Developing 2D and 3D Cadastral Registration System based on LADM: illustrated with Malaysian Cases

Nur Amalina ZULKIFLI, Alias ABDUL RAHMAN, Malaysia and Peter van OOSTEROM, the Netherlands

SUMMARY

This paper investigates several aspects of the Land Administration Domain Model (LADM, ISO 2012) associated to 2D and 3D cadastral situations within Malaysian cadastral registration system. Literature review shows that many countries propose their own profile based on the LADM such as The Netherlands, Portugal, Indonesia, Korea, Japan, Australia/ Queensland, Cyprus and others. Malaysia is one of the potential candidates towards LADM-based country profile, as proposed in this paper. Several aspects of the LADM such as the RRR's (Rights, Restrictions and Responsibilities), the 'Spatial Unit' and 'Party' will be described related to 2D and 3D cadastral situations within the UML modelling language as a tool for the data modelling. Code lists are used to describe a more open and flexible enumeration values and associated to Malaysian mapping standard. Code lists are useful for expressing a long, and potentially extensible, list of potential values. The code lists included in the LADM aim to allow the use of local, regional or national terminology. We plan to utilise cadastral datasets from Malaysian NMA (National Mapping Authority, 'JUPEM') and Land Office agency to illustrate the various cases. Note that the spatial data comes from JUPEM, and registration (non-spatial data) from the Land Office.

In this paper the modelling of Rights, Restrictions and Responsibilities (RRR) will be discussed with a focus on the modelling of holding shares in a RRR (Lemmen et al. 2010). A share in a right has a constraint that the sum of all shares should be equal to one. In principle, all rights, restrictions and responsibilities are based on an administrative source. A 'SpatialUnit' is a point (or, multi-point), a line (or, multi-line), representing a single area (or, multiple areas) of land (or water) or, more specifically, a single volume of space (or, multiple volumes of space). The individual points are associated to 'SpatialSource' class. 2D and 3D representations of spatial units use boundary 'face strings' and boundary 'faces'. Parties are natural persons, or group of persons, or juridical persons, that compose an identifiable single (legal) entity. A juridical person may be a company, a municipality, the state or a farmer cooperation.

Database construction for spatial and non spatial data will be carried out using Oracle Spatial. The database schema is based on the LADM conceptual model with a country profile for the Malaysian cadastral registration system. Data from the Oracle database can be accessed by Bentley MicroStation software for 2D and 3D visualisation and editing. The Structured Query Language (SQL) will be used to query and extract the data from the database.

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1. INTRODUCTION

Nowdays, most countries have developed their own land administration system. Some countries operate deeds registration, other title registration. Some systems are centralized, and others decentralized. Some systems are based on general boundaries approach, others on fixed boundaries. Some systems have a fiscal background, others a legal one (Bogaerts and Zevenbergen, 2001). LADM was introduced as a model to create standardized information services in an international context, where land administration domain semantics have to be shared between regions, or countries, in order to enable necessary translations.

In Malaysia, there are two organizations responsible for managing and maintaining the cadastral system. The Department of Survey and Mapping Malaysia (DSMM) deals with the cadastral survey with high accuracy survey determine the location, dimension and size of the properties. The Cadastral Survey System of DSMM is responsible for preparing, producing and managing the spatial component including the surveying and mapping of the cadastre parcels. The Land Registration System, which is non-spatial data is the responsibility of the Land Office. The Land Office deals with ownership registration, i.e. who owns what (Right, Responsible, Restriction), the RRRs. Both organizations have their own systems called CLRS (Computerised Land Registration System) in PTG (Pejabat Tanah & Galian) also known as Land Office and CDMS (Cadastre Data Management System) in DSMM. Unfortunately the systems are not integrated and still 2D in nature**.** Unique Parcel Identifier (UPI) was introduced to link the Land Office and DSMM where every parcel has a unique identity number to differentiate from other parcels.

Malaysia has standard codes for features and attributes code called MS 1759:2004. Basically, this standard codes only cover the spatial part and do not include non-spatial part like Right, Restriction and Responsibility (RRR). This paper proposes some codes for non-spatial data based on LADM. Current cadastral system in Malaysia is still not able to answer several 3D situations as proposed by Stoter (2004), Thompson and van Oosterom (2010), Hassan and Abdul Rahman (2010). Although the 2D cadastre still plays a dominant role in land administration in Malaysia, specific needs for the registration related to 3D cadastre based on LADM specifications need to be investigated further.

This paper is organized as follows: Section 2 gives an overview of Land Administration Domain Model (LADM). Spatial and non-spatial modelling is discussed in Section 3. Section 4, presents some illustrated cases from Malaysia and the prototype implementation using Oracle Spatial and Bentley Microstation. Finally, the conclusions are given in Section 5.

2. LAND ADMINISTRATION DOMAIN MODEL (LADM)

Land Administration Domain Model (LADM) is also identified as ISO 19152. LADM has been introduced as a model for land administration purposes. This model is designed as a basis for various land registration practice in different countries. The LADM provides an abstract, conceptual schema with three basic packages related to parties, rights, responsibilities and restrictions (RRRs) and spatial units with one subpackage: surveying and spatial representation. Two important goals of this model are to provide an extensible basis for the development and refinement of efficient and effective land administration system, based on model driven architecture (MDA), and to enable involved parties, both within one country and between different countries, to communicate, based on the shared vocabulary implied by the model. The three main packages of the LADM are summarized in the subsections below based on text from the official standards document ISO 19152.

2.1 Party package

The main class of this package is class LA_Party and with its specialisation LA_GroupParty. Parties are natural persons, or groups of persons, or juridical persons, that compose an identifiable single (legal) entity. A juridical person may be a company, or a municipality. A group party is any number of parties, forming together a distinct entity. A party membership in a group party is documented with attributes such as share in group and start date of membership in group.

