THREE-DIMENSIONAL STRATA OBJECTS REGISTRATION FOR LAND ADMINISTRATION DOMAIN MODEL

NUR AMALINA BINTI ZULKIFLI

UNIVERSITI TEKNOLOGI MALAYSIA

THREE-DIMENSIONAL STRATA OBJECTS REGISTRATION FOR LAND ADMINISTRATION DOMAIN MODEL

NUR AMALINA BINTI ZULKIFLI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Geoinformation)

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

DECEMBER 2021

DEDICATION

This thesis is dedicated to my family.

ACKNOWLEDGEMENT

First of all, thanks to Allah s.w.t for giving me strength and opportunity to complete my PhD's degree. I would like to thank my supervisor, Prof. Dr. Alias Abdul Rahman for his advise, guidance and continuous support. Many thanks go to Prof. Dr. Peter van Oosterom for assisting me to refine the conceptual model of Malaysian LADM country profile.

Special thanks to all members of the 3D GIS research lab for their supportive ideas and discussions. I also want to express my thanks to the staff of the Faculty of Built Environment and Surveying for their help and assistance. Thanks goes to Department Survey and Mapping Malaysia and land office officers for the data source.

An understanding and continuos support from my family and family in law are greatly appreciated especially my husband, Khairul Azhar Mohammad including my two kids, Muhammad Aqief Ainullah and Nur Ain Afeeya. Without them, it would have been imposible for me to complete this thesis.

Last and not least, the encouragement and prayers to The Almighty from my father, Hj. Zulkifli Mat Piah and my mother, Hjh. Salma Seman is touching and wonderful.

To those whose contributions I have neglected to note here, please accept my apologise. I owe you all a great debt.

ABSTRACT

Due to the rapid increase of urban population, intensive land development has resultedin complex building construction taking place above and below land surface.The conventional 2D cadastre system cannot accommodate complex or multiple ownership in the vertical dimension. Many cadastral models were developed to address this problem. However, these models must be evaluated to ensure their suitability to Malaysia's land administration system. The models were assessed to examine how dataare handled and to what extent they fulfil the criteria of the 3D cadastre, as well as the data modelling approaches, they employed to support the 3D data. Although 2D cadastre has long been around, creating and maintaining 3D cadastre remains a challenge. The LADM-ISO 19152 provides a conceptual description of the land administrationsystem, including a 3D cadastral registration. Standardisation provides the data model flexibility, making it much easier for spatial data handling. There have been several research and development activities in the past on the LADM. The focus of those studies was on the conceptual model, which has yet to be realised. Therefore, this study aimed to design a conceptual model and 3D strata objects registration database and develop LADM-based 3D strata object registration as a prototype. An accurate 3D cadastre and property, including strata, is crucial for the land administration system. In this study, the 3D information of strata objects based on LADM was validated. It was also possible to question or to view the 3D objects registration interactively compared to other previous works in this domain. Strata object registration has the following aspect such as parcel unit, accessory unit, common property unit, limited common property unit, and land parcel. Within the Malaysian authority, all these objects' representations are in 2D. This research focused on extending the representation of those strata objects to 3D. The prototype development began with data modelling (i.e., selecting relevant object classes and expanding the classes with attributes). It focused on data conversion from an existing database (i.e., strata.xml format) to an open-source database (i.e., PostgreSQL). The conversion process included two iterations (i.e., the context mapping and the output module for the database). The strata XML information was replaced with LADM related elements and attributes after the conversion. The visualisation and application modules were subsequently developed using an open-source platform (i.e., QGIS). The prototype is able to answer all questions related to strata aspects (i.e., ownership, share unit, Management Corporation (MC), spatial source document and strata objects). This work is anticipated to spearhead the national authorities in implementing strata objects registration to improve 3D cadastral objects management.

ABSTRAK

Pembangunan tanah secara intensif disebabkan oleh pertambahan penduduk bandar yang pesat telah mengakibatkan pembinaan bangunan yang kompleks berlaku di atas dan di bawah permukaan tanah. Sistem kadaster 2D konvensional tidak dapat menampung pemilikan kompleks atau pelbagai dalam dimensi menegak. Banyak model kadaster telah dibangunkan untuk mengatasi masalah ini. Walau bagaimanapun, model ini mesti dinilai untuk memastikan kesesuaiannya dengan sistem pentadbiran tanah Malaysia. Model tersebut dinilai untuk meneliti bagaimana data ditangani dan sejauh mana ia memenuhi kriteria kadaster 3D, serta pendekatan pemodelan data yang digunakan untuk menyokong data 3D. Walaupun kadaster 2D sudah lama wujud, membina dan mengekalkan kadaster 3D masih menjadi cabaran. LADM-ISO 19152 menyediakan perihalan konsep untuk sistem pentadbiran tanah, termasuk pendaftaran kadaster 3D. Pemiawaian menyediakan model data yang fleksibel, menyebabkannya lebih mudah untuk pengendalian data ruang.Terdapat beberapa aktiviti penyelidikan dan pembangunan ke atas LADM pada masalalu. Fokus kajian tersebut adalah pada model konseptual, yang sehingga kini belum dapat direalisasikan. Oleh itu, kajian ini bertujuan untuk mereka bentuk model konseptual dan pangkalan data pendaftaran objek strata 3D dan membangunkan pendaftaran objek strata 3D berasaskan LADM sebagai prototaip. Kadaster dan hartanah 3D yang tepat, termasuk strata, adalah penting untuk sistem pentadbiran tanah. Dalam kajian ini, maklumat 3D objek strata berdasarkan LADM telah disahkan. Ia juga boleh ditanya atau dilihat pendaftaran objek 3D secara interaktif berbanding dengan kajian terdahulu yang lain dalam bidang ini. Pendaftaran objek strata mempunyai aspek berikut seperti unit petak, unit aksesori, unit harta bersama, unit harta bersama terhad dan petak tanah. Dalamkalangan pihak berkuasa Malaysia, semua reprentasi objek ini adalah dalam 2D. Tumpuan utama penyelidikan ini adalah untuk memperluas representasi objek stratatersebut kepada 3D. Pembangunan prototaip bermula dengan pemodelan data (iaitu memilih kelas objek yang berkaitan dan memperluaskan kelas dengan atribut). Ini melibatkan penukaran data daripada pangkalan data sedia ada (iaitu format strata.xml) kepada pangkalan data sumber terbuka (iaitu PostgreSQL). Proses penukaran merangkumi dua lelaran (iaitu pemetaan konteks dan modul keluaran untuk pangkalan data). Maklumat strata XML diganti dengan elemen dan atribut berkaitan LADM selepas penukaran. Modul visualisasi dan aplikasi kemudiannya dibangunkan dengan menggunakan platform sumber terbuka (iaitu QGIS). Prototaip ini dapat menjawab semua soalan yang berkaitan dengan aspek strata (iaitu pemilikan, unit saham, Perbadanan Pengurusan (PP), dokumen sumber ruangan dan objek strata). Hasil kerja ini dijangka dapat memacu pihak berkuasa dalam melaksanakan pendaftaran objek strata untuk menambah baik pengurusan objek kadaster 3D.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	-	Two-Dimensional
3D	-	Three-Dimensional
3DCDM	-	3D Cadastral Data Model
AEC	-	Architecture, Engineering and Construction
AGM	-	Annual General Meeting
BC	-	British Columbia
BIM	-	Building Information Modelling
CAD	-	Computer Aided Design
DBMS	-	Database Management System
DDGLM	-	Department of Director General of Lands and Mines
DSMM	-	Department of Survey and Mapping Malaysia
DTD	-	Document Type Definition
EA	-	Enterprise Architect
EGM	-	Extraordinary General Meeting
FGDC	-	Federal Geographic Data Committee
GIS	-	Geographic Information System
HDM	-	Harmonized Data Model
ICSM	-	Intergovernmental Committee on Surveying and Mapping
IFC	-	International Foundation Class
LADM	-	The Land Administration Domain Model
LPO	-	Legal Property Object
MC	-	Management Corporation
MDA	-	Model Driven Architecture
NLC	-	National Land Code
OGC	-	Open Geospatial Consortium
ORDBMS	-	Object-Oriented Relational Database Management System
QGIS	-	Quantum GIS
SiFUS	-	Share Unit Formula
SLA	-	Singapore Land Authority

