use by the emergency services. Pictometry project currently the largest on-going data acquisition project in Europe (Lemmens et al., 2007). The project is covering a total of over nine hundred in Europe with fifty thousand inhabitants. Therefore there is no difficulty in acquiring data for every major city in Europe. Based on several justification statements above, there are possibilities to use Pictometry images to obtain 3D spatial object, especially for cadastre purposes regarding to building construction and part of building as an object of registration in cadastre spatial dataset.

This chapter also reviewed theoretical concepts related to 3D spatial modelling. Semantic of 3D spatial object is important to be underlined since it can varies depends on which domain it will be applied. The previous discussion presents two examples, of which an object can be defined, from topographic and cadastre point of view, will affect on how the object will be modelled. In geometric modelling, two aspects of 3D object, location and shape, are taken into consideration since it directly related to representing and storing the geometric properties of an object in 3D space. The previous discussion already identified two possibilities in adopting CSG and B-rep model for 3D object. Topological model which is based on mathematical concept about space and relation is also considered important element in developing 3D spatial modelling. The current state of topology model of 3D object only dwells in internal topology and it is still under realm of researches to establish a full 3D topological that will allows its full capabilities in 3D GIS environment.

Finally, the last section discuses the mean of representing and exchanging 3D geo-information. First section and third section describe two standard data model from two different domains, in this case LADM and CityGML. Both of these data model accommodate geometric and topology model but use different semantic in defining their object of interest. LADM as a standard data model in Land Administration domain surely can make a benefit from the development of CityGML since it is still being developed as a conceptual model unlike CityGML which already implemented as an application schema of GML. The design of GML is intended to support interoperability through a common data model (feature and properties), a mechanism to create and share application schema, thus very effective in maintaining and exchanging 3D information between data models.

3. 3D Legal Object: Cases Experiences and Lessons Learned

3.1. Introduction

This chapter aims to define legal basis on determining 3D legal object and to answer two of research questions, i.e. (1) and (2) which are define in table 1.1 of chapter 1. Land object as one of main element in cadastre are generally explained in section 3.2. Section 3.3 describes the background of multiple use of space in urban and built-up environment and its relation with cadastre. Section 3.4 will explain about 3D legal object in cadastre. Section 3.5 discuss about the need of 3D cadastre spatial model as extension of current cadastral map. Several experiences from specific countries related to 3D legal object registration are overviewed in section 3.6. Finally, discussions and critical evaluation concerning to 3D legal object will be given in section 3.7.

3.2. Land Object as Legal Object

Legal object is one of three core elements of cadastral systems, beside person and rights. In modern cadastre (Kaufmann and Steudler, 1998), legal object imposes identical juridical parameters. The objects are described by boundaries which distinguish where a right, responsibility, and restriction (RRR) ends and where it begins. On the contrary, if the object, in this case, is land or other land related object, have no definition in legal framework then it is distinguished only as physical object. Therefore, one should have the ability to distinguish between these two notions.

It should be emphasized that the aim of cadastre is to record or register RRR to land, as a legal object, as long as the right and interest are recognized by the law. Therefore, to which extent physical objects should be represented in cadastre mainly depends on the basis of the current legal framework (Van der Molen, 2003). The previous statement implies that physical object is not a legal entity until a right or an interest is attached to it. The next sub-section describes several concepts about land objects as legal objects.

3.2.1. Land Parcel

Land parcel is a single closed area or polygon that is determined geographically by its boundaries, contains land under homogeneous property rights and is held in an ownership (UN/ECE, 2004). Land parcel usually describe as an area although in the reality it may extend downwards to centre of the earth and upward as far as the owner has possible interest.

3.2.2. Real Property

Real property can be defined as an object to which legal rights may be attached, especially rights of ownership (UN/ECE, 2004). Practically, properties are often related to buildings which are associated with land. Multiple interests can exist on a property and they can be shared between many subjects in separate RRR (Kalantari et al., 2008).

3.2.3. Legal Property Object

The term of legal property object was purposed by Kalantari et al (2008). The concept of legal property object as a new data model arose on the basis of the close relation between each RRR and its spatial dimension. Therefore, the relation between these entities should be recognise and maintain together as a unique entity in cadastral information system (Kalantari et al., 2008). RRR can include private, public, political, environmental, social and economic interest; while spatial dimension can cover all shapes and dimension, either 2D or 3D.

3.3. Use of Space in Urban Area: Why We Have to Consider the 3D?

Urban environment has developed and become more independent in terms of providing their own needs (De Flander and Rovers, 2007), urban environment has the ability to organize it self by harvesting available crops within urban boundaries. These so called "urban crops" cover various elements, e.g. energy, forest, river, quarry, and space. The latest term, urban space, can be seen as means of urban setting to provide their needs by maximizing the limited resources which is land through multiple use of space which lies beneath or above land surface. Utilizing the available space in urban can be seen as the possible way to fulfil the needs of urban activities.

The use of space and even multiple use of space have become more intense due to fact that land, especially in urban area, can not be increased, thus becomes scarce resource, but on the other hand it has become the basis of human activities. As a result, various types of constructions are built on top of each other, e.g. underground parking lot, underground stations, tunnels, building which consist of shopping mall in ground level and apartment complex on top of it (Figure 3.2.1), sky-bridges which has function as commercial activities and lies on top of public road (Figure 3.2.2).

Figure 3.3.1. Bijnkorf building with mix used (mall and apartment complex) in Enschede, The Netherlands

Figure 3.3.2. Mangga Dua bridge use for commercial purposes on top public road in Jakarta, Indonesia

3.4. 3D Legal Object in Cadastre

Section 3.3 already mentions several concepts about legal object in cadastre domain. For the consistency of the research, the term of legal object will refers to real property. It will be used since the research focuses on the ownership of certain part of property which is laid above ground parcel in which separate legal recognition could be attached on it.

3.4.1. Legal Aspect of 3D Legal Object

Legal object in cadastre perspective is mostly related to pieces of land that may or may not include all things permanently attached to its surface. As being mention before, the increase pressure on land has consequence in the creation of interlocking and complex property situation. These situation involve multiple use of space has became interest in cadastre since it has direct relationship with ownership of a property (De Flander and Rovers, 2007). From cadastre perspective, although RRR of a person is applied on the basis of the surface of the earth, i.e. 2D parcel, they always relate to space in 3D (Stoter, 2004), e.g. if a building is a subject of right superficies than it should be registered in the cadastre, but if it is a part of a property than it is meaningless to register it.

Legal object as one of main element in cadastre consequently is affected by the extension of the third dimension in cadastre. One also have to start consider that the partition of property's boundaries is defined not only horizontally but also in vertical direction. In fact, the description of RRR on objects with vertical boundaries also already resolves by several legal instruments. Therefore, the existence of 3D legal object only has meaning if rights which are entitled to the object can be separated with the ownership right of the land, such as right of superficies (Paulsson, 2007; Van der Molen, 2003), accession (Van der Molen, 2003), condominium (Paulsson, 2007; Van der Molen, 2003), and joint ownership (Stoter, 2004).

3.4.2. Definition of 3D Legal Object

The term of 3D legal object is still difficult to be defined since it expresses differently from country to country depending on the institution, as well as the legal context and area where it is used. A study by Paulsson (2007) already reviewed several definitions of 3D legal object. On her research, she concluded that 3D legal object, or 3D property in her term, is real property which is bounded legally both in horizontal and vertical dimension, i.e. in length, width and depth. She also notes that her definition does not make emphasize on "property" in order to accommodate various type of property rights in different legal systems.

3.4.3. Forms of 3D Legal Object

Although there are various means on owning or using whole building or only part of it as 3D legal object, there is a still difficulty to classify these kind of legal object. Basically, the main problem of this categorization is due to large extend the fact that structure is acknowledged by the statute in which the system is working. Paulsson (2007) attempted to categorize the form of 3D property right and focused on two types of 3D legal object form which is considered as "real" form of 3D legal object, i.e. (1) independent 3D property and (2) condominium. Next sub section will describe these forms of legal object base on the categorization by Paulsson (2007), but since this research focuses on certain type of condominium property, an explanation about apartment right is discussed also.

3.4.3.1. Independent 3D Property

Independent 3D property is a form of a 3D real property where the ownership is registered separately from the underlying parcel. The term of "independent" itself emphasize the fact that this form object does not consist of common part or space and the right does not connected to parcel. This form of 3D property right is sometimes called “air rights” in United States (Paulsson, 2007). According to several legislations, 3D independent property does not have to be a close volume but it may extend as far into the ground or air as private ownership extends (Onsrud, 2003).

There are two classification of this form of 3D property. First, it can be consist of just a space volume without any bound to a building or construction and it is called *air-space parcel* (Paulsson, 2007). Secondly, it also can be related to a building or construction in which the owner is not the same as the owner of the parcel (Stoter, 2004) and it is called *3D construction property* (Paulsson, 2007). Based on the above classification we can see that this form of 3D legal object may cover various kind of infrastructure, e.g. pipeline, cables, and tunnels, as well as construction or building as an object of registration.

3.4.3.2. Condominium

Condominium is the most frequent form of 3D legal object which occur in most countries. The term of condominium is used to define type of property which consist of individual ownership of a dwelling in a building (Paulsson, 2007). Unlike independent 3D property, condominium property always includes a share in the related underlying parcel, and it may consist of several parts which are individual owned and parts that are arranged as co-ownership.

Condominium in most countries is used for residential purposes, thus it can refer to apartment ownership; but they also can be used for commercial or industrial purposes. Although there are vary form of condominium in each country, there some common feature which can be identified (Paulsson, 2007).

- Condominium property can be registered, mortgaged, and transferred;
- The owners have right exclusively to use their own individual unit, as well as the ground and the common parts;
- There are rules for management of common properties since they are considered as serving facility for various unit in the building;

Research by Van der Merwe (2002), which is based on survey on United State, Scotland, South Africa, and German statutes; concluded that the provision on the ownership distribution in condominium is still not mandatory but merely provides a background law since detail regulation on current matter is still documented in the current country.

3.4.3.3. Apartment

As being mention in section 3.4.3.2, apartment ownership is a form of specialization from the condominium property when the purpose of the building is only intended for residential purposes. Right of apartment is considered as a part of civil law jurisdiction which define a restricted right of use, giving the holder a share in a joint right of ownership with exclusive use of certain part of the building (ECE/ECE/Trade, 1995; Van der Molen, 2003).

There are two different systems to define how the apartment unit is owned. First is the so called *dualistic system* (Stoter, 2004), system which the apartment is owned independently and is regarded as a real property unit, while the common areas are held in co-ownership. Several countries adopt this system; such as Australia, Canada, Spain, Norway (Paulsson, 2007), France, and Germany (Stoter, 2004).

Second system is called *monistic system* (Van der Molen, 2003) or *unitary system* (Stoter, 2004). In this system; the whole complex, including building and the ground parcel, are co-owned by the apartment owners. They own certain share of common property and related to the share is an exclusive right to use apartment unit in the building, thus the share and right are considered as one unit. This type of system can be found in The Netherlands, Austria, Switzerland (Stoter, 2004), and Norway (Onsrud, 2003).

3.4.4. Features of 3D Legal Object

There are several features to characterize 3D legal object, such as boundary, common property, and owners association. The study about features of 3D legal object in this section is based on the research of Paulsson (2007).

3.4.4.1. Boundaries

Boundary determination is one of essential element in cadastral process. If property units are all connected with each other within the same building with sharing walls, floor, and ceiling; determining its boundary surely became challenging in this kind of situation and there are several possible ways to deal with this.

One can justify determining the boundary between individual unit by locating the boundary in the median line of walls, floor, and ceiling between separate units. This, however, led to one major question which is how to locate the centre of walls, ceiling, and floor. Another problem also arise when define the boundary within median line since surrounding masonry and certain structural parts will be located within the boundary thus the owner will be restrained from altering these parts.

Other possible way is by declaring that boundaries are located inside the surface of walls, floors, and ceiling; and what lies beyond that is common property, thus creating an isolated object from each other and the common property by physical features (Van der Merwe, 2002).

Boundary determination is very crucial, especially in the condominium case, since it not only related to determining the shape or volume of a legal object but it also has relation with responsibilities and restrictions, such as who has the responsibility to maintain and repair wall. If boundary was declared in surface of walls, floor and ceiling, this implies that walls partition between separate units are part of common property and it become responsibilities of all owners to maintain and repair these walls.

3.4.4.2. Common Property

The distinction between common property and individual condominium/apartment unit is important due to the differences in ownership and consequences stemming from it (Paulsson, 2007). Differences between condominium/apartment unit and common property are summarized in Table 3.1.

Table 3.1. Differences between condominium/apartment unit and common property

Condominium/Apartment Unit	Common Property
Owner has exclusive ownership or right to occupy	Owner has less right to use due to collective ownership
Maintenance of a unit is under owner responsibility	Maintenance of common property is under owners' association responsibility

To some extent, the content of the common property can be distinguish either inclusively by specifying all part of building that included as common property, or exclusively by declaring every part that is not included as individual properties.

In several legal systems, there is differentiation whether a common property is a general common property or limited common property (Paulsson, 2007; Van der Merwe, 2002). General common property is the parts of building that can be use by all owners, thus it is also became responsibilities of all owners maintain and preserve these parts of building. Examples of general common property are land below and surrounding the building, parking lot, foundation of building, and roof. Limited common property is the parts of building that are reserved for the use of just several owners and not all of them via an agreement of all owners. The purpose of such agreement is to acquire a fair share of cost for maintenance of that area (Paulsson, 2007). Examples of limited common property are stair, elevator, and entrance shared by apartments on just one floor. Common walls between two apartments also can be regarded as limited common property is some legal system.

3.5. 3D Cadastre Spatial Model

One of main element cadastre system is the cadastral map (UN/ECE, 2004). This map represents spatial element of legal object and give information about location of the object. Most countries still consider cadastral map as a two dimensional graphical representation of ownership of land. This map shows all legal object as 2D polygon which has to fulfil two criterion, completeness and up-to-date-ness. Completeness means that cadastral map should cover all registered object which lies within administrative area. Up-to-date-ness means that cadastral map should reflect current legal situation in the reality.