2.2 Administrative package

This package concerns the abstract class LA_RRR (with its three concrete subclasses LA_Right, LA_Restriction and LA_Responsibility), and class LA_BAUnit. A right is a formal or informal entitlement to own, to do something, or to refrain from doing something. Examples are: ownership right, tenancy right, possession, customary right or informal right. A right can be an informal use right. A restriction is a formal or informal entitlement to refrain from doing something, e.g. it is not allowed to build within 300 m of a fuel station, or a servitude or mortgage as a restriction to the ownership right. A responsibility is a formal or informal obligation to do something, e.g. the responsibility to clean a ditch, to keep a snow-free pavement, or to remove icicles from the roof during winter, or to maintain a monument. A BAUnit (an abbreviation for basic administrative unit) is an administrative entity consisting of zero or more spatial units (parcels) against which one or more rights, responsibilities or restrictions are associated, as included in a land administration (LA) system. An example of a BAUnit is a basic property unit with two spatial units (e.g. an apartment and a garage) with same RRRs and parties attached (e.g. single owner).

2.3 Spatial unit package

A spatial unit can be described as an area of land or water where RRRs (including social tenure relationships) apply. Spatial units can be represented as sketch-based units; text-based units; point-based units; line-based units; polygon-based units which are used when each spatial units recorded as a separate entity, and topology-based units which are used when spatial units share boundary representations. A spatial unit group is a group of spatial units, (e.g. section, a municipality, a department, a province or a country), or within a planning area. Note the spatial unit group has no RRRs (Baunits) attached and is just for usefull grouping; e.g. to support certain workflows. The spatial unit package has one surveying and spatial

representation subpackage, with classes such as LA_SpatialSource, LA_Point, LA_BoundaryFaceString and LA_BoundaryFace. Points can be acquired in the field by classical surveys, or with images. A survey is documented with spatial sources. A set of measurements with observations (distances, bearings, etc.) is an attribute of LA_SpatialSource. The individual points are instances of class LA_Point, which is associated with LA_SpatialSource. The two-dimensional boundary face strings (2D boundaries implying vertical faces forming part of the outside of a spatial unit) and the three-dimensional boundary faces (faces used in 3D representation of a boundary of a spatial unit) are used to provide the spatial representations associated to spatial units.

3. SPATIAL AND NON-SPATIAL DATA MODELLING

The study area for this research is at World Youth Foundation (WYF) building in the state of Melaka and some land parcels around that building. WYF is a commercial building with four storeys. The building is meant for 3D cadastral registration system meanwhile the land parcel around that building is for 2D cadastral system based on LADM. In this paper, 'MY' is a prefix for the Malaysian country profile, covering both the spatial and non-spatial data modelling as shown in Figure 1 and Figure 2. Attributes with type have codes and will be explain further in Section 3.2.

