# A UNIFIED 3D CADASTRE DATA MODEL – A GEOMETRIC APPROACH

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## Abstract

Urbanisation creates immense competition for space due to rural-urban migration. Hence, urban or city authorities need to plan, expand and use such three dimensional (3D) space above, on and below the city space. Thus difficulties in property ownership and the geometric representation of the 3D city space is a major challenge.This research, will investigate the concept of representing a geometric topological 3D spatial model capable of representing 3D volume parcels for man-made constructions above and below the 3D surface volume parcel. The 3D TIN model is adopted. The concepts, logical and physical models of 3D TIN for 3D volumes is presented and implemented to show man-made constructions above and below the surface parcel within a user friendly graphical user interface. The 3D TIN data model is significant and can be adopted as the unified model for 3D cadastre. Countries interested in adopting 3D cadastre can also adopt this data model for the LA_Spatial part of the Land Administration Domain Model (LADM) (ISO/TC211, 2012).

**Keywords: 3D Space, 3D TIN, 3D cadastre, volume parcels**

## INTRODUCTION

The world's population is about 6.572 billion, out of which the United Nations data indicated that about 3 billion people (46%) live in urban areas (UNCHS, 2007). Whereas about 66% of the entire world's population lived in the countryside in the early 1950s (World Bank, 2000), current estimates show that by 2030, about 61% of the total population in the world will be living in cities or urban areas. Continents like Europe and the Americas have stabilised their population growth and economy to a large extent and has determined the dynamic population of their city centres, hence space in such cities can be found above, on and below the city earth space. Urbanisation is characterised by the concentration of humans within an area of limited space attracted by the unique socio-economic activities and land marks that give cities its uniqueness (Masek *et. al.*, 2000). This urban space creates a unique and complex land ownership schema for most city centres, which is a challenge to most property owners and professionals at the same time.

3D spatial modelling is an abstract representation of reality using mathematically proven relationships defined as points, lines, polygon and solids to represent man-made and natural features above, on and below the surface of the Earth. 3D topology is the inter-relationships existing between these objects to enable visualization, query and analysis. 3D modelling of subsurface objects and their integration with the surface and above surface objects currently lacks behind despite efforts of researchers and the attempt at viewing above surface and subsurface man-made objects is still a challenge. The spatial model will represent 3D objects using the geometric primitives to build the model which can be represented in the form of cubes or solids from a wireframe, this is always not useful as the Level of realism for such a model becomes very low and hence recognition can be carried out only by experts, hence the Level of Detail (LoD) is introduced to make 3D objects achieve realism. Level of Details (LoD) for spatial objects has been extensively studied however these have not been extended to man-made features below the surface. LoD0 maps for surface and subsurface integration exist for most city centres but the 3D cadastre component is lacking in most city centres. Most current cadastral models are two dimensional (2D), for a modern city, complexities associated with land parcels such as space above or space below at specific heights belongs to specific individuals or groups, hence in 2D, the same piece of land can belong to multiple individuals with different interests. Examples of such structures can be condominiums, high rise buildings, complex buildings, shopping malls, train or pedestrian subways, parking lots and utility networks. One of the major problems in 2D is the situation of overlapping rights where there could be a building over a road with a tunnel underneath the road, this possesses a lot of challenges such as ownership and rights associated with such a complex situation (see Figure1). 2D land parcels cannot represent most of the rights associated with land. The above problems can be minimised if 3D spatial modelling techniques are adopted to distinguish between the various land parcel descriptions as they are all related to XY coordinates but with different heights to show the above 3D volume parcels, on volume parcels and below volume parcels. Section 2 introduces some current spatial models that can be applied to 3D cadastre.

**Fig. 1.** Complex cadastre (Hassan et al., 2010)

## REVIEW OF SPATIAL DATA MODELS

Spatial data models for surface and subsurface models have been studied by many researchers (Abdul Rahman and Pilouk, 2008; Wang, 2006; Breunig and Zlatanova, 2006 and Zhou *et al*, 2008). Principle in their research was enhanced forms of 3D Formal Data Structure (3D FDS) for 3D objects using 3D spatial data for both the surface and the subsurface. Molenaar (1990) proposed the 3D FDS for 2D GIS and this concept has been enhanced and made applicable by researchers for 3D Geographic Information Systems (3D GIS). This model has the point, line, surface and body as the entity object (see Figure 5). An enhanced data model of the 3D FDS has been studied by researchers such as the 3D Triangular Irregular Network (3D TIN) by Abdul Rahman (2000), Simplified Spatial Model (SSM) by Zlatanova (2000), Object Oriented Data Model (OODM) by Koshak and Flemming (2002), Object Oriented 3D (OO3D) by Shi *et al*, (2003), Urban Data Model (UDM) by Coors (2003) and the Object Oriented 3D Integrated Spatial Data Model (OO3D-ISDM) by Wang (2006). The current integrations for surface and subsurface involve 3D objects above or on the surface with geology at the subsurface. Most of the previously discussed models can be used for the 2D case because the geometric primitives in this case are the node, line and face which are the basic primitives for 2D. Most of these models have not been applied for 3D cadastre as the current prototypes are using the formation of polygons, first for the 2D cadastre, then extruding the footprints to create the 3D situation. The integration of 3D volume parcels with city modelling is also a challenge as this will enable developers interested in city developments view the cadastre situation of most cities.