The introduction of third dimension cadastral map or other spatial representation is still become dilemma since cadastral map in most countries still exist in two dimensional representation. The instalment of spatial representation of 3D legal object in cadastre is still being considered inefficient approach mostly because it requires high level of investment (Onsrud, 2003). On the contrary, the need and consideration in introducing spatial representation of 3D legal object in cadastre find its justification from several factors.

Van der Molen (2003) concluded that representation of such object is required since verbal description of 3D legal object seems impossible to be implemented for such object, and it is a useful extension of 2D cadastre especially to meet the requirement of speciality principle of cadastre. From technological aspect, Stoter and Van Oosterom (2005) noted that the realisation of spatial representation for 3D legal object in cadastre system is no longer impossible. In their research, they argued that the current developments in other domain, such as 3D GIS, 3D data collection, and 3D spatial modelling, makes 3D approach in cadastral mapping realizable.

Furthermore, matter concerning of spatial representation of 3D legal object also finds its justification and support in Cadastre 2014 statements although it does not describe the concerning issue explicitly (Stoter and Van Oosterom, 2006). While research by Stoter and Van Oosterom (2006) only gives emphasize only at the first statement of Cadastre 2014 as motivation in studying the 3D issue of cadastre, the recognition of 3D legal object representation can be realized in the third statement of Cadastre 2014. The implementation of cadastral model as a replacement of cadastral map gives possibility to extract different spatial representation.

3.6. Registration of 3D Legal Object in Several Countries

Phenomena of multiple use of space are increasing especially in major cities throughout the world. Many countries either developed or developing countries, has experience this phenomena as a result of the scarcity of land in urban area and the growth of human population, thus leading to the formation of 3D legal object or 3D property. Several countries try to accommodate 3D legal object in their registration system, either in cadastre or other public registration. In this sub chapter, we will have closer look at registration of 3D legal object from selected countries: Germany, The Netherlands, and Sweden. The selection of countries is base on several criterions.

First, they are selected base on the existed 3D legal object which is recognized by their legal system. In Germany and The Netherlands, form of 3D legal object which only being recognized are in form of condominium and apartment unit, while Sweden only recognizes independent 3D property in their jurisdiction (Paulsson, 2007).

Secondly, although Germany and The Netherlands have condominium or apartment registration in their system but they adopt different system. Germany adopts *dualistic system* for condominium or apartment registration, while The Netherlands adopt *unitary system*.

3.6.1. The Netherlands

Apartment ownership is the only case which 3D legal object considers to be an independent properties in cadastral registration in The Netherlands (Stoter, 2004). Apartment ownership, a*ppartemensrecht* according to Dutch Civil Code, means a share in the ownership of property involved in the division includes the right to exclusive use certain parts of the building which are use separately and land pertaining to the building. Owners of apartment units are co-owner of the entire building and ground parcel underneath it. Since The Netherlands adopt unitary system, a person does not legally own separate apartment unit, he or she only have exclusive right to use the unit (*exclusief gebruikersrecht*) (Stoter and Van Oosterom, 2006; Stoter, 2004).

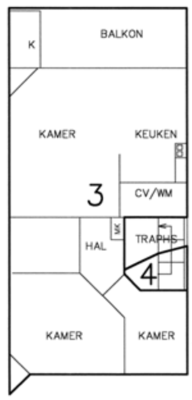


Figure 3.6.1. Plan of Apartment in the Netherlands' Cadastre
(Speckmann and Westenberg)

An apartment right is registered based on deed of division (*splitsingsakte*) (Stoter and Van Oosterom, 2006; Stoter, 2004). Apart to the deed, a plan which gives detail information about building, such as cross section and overview of every floor, also compulsory to be presented to the notary (Figure 3.6.1). The individual apartment unit then is assigned with unique number and the borders of the apartment are drawn using thick dark lines. The deed, which also contains the plan, is archived in the cadastral administrative registration.

3.6.2. Germany

The *Wohnungseigentum* is type of condominium ownership in Germany. With *Wohnungseigentum*, person can own a part of a building for residential or other purposes. There are condominium which is intended for residential purposes (apartment), *Wohnungseigentum*, and for commercial and offices, *Teileigentum* (Paulsson, 2007). Both type of condominium consist of part that individual ownership unit (*Sondereigentum*) and common property (*Miteigentum*). The German statute depicts *Sondereigentum* as part of the building which is intended for exclusive and independent use. This unit have to be clearly isolated from other *Sondereigentum* and *Miteigentum* base on independence and exclusiveness (Van der Merwe, 2002).

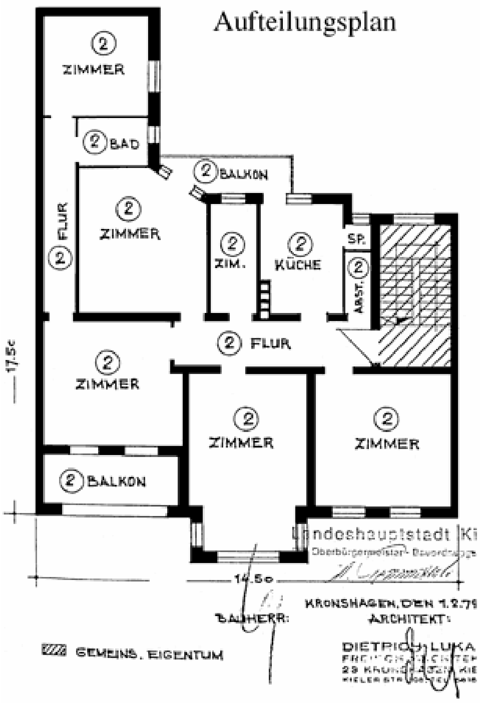


Figure 3.6.2. Subdivision Plan in German Cadaster
(Bongartz Immobilien Kreuzau)

The *Wohnungseigentum* is registered in real property register, where each of individual unit is registered separately. A subdivision plan (*Aufteilungsplan*) also should be presented and clearly distinguish individual unit and common property (Paulsson, 2007). The subdivision plan (*Aufteilungsplan*) consists of building drawing and it shows size and position of the building part with *Sondereigentum* and *Miteigentum* (Figure 3.6.2). Part that is considered as *Sondereigentum* has to be marked with number, if it is not marked then it is regarded as *Miteigentum* (Paulsson, 2007).

3.6.3. Sweden

Unlike The Netherlands and Germany, Sweden legal system only acknowledges independent 3D property. The main reason behind this is that the cadastral legislation in Sweden also recognises other object that are connected to land, such as building, utilities, and other facilities, as property unit beside land itself (Jansson and Eriksson, 2002). Other reason is to avoid empty, air space right property unit, thus it has to relate to a physical construction (Stoter, 2004). Such property is called *3D-fastighet* (Paulsson, 2007). The legal system also allows to real construction to be divided into different property (Stoter, 2004).

The 3D legal object is formed by cadastral process base on the Real Property Formation Act. The process of 3D legal object formation is the same as the case of traditional 2D legal object. Information about 3D space and building type will be recorded in cadastral registration. The information of 3D legal object in Sweden cadastre also includes boundaries, right, restriction, and position which are defined by XYZ coordinates. For boundary determination, it is described in cadastral document through text, map, and illustrations.

Apart from the establishment of Real Property Formation Act, it is still not clear on how to document 3D legal object in cadastral registration. At this moment, the footprint of 3D legal object is still being used to drawn the object in cadastral map, thus it registered the same way as 2D legal object (Stoter, 2004).

3.7. Discussion and Critical Evaluation

In this chapter we discuss about experiences on 3D legal object. Urban areas in many countries throughout the world are facing the increase pressure of land in order to fulfil the various activities of its population, either for living purposes, economic and commercial activities, industry, and other social activities. This pressure has an implication in the creation of multiple use of space in urban built up areas. As a result, various constructions are built on top of each other creating an interlocking and complex situation where each layer of construction might have different type of use and open possibility to subdivided land in vertical ways.

Land as the basis of human activities can be seen as a legal object and it is also activated by the extension of 3rd dimension in cadastre due to the multiple use of space. Therefore, the term of legal object, which is defined in horizontal plane (2D), is not suitable to describe such an object which lies in space (3D). Definition of 3D legal object in this research is adopted from Paulsson (2007) since it gives definition in wide and general ways in order to accommodate all form of 3D legal object. For more specific definition, each country has to provide its own legal definition according to its specific legal system.

There are two forms of 3D legal object identified in this research. First form is independent 3d property. This form of object does not have distinction between individual and common part and the right does not connected to the land parcel. Second form of 3D legal object is condominium or apartment if the object is specified for residential purpose. There are two distinct components in this form of object. First is individual unit which are intended for exclusive use by unit owner and secondly, common properties which are intended to be used collectively by all owners.

The distinction between individual and common properties in condominium or apartment is important for the following reasons. Firstly, the owner of individual unit has exclusive use or ownership with regard to those parts that included in their unit; on the contrary they only have collective ownership over the common property. Secondly, the responsibility of maintaining individual unit lies on the owner whereas the responsibility of the common property must be borne collectively by all owners with a share in the common property.

From comparison of 3D legal object registration based on three different countries, there are some similarities. First, the presence of drawing plan or subdivision plan which gives detail information about the unit is a requirement one has to fulfil to register a 3D legal object. Secondly, the plan which contains spatial information about the object is only kept as a part of administrative record in cadastral registration, with exception in Sweden case where it is represented in cadastral map but only as a building footprint, without any link with cadastral spatial dataset.

In depth discussion from conceptual framework of 3D legal object and experience learned from several countries gave us information concerning to legal specification od 3D legal object. This legal specification is described in the following:

- Rights which are entitled to the 3D legal object can be separated with the ownership right of the land or ground parcel
- 3D legal object is real property which is bounded legally both in horizontal and vertical dimension, i.e. in length, width and depth
- For condominium/apartment, there are differences in the right use of certain part which can be exclusively use (individual space) and other part that co-owned (common space)
- For condominium/apartment with dualistic system, part of building which is considered individual space is entitled by individual ownership right while common part is entitled by co-ownership right. Exclusive right of use/ownership is separated with share.
- For condominium/apartment with unitary system, the whole complex, including building and the ground parcel, are co-owned by the apartment owners. Exclusive right of use and share is considered one unit.

4. Data Acquisition Techniques for 3D Legal Object

4.1. Introduction

This chapter explains a stepwise process taken to answer research question (2), (3), and (4) addressed in table 1.1. Identifying semantic which becomes the basis on delineating legal boundary is discussed in section 4.2. Experimental approach to acquire 3D legal object is presented in section 4.3. Finally, section 4.4 is devoted to discussion and critical evaluation for this chapter.

4.2. Identification of Semantic

Determining semantics of a spatial object is the first step that one has to fulfil before preceding the experimental approach of acquiring 3D spatial object. In this research, the 3D spatial object is modelled semantically from topographic perspective since the data acquisition process mainly concerns a physical object. The semantic model of a 3D physical object in this research is developed using CityGML conceptual model as reference. On the other hand, semantics of 3D legal object are also modelled from cadastre perspective.

This model then will be transferred into legal semantic model based on legal specification which has already been discussed in chapter 3 (Figure 4.2.1). Legal semantic knowledge becomes the basis in the experimental approach of acquiring 3D legal object since it will determine the status of legal boundaries; such as which side of wall that we can assume as the boundary of the apartment, the median or the inside surface; do we have to treat windows and doors apart from the boundary or treat them as a part of boundary. These boundaries determination will become rules of thumb in extracting 3D legal object geometry.

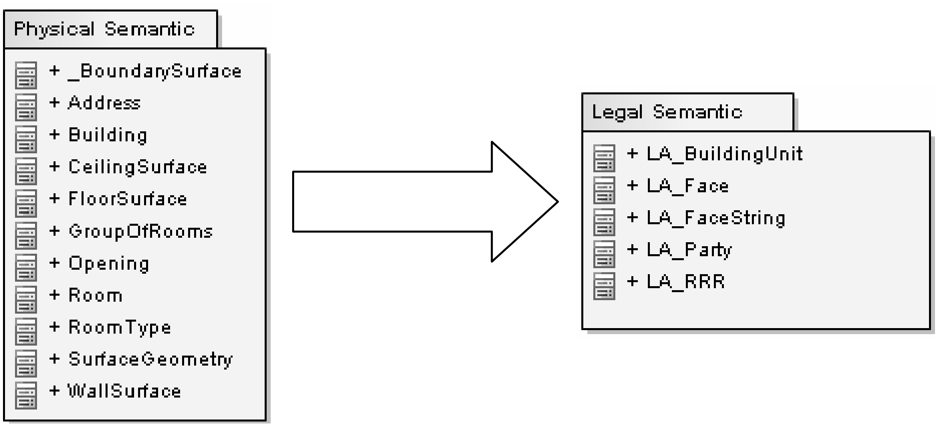


Figure 4.2.1. Transfer of Semantic Information

4.2.1. Semantic Model of 3D Physical Object

Semantics of 3D physical object or a building are derived from architectural drawing. As mentioned before, architectural drawing contains rich information about physical appearance of building. Information about walls, floors, ceilings, windows, doors, room partitions which compose the whole building are available in the drawing either as a graphical or in textual information (see Figure 4.2.2).