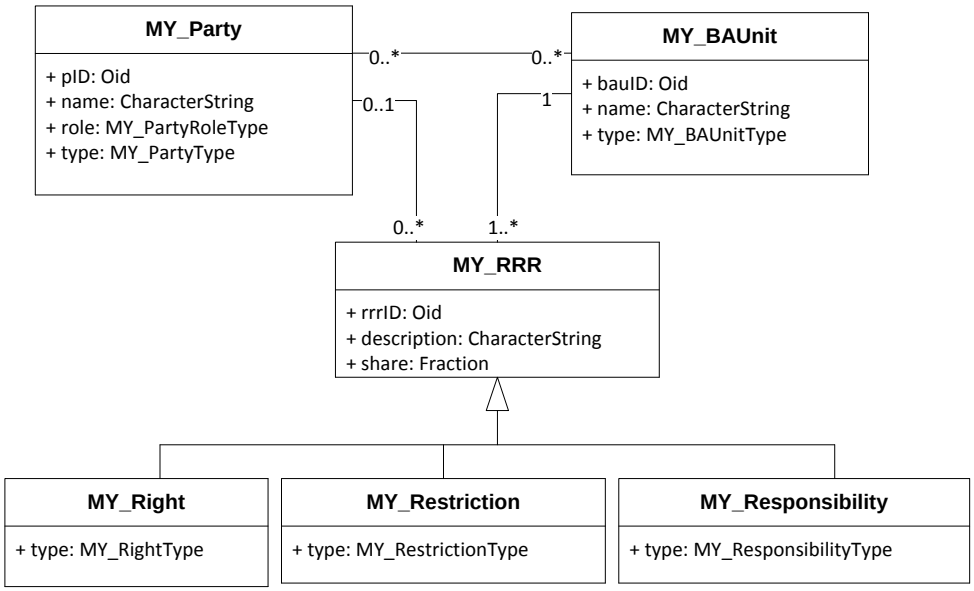

Figure 1. Non-spatial data modelling based on LADM

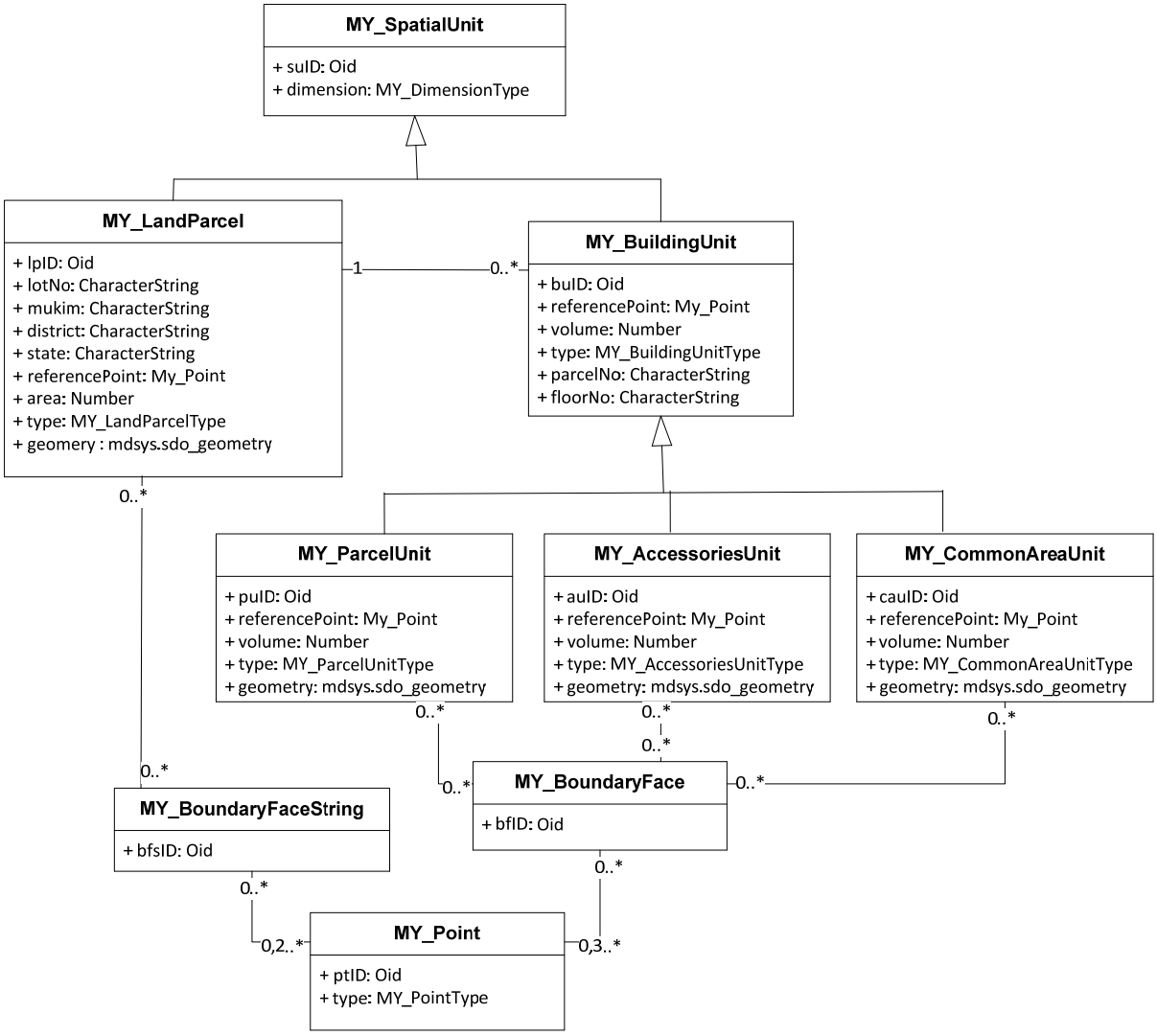

Figure 2. Spatial data modelling based on LADM

3.1 Unique Parcel Identifier (UPI)

Unique Parcel Identifier (UPI) was introduced to create a linkage between Land Office (non-spatial data) and DSMM (spatial data). It also makes every parcel has an unique identity number to differentiate them with other parcel. Figure 3 and Figure 4 shows the UPI for land parcel (2D) and building unit (3D).

04010800015662

04 = State code
01= District code
08 = Mukim code
000 = Section code
15662 = Lot number

Figure 3. UPI for land parcel (2D), lpID in country profile

04010800015662(S)846(B)M1(M)1

04 = State code
01= District code
08 = Mukim code
000 = Section code
15662 = Lot number
(S)846 = Scheme number
(B)M1 = Main building number
(M)1 = 'Menara' @ Tower number

Figure 4. UPI for building unit (3D) – main block, buID in country profile

In one scheme for building (3D), it also possible to have a provisional block. Based on Strata Titles Act 1985 (section 4), provisional means : a) in relation to a proposed strata plan, a block in respect of a building proposed to be, or in the course of being, erected, for which a separate provisional strata title is applied for; b) in relation to an approved strata plan, such a block shown therein, for which a provisional strata title is to be registered; c) in relation to a book of strata register, such a block shown therein, for which a provisional strata title has been registered. The code for provisional block in that building starts with P. The Figure 5 shows an example of UPI for provisional block.

04010800015662(S)846(B)P1

Figure 5. UPI for building unit (3D) – provisional block

UPI for building unit (3D) will be divided into three subdivisions: these are parcel unit, accessories unit and common area unit. The Figure 6, Figure 7 and Figure 8 show examples of UPI for parcel unit, accessories unit and common area unit. Parcel unit, in relation to a subdivided building, means one of the individual units comprised therein, which (expect in the case of an accessory parcel) is held under separate strata title. Accessories unit means any parcel shown in a strata plan as an accessory parcel which is used or intended to be used in conjunction with a parcel. Common area unit means so much of the lot as is not comprised in any parcel (including any accessory parcel), or any provisional block as shown in an approved strata plan.

04010800015662(S)846(B)M1(M)1(T)1(P)1

(T)1 = 'Tingkat' @ Floor number
(P)1 = Parcel unit number

Figure 6. UPI for parcel unit in building, puID in country profile

04010800015662(S)846(B)M1(M)1(T)1(A)1

(A)1 = Accessories unit number

Figure 7. UPI for accessories unit in building, auID in country profile

04010800015662(S)846(B)M1(M)1(T)1(C)1

(C)1 = Common area unit number

Figure 8. UPI for common area unit in building, cauID in country profile

3.2 Code list

Based on spatial and non-spatial data modelling above, several classes have code list. In Malaysia, we have standard codes for features and attribute code (MS 1759: 2004). Malaysian standard codes basically cover the spatial part and rarely cover non-spatial part likes Right, Restriction, and Responsibility type. Figure 9 and Figure 10 shows the spatial and non spatial codes.