SMA	-	Strata Management Act
STA	-	Strata Title Act
UML	-	Unified Modelling Language
URA	-	User Requirement Analysis
XML	-	Extensible Markup Language
XSD	-	XML Schema Definition

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

A conventional cadastral registration is made up of a set of cadastral maps containing cadastral parcels, each having its own parcel numbers and a paper archive within which property information is maintained. In some developed countries such as Malaysia, Singapore, Netherland and Australia, analogue cadastral registrations have been converted into digital registrations. Parcel information including spatial and administrative originally kept in paper maps have increasingly been replaced by the Geographic Information System (GIS) and Computer Aided Design (CAD) or even more advanced (i.e. with spatial Database Management System (DBMS)). A link established between digital cadastral map and administrative database enables both spatial and administrative components of cadastral registrations to be queried and the outcomes may also be combined. A more advanced systems has also enabled the cadastral registration to integrate both spatial and administrative components which allowed queries to be carried out in one integrated environment.

A rapid increase of urban population has raised demand for urban space in terms of providing housing, workplace and other infrastructures. With limited urban space, urban land is inevitably exploited and utilized to its maximum capacity. In many highly urbanised areas, a piece of land can hold multi-storey buildings such as condominiums owned by multiple owners. In terms of land administration, both land and property information i.e., geometric and legal data of a property can mostly be addressed by two-dimensional (2D) cadastral registration (Kalantari et al., 2008). Thus far, land administrations have relied on the conventional 2D cadastre. However, in recent decades, technological advances have given rise to complex building construction which resulted in condominium, shopping and business complex and engineering construction like tunnel, car park, pedestrianized areas both above and

below land surface. The conventional 2D cadastre system does not have the capability to accommodate complex or multiple ownership in the vertical dimension. The third dimension therefore has to be incorporated into the land registration system to reflect the multi-level reality.

Registration related to three-dimensional (3D) cadastre however, requires specific requirements which consequently raised problems as demonstrated by the situation in various countries such as Sweden, Australia, Canada, Indonesia, Netherland, Singapore and Malaysia (Stoter, 2004; Thomson & Oosterom, 2010; Oosterom 2018). Some of these countries are presently using conventional strata titles to establish 3D cadastre, while others have already initiated efforts to strengthen the 3D cadastral systems. Sweden for instance, introduced a new law to facilitate 3D strata objects (Julstad & Ericsson, 2001; Mattsson, 2003). The law promulgated (passed) in January 2004 was deliberated by a special committee tasked by the Swedish government to overcome problems of multiple uses in a building. The committee main suggestion is to set up 3D property registration similar to 2D property. Such solutions will allow 3D properties to be mortgaged since 3D property information can be accessed using the real property register. The proposal, however required that the 2D essential property concept should be adhered to as the 3D cases are relatively small. The new 3D properties should be able to conform to the 2D's structure. Although this law is able to overcome the legal issues, however, cadastral issues still need to be addressed. The issues include how to document the constructions, methods to register and how can it be visible on the cadastral map.

In Queensland, Australia, the 3D registration was made possible since 1977. Queensland's juridical framework originally founded on the Common Law, allowed the creation of multi-level property units either with freehold or leasehold status. Nevertheless, the registration only include building plans on the survey map. It has yet to solve the aspects of 3D property units related to information of the 3D property situation and register rights on volumes (Stoter et al., 2004). The weakness of this solution is its inability to view 3D information interactively since the 3D information is drawn on paper. It will be difficult to interpret the situation correctly in cases involving complex volumetric strata objects.

In British Columbia, (BC) Canada, the Land Title Act of British Colombia 1996, (Section 139) provides a right to a parcel owner to subdivide his land into parcels above the ground which may continue, or created below the surface. In this case, subdivision can only be carried out to parcels having 'fee simple estate'. Fee simple ownership is recognised as absolute ownership which entitled the owners to fully enjoy his property including subdivision although it will be subjected to zoning restrictions. In BC, the provisions of the Condominium Act will be applied to further division of the air-space parcel, known as strata lots or 'flying fees'. A building strata plan provides the buildings and land subdivisions into strata lots. A tenant's interest in the remaining common areas will also be attached to the strata lots. The new strata lots either freehold or leasehold enjoyed the same status as those registered with the Land Title Office. It is compulsory for a strata plan to have the blueprint of proposed project, the boundaries of the lot as well as the location of the buildings. In BC, land registration has the survey plans as part of the titles. However there is no overall map covering all existing parcels. Since 2D cannot offer an integrated view, it is difficult to see an overall view of certain situations, for example, parcels, whether two neighbouring parcels overlap since strata lots are not part of the view.

In Indonesia, the Multi-level Apartments and Strata Title (Act No. 20/2011) and the Land Office Executive Order No. 1/2010 are both used to govern strata objects (Anonim, 2010). The Act No.20/2011 regulates the rights to build, manage, and use of apartment buildings. It utilises the principles of acquisition and registration of ownership rights of apartment rooms. As defined by the Act, an apartment building consists of common objects, common rooms and apartment rooms that can be owned by individuals or parties. In addition, the land office provides guidelines on technical implementation based on a standardised set of services in every land offices in Indonesia which include survey, right registration, right transfer, etc. The Land Administration Domain Model (LADM) was selected for the country as the national model standard to embark on the 3D cadastral registration, however validation of LADM has yet to be carried out (Sucaya, 2009). In addition the work on LADM has not addressed the 3D space ownership. Other research on 3D cadastre prototype evaluation was only focused on the visualization aspect without considering the existence of national regulation and international standards (Aditya et al., 2011).

The Netherlands has recognised multi-level property rights even before the Dutch cadastre was established in 1832 as exemplified by the underground cellars of the public street in the city of Utrecht. In recent years, multi-level uses have include mix commercial complexes, public transport terminals and parking units or buildings over highways (Stoter & Salzmann, 2003; Stoter & Ploeger 2003; Stoter et al. 2013). Stoter et al. (2017) presented the first registration of an interactive 3D visualisation of legal volumes in the land registers. Two cases were used to demonstrate the advantages of the 3D approach compared to the 2D system. The 3D system enabled all legal aspects of a multi-level property to be viewed interactively. A 3D registration of multi-level properties therefore provide a better understanding of multi-level ownership. However, this system has to be standardised in terms of registration, queries and updating to allow the registration process to be officially implemented.