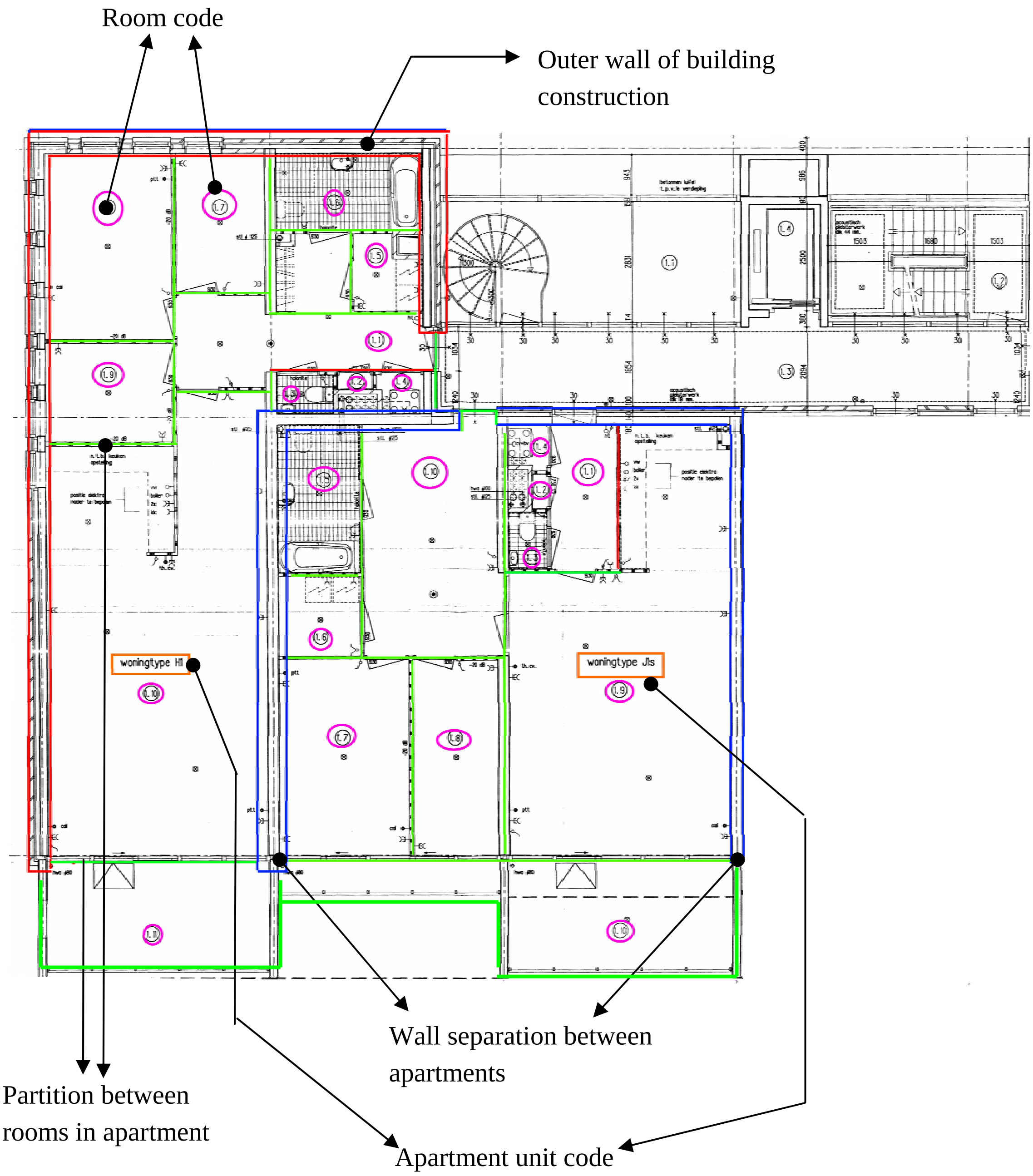


Figure 4.2.2. Semantic Information in Architectural Drawing

All of this semantic information is modelled in Unified Modelling Language (UML) class diagram which can bee seen in Figure 4.2.3. The fundamental class of the model is class *Building*. Attribute of *Building* is name of the building. *Building* class accommodate the building.

Room is a class that defines the smallest partition of a building. It defines type of room such as kitchen, bed room, bath room, or even entrance. *Room* not always consist of close bounded space or finished construction, examples of room that is not completely close are balcony and emergency stairs room that exist in every floor. Class *GroupOfRoom* is an aggregation hierarchy from room, in some cases it may exist as a composition from at least one room, thus it forms an apartment unit.

Classes *Building*, *Room* and *GroupOfRoom* in the reality are bounded by surface, then it is possible to distinguish bounding surface as own thematic object. These surfaces can be classified as *Roof*, *Wall* and *Floor*. *Roof, Wall, and Floor* is construction part that has two side of surface with different width depends on its construction material. The geometric property of these is described as *SurfaceGeometry* that defines the whole building, room and group of room with GM_Surface as the geometry's type. With GM_Surface, each side of wall, roof, and ceiling can be modelled geometrically with set of face thus creating bounding box type of object.

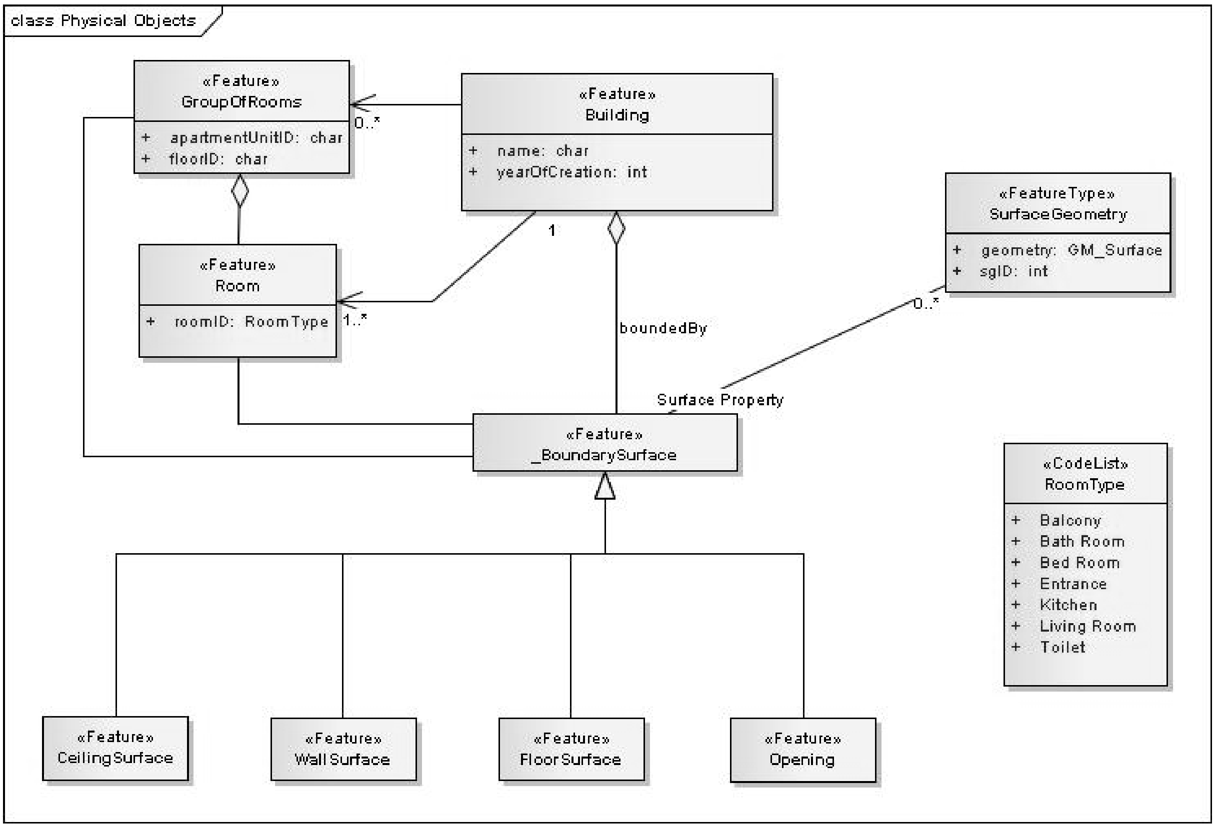


Figure 4.2.3. Semantic Model of a Apartment Building as 3D Physical Object

From semantic model and description mentioned above, we present several characteristics of apartment based on physical semantic information.

- Wall as a physical entity consist of inside and outside surface and in middle there is masonry
- Wall that coincide with part that bounded building construction act as boundary surface for certain individual unit or apartment
- Walls between apartments separate each apartment and also act as boundary surface for each apartment
- Walls partition between room, i.e. kitchen, bed room, living room, balcony, within apartment are considered as part of apartment itself

- Any type of opening, such as windows and doors are considered as one part of wall that create boundary surface of apartment
- Room code is a unique identifier for each room partition and defines the function of room
- Apartment unit code is identifier for each apartment and defines type, location, and shape/area of an apartment unit.
- Each apartment must designated specifically to an address which consist of house number, street name, and zip code
- Composition of individual apartment units and other group of rooms, e.g. entrance in each level and roof, form whole building

4.2.2. Semantic Model of 3D Legal Object

Semantic model of 3D legal object in this research is based on the profile of The Netherlands cadastre registration from LADM with a modification. LADM consists of one five main package and each package are maintained and developed independently. Term, definition, and class diagram of LADM can be seen in ISO (2009). Although LADM not only mainly concerns in 2D legal object and its relation within cadastral domain but it also can be expanded to accommodate 3D legal objects. Several packages of LADM are identified and used with their relations in defining 3D legal object as the main focus in this research. These packages are Party Package, Administrative Package, Spatial Unit Package, Surveying Package, and Spatial Description Package which are already reviewed in section 2.5.1.

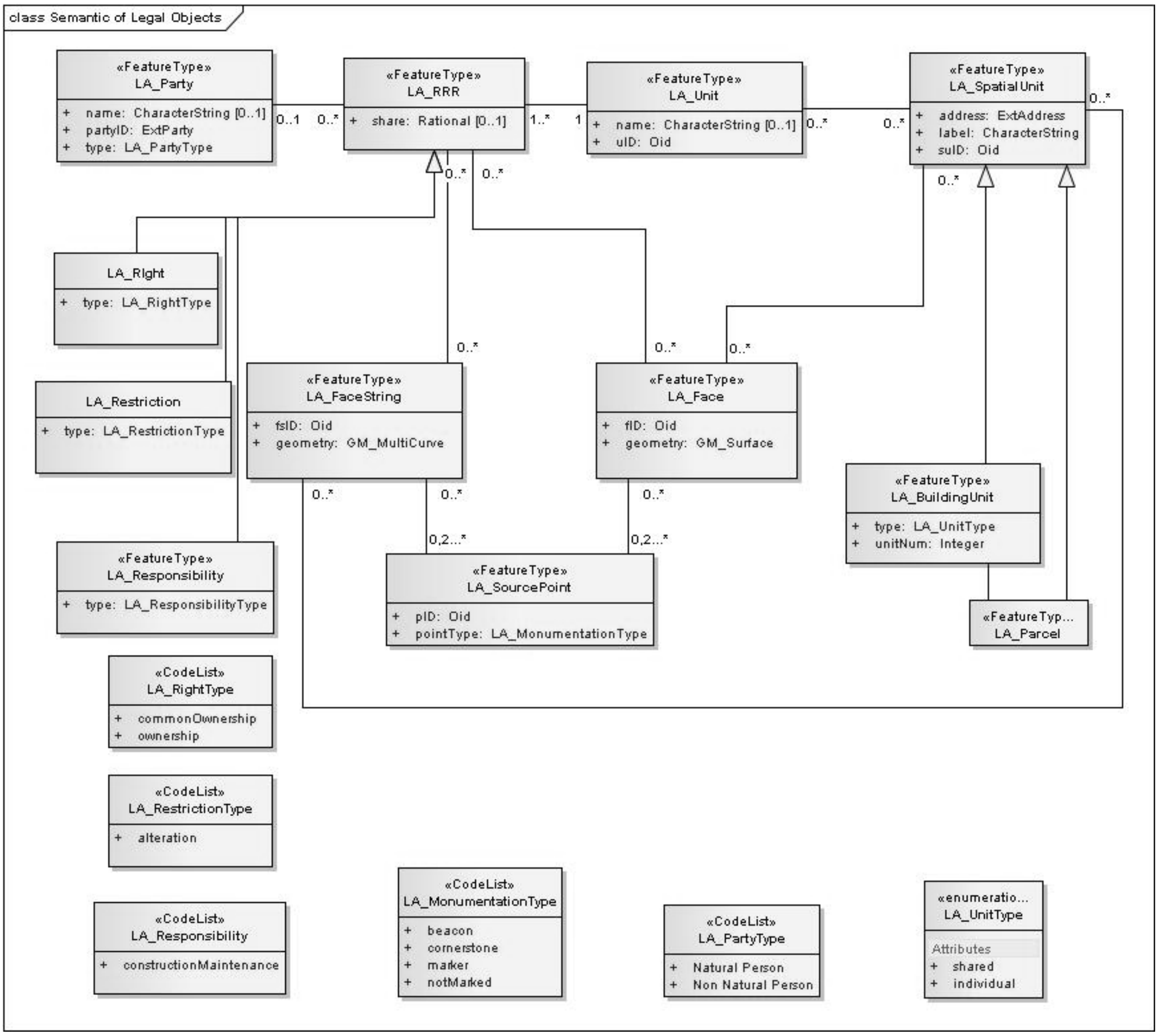


Figure 4.2.4. Semantic model of Apartment as 3D legal object

Although the main purpose of LADM is to develop data model for land administration or cadastre, we identified several of classes of LADM which can be used to define semantic of 3D legal object. Semantic model that we adopt from LADM can be seen in Figure 4.2.4 and several of classes we identified are:

LA_Party

LA_Party specify person, group of person, natural or non natural person, who held ownership right over 3D legal object. Attributes of LA_Party are name, partyID, and type of party. LA_Party is one of semantic of 3D legal object. An object does not exist in cadastre system as legal object if there i no party who claim ownership over the object.

LA_RRR

LA_RRR is an abstract class where its instances exist in the specialization class (LA_Right, LA_Responsibilty, and LA_Restriction). Attribute of LA_RRR is share and it is inherited to specialization class; hence there is share in right, share in restriction, and share in responsibilities. In LADM, LA_RRR is associated to LA_Party and LA_Unit, therefore share over RRR is only effected both party and unit. This relation is well fitted for 2D case where various RRRs are established over homogenous area. In 3D legal object, we found that share of RRR could be associated to boundary. In some legal statute, wall separates one apartment from another is defined as limited common property where the responsibility in the maintenance of this wall lies within those two apartments' owner while the share of each apartment lies exclusively to each owner.

LA_Right

LA_Right is a specialization class of LA_RRR. Attribute of this class is type of right. In 3D legal object case, there are only two types of ownership rights, i.e. ownership and common ownership. Ownership right is exclusive right of use for individual apartment unit. This means that the owner has greater right over his or her unit as well as power to alter his or her apartment. Common ownership right is a collective right of use over common property (see section 3.4.4.2). Common ownership right is more restricted compare to ownership right. Owner has to realize that share of right, restriction, and responsibility is collectively owned with other owner.