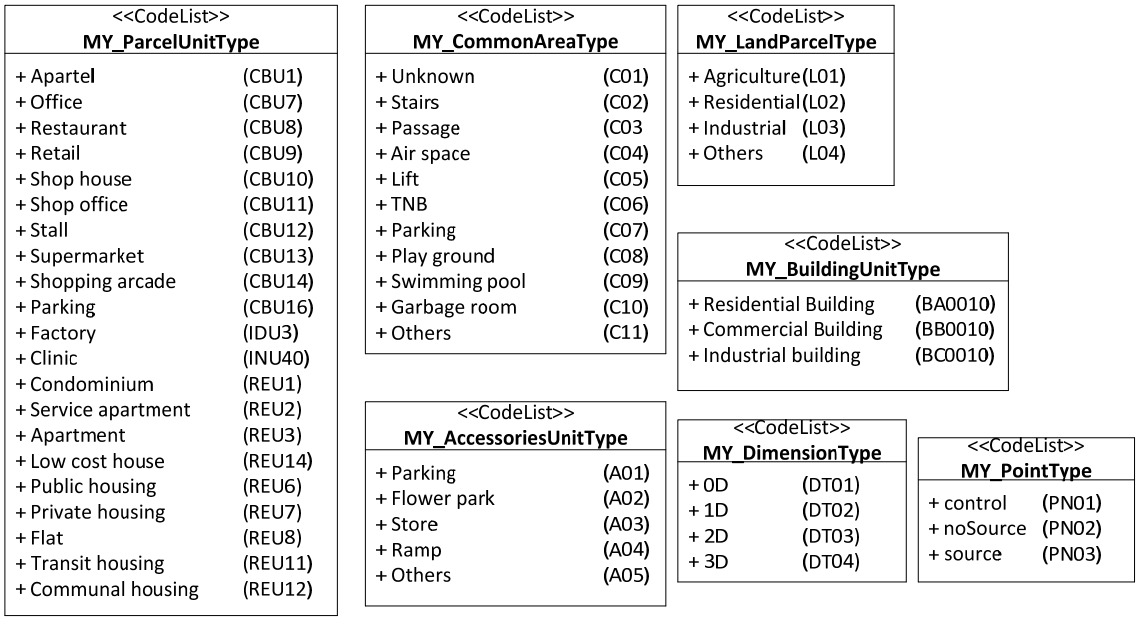

Figure 9. Code list for spatial package (Malaysian specific code list values, with exception of MY_DimensionType and MY_PointType, which are from generic LADM code list)

Newly proposed code lists for non-spatial package not captured in the current Malaysia standard are presented in Figure 10 and are mainly based on example code list values in LADM informative annex J.

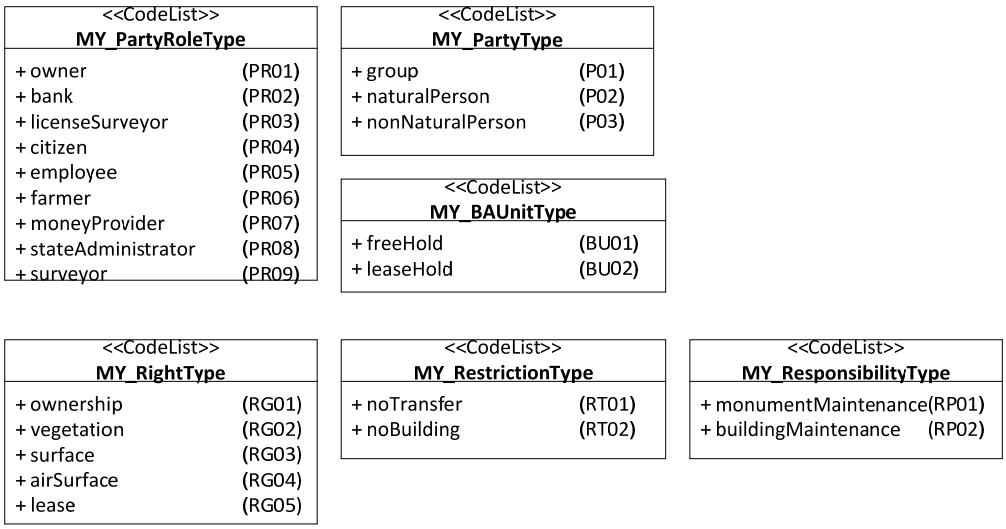

Figure 10. Code list for non-spatial package (party and administrative package)

4. THE CASE STUDY

In Malaysia, ownership for building subdivision is called strata title. Strata title is different from the land title. Share units in strata title is determined by area of each parcel units. Meanwhile, for land title, the share units are based on agreement that was made between the owners of the land. For example, there are five owners on one land named with individual A, B, C,D and E with their share units: A (6/20), B (2/20), C (2/20), D (7/20) and E (3/20). The total number for share units in land title must equal to 1. If there are only one owner in land title, the share units is just 1 and do not have fraction.

The total share units for building (strata title) also include the provisional block. For an example, strata schema for World Youth Foundation (WYF) building has one provisional block (as mentioned in the preceding section. Thus, the share units for that block also calculated in that strata schema. Table 1 show the share units that for each parcels in WYF building. The total share units in strata schema for WYF building is 1537.

4.1 The physical model

For this project, the conceptual model has been transformed into a physical model with seven tables, which represent spatial and non-spatial data as shown in Table 2. MY_Party, MY_BAUnit, MY_RRR represent non-spatial data. On the other hand, MY_SpatialUnit, MY_LandParcel, My_BuildingUnit and MY_PACunit represent spatial data. MY_PACunit is a combination of MY_ParcelUnit, MY_AccessoriesUnit and MY_CommonAreaUnit. Based on LADM, there are two type of parties: natural and non-natural person. Natural person is a individual person such as the owner, employee and so on. Meanwhile, non-natural person is like an organization or company. In this project, ID for natural person is based on their identity card (IC) number and id for non-natural person is based on company registration number.

Basic administrative unit ID for this research is based on ownership number or title number of the property (land parcel or building unit). Currently, there is no id attribute for the RRR class. We propose in the Malaysian country profile to use the new attribute for RRR classes known as rrrID in LADM. RRR id in this project is same as Unique Parcel Identifier (UPI) of the objects. Spatial unit ID is based on number of certified plan (CP). For this research, spatial unit are divided into two parts which are land parcel (2D) and building unit (3D). Building unit also divided into three parts which are parcel unit, accessories unit and common area unit. ID for for land parcel and building unit (including parcel unit, accessories unit and common area unit) are based on UPI. UPI is important for this research. It will be use to query spatial and non spatial data from database. Table 3 show some examples of ID for each table.