Singapore introduced the Land Titles (Strata) Act (Chapter 158) in 1967 in order to manage buildings or land subdivisions into strata units. Presently, in addition to the Strata Act, the Building Maintenance and Strata Management Act 47/2004 (BMSMA, 2004) is also used to administer the strata developments (Christudason, 2007). Considered as one of the most densely populated island states, the Singapore Government is deeply committed to ensure land resources is used in a sustainable manner. The Singapore Land Authority (SLA) responsible for cadastral integrity therefore aims to provide an efficient land management system. At present, a 2D system is used to record property rights using the surface parcel to represent fundamental ownership. Volumetric parcels which include airspace, strata lots and subterranean are also recorded in the system which raises the issue of height information which is not rigorously addressed. At present, the strata and accessory lots are not synchronised in the survey practice and the centre of the wall is generally taken as the boundary of a property (Khoo, 2011). The increasingly complex 3D developments, involving interlocking complexes, multi-level train terminals, and underground spaces present a challenge to the land administration system. Such complexity is much anticipated in the future which therefore raise the needs for the 3D system.

In Malaysia, the Torrens system which was introduced during the British administration has been applied to the land administration until the present time. For the system to be effective, it is required that all dealings in land must be registered. Each piece of land will have one document of title, known as a Register Document of Title which contains all the legal materials registered to the title in the land. The National Land Code (NLC) 1965 was introduced in the country to ensure uniformity in administering land matters. The strata title was provided by certain provisions addressing subsidiary titles in the NLC. This was to accommodate an increasing development of high rise residential buildings particularly in urban areas. The strata title is the outcomes of the building subdivision in horizontal manner, or airspace, as opposed to the vertical subdivision. The legal provisions on strata titles in the NLC have been revised several times prior to the introduction of the Strate Title Act in1985. The 1985 Strata Title Act has also undergone several changes, the latest being the Strata Title (Amendment) Act 2013 (STAA 2013). The later amendments include the establishment of the Electronic Land Administration System of Strata Titles; the designation of limited common property, and the formation of subsidiary management corporations to represent the various interests of owners. Nevertheless, the current strata objects registration in Malaysia has yet to address the various 3D issues (i.e. visualization, boundary representation, data acquisition, database management system, topology and legal aspects), as reported by Hassan and Abdul Rahman (2010), Abdul Rahman et al. (2011), Nasorudin et al. (2016), Mohd Hanafi and Hassan (2019), and Hashim et al. (2018).

A successful development of the cadastral system including 3D strata objects registration requires a data model which should adequately accomplished the required functions. The complexity of cadastral legal objects (i.e. strata objects) needs to be reflected by the model. Thus, the theories related to the development of legal and geometry data models for cadastral domain needs to be examined before deciding on the most appropriate data model for strata objects. This research reviews several legal and geometry data models for cadastral domain such as the 3D Cadastral Data Model (Aien, 2013); ePlan Model (ePlan, 2010); Legal Property Object Model (Kalantari et al., 2008); Federal Geographic Data Committee (FGDC) Standard Reference Model (FGDC, 1996); Core Cadastral Data Model (Henssen, 1995); Building Information Modelling (Borrmann et al., 2018); CityGML (Kutzner et al., 2020) and Land

Administration Domain Model (Lemmen, 2012). Assessment of these data models will be based on selected criteria (i.e. basic spatial unit, other types of spatial units, core objects, applications, reference documents, other types of interest, semantic level, temporal aspects and architecture). These criteria were selected to enable an assessment of data models from various aspects at the same time, obtain information on the methods of managing ownerships of spatial unit in land administration (i.e. strata objects registration). These criteria facilitate the exploration of the data models in more detailed manner. This assessment also enables a further understanding of important data models, their advantages and disadvantages in order to select the most suitable model for strata objects registration in Malaysia. The details of these legal and geometry data models for cadastral domain will be examined in Chapter 2.

LADM is a conceptual model which has been internationally accepted as a standard model to record and manage cadastral data. The LADM standard – ISO 19152 serves two goals. First, to facilliate the development of the application software for land administration based on the Model Driven Architecure (MDA). Second, to establish a shared ontology implied by the model. This allows communication between involved persons within one country and between different countries (Lemmen, 2012). To date a number of countries have developed their country profiles based on LADM. These include Turkey (Kara et al., 2018), Poland (Bydlosz, 2013), Croatia (Vucic et al., 2013), Korea (Kim et al., 2013; Jeong et al., 2012), Indonesia (Budisusanto et al., 2013, Indrajit et al., 2018), Malaysia (Zulkifli, 2014; Zulkifli et al., 2015) and The Netherlands (Lemmen et al., 2010), however, most of the proposed country profiles are still at the conceptual stage, thus yet to be implemented.

The Malaysia LADM country profile has introduced a 3D cadastre model (Zulkifli & Abdul Rahman, 2021; Zulkifli et al., 2015; Zulkifli, 2014; Zulkifli et al., 2014). The profile, however, include 2D topology model without the 3D topology model of a spatial unit. Rapid urbanisation experienced by the country witnessed more intensified usage of space which require a system of land administration which is more efficient. Thus, the Malaysian LADM country profile need to be extended to include a 3D strata objects registration system which addresses all questions related to strata aspects such as ownerships, share units, area or volume of parcel unit, boundary,

spatial source document, strata objects and management unit (or Management Corporation (MC). In this research, one of the major tasks is to enhance the current strata objects registration that incorporates the LADM standard. In case of strata objects, Malaysian national mapping agency uses strata XML to store strata objects information which unfortunately is not based on the LADM standard. Hence, conversion is required in line with data requirements in LADM domain. This research therefore aims to enhance the current strata objects registration which incorporates the LADM standard. In this context, the LADM will provide an abstract model to develop a tangible application including a 3D strata objects model. This research is not only useful to Malaysia, but also relevant to other countries that have similar strata system.

1.2 Problem Statements

Rapid urbanisation creates pressure on urban land as there is increasing needs for more urban housing and other services. The need for more space, has generated creative architecture and innovative construction which resulted in multi-storey constructions and complex infrastructures above and below ground. A land parcel with a 3D development will further create interests to property owners. This in turn creates a need to integrate the third dimension into the cadastral systems in order to establish an efficient 3D strata objects management and registration.

In most jurisdictions, a 3D strata objects registration contains 2D paper-based diagrams which does not allow users to make further queries. Thus, users will unlikely measure the length, area, and volume when using the 2D system. Further query, spatial analysis and 3D visualisation are also not allowed and it is not possible for users to investigate the 3D objects and examine 3D information in a more detailed manner. A 3D strata objects registration should be able to store, manipulate, update and support 3D visualisation strata objects. It should also be possible to undertake queries and analysis. Boss and Streilein (2014) observed the 3D visualisation has now come into the mainstream, but 3D analysis has not. User-friendly tools for 3D analysis also are still missing (Stoter, 2004; Khuan et al., 2008; Janecka & Kara, 2012; Janecka & Karki, 2016; Janecka & Navratil, 2019).