LA_Responsibility

LA_Responsibility is a specializaton class of LA_RRR. Attribute of LA_Responsibility is type of responsibility. In 3D case, term of responsibility is mainly comprised of responsibility to maintain common property or part of masonry that form construction of the building. The responsibility of maintenance is realized through agreement between all owners. In some cases where statute recognizes limited common property, responsibility of this part only affect limited number of owners.

LA_Restriction

LA_Restriction is a specialization class of LA_RRR. Attribute of the class is type of restriction. In 3D case, restriction in individual apartment unit mainly relates to the alteration of wall that consider as one part of construction. Similar with responsibility, restriction in 3D legal object also could be related to boundary.

LA_LAUnit

LA_Unit is class that maintain description of legal entity which become object of registration. LA_Unit consists of zero or more spatial description. Attributes of LA_Unit are name of unit and unit identifier.

LA_SpatialUnit

LA_SpatialUnit is class that describe type of legal object with its spatial description. This spatial description could be existed as text (verbal description), point, polygon, or topological spatial unit. LA_SpatialUnit accommodate 2D and 3D spatial unit by its specialization class, i.e. LA_Parcel, LA_BuildingUnit, LA_Building, and LA_Networks.

LA_BuildingUnit

LA_BuildingUnit is subclass of LA_SpatialUnit. LA_BuildingUnit class accommodate 3D legal object such as apartment unit and common unit which in the reality is part of legal building, therefore building could be formed from composition of building unit. Attributes of LA_BuildingUnit are type of building unit (individual or shared), and unit number. LA_BuildingUnit (and LA_Building) provides registration of 3D legal object as a separate entity. Since registration of 3D legal object may or may not relate to the ground parcel (Paulsson, 2007; Van der Merwe, 2002), there should be association between LA_BuildingUnit (or LA_Building) with LA_Parcel.

LA_Parcel

LA_Parcel is a class that maintain description of spatial unit as an area under homogenous real property right. Although the tendency of parcel is more to 2D perspectives, share of RRR of apartment unit, common unit, and even building can not be separated with the ground parcel according to some statute. Therefore, association between LA_Parcel and LA_BuildingUnit (or LA_Building) is preferable.

LA_Face

LA_Face is one of two classes in spatial description package. The other class is LA_FaceString. Face (and FaceString) is the key concept in describing 2D and 3D legal object geometric description. While FaceString use line-string as boundary of area (2D), concept of Face which uses surfaces is more applicable for describing 3D legal object boundary as set of faces. Face (and FaceString) is a result of interpolation of boundary point which is defined in LA_SourcePoint.

LA_SourcePoint

LA_SourcePoint stores information concerning to boundary point of legal object as a point geometry. One of attributes of LA_SourcePoint is type of point or type of monumentation in field. It is common in boundary demarcation process to place certain type of monumentation, i.e. corner stone, beacon, marker, or concrete mark; we found out that boundary point can not be established as monumentation, or marked as not mark, since it is located either inside or within construction of building.

From semantic model and several classes of 3D legal object mention above, we evaluate several characteristic of apartment from legal semantic information.

- Party (or people) and RRR are semantic that can not be separate from apartment as 3D legal object
- In 3D case, RRR’s are not only relevance with object itself but also affect on boundary of an object. It is possible that one boundary in an apartment has multiple share while other boundary for the same apartment has only one share of RRR.
- Geometric description of 3D legal object or boundary also can be considered as semantic. In semantic model of 3D legal object based on LADM, geometric description of the object is defined as set of faces and its coordinates are stored in separate classes.
- In the reality, it is possible that an apartment consist of room that has unenclosed contiguous space (such as balcony or patio). For this kind of boundary, an imaginary lines, vertical or horizontal, is drawn as the continuation of boundary for the unit.

Based on evaluation of semantic models of apartment as physical and legal object, and legal requirement which is already discussed in chapter 3, we can derive two possibilities rules in determining legal boundary of individual apartment unit. This means that every component that is not coupled with these rules is considered as common property.

Rule 1

Delineation of centre line of surface, e.g. walls, roofs, ceilings, hence walls which separate between units are co-owned by owners and their share is embedded to each boundary. This rule can be applied for unitary system.

- Delineation of boundary located on outer walls of building is performed according to their outer surface. Responsibility and restriction rest with apartment owner (limited common properties).
- Walls, ceiling, and floor which separate apartment unit are delineated in their median line. Responsibility and restriction are shared between neighbouring parties (limited common property)
- Partition walls, e.g. bed room, bathroom, kitchen, balcony, living room, are considered as part of individual space.

Rule 2

Determine that the boundary is within the inner surface of walls, roofs, ceilings, thus walls which separate between units are considered as part of construction (common space). This rules create an encapsulated space, every partition is considered as part of construction and co-owned by all the owners. This can be applied for unitary and dualistic system

- Every walls, ceilings, floor, and roof is part of whole construction and is considered as part of common space. Responsibility and restriction are shared by all owners.
- Boundaries of apartment unit is located in the inside surface of wall, ceiling, and floor. Hence, responsibility and restriction only fall to the owner.
- Partition walls, e.g. bed room, bathroom, balcony, kitchen, living room, are considered as part of individual space.

4.3. Experimental Approach to Acquire 3D Legal Object

Experimental approach in this research mainly involves 3D object measurement reconstruction techniques by non contact method. This process mostly uses to extract physical object in topographical sense. While it is clear that physical object can be distinguished by its boundaries according to its physical appearance, a legal object might came with different conception. A legal object is an abstract object and its boundaries may or may not coincide with physical boundaries. Base on the later statement, implementing this process to extract 3D legal object is surely an experimental approach. Since the techniques can be implemented using various data sources (see Figure 2.3.1), this research only experiment with two data source or dataset, i.e. architectural drawing and pictometry images using IBM methods.

4.3.1. 3D Object Measurement and Reconstruction Using Architectural Drawing

As have been revealed from discussion in chapter 3, the availability of subdivision plan or drawing plan is one of requirement of apartment or other 3D legal object registration in several countries. This subdivision plan is based on architectural drawing from building developer. Unlike subdivision plan which already consist of room partition, boundaries delineation and unique identifier number for each unit, architectural drawing which used in this research still consist of rich construction information (see Figure 4.2.2), thus it does not contain any legal information which can be use for apartment registration especially related to boundary delineation.

4.3.1.1. Converting Architectural Drawing into Digital Format

Architectural drawing is one of data source that can be utilized to reconstruct 3D spatial object. Since the drawing mostly still in paper format, it should be converted into digital form using scanner before it can be digitized. One has to consider the result of scanning process since most of consumer type scanners lack of calibration; hence the result is affected by geometric distortion. Furthermore, the effect of distortion will affect the digitizing process. To eliminate error cause by this distortion, a geometric correction on the digital drawing can be implemented, either using CAD program which is designated for mapping or using more sophisticated image processing software. Since the drawing also contains width and length distance of the building, then these values can be used as a reference values for geometric correction. Other factors that also determine the quality aspect of the result are resolution of the scanner and the scale of the drawing.

4.3.1.2. Digitizing Process

After correcting the error, digitizing process can be conducted on the drawing using CAD program, the result is a 3D CAD model of the apartment unit in wire-frame model. The digitizing method can be chosen between automatic, semi-automatic, or manual digitizing. The selection of method mainly depends on the quantity of information of the scanned drawing. If the drawing only contains few type of information then choosing automatic method might be suitable. But if the drawing contain complex and various type of information then it would be wise to select manual method.

The above consideration in selecting digitizing method is suitable to be implemented in ideal term and condition. One still has to consider on the quality of scanned drawing since it might be affected by distortions caused by scanner instrument. These distortions can affected both the geometric quality and the resolution of the drawing. Therefore, manual digitizing method is still producing the best result among other digitizing method, although it is still time consuming process.

4.3.2. 3D Object Measurement and Reconstruction Using IBM

Another method to obtain 3D spatial object is IBM. This method uses multiple images to reconstruct geometric surface of a topographical object. IBM method can be used to process images from various data sources, such as aerial images and terrestrial images.

As illustrated in Figure 4.3.1 below, the implementation of IBM method in this research is begun with camera calibration. Second step is geometric modelling of topographical object according to their semantics'. After a model is created, quality assessment is performed. The last step of the process is converting the existing model into CAD model in order to assign semantic attribute of the object.

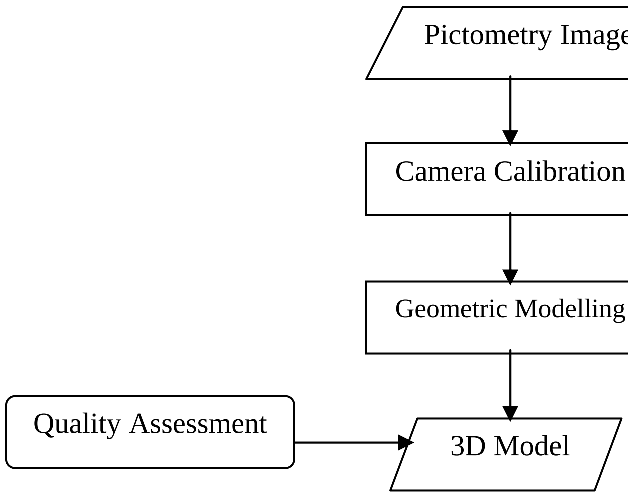


Figure 4.3.1. Workflow of IBM implementation

4.3.2.1. Camera Calibration

The first step in generating 3D model from pictometry images is reconstruction of camera orientation parameters or calibration. Camera calibration process can be done by self calibration process. Self calibration is a term mostly is used in computer vision in performing determination of camera parameters, internal orientation parameters, and external orientation parameters simultaneously in single process.

Self calibration process can be accomplished by y using images of an object and measuring well defined object points given by object space coordinates. These calibration points act as a tie points or common points because each of this point has to be exist in at least two images and the configuration of these points have to be well spread. For this purpose, numbers of calibration points are defined spread out in every image to achieve maximum result from the calibration process. The calibration process then calculates the orientation parameter of the camera, i.e. principal point, focal length, and external orientation parameter with respect to coordinate system.

The Quality of camera calibration can be assessed by analysing the residual value of each point after calibration process. Residual value is the distance in pixels between the 2D calibration points placed in the image and its corresponding point in the 3D coordinate spaces after being re-projected onto the image.

4.3.2.2. Geometric Modelling

Once the images are calibrated and are oriented, geometric modelling of an object can be performed by creating shapes and forms onscreen using one or more types of geometry. In several commercial packages, creating a geometric model usually performed by drawing a geometry primitives. These primitives can be in form of a box, cylinder, plane, or circle shape. By implementing the primitives correspondence to topographical object facades such as building, 3D geo-information can be extracted (see Figure 4.3.2). For more complex object, it is necessary to drawing several primitives and later merges them into one object.

Figure 4.3.2. Implementing Geometry Primitives to Model a Building

In basic photogrammetry, principal point and external orientation parameters act as parameters in transformation equation. This equation is used to reconstruct 3D coordinates of an object in space from 2D image. This equation can be applied vice versa meaning that if we already define object in space we can re-project it into 2D image and this is how IBM work in geometric modelling. First we select a geometric primitive which still has relative shape and dimension. This primitive is re-projected back into 2D image to be fitted with object that being modelled.

So far, the IBM method which has been discussed is mainly used to extract 3D spatial object of a building according to their external appearances. Since this research is focused on apartment unit as a 3D legal object, which is physically situated in the inside part of a building, it seems very challenging to implement IBM method to acquire this kind of spatial object. Because we can not determine the inside situation of the building straightforwardly from the image, we might have to consider to use semantic information of the building to accomplish this challenge. Information about numbers of windows, balconies, and elevator shaft can help us to model internal part of the building. Since every apartment has certain number of balconies depends on apartment's type then information about balconies helps us in determining width of apartment. Number of windows also can be used to determine boundary between two apartments is coincided inside the building.

4.4. Discussion and Critical Evaluation

This chapter explained the approach in acquiring 3D legal object and how a data acquisition approaches that mostly used for physical object can be implemented for legal object. The experimental approach which proposed in this chapter mainly compromises two concepts. First concept is identifying semantic knowledge to develop rules in determining legal boundaries of 3D legal object. Secondly, implement these rules in extracting 3D geometric model of whole objects.

Developing semantic knowledge is the essential part. This research develops semantic model of the 3D spatial object according to physical and legal perspectives. Semantic model of 3D physical object is built using CityGML as reference. Although it refers to CityGML, it does not mean that it completely built upon it but rather is the basis of analysis on how relation of each semantic is defined. For semantic of 3D legal object, this research adopt LADM as semantic model of 3D legal object. Although LADM is developed to model all data and process involves in land administration domain using UML classes diagram, we identify that classes in LADM also act as semantic for 3D legal object. Hence, LADM is also suitable as semantic model for 3D legal object. This semantic model confronted with legal requirement and specification which are already discussed in previous chapter. The analysis of this will derives rules on how legal boundary can be delineated; hence 3D legal object can be extracted using the experimental approach.

Experimental approach mainly involves 3D object measurement and reconstruction technique by non contact method. Two datasets are selected, which are architectural drawing and pictometry images. 3D reconstruction using architectural drawing is employed by digitizing it. The quality of digitizing result is mainly affected by the result of scanning process, therefore geometric correction is needed. IBM method is already implemented to extract 3D physical object, to implement this method for 3D legal object is a challenging task since not all of the object may appear in images. Therefore secondary information might be useful to overcome with this problem.

5. Experimental Results

5.1. Introduction

This chapter presents the results and findings obtained after the implementing the data into the experimental approach as described in previous chapter. This section begins with implementation of data into experimental approach and shows result of experimental approach in section 5.2, followed by findings of the experiment result in section 5.3. Section 5.4 presents the summary of findings from experimental result. For implementation of data into experimental approach, Autodesk AutoCAD Map version 9 and Autodesk ImageModeller 2009 were used for 3D legal object geometric modelling, while converting and visualization of data are done using FME 2008 Workbench and Aristotles-V1.2.01.