Table 1. Share units for each parcel in WYF building strata schema

Block	Floor	Parcel	Share units
M1 (main block)	1	1	31
		2	31
		3	31
		4	14
		5	31
		6	31
		7	31
		8	31
		9	87
		10	2
	2	11	33
		12	33
		13	33
		14	14
		15	33
		16	33
		17	33
		18	33
		19	90
	3	20	33
		21	33
		22	33
		23	14
		24	33
		25	33
		26	33
		27	33
	4	28	33
		29	33
		30	33
		31	12
		32	33
		33	33
		34	33
		35	33
P1 (provisional block)			394
TOTAL			**1537**

Table 2. Description of tables

Entity Name	Field Name	Descriptions
MY_Party	pID (PK)	ID of the party
	bauID (FK)	ID of the basic administrative unit
	name	Name of the party
	role	Role of the party
	type	Type of the party
MY_BAUnit	bauID (PK)	ID of the basic administrative unit
	suID (FK)	ID of the spatial unit
	name	Name of the basic administrative unit
	type	Type of the basic administrative unit
MY_RRR	rrrID (PK)	ID of the right, restriction and responsibility (RRR)
	bauID (FK)	ID of the basic administrative unit
	pID (FK)	ID of the party
	share	Number of the share units
	rightType	Type of right
	restrictionType	Type of restriction
	responsibilityType	Type of responsibility
	description	Description of the RRR
MY_SpatialUnit	suID (PK)	ID of the spatial unit
	bauID (FK)	ID of the basic administrative unit
	dimension	Dimension of the spatial unit
MY_LandParcel	lpID (PK)	ID of the land parcel
	bauID (FK)	ID of the basic administrative unit
	suID	ID of the spatial unit
	buID (FK)	ID of the building unit
	lotNo	Lot number of the land parcel
	mukim	Mukim of land parcel
	district	District of land parcel
	state	State of land parcel
	area	Area of the land parcel
	type	Type of the land parcel
	geometry	Geometry of the land parcel (2D)
MY_BuildingUnit	buID (PK)	ID of the building unit
	bauID (FK) suID	ID of the basic administrative unit ID of the spatial unit
	lpID (FK)	ID of the land parcel
	Type	Type of the building unit
	parcelNo	Total number of parcels in the building unit
	floorNo	Total number of floors in the building unit
MY_PACunit	pacID (PK)	ID of the parcel, accessories and common area unit.
	bauID (FK)	ID of the basic administrative unit
	suID	ID of the spatial unit
	buID	ID of the building unit
	Volume	Volume of the PAC unit
	Code	Code for PAC unit
	Type	Type of the PAC unit
	Floor	Floor number of the PAC unit
	Description	Description of the PAC unit
	Geometry	Geometry of the PAC unit (3D)

Table 3. Example of ID for each table

Class	ID
Party (pID)	127987-D
RRR (rrrID)	04010800015662(S)846(B)M1(M)1(T)1(P)1
Basic Administrative Unit (bauID)	040108PM00001420
Spatial Unit (suID)	04-42351
Land Parcel (lpID)	04010800015662
Building unit (buID); Building unit - main block (M) Building unit - provisional block (P)	 04010800015662(S)846(B)M1(M)1 04010800015662(S)846(B)P1
PACunit (pacID); Parcel unit Accessories unit Common area unit	 04010800015662(S)846(B)M1(M)1(T)1(P)1 04010800015662(S)846(B)M1(M)1(T)1(A)1 04010800015662(S)846(B)M1(M)1(T)1(C)1

4.2 Database construction

Database construction is based on Oracle spatial. Oracle spatial uses the MDSYS.SDO_GEOMETRY type (see Annex A for explanation). In the Malaysian country profile, no topology structure is used. In managing 2D and 3D spatial object, Oracle Spatial supports storage for 3D points, lines and polygons. In Table 2, MY_LandParcel represent 2D cadastral object (polygon, GTYPE=2003), and MY_PACunit represent 3D cadastral object (building unit). In MY_PACunit, the 3D cadastral objects are stored by multipolygon method (GTYPE=3007). Oracle spatial also has a solid type, which in theory is preferred above the multipolygon, but drawback is that not all tools are capable of handling the solid type, therefore the multipolygon was used instead. Figure 11 and Figure 12 shows how to store 2D and 3D cadastral data using Oracle Spatial.

```
INSERT INTO MY_LANDPARCEL VALUES (
'04010800015662',
'040108PM00001420',
'04-42351',
'04010800015662(S)846(B)M1(M)1',
'LOT 15662',
'BUKIT KATIL',
'MELAKA TENGAH',
'MELAKA',
'15243 METER PERSEGI',
'L03',
MDSYS.SDO_GEOMETRY(
2003,24571,NULL,
MDSYS.SDO_ELEM_INFO_ARRAY(1,1003,1),
MDSYS.SDO_ORDINATE_ARRAY (
23760.739732,12526.967747,23764.120124,12529.857883,23764.146353,12530.177957,
23763.122615,12531.371914,23763.166398,12531.942536,23765.33952,12533.79983,
23765.36406,12534.120404,23763.19715,12536.655672,23758.092262,12532.293218,
23757.968013,12530.714111,23760.739732,12526.967747)));
```

Figure 11. Insert 2D data using Oracle Spatial (note GTYPE 2003 stand for a 2D polygon)

```
INSERT INTO MY_PACUNIT VALUES (
'04010800015662(S)846(B)M1(M)1(T)1(P)1',
'040108PM00001420',
'04-42351',
'04010800015662(S)846(B)M1(M)1',
'803 METER PADU',
'P',
'CBU7',
'1',
'',
MDSYS.SDO_GEOMETRY(3007,24571,NULL,
MDSYS.SDO_ELEM_INFO_ARRAY(
1,1003,1,
16,1003,1,
31,1003,1,
46,1003,1,
61,1003,1,
76,1003,1),
MDSYS.SDO_ORDINATE_ARRAY(
23763.508701,12534.314343,0.193868,23763.508701,12534.314343,0,23763.238999,12534.084021,0,
23763.238999,12534.084021,0.193868,23763.508701,12534.314343,0.193868,23763.238999,12534.084021,0.193868,
23763.238999,12534.084021,0,23764.154808,12533.005249,0,23764.154808,12533.005249,0.193868,
23763.238999,12534.084021,0.193868,23764.42451,12533.235571,0.193868,23764.42451,12533.235571,0,
23764.154808,12533.005249,0,23764.154808,12533.005249,0.193868,23764.42451,12533.235571,0.193868,
23763.508701,12534.314343,0.193868,23763.508701,12534.314343,0,23764.42451,12533.235571,0,
23764.42451,12533.235571,0.193868,23763.508701,12534.314343,0.193868,23764.42451,12533.235571,0,
23763.508701,12534.314343,0,23763.238999,12534.084021,0,23764.154808,12533.005249,0,
23764.42451,12533.235571,0,23764.42451,12533.235571,0.193868,23763.508701,12534.314343,0.193868,
23763.238999,12534.084021,0.193868,23764.154808,12533.005249,0.193868,23764.42451,12533.235571,0.193868)));
```

Figure 12. Insert 3D data using Oracle Spatial (note GTYPE 3007 stand for a 3D multipolygon)

4.3 Query in Bentley Microstation

In Bentley Microstation, the query is conducted via the visual SQL Query Builder. Figure 13 shows the list of spatial attributes based on the selected table MY_LandParcel. The query for spatial table is conducted by selecting the attributes from this table. The output of the experiment can be seen in Figure 14 and Figure 15. The same method is also applied for querying 'Party' and 'RRR' tables. Figure 16 and Figure 17 shows the result of the query for 'Party' and 'RRR' tables.