In Malaysia, the cadastral system is managed and maintained by two different organizations namely the Department of Director General of Lands and Mines (DDGLM) and the Department of Survey and Mapping Malaysia (DSMM). The departments are under the umbrella of the Ministry of Water, Land and Natural Resources. Among the functions of DSMM is providing cadastral survey information which includes the measurements, size and location of properties. Thus, DSMM is given the tasks to prepare the Certified Plan (CP), produce and manage the spatial component including survey and cadastral maps. The main function of the DDGLM is to oversee the legal aspects of land administration. The DDGLM therefore deals with property ownership registration. Each of these organizations has its information management systems, namely the 'eTanah' for the DDGLM and 'eKadaster' in DSMM which are two independent systems and in 2D. It is however difficult to maintain and up-date the two separated registrations manually. In an integrated cadastre, land registration should complement cadastral registration. Thus, information can be made more efficient in case of 3D strata objects by combining both land and cadastral registration.

LADM covers both spatial and administrative aspects. Previous works suggest that the utilization of LADM for a cadastral domain (e.g. strata objects registration) has significant impacts (Lemmen, 2012; van Oosterom et al., 2011; Pouliot, 2011; Hespanha, 2012; Sucaya, 2009). Although strata registration in most countries has similar fundamental characteristics, there exists several differerences between countries due to dissimilarities in terms of legislation and regulations. In Malaysia, several studies on the strata registration system have been undertaken to address various 3D situations. These include a proposal to develop a strata object database based on LADM (Nasorudin et al., 2016). However, the study used shp. file data format instead of strata XML for the database development. The DSMM is currently using strata XML to store the strata objects. The strata XML need to be converted to LADM – based first, before it proceeds to database development. Hashim et al. (2018) discussed the needs of 3D strata registration via IndoorGML approach. The study was very much focus on the data acquisition technique using Light Detection and Ranging (LIDAR) dataset for strata registration purposes and does not involved LADM standard. Rajabifard et al. (2018) and Rajabifard et al. (2019) investigated how the current 2D National Digital Database (NDCDB) could be upgraded to 3D for the

implementation of 3D – NDCDB based on LADM compliance. Their primary focus, however, was on 2D lot, not the strata objects. A conceptual data model based on the integration of LADM and IndoorGML for strata purposes was proposed by Mohd Hanafi and Hassan (2019). An IndoorGML – LADM is one of the recent examples of combining indoor space and legal object. However, this proposed integration model still could not answer many questions related to strata aspects (e.g. share unit and boundary).

At present, the Malaysian LADM Country Profile that is being developed, provides standardized class names for spatial and administrative data. To date, the Malaysian LADM country profile has yet to be implemented. The conceptual model (i.e. the country profile) however needs to be assessed and Zulkifli et al. (2015) suggested that a prototype need to be established to determine the model's limitations. As mentioned earlier, several studies namely Mohd Hanafi and Hassan (2019), Hashim et al. (2018), Rajabifard et al. (2018), and Nasorudin et al. (2016) have examined various issues related to strata registration, however, none has addressed the strata conversion to enable the implementation of the Malaysian LADM country profile. In order to implement the country profile, data from authorities responsible for mapping have to be converted first to enable its integration into the model. In case of strata objects, the mapping authority uses Strata XML to store strata objects information which unfortunately is not based on LADM standard. Hence, further work is needed to convert the Strata XML to LADM standard. It is important to convert the Strata XML to the LADM standard to facilitate communication between different agencies which govern land administration in the country and eventually supports the development of strata objects registration. This research intends to investigate the conversion of Strata XML to LADM standard with regards to 3D strata objects registration and develop a prototype that would be able to address questions related to strata aspects i.e. ownership, share unit, Management Corporation (MC), spatial source document and strata objects. It is anticipated that the outcomes of the study would drive the authorities to improve the land administration system especially strata objects registration.

1.3 Research Questions

This research will address the following questions:

i. Why LADM is chosen as the legal and geometry data model for cadastral domain?
   - What motivates the use of this model as compared to other data model?
   - What are the strength and weakness of other models? (i.e. Core Cadastral Data Model; FGDC Standard Reference Model; Legal Property Object Model; ePlan Model; 3D Cadastral Data Model; Building Information Modelling; CityGML)

ii. How to develop a strata objects model in LADM?
   - How LADM can be utilized for 3D strata objects?
   - Which LADM classes are used to develop the conceptual model?
   - How to map strata related objects within LADM?
   - How modelling tools such as the Unified Modelling Language (UML) works with LADM?

iii. How can a database be developed based on LADM?
   - How to utilise Extensible Markup Language (XML) to integrate varied strata objects with LADM?
   - What type of digital data of a building can be used as a data source?
   - How information can be extracted from a 3D building data and added into the model?
   - What is the appropriate DBMS software (e.g. PostgreSQL or Oracle Spatial) to be used in this research?

iv. How to implement and validate the model?
   - How to interpret the conceptual model to a physical model?
   - How to manage, assign and implement the various types of identifier and code list values?

- How to implement the various constraints?
- How can the implemented model be evaluated?

1.4 Aim and Objectives

The aim of this research is to design and implement 3D strata objects registration based on LADM. This will be achieved through the following objectives:

i. To identify the most suitable data model for 3D strata objects registration.
ii. To design a 3D strata objects conceptual model based on the selected data model.
iii. To design a 3D strata objects registration database based on the selected data model.
iv. To develop a 3D strata objects registration prototype based on the selected data model.

1.5 Scope of Research

The scope of this research as follows:

i. The main focus of this research is to provide technical solutions to implement a 3D strata objects registration within LADM framework in Malaysia. The conceptual models of 3D strata objects – LADM based are designed, tested and developed into a prototype to ascertain whether it is able to handle issues related to strata objects. This research addresses 3D strata objects registration in particular and will not include other aspects such as taxation, valuation and land use. Topology part of a spatial unit is also not within the scope of this research.
ii. The area of research is the Perdana Parkcity project in the City of Kuala Lumpur. Perdana Parckcity project is a mixed development comprising one

condominium block of twenty seven storeys and seventy six land parcels with three storey houses. This area was choosen because, its contains all the strata objects in this study such as parcel unit, accessory unit, common property unit and land parcel.

iii. The data of this research consist of secondary data such as Strata XML format (refer Appendix A) and building pelan (refer Appendix B) obtained from the DSMM.

iv. In this research, UML class diagram was created using Enterprise Architect (EA) which was selected since it has all the ISO models for land administration. It can also perform highly automated transformation of UML diagram, to database tables SQL DDL scripts for data storage or XML schema for data exchange format.

v. This research utilize an open source GIS programme which was selected due to its cost-effective installation, operation, and maintenance of spatial information. This research focuses on the data conversion from an existing database i.e. Strata XML format to an open source database (i.e. PostgreSQL). The visualization and application modules are developed by using an open source platform (i.e. QGIS). The program is developed using C# NetCore initialized with desktop form.

1.6 Research Methodology

This section briefly describes the methodology of the research. The methodology for this research consists of five phases. These are literature review, the development of a conceptual model of strata objects based on Malaysian LADM country profile, data collection and database construction. It also includes programming codes for Strata XML to LADM conversion and application for 3D strata objects registration. Figure 1.1 is the detailed research framework for this research.