5.2. Implementation and Result

5.2.1. Study Area

To analyze methods of data acquisition of 3D geo-information for cadastre purposes, a study area was selected. The study area which is chosen in this research is an apartment complex which consists of 20 apartment units. The building or apartment complex is situated in Enschede municipality and its name is "Palazzo Cicero" (see Figure 5.2.1). The selection of study area is based on two criterions. First, the individual apartment unit has to be registered as an individual ownership separately with the ownership of underlying parcel in The Netherlands Kadastre registration database. Secondly, the building must consist of individual property and common property.

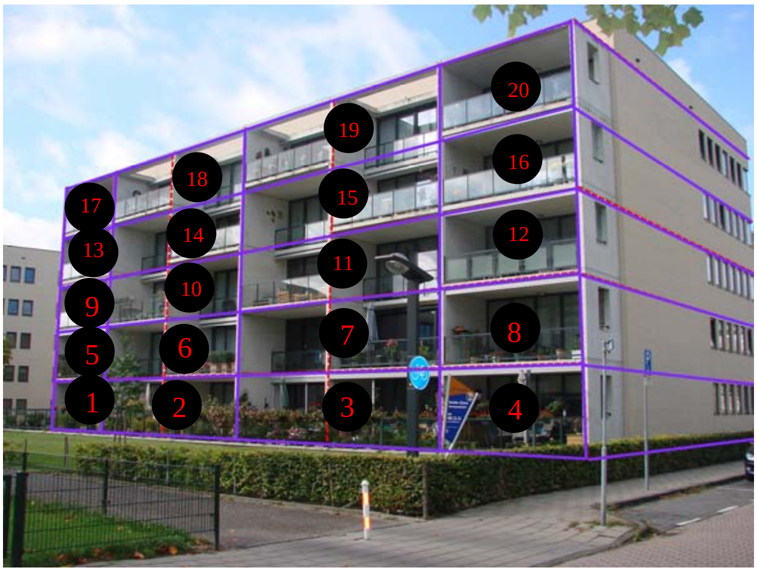


Figure 5.2.1. Apartment complex "Palazzo Cicero" used as study area

5.2.2. Data Collection

Several data are acquired during the research in order to be implemented in the experimental approach. Cadastral data which consist of owner, right, object of registration, and parcel data are obtained from The Netherlands Kadaster in form of database. Cadastral data which is being kept in The Netherlands Kadaster only contain administrative land registration for apartment registration in their database. Unlike 2D legal object, e.g. parcel, there is no spatial representation of 3D legal object in The Netherlands Kadastre cadastral map. Example of both 2D parcel and apartment ownership data can be seen in table 4.1 below.

Table 5.1. Cadastral Data of Pallazo Cicero Apartment and Ground Parcel

No	Object Id	Owner Name	Right Type	Street Name	Zip Code	House Number
1	ESD00B 07792G0000	VERENIGING VAN EIGENAARS APPARTEMENTEN COMPLEX PALAZZO CIRERO	VE			
2	ESD00B 07816A0001	GRIETINUS	VE	BEUKINKSTR	7511RP	50
3	ESD00B 07816A0001	GRIETJE	VE	BEUKINKSTR	7511RP	50
4	ESD00B 07816A0002	BERTUS JACOBUS	VE	BEUKINKSTR	7511RP	52
5	ESD00B 07816A0002	MINI JOHANNA	VE	BEUKINKSTR	7511RP	52
6	ESD00B 07816A0003	PIETER	VE	BEUKINKSTR	7511RP	54
7	ESD00B 07816A0003	ANNA IRENE	VE	BEUKINKSTR	7511RP	54
8	ESD00B 07816A0004	CHRISTIAAN	VE	BEUKINKSTR	7511RP	56
9	ESD00B 07816A0004	MARIJKE	VE	BEUKINKSTR	7511RP	56
10	ESD00B 07816A0005	JOHAN LODEWIJK	VE	BEUKINKSTR	7511RP	58
11	ESD00B 07816A0005	EMMA	VE	BEUKINKSTR	7511RP	58
12	ESD00B 07816A0006	HENDRIK JAN	VE	BEUKINKSTR	7511RP	60
13	ESD00B 07816A0006	JACOBA CORNELIA	VE	BEUKINKSTR	7511RP	60
14	ESD00B 07816A0007	GRADUS JOHANNES	VE	BEUKINKSTR	7511RP	62
15	ESD00B 07816A0007	SANDRA	VE	BEUKINKSTR	7511RP	62
16	ESD00B 07816A0008	WIM	VE	BEUKINKSTR	7511RP	64
17	ESD00B 07816A0009	HENDRIKUS FRANCISCUS JOHANNES	VE	BEUKINKSTR	7511RP	66
18	ESD00B 07816A0009	EVERDINA HENDRIKA	VE	BEUKINKSTR	7511RP	66
19	ESD00B 07816A0010	GRADUS BERNARDUS	VE	BEUKINKSTR	7511RP	68
20	ESD00B 07816A0010	HENRIETTE	VE	BEUKINKSTR	7511RP	68

VE: full ownership

Object id which is indicated in table 4.1 above is an identifier which signifies an object of registration or property unit according to The Netherlands Kadaster database. Suffix G (ESD00B 07792G0000) in object_id column from table 5.1 shows that this number refers to right of ownership for the ground parcel, while suffix A, e.g. ESD00B 07816A0001, refers to an apartment right. Five digit numbers in the object id code indicate parcel identifier and acts as a link between property unit and cadastral spatial database or parcel database. Although it seems there is a link between property unit database and parcel database, only property unit which contains suffix G in the object id, or ground parcel, that being kept in the parcel database. In other word, there is no spatial information for individual apartment since they are not recorded in cadastral spatial database.

For 3D modelling purposes, this research uses approaches using two different dataset. First dataset is architectural drawing of the building being collected from Enschede Municipality (dataset 1). This dataset consists of four drawings in paper format, each of them has A0 size format with scale of 1:50. Three of them depict the blueprint of the building for each floor and one drawing shows profile situation of the building. From dataset 1, we obtain semantic information, such as type of apartment, type of room, number of rooms, type of bounded surface; and these semantic is consistent with the semantic model we discussed in section 4.2.1.

Second dataset is pictometry images which were acquired from BLOM UK (dataset 2) and provided by Dr. Markus Gerke from Department of Earth Observation Science, International Institute of Geo-information Science and Earth Observation. Dataset 2 consists of six pictometry images and they have been calibrated. Four samples of this dataset can be seen in Figure 4.1.2 below and technical specification of the image can be seen in Table 4.2.

Figure 5.2.2. Samples of dataset 2

Table 5.2. Technical Specification of Pictometry Imagery

Sensor array	36 x 24 mm
Image size	4008 x 2672 pix^2
Pixel Size	9x9 microns
Focal length	Approx. 85 mm
Flying height above ground	Approx. 920 m
Inclination angle for oblique camera	45°

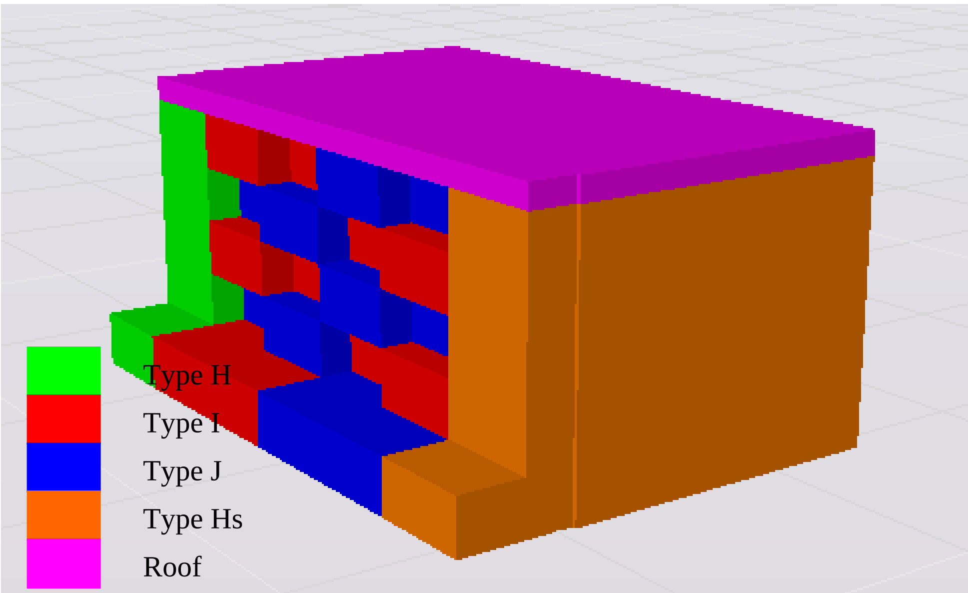
5.2.3. Extracting 3D Legal Object Geometry

Base on semantic analysis concluded in previous section, now we can perform 3D object reconstruction base on the suitable rules which can be applied in the study area. Hence, delineation of boundary is performed according to **Rule 1**. Following this rule, now we can determine in which surface the boundary lies. This rule is applied for each type of apartment and will give insight on which of surface the legal boundary lies.

5.2.3.1. Dataset 1

First step in modelling apartment unit in study area using dataset 1 is to convert the dataset into digital format with scanner. We used large format scanner to convert dataset 1. Resolution of the scanner is 300 dots per inch (dpi) and it is work based on push-broom method. We can calculate the accuracy of the scanned image based on resolution of the scanner and scale of the drawing. From calculation we got value of 2 mm for the accuracy. As being discussed in chapter 3, we have to perform geometric correction on the scanned drawing and then digitize them. The push-broom method used in this type of scanner gives contribution on distortion of the resulting scanned image. For reducing the effect of the distortion by scanner instrument, a geometric correction is performed using non-linear transformation or three parameter transformation. References values that we used for correction process are distance value from architectural drawing.

Textual information in blueprint drawing gives us clear information about floor number, type of wall, type of opening (doors and windows), type of apartment unit, and type of room. Since blueprint drawing only provides information in 2D environment, information on elevation can be derived from profile drawing. For dataset 1, we applied manual digitizing method to digitize boundaries of each apartment unit. For this purpose, we choose triangular mesh to model the surface of each boundary. Figure 5.2.3 illustrates the result of dataset 1 in CAD model.



.

Figure 5.2.3. CAD Model of Dataset 1

5.2.3.2. Dataset 2

Each apartment unit in study area from dataset 2 is modelled using IBM method. To create 3D model, the object to be modelled have to be shot from different viewpoints. Identifying common characteristic on the object in each of images displayed will provide information that it needs to automatically calculate the position, orientation, and camera's parameters used to taken the photos.

Camera Calibration

From camera calibration data we received, the calibration process was performed using 28 calibration points. These points are spread out in a well define location so it can be identified from several images. Four of these points are also act as ground control point, thus all images was already defined in specific coordinate system. The average residual of the calibration process is 0.5 meter in ground resolution. The complete result of the calibration process can be seen in Appendix A.

3D Geometric Modelling of Dataset 2

3D geometric modelling is carried out by using box as geometric primitives. The primitive is refined according to characteristic of the building, such as upper or lower corner of the building. Later, each surface of the primitive can be dragged along three coordinate axes, XYZ. Surface also can be snapped base on node and edge of neighbouring object, thus preventing gap between the two.

Since the shape of apartment unit can not be determined straightforwardly from the image, it is necessary to use secondary information to determine this. As being analyze from the original dataset 1, we found out that each floor of the building is consist of four type of apartment, i.e. type H, type Hs, type I, type J, and one entrance room as common unit (see Figure5.2.4).

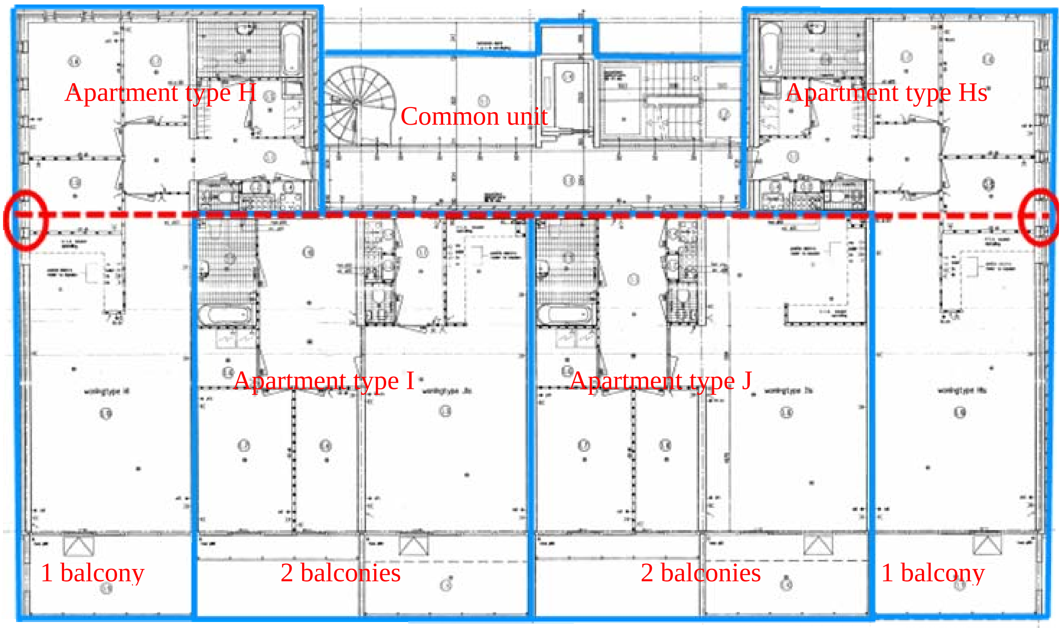


Figure 5.2.4. Identifying constrains for IBM approach

The blue colour outlines the boundary of each unit. Each apartment has a significant number of balconies. For example, apartment type H and Hs only has 1 balcony while type I and J has two balconies. Base on this information we can model the front side of each of apartment unit using box primitives fitted in balconies. Implementation of 3D box into significant balcony is illustrated in Figure 5.2.5(a).

Other information that can be useful to model apartment is the information about window. Several apartments, i.e. type H and Hs, have unsymmetrical shape, and part of its boundary is coincide with apartment type I, J, and common unit as indicate in Figure 5.2.4 as red colour dash line. This dash line is intersected with window number 7 in each side wall of the building (indicated by red circle in Figure 5.2.4). With this information we can put a point as co-planarity constrain in images. Since the point is located in 3D coordinate space, it forms an imaginary plane in each of its axis (X, Y, and Z).