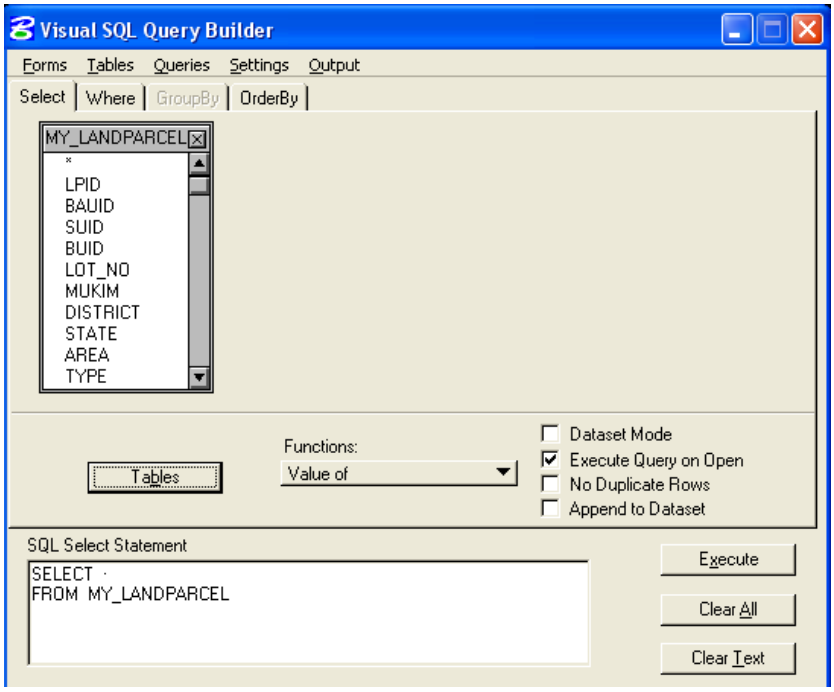

Figure 13. Visual SQL Query Builder with list of spatial attributes

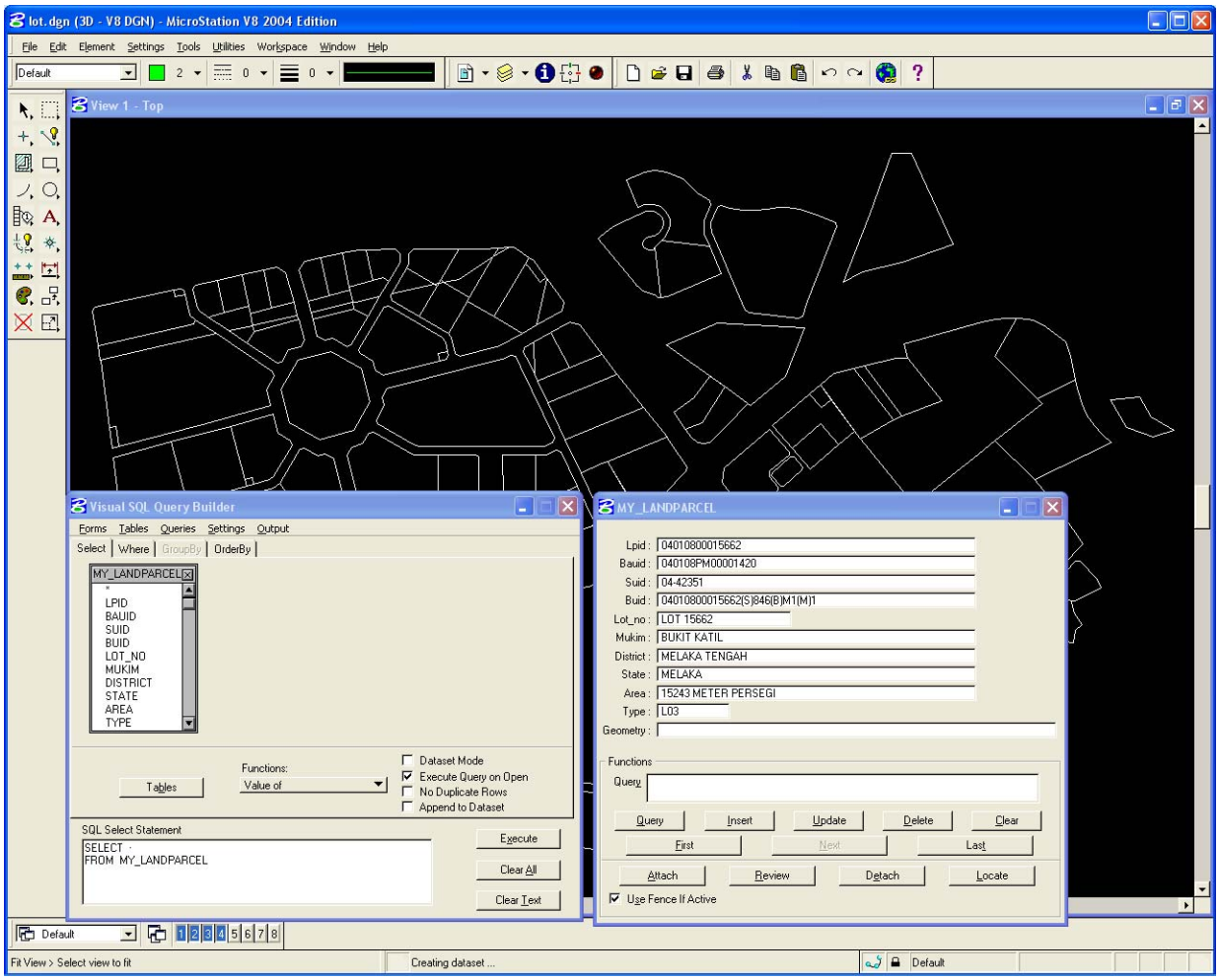

Figure 14. 2D data query and visualisation using Bentley Microstation

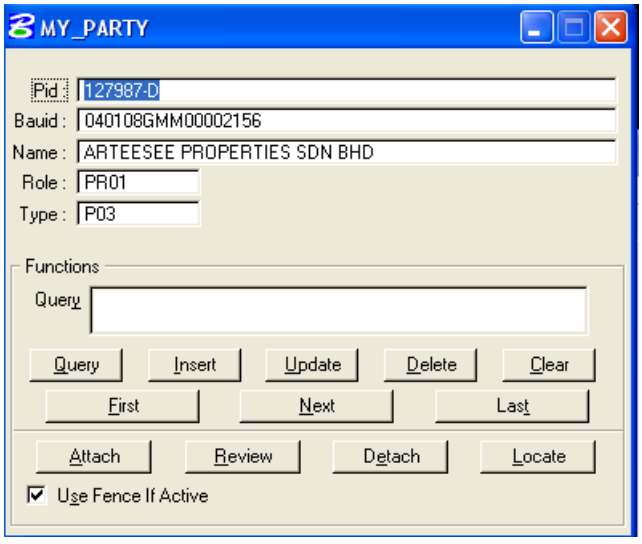

Figure 16. Data from query on 'Party' table

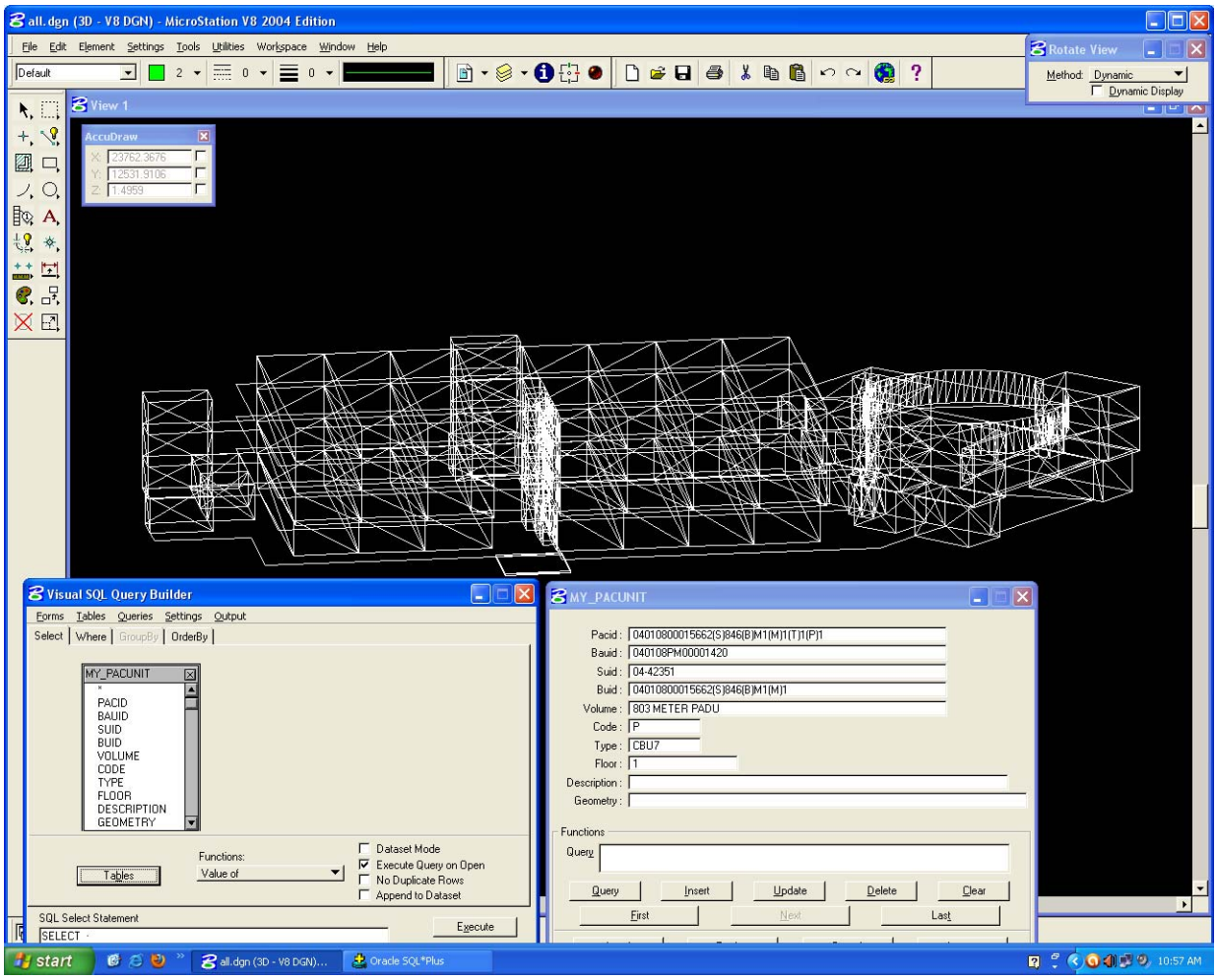

Figure 15 3D data query and visualisation using Bentley Microstation

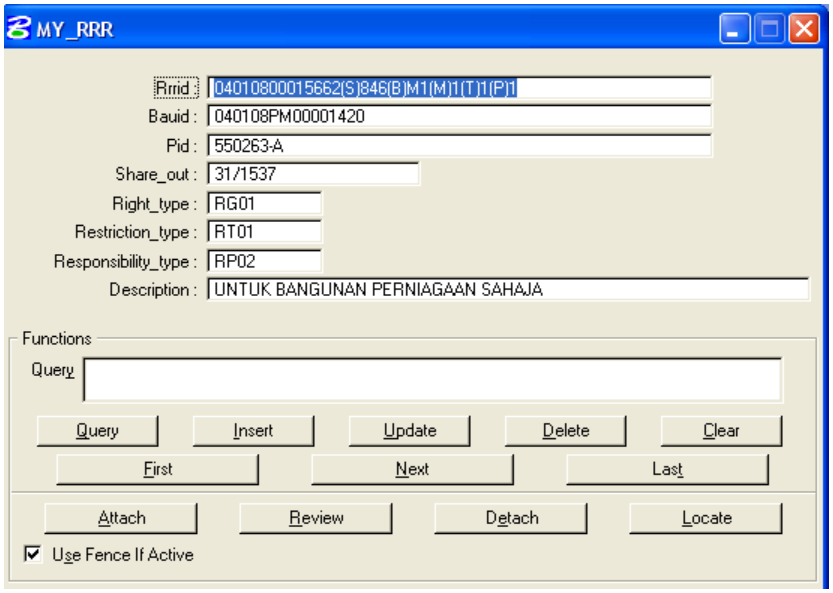

Figure 17. Data from query on 'RRR' table

5. CONCLUSIONS

This paper attempts to describe the utilization of the Land Administration Domain Model (LADM), in particular the Parties, the Rights, Restrictions and Responsibilities (RRRs) and the relationship with spatial data for 2D and 3D Cadastral environment. Recent works suggest that the utilization of LADM international standard for cadastral domain is very much relevant as mentioned by the following researchers; Lemmen (2012), Van Oosterom et al (2011), Pouliot (2011), Hespanha (2012), and Ary Sucaya (2009).

Refering to conceptual model that is proposed in this paper, LADM provides standardized class names for spatial and non-spatial data. For spatial data class, they have their own standard name called SpatialUnit. In this project, SpatialUnit is divided into two parts, which are Land Parcel (2D) and Building Unit (3D). Building Unit is also divided into three divisions, which are Parcel Unit, Accessories Unit and Common Area Unit. PACunit is a combination of Parcel Unit, Accessories Unit and Common Area Unit classes.

Query 2D spatial object in this project is based on MY_LandParcel table. Meanwhile, we use MY_PACunit to query the 3D spatial object. MY_Party and MY_RRR is used to query non-spatial data. Besides, UPI also is important to link between spatial and non-spatial data. It is also used to query data from spatial and non-spatial data. A new code lists for spatial and non-spatial data to improve the Malaysian standard are also proposed. We plan to continue this research and apply the proposed country profile (based on the LADM conceptual model) to various types of 2D and 3D cadastral situations which are relevant to registration and mapping agencies in Malaysia.