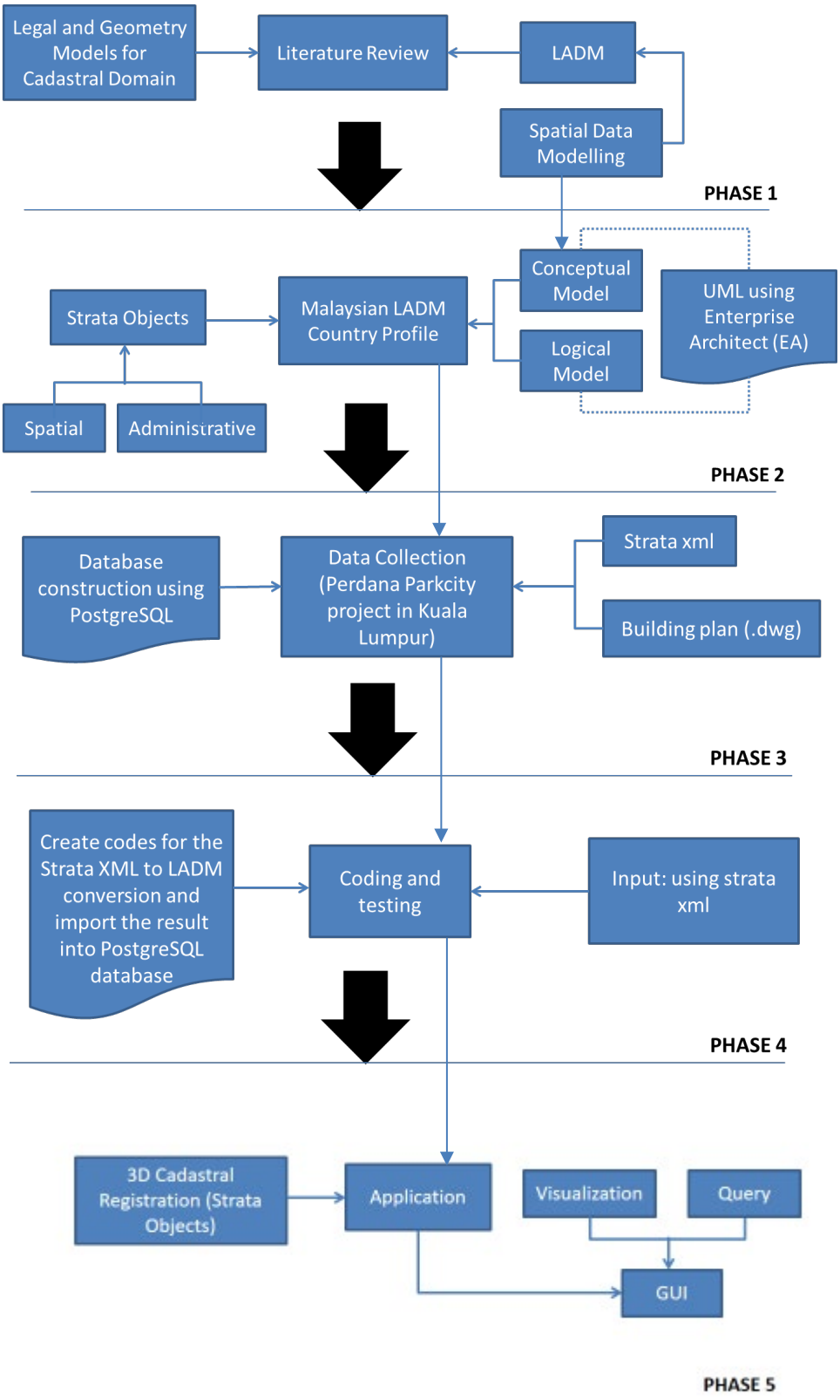

Figure 1.1 Research framework

From Figure 1.1, the phases are explained as follows:

i. First phase: Literature review

This involves an overview and assessment of the legal and geometry models for cadastral domain. These include: Core Cadastral Data Model, FGDC Standard Reference Model, Legal Property Object Model, ePlan Model, 3D Cadastral Data Model, Building Information Modelling, CityGML and Land Administration Domain Model – ISO 19152. Assessment of the various models is relevant in order to choose an appropriate model for strata objects registration in Malaysia. These data models are assessed based on selected criteria (i.e. core objects, basic spatial unit, other forms of spatial units, reference documents, applications, inclusion of other types of interest, temporal aspects, semantic level and architecture).

ii. Second phase: Development of the conceptual model of strata objects based on Malaysian LADM country profile

This phase involves the formulation of a spatial data modelling concept. The Unified Modelling Language (UML) is used to develop the conceptual and logical model for strata objects models. Enterprise Architect (EA) is used to develop the UML diagrams for strata objects models. The development of the strata objects model will address a wide range of objects such as parcel unit, accessory unit, common property unit, limited common property unit and land parcel. The conceptual model of strata objects is also divided into two parts (i.e. spatial and administrative parts).

iii. Third phase: Data collection and database construction

This research requires spatial data which will be collected from the DSMM in Kuala Lumpur. The spatial data contains Strata XML and building plan in .dwg format located in the study area. The study area that has been identified in this research is the Perdana Park city project. PostgreSQL is used to develop the database.

iv. Fourth phase: Programming codes and testing

Programming codes are used to develop conversion of strata xml to LADM standard. Codes for conversion programming is developed using C#. Data from Strata XML is used as an input. The result of the conversion is imported to the PostgreSQL database.

v. Fifth phase: Application

This phase involves the development of 3D strata objects registration application. Data from PostgreSQL database is linked to Quantum GIS (QGIS) software for visualisation and query purposes. Several analyses and evaluation (e.g. set of queries to identify feature strata objects) will be carried out to obtain results from the 3D strata objects registration application. The efficiency of the developed application will also be evaluated.

1.7 Research Significance

The following are the research's importance and contributions:

i. Full version management and inclusion of historic information for 3D strata objects registration.
ii. Explicit linking of all land administration information and source documents (i.e. titles, certified plans).
iii. Possibility to group multiple spatial units in one basic administrative unit with same right attached (e.g. parcel unit and accessory unit in term of strata objects).
iv. Establishment of well-defined Malaysian country profile especially for strata objects based on LADM.
v. Possibility of applying similar approach to other countries which utilise similar strata system.

1.8 Structure of Thesis

Chapter 1 discusses the need for 3D cadastral registration based on LADM standard. It also explains the scopes, problems related to the cadastral registration (i.e. strata objects) and the research objectives. This chapter also provides the research flow chart.

Chapter 2 reviews the various legal and geometry models for cadastral domain that are currently available. Eight legal and geometry data models for cadastral domain have been identified for this purpose (i.e. Core Cadastral Data Model, FGDC Standard Reference Model, Legal Property Object Model, ePlan Model, 3D Cadastral Data Model, Building Information Modelling, CityGML and Land Administration Domain Model). These data models are evaluated and compared based on a set of parameters (core objects, basic spatial units, other types of spatial units, reference documents, applications, including other types of interest, temporal aspects, semantic level, and architecture).