With this co-planarity constrain, we fit the primitive and drag it along one of its axes until in meet with this constrain (see Figure 5.2.5(b)).

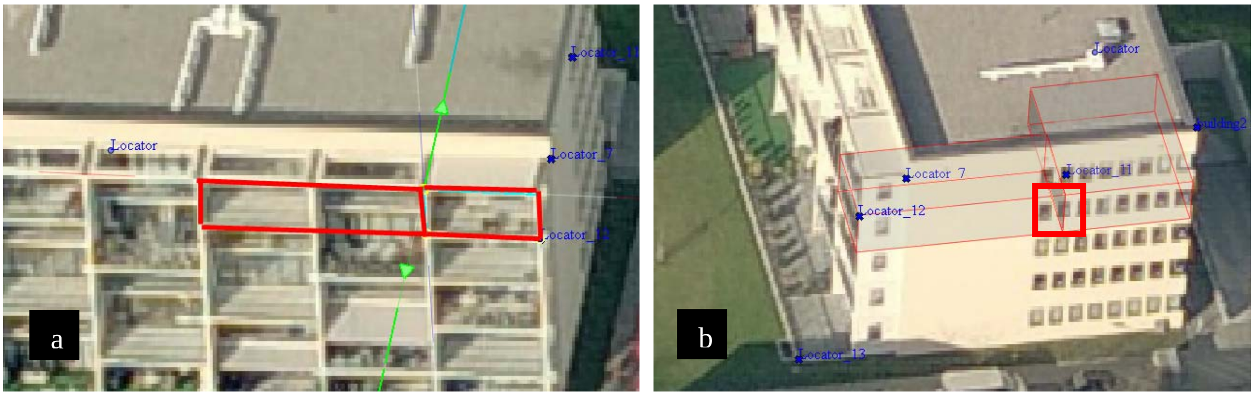


Figure 5.2.5. Identifying Number of Balconies (a) and Windows (b) to Create 3D Model

5.2.4. Geometric Analysis

The geometric analysis was done in order to measure the quality of 3D model from dataset 1 and dataset 2. The geometric analysis consists of geometric correction analysis, camera calibration analysis, and 3D geometric model analysis. Geometric correction analysis was done for dataset 1; camera calibration analysis was performed only for dataset 2; while 3D geometric model analysis was performed for both dataset.

5.2.4.1. Geometric Correction Analysis

As being mention in section 4.3.1.1, use of consumer type large scanner is lack of calibration compare to high precision scanner. To assess the geometric correction we performed quality analysis based on distance comparison and orthogonal constrain of the building. We use the width of front side of the building and the sidewall of the building as comparison. For this purposes, we compare the distance value from raw data of architectural drawing and the distance value after transformation. From the comparison we get a result that the differences are 1 to 3 cm. The significant distortion in the scanned image is the non linear projective distortion caused by the push-broom method of the scanner. As a result front side and side wall which are in the field are orthogonal to each other, appears as non orthogonal angle in scanned drawing.

5.2.4.2. Camera Calibration Analysis

There are two schemes to analyze the quality of camera calibration. First scheme is by analysing the residual of calibration which being calculated by software. The result of the first scheme is 0.5 meters in ground resolution. The second scheme is by calculating standard deviation using equation from Gerke (2009). For the second scheme, expected accuracy (or standard deviation a-posterior) is calculated from two set of images. First set is a consecutives images taken from across track orientation, i.e. they in-close a right angle with the base. Image selected for first set is EnschedeSouthEast_013.jpg and EnschedeSouthEast_014.jpg. Second set of images is taken from flight direction, i.e. EnschedeSouthEast_008.jpg and EnschedeSouthEast_009.jpg. The standard deviation value then used to measure the accuracy of calibration point which is positioned on the building. Calibration points and the result of camera calibration analysis are shown in Figure 5.2.6 and Table 5.4 below.

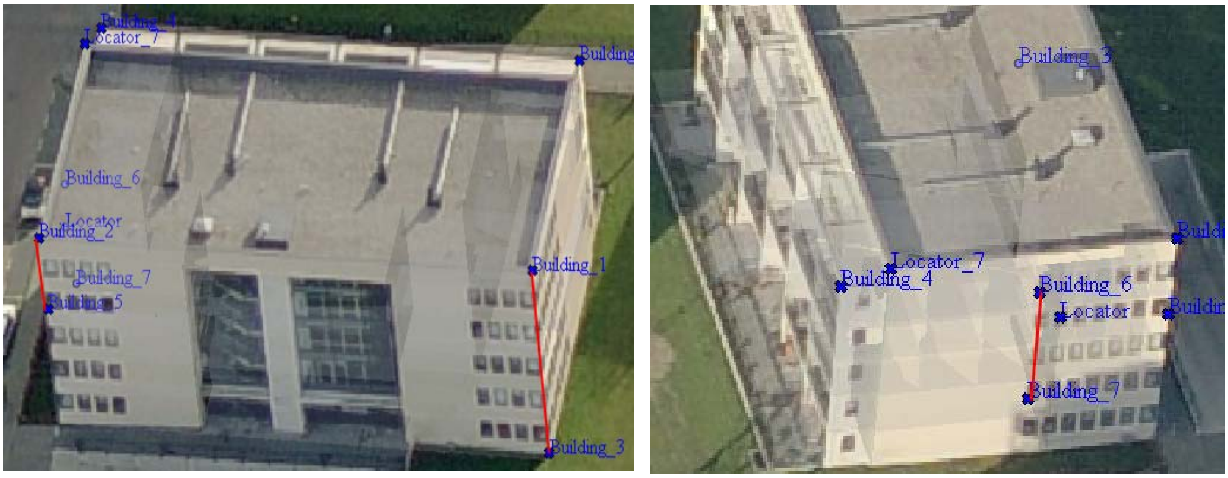


Figure 5.2.6. Location of calibration points that being observed

Table 5.3. Result of camera calibration using standard deviation

Coordinates	Calibration Points		diff	Sh	Residual
	Building6	Building7			
X	8551.26	8551.26	0.00	0.19	0.19
Y	1147.28	1147.23	0.05	0.19	0.14
	Building2	Building5			
X	8551.16	8551.14	0.02	0.19	0.17
Y	1155.16	1155.14	0.02	0.19	0.17
	Building1	Building3			
X	8518.25	8518.24	0.01	0.19	0.18
Y	1154.84	1154.90	-0.06	0.19	0.13
			Average Residual		0.16

All value is in meters
Diff is differences between coordinates value
Sh is a-posterior standard deviation

The full result of camera calibration analysis can be seen in Appendix B.

5.2.4.3. 3D Geometric Model Analysis

Distance measurement from architectural drawing is selected as a reference value because it could provide value on some part that can not be measured in the field. The analysis is carried out by comparing measurement samples of apartment unit type H on the first floor from dataset 1 and 2 with the reference value. Figure 5.2.7 shows measurement samples for the analysis, while Table 5.5 highlighted the result of analysis.

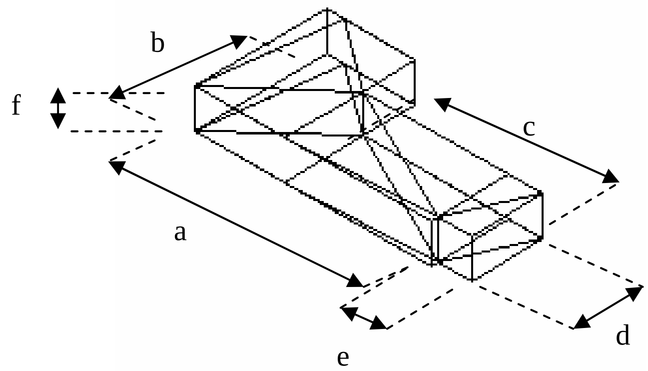


Figure 5.2.7. Samples of Measurement for Geometric Analysis

Table 5.4. Result of Geometric Analysis

Distance	Ref	AD	Diff Ref-AD	Picto	Diff Ref-Picto
a	17.08	17.18	-0.1	17.25	-0.17
b	9.65	9.63	0.02	9.85	-0.2
c	12.95	12.98	-0.03	12.27	0.68
d	5.4	5.97	-0.57	5.33	0.07
e	2.65	2.48	0.17	2.61	0.04
f	2.8	2.8	0	2.93	-0.13

All distance are in meter
Ref : reference distance
AD : distance from architectural drawing measurement
Picto : distance from pictometry image measurement
Diff Ref-AD : distance difference between reference and architectural drawing
Diff Ref-Picto: distance difference between reference and pictometry

5.2.5. Visualization of 3D Geometric Model

There are lot of software packages that could visualize 3D Model, such as VRML, Autodesk 3DSMAX, Autodesk AutoCAD, Autodesk LandXplorer, and Aristotles. Unfortunately most of software only capable to visualize the model but can not performs data manipulation. From several software mentioned above only AutoCAD, LandXplorer, and Aristotles have the ability to manipulate data. Among those three, only Aristotles is built upon open source platform; therefore it is suitable to visualize and manipulate 3D model of the result. Figure 5.2.8 and 5.2.9 consecutively show the result from dataset 1 and dataset 2 in Aristotles.

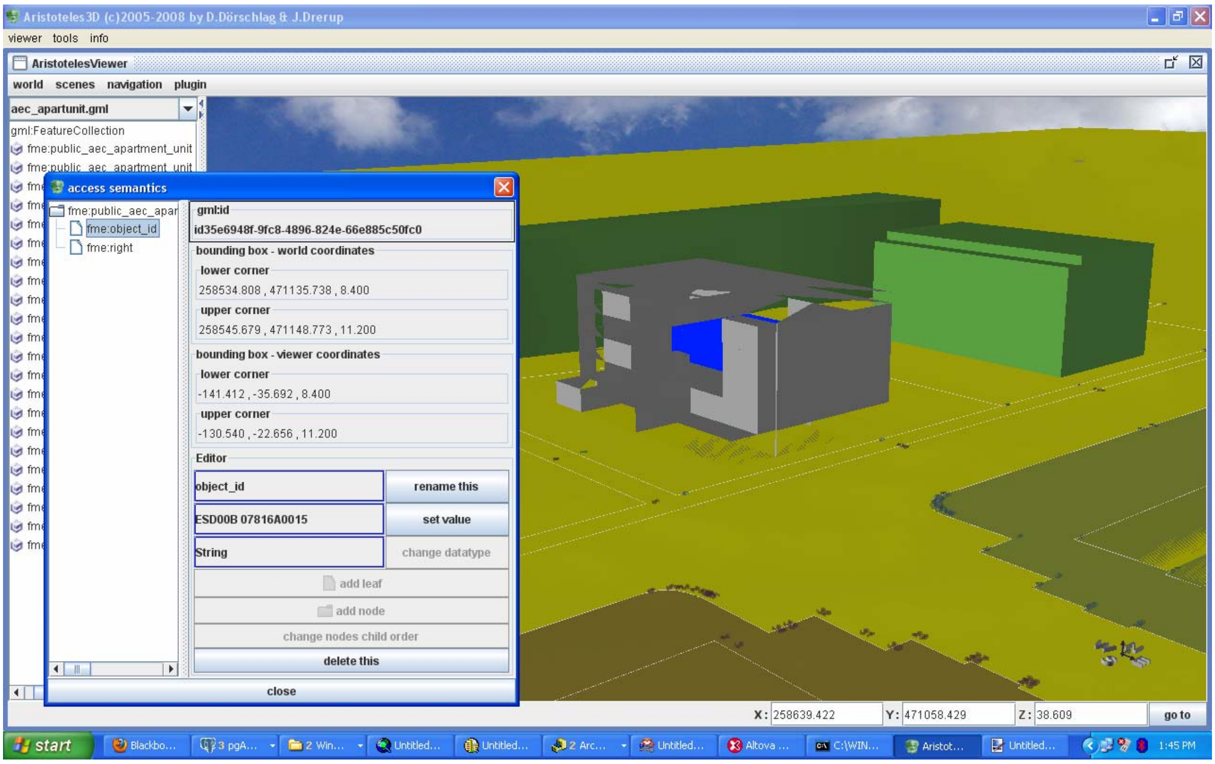


Figure 5.2.8. Dataset 1 in Aristotles

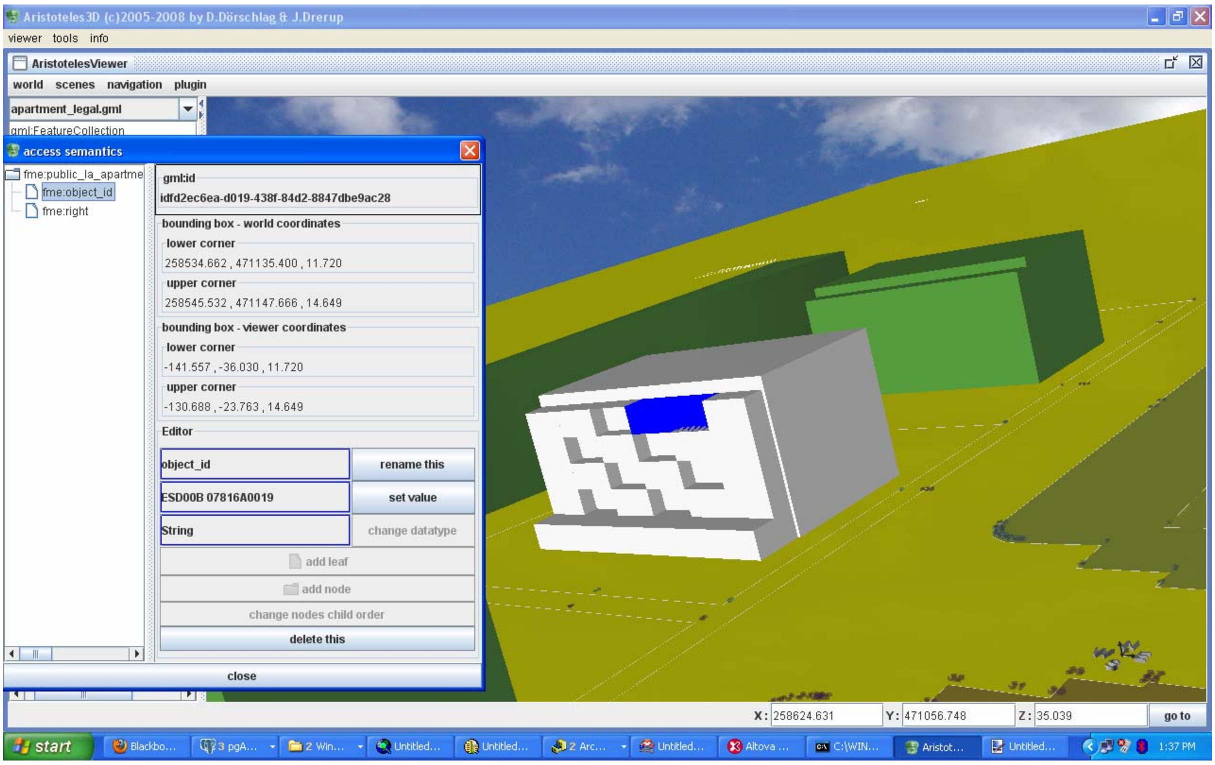


Figure 5.2.9. Dataset 2 in Aristotles

5.3. Findings

This section aims to evaluate and report several finding we experienced and found after implementation of real data into the proposed approach. There are four aspects we focus on the evaluation and report. Implementation of rules in determining legal boundary is the first aspect we evaluate in section 5.3.1. Follow by evaluation and report of findings on semantic model of 3D physical object and semantic model of 3D legal object in section 5.3.2. Evaluation and findings of extraction of 3D legal object geometry is presented in section 5.3.3. Finally, section 5.3.4 evaluates the result of visualisation.