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ANNEX A. ORACLE SDO_GEOMETRY

MDSYS.SDO_GEOMETRY type to store spatial data which is defined as (information from the Oracle spatial manual):

```
CREATE TYPE sdo_geometry AS OBJECT (
   SDO_GTYPE NUMBER,
   SDO_SRID NUMBER,
   SDO_POINT SDO_POINT_TYPE,
   SDO_ELEM_INFO MDSYS.SDO_ELEM_INFO_ARRAY,
   SDO_ORDINATES MDSYS.SDO_ORDINATE_ARRAY);
```

SDO_GTYPE is a number that defines the overall shape. It describes the end result of the ordered combination of elements. SDO_GTYPE is a four-digit integer. The first digit represents the number of dimensions. The second digit represents the linear representation, which is important for a three or four-dimensional shape. In a two-dimensional shape the value is zero. The last two digits represent the shape. SDO_SRID number describes the coordinate system to use. This field is used to guarantee that all geometries within the table

column use the same coordinate system. It also defaults to Cartesian coordinate system if set to null. Spatial also allows for the definition of a single point within a geometry. This point could be used for label placement, measurement determinations, and so on. If a two-dimensional geometry is used, z may be left null. The entire SDO_POINT value may be set to null.

SDO_ELEM_INFO_ARRAY describes the multiple elements within the SDO_ORDINATES_ARRAY. An SDO_ELEM_INFO ARRAY is understood as three values at a time. Each set of three values describes an element of the geometry. SDO_ORDINATES_ARRAY is a list of all the vertices that define the geometry. The SDO_ORDINATES_ARRAY values are read in pairs, with the first value being x and the second value being y. If there are a three-dimensional geometry, the values would be read in triplets, with the last value being z.

BIOGRAPHICAL NOTES