In Chapter 3, the development of conceptual model for Malaysia using LADM concepts will be described. Since the main focus of the research is on the strata objects, a detailed explanation of strata title and strata objects (i.e. parcel unit, accessory unit, common property unit and limited common property unit) are discussed. The concept of a strata model is a part of the Malaysian LADM Country Profile. Thus, the development of Malaysian LADM country profile is also presented. Unified Modelling Language (UML) is a standard language for designing the conceptual models. Therefore, the terms used in UML (i.e. association, generalization, aggregation, composition, multiplicity and association class) will be briefly explained. The conceptual model of strata objects together with the code lists (i.e. spatial and administrative) and their characteristics (i.e. classes, attributes, relationships and constraints) are also discussed.

Chapter 4 discusses the conversion of the available building strata schema into LADM model, specifically for 3D strata objects. Hence, the Strata XML and LADM context are also elaborated in this chapter. XML syntax is used to develop the existing

building strata schema. The experimen's workflow which consists of Strata XML data conversion collected from the field into the database with LADM data model will be demonstrated. The results of the conversion are imported into the PostgreSQL database for further application.

Chapter 5 describes the database design and implementation of 3D strata registration based on LADM. The key aspects of the application that the model is based on LADM. The database design of the 3D strata object registration is realized using PostgreSQL database. The database is then connected to QGIS software for visualization purposes. The attribute query and operation can be retrieved from the database to be edited.

Chapter 6 concludes the research and offers suggestions for future research.

REFERENCES

Abdul Rahman, A., Teng, C. H., & Van Oosterom, P. J. M. (2011). Embedding 3D into mutipurpose cadastre. In *FIG Working Week 2011 – Bridging the Gap between Cultures*, 18-22 May 2011, Marrakech, Morocco.

Aditya, T., Iswanto, F., Wirawan, A., & Laksono, D. P. (2011). 3D cadastre web: Prospects and developments. In E. Fendel, P. V. Oosterom, H. Ploeger, J. Stoter, A. Streilein, & T. Tijssen (Eds.), *2nd International Workshop on 3D Cadastres*, Delft, FIG & TU Delft.

Agarwal, S., & Rajan, K. S. (2016). Performance analysis of MongoDB versus PostGIS/PostGreSQL databases for line intersection and point containment spatial queries. *Spatial Information Research*, *24*(6), 671–677.

Aien, A. (2012). 3D Cadastral Data Model: A foundation for developing a national land information infrastructure. In A. Rajabifard et al. (Eds.), *A National Infrastructure for Managing Land Information - Research Snapshot* (pp. 116-121). Melbourne: The University of Melbourne.

Aien, A. (2013). *3D cadastral data modelling* (PhD thesis, University of Melbourne). Victoria, Australia.

Anonim (2010). Head of National Land Office's Executive Order Number 1/2010 on Services Standards on Land Registration. Badan Pertanahan Nasional Republik Indonesia (BPN-RI).

Anonim (2011). Law Number 20/2011 on Apartment.

Ary Sucaya, I. K. G. (2009). Application and validation the Land Administration Domain Model in a real life situation (A case study in Indonesia) (MSc thesis, Delft University of Technology). Delft, Netherlands.

Booch, G., Rumbaugh, J., & Jacobson, I. (2005). *The unified modeling language user guide* (2nd ed.). Addison: Wesley Professional.

Boss, H., Å., & Streilein, A. (2014). 3D data management – Relevance for a 3D cadastre position. In Proceedings of the 4th International Workshop on 3D Cadastres, 9-11 November 2014, Dubai, United Arab Emirates.

British Colombian Government (1996). Land Title Act.

Budisusanto, Y., Aditya, T., & Muryamto, R. (2013). LADM implementation prototype of 3D cadastre information system for multi-level apartment in Indonesia. In *Proceedings of the 5th Land Administration Domain Model Workshop*, 24-25 September 2013, Kuala Lumpur, Malaysia, pp. 465-475.

Bydlosz, J. (2013). Towards LADM country cadastral profile – Case Poland. In *Proceedings of the 5th FIG Land Administration Domain Model Workshop*, 24-25 September 2013, Kuala Lumpur, Malaysia, pp. 247-260.

Chen, P. P. (1976). The entity relationship model: Toward a unified view of data. *ACM Transactions on Database Systems, 1*(1), 9-36.

Christudason, A. (2007). Optimisation of land use through innovative legislation in Singapore. In *Proceeding of 9th PRRES Conference*, 19-22 January, Brisbane, Australia.

Cumerford, N. (2010). The ICSM ePlan protocol, its development, evolution and implementation. Paper presented at the *FIG Congress 2010*, 11-16 April 2010, Sydney, Australia.

Easthope, H., & Randolph, B. (2009). Governing the compact city: The challenges of apartment living in Sydney, Australia. *Housing Studies*, *24*(2), 243-259.

Eliades, Y., & Arias, P. (2012). Extending UML for modelling geographical information systems. In *Proceeding of International Conference of GIS-Users*, Taza GIS-Days.

ePlan (2010). *ePlan model version 1.0*. Retrieved from http://icsm-eplan.govspace.gov.au/files/2010/11/ICSM-ePlan-Model-v1.0.pdf

Eriksson, G., & Jansson, L. (2010). Strata titles are introduced in Sweden. In *Proceedings of FIG Congress 2010*, 11-16 April 2010, Sydney, Australia.

FGDC (1996). Cadastral Data Content Standard for the National Spatial Data Infrastructure - Version 1.1.

FGDC (2008). Cadastral Data Content Standard for the National Spatial Data Infrastructure - Version 1.4.

Fowler, M. (2003). UML distilled: A brief guide to the standard object modeling language (3rd ed.). Addison: Wesley Professional.

Gerremo, J., & Hansson, J. (1998). *Ownership of real property in British Colombia, a legal study* (MSc Thesis, Royal Institute of Technology). Department of Real Estate Planning and Land Law, Stockholm.

Hashim, M. N., Hassan, M. I., & Abdul Rahman, A. (2018). 3D modelling towards strata registration. In Proceedings of International Conference on Geomatics and Geospatial Technology (GGT 2018), 3-5 September 2018, Kuala Lumpur, Malaysia.

Hassan, M. I., & Abdul-Rahman, A. (2010). An integrated Malaysian cadastral system. *FIG Congress 2010*, Sydney, Australia.

Henssen, J. (1995). Basic principles of the main cadastral systems in the world. Paper presented at the *Seminar Modern Cadastres and Cadastral Innovations*, Delft, The Netherlands, pp. 5-12.

Henssen, J. (2010). Land registration and cadastre systems: Principles and related issues. Germany.

Hespanha, J. P. (2012). Development methodology for an integrated legal cadastre-deriving Portugal country model from the land administration domain model (PhD thesis, Delft University of Technology). Delft, The Netherlands.

ICSM (2008). *ICSM Harmonised Data Model, Version 2*. Retrieved from http://www.icsm.gov.au/hdm/model2/hdm_V2.html.

Indrajit, A., Ploeger, H., van Loenen, B., & van Oosterom, P. J. M. (2018). Designing open spatial information infrastructure to support 3d urban planning in Jakarta Smart City. In *Proceedings of the 6th International FIG 3D Cadastre Workshop* (pp. 329). Delft: FIG (International Federation of Surveyors).