5.3.1. Implementation of Rules in Determining Legal Boundary

As have been discussed in chapter 4, we developed two rules in determining legal boundary of 3D legal object based on theoretical aspect of 3D legal object or 3D property, and experience of several countries in registering 3D legal object according to their legal statute (see chapter 3). Just to remind us again, rule 1 is developed based on theory that boundary of 3D legal object is delineated in the middle of wall, ceiling, and floor; while rule 2 is developed based on theory that boundary of 3D legal object is located in the inside surface of every wall, ceiling, and roof thus creating an isolated object.

In the implementation phase we decided to adopt rule 1 as the basis of our work in extracting 3D legal object geometry. The decision was made because rule 2 could not be implemented for all datasets we used. It is possible for dataset 1, which is architectural drawing, to implement rule 2 because from this dataset it is very easy to distinguish each side of wall, ceiling, and floor visually from the drawing. For dataset 2, adoption of rule 2 is difficult due to the limitation of geometric resolution of the image. Dataset 2, which is Pictometry image, is taken from 920 m above ground with ground resolution 9 cm for object around centre of projection, but for object that is located far away from centre of projection the resolution could reach 18 cm of resolution.

5.3.2. Semantic Model of 3D Physical and 3D Legal Object

Semantic model of 3D physical object was developed based on CityGML data model. In building this semantic model first we analyze graphical and textual contents of the architectural drawing and later we also analyze the visual and graphical feature of object that we study from pictometry image. From these analysis we found that semantic model of 3D physical object contain type of features that define a building as physical object. These features consist of type of surface that bound the object, such as roof, ceiling, floor, and wall. Other important features that we found are the presence of room and group of room which create partition of 3D physical object but these features only could be identified from architectural drawing and not from pictometry image because pictometry image could only give semantic information form external appearance of the object.

For semantic model of 3D legal object, we adopt LADM for this purpose. Although we realize that the aim of LADM is not for semantic model but we found that several class of LADM could be treated as semantic for legal object, specifically for 3D legal object as the main subject of this research. Three main class of LADM, i.e. LA_Party, LA_RRR, and LA_Unit are essential and mandatory. Definition of 3D legal object can not exist if one of these three classes is not present. An important finding that we found from semantic model of 3D legal object is the share of RRR and its relation with boundary. In LADM, share of RRR effect people as the owner and unit or object as a unique and homogenous area, this is correct for 2D case. But in 3D legal object we found that share of RRR is not only affect people and unit but also boundary. And the share could be varying for different boundary depends on the agreement that was made between the owners.

5.3.3. Extraction of 3D Legal Object Geometry

Extraction of 3D legal object in this research was performed using two dataset. Extraction of 3D legal object using dataset 1 was done by digitizing process. Unlike digitizing polygon area where continuous lines is digitized according to its reference, digitizing 3D volumetric space is different process. In digitizing 3D legal object, each surface has to be digitized as triangular face and it requires at least two triangular faces to draw one surface. The more complex the shape of 3D legal object, more triangular faces are digitized and it also means more time needed to model the object.

For dataset 2, extraction of 3D legal object is performed using IBM approach. We found that this approach is more efficient that digitizing approach since we do not have to digitize triangular faces but rather fitting primitives into the image. Type of constrain that we used in the approach is useful in extracting geometries of the object which can not be identified visually from the image.

From 3D geometric model analysis in section 5.2.4.3, we found that in overall both datasets has the same accuracy level. Only for one surface, dataset 2 show significant difference from the reference value. This surface actually is the facades that can not be seen from the image and was modelled based on the constrain point we put in the window.

5.3.4. Visualisation Result

From the visualisation on the software we chose, we found out that 3D model from dataset 2 give better visualisation then dataset 1. Visualisation in software is a process of rendering triangular faces from 3D geometric model. These triangular faces have to be orderly arranged to give proper visualisation. In utilising dataset 1, we use manual digitizing method and there is possibility that set of triangular faces are not in organized manner. In dataset 2, 3D geometric model is built from primitives where triangular faces are already in correct order.

5.4. Summary of Findings

Based on desk research we found that there are two rules to distinguish 3D legal object from physical object. These rules become basis in determining legal boundary which used to extract 3D legal object. Rule 1, where boundaries lines are determined in the median of perimeter surface, is chosen in the implementation stage and shows proper result. Although rule 2, where boundaries lines are determined in inside part of perimeter surface, also can be implemented to extract 3D legal object but it is difficult to implement in this research due to limitation of one of dataset.

Semantic model that we develop in this research basically consists of two semantic models. First model, semantic model of the building was developed from topographical perspective and the result is semantic model of 3D physical object. This model gave us information about structure and composition of building. Second semantic model is semantic model of 3D legal object. It was developed based on LADM. From this model we found that LADM able to accommodate 3D legal object in their data model and we identified that classes of LADM also act as semantic to define the meaning of 3D legal object.

In this research we experimented with two different data sources to extract 3D legal object. These data sources were processed with different approaches. First data source is an architectural drawing which was processed through digitizing approach. Second data source is oblique aerial images, i.e. pictometry, which was processed using IBM method. The result from these two data sources shows that both models are appropriate to be implemented for acquiring geometric properties for 3D legal object.

In term of visualisation, the model which was produced from pictometry images shows more promising result compare to architectural drawing.

6. Conclusions and Recommendations

This chapter presents conclusion and recommendation derived from this thesis on the basis of the objectives and research question mention in chapter 1. The main objective of this research is to investigate a data acquisition method for 3D cadastral legal objects using the available data sources. The main objective was divided into two sub objectives. (1) To analyse the requirements of 3D legal object registration. (2) To explore the suitability of 3D data acquisition for 3D legal object registration using architectural drawing data and oblique aerial image data. This research was accomplished through desk research and 3D object measurement and reconstruction. Overall conclusion which is drawn based on revisiting each research question is presented in section 6.1. Section 6.2 describes some recommendation for further research related to 3D cadastre and utilization of 3D geo-information for cadastre purposes.

6.1. Conclusions

This section presents conclusion of the thesis drawn from revisiting research questions in table 1.1.

What are the legal requirements to register a 3D legal object?
Through desk research on legal statute of 3D cadastre and experience learned from several countries, there are two types of 3D legal object or 3D property that become subject of cadastral registration. These two types of objects are (1) independent 3D property and (2) condominium, including apartment. Several countries acknowledge the registration for these types of objects with requirements, such as an application admission, prove of transfer, and a subdivision plan.

Is it necessary to represent these types of legal objects in 3D geometric representation?
3D geometric representation is a useful extension to the cadastral dataset as has been discussed in chapter 3. With the support of technological developments in 3D data acquisition and 3D spatial modelling, it is possible nowadays to extent cadastral dataset with 3D geometric properties as an attribute and visualizes it using commercial and open source software to give access to the user who needs this type of information. The issue of interoperability is not a barrier anymore with GML format where both data model and data can be kept in platform independent format, and 3D geometric data, along with its descriptive attributes, can be shared and exchanged to other platforms who comply with OGC format.

What approach can be used to obtain 3D geo-information?
There are many technical approaches in acquiring 3D geo-information as has been discussed in section 2.3. From these various approaches, this research explored two approaches namely CAD modelling using architectural drawing and Image Based Modelling using pictometry image. Implementation of selected approaches as discussed in section 5.2 show potential results for obtaining 3D geo-information for cadastre purposes.

What rules can be applied to extract 3D legal object in the proposed method

Until now there are no standard rules on determining the legal boundaries of 3D legal object. Several countries adopt rules where legal boundary is laying on the inside surface of the perimeter wall, ceiling, and floor. Others follow rules where legal boundaries are determined as an imaginary median line which lay on perimeter surfaces.

Does the use of oblique images (Pictometry) offer improvement for acquiring 3D legal object?
Pictometry offers improvement in obtaining geo-information about 3D legal object. In terms of processes, the use of pictometry with Image Based Modelling method is more time effective and the accuracy of the result is comparable to other methods. Another improvement that pictometry offers is the measurement value of the object reflects the value in the field compared to the architectural drawing, where the measurement values are actually planned values before the building was constructed.

Overall Conclusion of the Research
3D cadastre can be seen as a newly emerging concept; this concept surely changes the perspectives on capturing data to human land relation. Land can not be viewed as 2D entity anymore but as 3D entity where it consists of its surface, its space above, and its ground below. Until now, parcel is the most used term to represent land as legal object of registration where sets of rights, restrictions, and responsibilities are established on it. Due to increase pressure on land in urban area, these set of rights are not only established on land itself but can also be established on object that is erected on land, such as building and condominium or apartment. Thus the term of 3D legal object is introduced in this research. 3D legal object is seen as a volumetric object where a set of right, restriction, and responsibility is established in it. Set of faces which create vertical and horizontal division acts as a boundary to represent this object as a unique and identifiable object.

In relation with the boundary of an apartment unit as 3D legal object, boundary determination for this object can not be treated similarly like parcel boundary. It is difficult to conduct cadastral survey for 3D legal object and it is also impossible to set up a boundary mark along its corner since the object is located inside the building. Until now, the only way to determine the boundary of an apartment unit is by delineating boundary line from architectural drawing which later is drawn as a subdivision plan in the notary. Another approach to determine legal boundaries of an apartment unit using systematic oblique aerial image (pictometry) is tested in this research. From the test result we conclude that this approach could provide an alternative solution for determining legal boundaries of apartment units.

6.2. Recommendations

Although this research is closely related to 3D cadastre, it merely focuses on technical aspect of 3D cadastre especially the data acquisition approach for 3D legal object. Due to the limited time frame of the research, this research concentrates on investigating data acquisition approach for one type of 3D legal object which is an apartment complex. Therefore, it is recommended to explore other technical approaches to capture other type of 3D legal object.

One of the steps in this research is to identifying and developing semantic model of 3D physical object and 3D legal object. The experiment on these two models was done on the basis that 3D data acquisition was mainly used for topographic object while the interest of the research is on 3D legal object. Conceptually, the two models are different since they describe the meaning (semantics) of an object from two different domains. One of the limitations of this research is our inability to investigate the data conflict between these models and to bridge the gap and provide for exchangeable information between the two models. Therefore it is recommended for future research to investigate the issue of data conflict between these two semantic models.

This research was also limited to 3D data capture, modelling, and visualisation of 3D legal object in a virtual environment. A study can be conducted to investigate how to store and maintain 3D legal object in a spatial data in database environment. The availability of free and open source platforms, such as PostGIS and Aristotles, makes it possible to store, keep the data up-to-date, and able to visualise and analyse the data.

The model which is built on this research is drawn on the basis of theoretical concept of 3D cadastre, 3D property right, and experiences learned form other countries. Therefore, it is recommended to conduct study to validate the model through user requirement survey and comparison with other existing model, in this case CityGML.

References

Ary Sucaya, I.K.G., 2009. *Application and Validation the Land Administration Domain Model in Real Life Situation : a Case Study in Indonesia*, ITC, Enschede, 92 pp.

Billen, R. and Zlatanova, S., 2003. *3D Spatial relationships Model: a Useful Concept for 3D Cadastre?*, 3D Cadastres, pp. 411-425

Cox, S., Daisey, P., Lake, R., Portele, C. and Whiteside, A., 2004. *OpenGIS Geography Markup Language (GML) Implementation Specification*. OpenGIS project document reference number 03-105r1.

De Flander, K. and Rovers, R., 2007, *Harvesting Urban Space*, http://www.sustainablebuilding.info/post-crash/files/urban%20space-exploration-deflander-rovers-010607.pdf, August 11, 2009

De Soto, H., 2003. *Mystery of Capital : Why Capitalism Triumphs in the West and Fails Everywhere Else*. Basic Books, New York, 275 pp.

ECE/ECE/Trade, 1995. *Guide on the adaptation of real property laws in the countries of Central and Eastern Europe*, Geneva, Switzerland.

El-Hakim, S. and Beraldin, J.A., 2008. *Sensor Integration and Visualisation*. In: J. Fryer, H. Mitchell and J.H. Chandler (Editors), Applications of 3D measurement from images. Whittles Publishing, Boca Raton, pp. 259 - 298.

Frueh, C., Jain, S. and Zakhor, A., 2005. *Data Processing Algorithms for Generating Textured 3D Building Facade Meshes from Laser Scans and Camera Images*. International Journal of Computer Vision, 61(2): 159-184.

Fuchs, C., 1996. *OEEPE study on 3D city models*. Report of the Institute.