Nur Amalina Zulkifli is a researcher at the Department of Geoinformation, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia (UTM), Skudai, Johor in Malaysia. She received a degree in Surveying Science and Geomatics from Universiti Teknologi MARA (UITM) in 2008. She is currently working on her MSc research concerning Land Administration Domain Model (LADM) for 2D and 3D cadastral registration.

Alias Abdul Rahman is a Professor at the Department of Geoinformation, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia (UTM), Skudai, Johor in Malaysia. He received a degree in Surveying and Mapping Sciences from North East London Polytechnic, England, UK in 1987, Postgrad Diploma in GIS from ITC, Netherlands, and MSc in GIS also from ITC, Netherlands. In 2000 he received his PhD degree from University of Glasgow, Scotland, U.K. Currently he serves as Chair for ISPRS Commission II/5 from 2008 2012 on Multidimensional GIS and Mobile Data Model.

Peter van Oosterom obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, The Netherlands. In 1990 he received a PhD from Leiden University for this thesis ‘Reactive Data Structures for GIS’. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague, The Netherlands as a computer scientist. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, where he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology (OTB institute) and head of the section ‘GIS Technology’. He is the current chair of the FIG joint commission 3 and 7 working group on ‘3D-Cadastres’ (2010-2014).

CONTACTS

Nur Amalina Zulkifli
Universiti Teknologi Malaysia
3D GIS Research Lab
Faculty of Geoinformation and Real Estate
81310 UTM Skudai
Johor
MALAYSIA
Phone: +6030794755
E-mail: namalina69@live.utm.my

Alias Abdul Rahman
Universiti Teknologi Malaysia
3D GIS Research Lab
Faculty of Geoinformation and Real Estate
81310 UTM Skudai
Johor
MALAYSIA
Phone: +6030794755
E-mail: alias@utm.my

Peter van Oosterom
Delft University of Technology
Faculty of Architecture and the Built Environment
Department OTB, GIS-technology Section
P.O. Box 5030
2600 GA Delft
THE NETHERLANDS
Tel. +31 15 2786950
E-mail: P.J.M.vanOosterom@tudelft.nl
Website: http://www.gdmc.nl