ISO 19152 (2012). Geographic Information – Land Administration Domain Model (LADM). Version 1 December 2012.

Janecka, K., & Kara, M. (2012). Advanced data structures for surface storage. In *Proceedings of GIS Ostrava 2012 – Surface Models for Geosciences*, VŠB-TUO, Ostrava.

Janecka, K., & Karki, S. (2016). 3D data management (overview report). In *Proceedings of 5th International FIG 3D Cadastre Workshop*, 18-20 October 2016, Athens, Greece.

Janecka, K., & Navratil, G. (2019). Geospatial data in support of 3D cadastre. In *Article of GIM International*. Retrieved from https://www.gim-international.com/content/article/geospatial-data-in-support-of-3d-cadastre-2.

Jeong, D. H., Jang, B. B., Lee, J. Y., Hong, S. I., van Oosterom, P., De Zeeuw, K., Stoter, J., Lemmen, C., & Zevenbergen, J. (2012). Initial design of an LADM-based 3D cadastre – Case study from Korea. In *Proceedings of the 3rd*

International Workshop on 3D Cadastre, 25-26 October 2012, Shenzhen, China, pp. 159-184.

Julstad, B., & Ericsson, A. (2001). Property formation and three-dimensional property units in Sweden. In *FIG Workshop on 3D Cadastres*, November, Delft.

Kalantari, M., Rajabifard, A., Wallace, J., & Williamson, I. P. (2008). Spatially referenced legal property objects. *Land Use Policy, 25*(2), 173-183.

Kalantari, M., Lester, C., Boyle, D. R., & Coupar, N. (2009). Towards eLand Administration – electronic plans of subdivision in Victoria. In O. B. et al. (Eds.). Paper presented at *The Proceedings of the Surveying & Spatial Sciences Institute Biennial International Conference*, Adelaide 2009, Surveying & Spatial Sciences Institute, pp. 155-162.

Kara A., Isikdag U., Cagdas V., van Oosterom P., Lemmen C., & Stubkjaer E. (2018). A database implementation of LADM valuation information model in Turkish case study. In *7th International FIG Workshop on the Land Administration Domain Model*, 11-13 April 2018, Zagreb, Croatia.

Kara A., Cagdas V., Isikdag U., van Oosterom P., Lemmen C., & Stubkjaer E. (2021). The LADM valuation information model and its application to the Turkey case. In . *Land Use Policy,* 104, 105307.

Khoo, V. H. S. (2011). 3D cadastre in Singapore. In *Proceedings of 2nd International Workshop on 3D Cadastres*, 16-18 November 2011, Delft, The Netherlands.

Khuan, C. T., Abdul-Rahman, A., & Zlatanova, S. (2008). 3D solids and their management in DBMS. In *Advances in 3D Geoinformation Systems* (pp. 279-311). Berlin, Heidelberg: Springer.

Kim, T. J., Lee, B. M., & Lee, Y. H. (2013). A strategy for developing the cadastral system of cadastral resurvey: Project based on International Standard (LADM) in South Korea. In *Proceedings of the 5th FIG Land Administration Domain Model Workshop*, 24-25 September 2013, Kuala Lumpur, Malaysia, pp. 261-273.

Kolbe, T. H. (2009). Representing and exchanging 3D city models with CityGML. In J. Lee & S. Zlatanova (Eds.), *3D Geo-Information Sciences*. Berlin: Springer.

Larman, C. (2004). Applying UML and patterns: An introduction to object-oriented analysis and design and iterative development (3rd ed.). Prentice Hall.

Laurini, R. (2001). Information systems for urban planning, a hypermedia cooperative approach. London: Taylor and Francis.

Lemmen, C. (2010). The social tenure domain model, a pro-poor land tool. FIG Publication No 52.

Lemmen, C. H. J., van Oosterom, P. J. M., Eisenhut, C., & Uitermark, H. T. (2010). The modeling of rights, restrictions and responsibilities (RRR) in the Land Administration Domain Model (LADM). *FIG Conference 2010*, Sydney, Australia.

Lemmen, C. (2012). *A domain model for land administration* (PhD thesis, Delft University of Technology). Delft, The Netherlands.

Marquez, A. (2015). *PostGIS essentials: Learn how to build powerful spatial database solutions with PostGIS quickly and efficiently*. Community experience distilled. Birmingham: Packt Publishing.

Mattsson, H. (2003). Towards three dimensional properties in Sweden. In *32nd International Symposium,* 24-25 October 2003, Strasbourg.

Mikiewicz, D., Mackiewicz, M., & Nycz, T. (2017). *Mastering PostGIS: create, deliver, and consume spatial data using PostGIS*. Retrieved from http://proquest.safaribooksonline.com/?fpi=9781784391645

Mohd Hanafi, F., & Hassan, M. I. (2019). The integration of 3D spatial and non-spatial component for strata management. In *Proceedings of 6th International Conference on Geomatics and Geospatial Technology (GGT 2019)*, 1-3 October 2019, Kuala Lumpur, Malaysia.

Nasorudin, N. N., Hassan, M. I., Zulkifli, N. A., & Abdul Rahman, A. (2016). Geospatial database for strata objects based on Land Administration Domain Model (LADM). In *Proceedings of International Conference on Geomatics and Geospatial Technology (GGT 2016)*, 3-5 October 2016, Kuala Lumpur, Malaysia.

Palsson, J. (2012). Swedish 3D property in an international comparison. In *Proceedings of 3rd International Workshop on 3D Cadastres: Developments and Practices*, 25-26 October 2012, Shenzhen, China.

Pinet, F., Kang, M. A., & Vigier, F. (2005). Spatial constraint modelling with a GIS extension of UML and OCL: Application to agricultural information systems. Verlag Berlin Heidelberg: Springer.

Pokorny, J. (2013). NoSQL databases: A step to database scalability in web environment. *International Journal of Web Information Systems*, *9*(1), 69-82.

Pouliot J., Marc V., & Abbas B. (2011). Spatial representation of condominium/co-ownership: Comparison of Quebec and French cadastral system based on LADM specifications. *2nd International Workshop on 3D Cadastres*.

Rajabifard, A., Agunbiade, M., Kalantari, M., Yip, K. M., Atazadeh, B., Badiee, F., Isa, M. N., Adimin, M. K., Chan, K.L., Aien, A., Olfat, H., Shojaei, D., & Anaraki, M. R. (2018). An LADM-based approach for developing and implementing a national 3D cadastre: A case study of Malaysia. In *Proceedings of 7th International FIG Workshop on the Land Administration Domain Model*, 11-13 April 2018, Zagreb, Croatia.

Rajabifard, A., Atazadeh, B., Yip, K. M., Kalantari, M., Anaraki, M. R., Olfat, H., Badiee, F., Shojaei, D., Aien, A., Olfat, H., Shojaei, D., Chan, K. L., & Mohd Zain, M. A. (2019). Design and implementation of a 3D national digital cadastral database based on Land Administration Domain Model: Lessons learned from a 3D cadaster project in Malaysia. In *Proceedings of 8th International FIG Workshop on the Land Administration Domain Model*, 1-3 October 2019, Kuala Lumpur, Malaysia.

Stadler, A., & Kolbe, T. H. (2007). Spatio-semantic coherence in the integration of 3D. Paper presented at the *5th International ISPRS Symposium on Spatial Data Quality ISSDQ 2007*, Enschede.