Gerke, M., 2009. *Dense Matching in High Resolution Oblique Airborne Images*. In: CMRT09: Object extraction for 3D city models, road databases and traffic monitoring : concepts, algorithms and evaluation, Paris, 3-4 September 2009. / ed by U. Stilla, F. Rottensteiner and N. Paparoditis. ISPRS, 2009. pp 77-82.

Gerke, M. and Nyaruhuma, A.P., 2009. *Incorporating Scene Constraints Into The Triangulation of Airborne Oblique Images*. In: ISPRS conference : High-Resolution Earth Imaging for Geospatial Information: ISPRS XXXVIII 1-4-7/WS, 2-5 June, 2009 Hannover, Germany. 6 p.

Gruen, A., Remondino, F. and Zhang, L., 2005. *The Bamiyan project: multi-resolution image-based modeling*. ISPRS Highlights, 10(2).

Henssen, J.L.G., 1990. *Cadastre, Indespensable for Development*. Inaugural Address at International Institute for Aerospace Survey and Earth Science (ITC).

Hohle, J., 2008. *Photogrammetric Measurements in Oblique Aerial Images*. Photogrammetrie Fernerkundung Geoinformation(1): 7-14.

ISO/TC 211, 2009. *Committe Draft (CD), Geographic Information - Land Administration Domain Model (LADM)*. ISO, Lysaker, Norway, pp. 87 pp

Jansson, L. and Eriksson, G., 2002. *Reforming the Swedish Cadastre*, Proceeding FIG XXII International Congress, Washington, DC.

Kalantari, M., Rajabifard, A., Wallace, J. and Williamson, I., 2008. *Spatially referenced legal property objects*. Land Use Policy, 25(2): 173-181.

Katerina, N., Theoni, G., Apostolos, A. and Alexandra, K., 2003. *Legal And Technical Processes For Registering 3D Property Objects*, Workshop: Spatial Information Management for Sustainable Real Estate Market Best Practice Guidelines on Nation-wide Land Administration, Athens, Greece

Kaufmann, J. and Steudler, D., 1998. *Cadastre 2014 : a vision for a future cadastral system*. International Federation of Surveyors (FIG), 44 pp.

Kerle, N.e. et al., 2004. *Principles of remote sensing : an introductory textbook*. ITC Educational Textbook Series;2. ITC, Enschede, 250 pp.

Kernighan, B. and Van Wyk, C., 1996. *Extracting geometric information from architectural drawings*, Applied Computational Geometry Towards Geometric Engineering, pp. 167-176.
Kolbe, T., Groger, G. and Pliimer, L., 2008. *CityGML-3D city models and their potential for emergency response*. Geospatial Information Technology for Emergency Response: 257.
Kolbe, T.H., Gröger, G. and Plümer, L., 2005. *CityGML – Interoperable Access to 3D City Models*. In: v. Oosterom, Zlatanova and Fendel (Editors), International Symposium on Geo-information for Disaster Management. Springer Verlag, Delft
Lemmen, C.H.J., van Oosterom, P.J.M., Uitermark, H.T., Thompson, R. and Hespanha, J., 2009. *Transforming the Land Administration Domain Model LADM into an ISO Standard - ISO19152*. In: Proceedings of the FIG working week : Surveyors key role in accelerated development, Eilat, Israel, 3-8 May, 2009. 24 p.
Lemmens, M., Lemmen, C.H.J. and Wubbe, M., 2007. *Pictometry: Potentials for Land Administration*, 6th FIG Regional Conference, San Jose
Mayer, H., 1999. *Automatic Object Extraction from Aerial Imagery-a Survey Focusing on Buildings*. Computer vision and Image Understanding, 74(2): 138-149.
Mitchell, H., 2008. *Fundamentals of Photogrammetry*. In: J. Fryer, H. Mitchell and J.H. Chandler (Editors), Applications of 3D measurement from images. Whittles Publishing, Boca Raton, pp. 9 - 35.
Molenaar, M., 1992. *Topology for 3D Vector Maps*. ITC journal : bulletin de l'ITC(1).
Molenaar, M. and van Oosterom, P.J.M., 2009. *Conceptual Tools for Specifying Spatial Object Representations*. In: Manual of Geographic Information Systems / ed. by M. Madden. Bethesda : American Society for Photogrammetry and Remote (ASPRS), 2009. ISBN 1-57083-086-X pp. 47-69.
Monaghan, B., 1967. *Terrestrial Photogrammetry Applied to Architecture*, Laval University, Laval, 87 pp.
Oldfield, P., 2002, *Domain Modelling*, Appropriate Process Movement, http://www.aptprocess.com/whitepapers/DomainModelling.pdf, 30-October-2009
Onsrud, H., 2003. *Making a Cadastre Law for 3D Properties in Norway*. Computers, Environment and Urban Systems, 27(4): 375-382.
Open Geospatial Consortium, 2007. *OpenGIS Geography Markup Language (GML) Encoding Standard. OGC Document Number: 07-036*.
Paulsson, J., 2007. *3D Property Rights - An Analysis of Key Factors Based on International Experience*. Department of Real Estate and Construction Management, School of Architecture and Built Environment, Royal Institute of Technology (KTH), Stockholm, 349 pp.
Petrie, G., 2009. *Systematic Oblique Aerial Photogrammetry Using Multiple Digital Frame Camera*. Photogrammetric & Remote Sensing, 7(2): 102 - 108.
Remondino, F. and El-Hakim, S., 2006. *Image-based 3D Modelling: A Review*. The Photogrammetric Record, 21(115): 269-291.
Rottensteiner, F., 2002. *Semi - Automatic Extraction of Buildings Based on Hybrid Adjustment Using 3D surface Models and Management of Building Data in a TIS Topographical Information System*. Geowissenschaftliche Mitteilungen : Schriftenreihe der Studienrichtung Vermessungswesen und Geoinformation, Technische Universität Wien. Technische Universität Wien, Wien, 186 pp.
Song, Y., Wang, H., Hamilton, A. and Arayici, Y., 2009. *Producing 3D Applications for Urban Planning by Integrating 3D Scanned Building Data with Geo-spatial Data*, 3D Geo-Information Sciences, pp. 397-412.
Stoter, J., Sørensen, E. and Bodum, L., 2004a. *3D registration of real property in Denmark*, Proceedings of FIG Working Week, Athens, Greece
Stoter, J., Van Oosterom, P., Ploeger, H. and Aalders, H., 2004b. *Conceptual 3D cadastral model applied in several countries*, Proceedings of the FIG working week 2004 : The Olympic spirit in surveying Athens, Greece
Stoter, J. and Van Oosterom, P.J.M., 2006. *3D Cadastre in An International Context: Legal, Organizational, and Technological Aspects*. Crc Press.
Stoter, J. and Zlatanova, S., 2003. *3D GIS, where are we standing*. Citeseer
Stoter, J.E., 2004. *3D Cadastre*, Nederlandse Commissie voor Geodesie (NCG), Delft, 327 pp.

Stoter, J.E., de Kluijver, H. and Kurakula, V., 2008. *3D noise mapping in urban areas*. International journal of geographical information science = IJGIS, 22(8).

Stoter, J.E. and Ploeger, H.D., 2003. *Porperty in 3D : registration of multiple use of space : current practice in Holland and the need for a 3D cadastre*. Computers, Environment and Urban Systems : an international journal, 27(6).

Stoter, J.E. and Van Oosterom, P.J.M., 2005. *Technological aspects of a full 3D cadastral registration*. International journal of geographical information science (IJGIS), 19(6).

Suveg, I. and Vosselman, G., 2004. *Reconstruction of 3D building models from aerial images and maps*. ISPRS Journal of Photogrammetry and Remote Sensing, 58(3-4): 202-224.

Tao, V., 2004. *3D Data Acquisition and Object Reconstruction for AEC/CAD*. Acces Date: 8 October 2009, http://www.directionsmag.com/article.php?article_id=628

Tempfli, K., 1998. *3D Topographic Mapping for Urban GIS*. ITC journal : bulletin de l'ITC(3-4).

UN/ECE, 2004. *Guidelines on Real Property Units and Identifiers*. ECE/HBP/135. New York and Geneva. Acces Date: 14-10-2009, www.unece.org/env/documents/2005/wpla/Guidelines_On_Real_Property_Identifiers.pdf

Van der Merwe, C., 2002. *The Distribution of Ownership in an Apartment Ownership or Condominium Scheme*. Georgia Journal of International and Comparative Law: 101-137.

Van der Molen, P., 2003. *Institutional aspects of 3D cadastres*. Computers, Environment and Urban Systems, 27(4): 383-394.

Vosselman, M.G., 2008. *Laser scanning*. In: Encyclopedia of GIS / ed. by S. Shekhar and H. Xiong. Berlin : Springer, 2008. ISBN 978-0-387-35973-1 part 15. pp. 609-612.

Wang, Y., Schultz, S. and Giuffrida, F., 2008. *Pictometry Proprietary Airborne Digital Imaging System and Its Application in 3D City Modelling*. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII.

Yu, S.M., Han, S.S. and Chai, C.H., 2007. *Modeling the value of view in high-rise apartments: a 3D GIS approach*. Environment and Planning B-Planning & Design, 34(1): 139-153.

Zlatanova, S., Rahman, A.A.A.A. and Shi, W., 2004. *Topological models and frameworks for 3D spatial objects*. Computers & Geosciences, 30(4): 419-428.

APPENDIX A

Camera Position/Orientation and Calibration Result

Camera Position and Orientation

Image	Camera Position (m)			Camera Rotation			Focal Length (mm)
	X	Y	Z	Omega	Phi	Kappa	
EnschedeSouthEast_003.jpg	8745.88	-61.11	953.65	52.75	-0.3592	3.679	84.2343
EnschedeSouthEast_008.jpg	9517.43	843.82	963	49.94	-0.929	80.73	84.6154
EnschedeSouthEast_013.jpg	8286.89	2066.2	960.89	47.27	-0.0741	-174.5	84.8917
EnschedeSouthEast_014.jpg	8718.32	2071.9	959.23	46.44	0.6412	-176.8	84.8917
EnschedeSouthEast_017.jpg	7490.03	1187.6	965.06	51	-1.4954	-95.09	84.6154
EnschedeSouthEast_009.jpg	9932.41	854.12	973.66	49.64	-0.3863	84.9	84.6154

Calibration Result

Point Id	Camera's Coordinates (m)			Residual (pix)
	X	Y	Z	
GCP301	8114.09	887.961	41.69	**0.52**
GCP302	8375.64	862.3	42.983	**0.483**
GCP303	8365.36	932.795	43.274	**0.7**
GCP304	8380.54	975.58	43.119	**0.07**
GCP305	8399.89	1106.5	43.203	**0.6**
GCP309	8900.23	1285.25	49.664	**0.55**
GCP310	8922.83	1001.97	47.324	**0.725**
GCP311	8718.13	921.704	45.456	**0.3425**
GCP312	8566.4	997.369	46.241	**0.2883**
Locator_2	8614.67	952.884	76.519	**0.335**
Locator_3	8600.34	1142.36	73.461	**0.4917**
Locator_4	8600.24	1107.11	73.552	**0.9217**
Locator_5	8589.28	1142.32	73.48	**0.685**
Locator_6	8615.85	964.333	76.561	**0.5883**
Ti13	8605.14	779.109	53.652	**0.25**
Ti15	8748.33	985.327	71.792	**0.375**
Ti16	8942.29	930.336	47.223	**0.45**
Ti17	-17.806	0.287	0	**0.39**
Ti19	8172.24	858.327	57.347	**0.79**
Ti20	8411.04	989.849	64.994	**0.6175**
Ti21	8693.39	1215.54	59.57	**0.41**
Ti22	8688.43	955.926	76.574	**0.7883**
Ti23	8548.21	1280.63	63.301	**0.618**
Ti24	8599.23	973.786	85.1	**0.81**
Ti25	8574.12	975.93	85.009	**0.5167**
Ti26	8640.54	1012.71	60.339	**0.5267**
Ti27	8779.06	1265.57	64.299	**0.8075**
Ti28	8848.64	1140.87	64.831	**0.2725**
Building_1	8518.25	1154.84	61.699	**0.26**
Building_2	8551.16	1155.16	61.66	**0.1667**
Building_3	8518.24	1154.9	46.346	**0.4533**
Building_4	8551.01	1135.36	60.406	**0.17**
Building_5	8551.14	1155.14	55.706	**0.3575**
Building_6	8551.26	1147.28	58.566	**0.1675**
Building_7	8551.26	1147.23	50.202	**0.1475**
Building_8	8518.7	1135.07	60.356	**0.20167**
			Average Residual	**0.46797**

APPENDIX B

Quality Analysis on Camera Calibration

Focal Length **0.085**
Pixel Size **0.000009 (m)**

Image	Camera	dist (H)	Base	Scale	H'	H/b*scale*spx	S'h	S'xy	Sh
EsdSE_009	9932.41 854.118 973.611	920.00	415.24	15306.78	1301.08	0.86	0.24	0.14	0.20
EsdSE_008	9517.43 843.816 962.995	920.00							
EsdSE_013	8286.89 2066.23 960.89	920.00	431.47	15306.78	1301.08	0.83	0.23	0.14	0.19
EsdSE_014	8718.32 2071.87 959.23	920.00							
							Average		**0.19**

Coordinates	B6	B7	diff (m)	Sh (m)	Residual (m)
X	8551.26	8551.26	0.00	0.19	**0.19**
Y	1147.28	1147.23	0.05	0.19	**0.14**

Coordinates	B2	B5	diff (m)	Sh (m)	Residual (m)
X	8551.16	8551.14	0.02	0.19	**0.17**
Y	1155.16	1155.14	0.02	0.19	**0.17**

Coordinates	B1	B3	diff (m)	Sh (m)	Residual (m)
X	8518.25	8518.24	0.01	0.19	**0.18**
Y	1154.84	1154.90	-0.06	0.19	**0.13**
			Average Residual (m)		**0.12**

Where:
Camera is the position of the camera indicates by its coordinates
dist (H) is flying distance base on vertical height
Base is the distance between two principal points of camera
Scale is the scale of image in nadir angle
H/b *scale * spx is scale of image according to the incident angle of the camera
S'h is standard deviation in Z direction
S'xy is standard deviation in plane (XY) direction
Sh is the total standard deviation