Stoter, J. E., & Ploeger, H. D. (2003). Property in 3D-registration of multiple use of space: Current practice in Holland and the need for a 3D cadastre. *Computers, Environment and Urban Systems, 27*(6), 553-570.

Stoter, J., & Salzmann, M. (2003). Towards a 3D cadastre: Where do cadastral needs and technical possibilities meet?. *Computers, Environment and Urban Systems, 27*(4), 395-410.

Stoter, J. E. (2004). *3D Cadastre* (PhD thesis, Delft University of Technology). Delft, The Netherlands.

Stoter, J., Oosterom, P., Ploeger, H., & Aalders, H. (2004). Conceptual 3D cadastral model applied in several countries. In *Proceedings of FIG Working Week 2004*, 22-27 May 2004, Athens, Greece.

Stoter, J., Ploeger, H., & van Oosterom, P. (2013). 3D cadastre in The Netherlands: Developments and international applicability. *Computers, Environment and Urban Systems, 40,* 56-67.

Stoter, J., Ploeger, H., Roes, R., Riet, E. V. D., Biljecki, F., Ledoux, H., Kok, D., & Kim, S. (2017). Registration of multi-level property rights in 3D in the Netherlands: Two cases and next steps in further implementation. *ISPRS International Journal of Geo-Information, 6*(6), 158.

Strata Title Act (1985). *Strata Title Act*.

Strata Title Amendment Act (2013). *Strata Title Amendment Act*.

Sucaya, I. A., & Ary, K. G. (2009). Application and validation the land administration domain model in real life situation: A case study in Indonesia. *Geo-Information Management and Land Administration.* Enschede, ITC.

Thompson, R., & van Oosterom, P. (2010). Integrated representation of (potentially unbounded) 2D and 3D spatial objects for rigorously correct query and manipulation. In *5th International 3D GeoInfo Conference*, November 2010, Berlin, pp. 17.

Van Oosterom, P. J. M, Lemmen, C. H. J, Uitermark, H., Boekelo, G., & Verkuijl, G., (2011). Land administration standardization with focus on surveying and spatial representations. In *Proceedings of the ACMS Annual Conference Survey Summit*, San Diego, pp. 28.

Vucic, N., Markovinovic, D., & Micevic, B. (2013). LADM in the Republic of Croatia: Making and testing country profile. In *Proceedings of the 5th FIG Land Administration Domain Model Workshop*, 24-25 September 2013, Kuala Lumpur, Malaysia, pp. 329-344.

Zhang, L., & Yi, J. (2010). Management methods of spatial data based on PostGIS. In *2010 Second Pacific-Asia Conference on Circuits, Communications and System*, pp. 410-413. IEEE.

Zulkifli, N. A., Abdul Rahman, A., Jamil, H., Teng C. H., Tan L. C., Looi K. S., Chan K. L., & van Oosterom, P. (2014). Towards Malaysian LADM country profile for 2D and 3D cadastral registration system. In *Proceedings of FIG Congress 2014*, 16-21 June 2014, Kuala Lumpur, Malaysia.

Zulkifli, N. A. (2014). Adoption of land administration domain model for land administration in Malaysia (MSc Thesis, Universiti Teknologi Malaysia).

LIST OF PUBLICATIONS

Journals

1. **Zulkifli, N. A.**, Abdul Rahman, A., & Siew Chengxi, B. (2021). Design and implementation of 3D strata objects registration based on LADM – A case study in Malaysia. *Land Use Policy, 108,* 105497, (IF 5.398).

2. **Zulkifli, N. A.**, Abdul Rahman, A., van Oosterom, P., Tan, L. C., Jamil, H., Teng, C. H., Looi, K. S., & Chan, K. L. (2015). The importance of Malaysian Land Administration Domain Model country profile in land policy. *Land Use Policy, 49,* 649-659, (IF 5.398).

Proceedings

1. **Zulkifli, N. A.**, & Abdul Rahman, A. (2021). Converting tool from strata XML to LADM. *Geoinformation Research Colloquium Scientific English-Day*, 6th edition, 30 June 2021, Casablanca, Morocco.

2. **Zulkifli, N. A.**, & Abdul Rahman, A. (2020). Strata objects registration based on Land Administration Domain Model (LADM). *Scientific English-Day*, 5th edition, 18 June 2020, Casablanca, Morocco.

3. **Zulkifli, N. A.**, & Abdul Rahman, A., & Siew Chengxi, B. (2019). Database design and development of 3D cadastral registration based on LADM. *8th International FIG Workshop on the Land Administration Domain Model*, 1-3 October 2019, Kuala Lumpur, Malaysia.

4. Jamil, H., Isa, M. N., Teng, C., Chan, K. L., Rahman, A. A., Hassan, I., Musliman, I. A., Ujang, U., Siew, B., Karim, H., **Zulkifli, N. A.**, Azri, S., & van Oosterom, P. J. M. (2017). Converting the strata building to LADM. In P. Halme (Ed.), *Proceedings FIG Working Week 2017*, 29 May - 2 June 2017, Helsinki, Finland.

5. **Zulkifli, N. A.**, Abdul Rahman, A., & Hassan, M. I. (2016). Design of 3D topological data structure for 3D cadastre objects. In The International Archives of the Photogrammetry, Remote Sensing and Spatial Information

Science, Volume XLII-4/W1. *International Conference on Geomatic and Geospatial Technology (GGT) 2016*, 3-5 October 2016, Kuala Lumpur, Malaysia.

6. **Zulkifli, N. A.**, Abdul Rahman, A., & van Oosterom, P. (2015). An overview of 3D topology for LADM-based objects. In The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, Volume XL-2/W4. *Joint International Geoinformation Conference (JIGC)*, 28-30 October 2015, Kuala Lumpur, Malaysia.

7. **Zulkifli, N. A.**, Abdul Rahman, A., Hassan, M. I., & Tan, L. C. (2015). Conceptual modelling of 3D cadastre and LADM. In *Proceeding of WCS-CE – The World Cadastre Summit, Congress & Exhibition*, 20-25 April 2015, Istanbul, Turkey.

8. **Zulkifli, N. A.**, Abdul Rahman, A., & van Oosterom, P. (2014). 3D strata objects registration for Malaysia within the LADM framework. In *Proceeding of 4th International FIG 3D Cadastre Workshop*, 9-11 November 2014, Dubai, United Arab Emirates.

9. **Zulkifli, N. A.**, Abdul Rahman, A., Jamil, H., Teng C. H., Tan L. C., Looi K. S., Chan K. L., & van Oosterom, P. (2014). Towards Malaysian LADM country profile for 2D and 3D cadastral registration system. In *Proceedings of FIG Congress 2014*, Kuala Lumpur, Malaysia, 16-21 June 2014 (peer-review).

10. **Zulkifli, N. A.**, Abdul Rahman, A., Jamil, H., Teng C. H., Tan, L. C., Looi, K. S., Chan K. L., & van Oosterom, P. (2014). Development of a prototype for the assessment of the Malaysian LADM Country Profile. In *Proceedings of FIG Congress 2014*, Kuala Lumpur, Malaysia 16-21 June 2014.