The Open Geospatial Consortium (OGC) recommends the Boundary representation (B-rep) for the development of city models (OGC, 2012), the B-rep approach can also be used to create most of the models in CityGML (City Geography Markup Language). 3D city models such as the City Geography Markup Language (CityGML) and the Keyhole Markup Language (KML) are being used and have been accepted as a standard for the exchange of 3D information (Ross et. al., 2009). According to Kolbe (2009) CityGML is to provide a city model, which can be applicable to many disciplines such as urban planning, disaster management, rescue operations, floods, noise mapping, cadastre, and facility management, the introduction of Application Domain Extensions (ADE) will help to achieve more of the application areas. Projects such as Cityserver3D, Geoserver, RedSpider, GeoOxygene, Deegree. Oracle spatial and many others implement the Open Geospatial Consortium (OGC) and the International Organisation for Standardisation (ISO).

An enhanced 3D TIN geometric cadastral model is proposed to show locations for 3D objects above and below the city earth surface; for the unified model, this seeks to combine 3D TIN with the solid being formed by tetrahedrons. This presents topology as a solid, composed of tetrahedrons, surface composed of triangles, a line is composed of arcs and points are also nodes to create 3D volumes. Above surface objects include buildings and city furniture which could be made up of trees, lamp posts etc, on surface objects are composed of the terrain model, land use and land lots or parcels. Objects below the surface will constitute geology and man-made objects such as parking areas, storage facilities, tunnels, rail lines, basements etc. Buildings are 3D objects above the surface, humans and other living things use above surface objects as places of abode, work, storage, car parks and for other activities. This section proposes the 3D TIN as a model that can be relied on to represent the spatial data model for 3D cadastre and other applications in relation to the city environment. Section 3 will introduce 3D cadastre and current cadastre models.

## 3D CADASTRE

At the centre of any land administration (LA) system is the cadastre which exhibits or shows the record of all interests associated with land, this is described as the rights, restrictions and responsibilities (RRRs) associated with the land. The cadastre usually will include the geometric dimensions of the parcel, the interest, ownership and value among other attributes of the land. It is said nobody has absolute ownership of land but rather own rights to the land according to or in relation to local laws, practices and encumbrances. Land in this context refers to the Earth surface which consists of the physical land and all water bodies (i.e. ocean, sea, river, lake, etc).

Some countries have already set up a multipurpose cadastre (MPC) for their various jurisdictions, most of these cadastres are currently in 2D, a hybrid 2D/3D cadastre has been proposed by Stoter (2004), whilst some countries are aiming towards the full implementation of the 3D cadastre. The data model for 2D cadastre is polygonal in shape, this consists of nodes, edges and the surface (land), the data is usually in vector format with spatial information such as the xy coordinates, distances and bearings between the nodes, or or the survey beacon. The 3D data model is obtained by the inclusion of depth (z) to the 2D data model. A volume space will consist of a set of faces which enclose a 3D space representingthe 2D land surface as a 3D volume parcel (Stoter, 2004; Abdul Rahman et al, 2011, 2012; Lemmen, 2012) A few examples of MPC in other countries will be highlighted in this section.

In the Netherlands, parcel ownership is 2D with property rights and 3D boundaries. Parcel ownership can be related to space above and below the parcel surface with descriptions such as high above or as low below. Ownership rights relates to apartments with homogeneous units, superficies rights regarding the construction type and leasehold type, easement rights relating to line of sight, access to air space or column and right of way in relation to utilities such as cables snd pipelines (Lemmen 2012). Research into 3D cadastre is being led by van Oosterom, Lemmen and Uitermark which has culminated in the Land Adminstration Domain Model (LADM) proposed by the International Federation of Surveyors (FIG) and accepted as an ISO standard on the 1st November 2012 (FIG, 2012).

The Swedish MPC dates as far back as 1628 with the establishment of the National Land Survey and became a fully automated system in 1976 (Ericsson, 1995). This consists of the property register, land register and a register of buildings. The property register consists of all physical measurements of the land parcel including coordinates, area, designation, street address, easements and zoning regulations. The land register deals with all the legal information about the land parcel such as parcel owner, address, registration number, mortgages, encumbrances, notifications, bankruptcy and restoration orders among others. The register of buildings consists of all building structures on the parcel including current state of buildings, use and value of building, building permit and regulations, land use, environmental considerations among others. The Swedish multipurpose cadastre covers the whole country and is guaranteed by the Swedish government with avenues for compensation should a parcel owner suffer losses (Ericsson, 1995). According to Ericsson (2008), the Swedish land surveyor has the total responsibility for the activities outlined in the Swedish cadastre and is given the mandate to take legal, economic and technical decisions concerning land parcels in consultation with municipal, county and other land related agencies such as the road agency, acting in accordance to the land policies, regulations and laws of the country. This cadastre is 2D.

The Danish multipurpose cadastre has been in place since 1986 and full automation was achieved by 1997 with a web map service (WMS) in place by 2003 (Jorgen, 2004). This included the use of GIS and web applications for accessibility for a wide range of applications. Jorgen (2004) enumerated some of the challenges as being legal, organizational and technological.

Italy operates the Catasto-cumini managed by the Ministry of Finance's Department of Territory. This uses GIS with aerial photographs and satellite imagery in the compilation of land parcels (ESRI, 2005).

The Valuation and Lands Agency (VLA) in Belfast, Northern Ireland uses GIS for the domestic revaluation of more than 700,000 parcels. The computer assisted mass appraisal (CAMA) system is built using ArcGIS and is being implemented by NovaLIS technologies, along with other partners including ESRI (UK) Ltd. This system is primarily used for the collection of taxes (ESRI, 2005).

Ghana implemented the MPC in the form of a Land Title Registration (LTR) which was to replace the deeds registry which was flawed due to multiple sales of a particular land parcel, Ako-Adjei et. al., (2010) reiterated that the processes governing land acquisition must be transparent and open to all stakeholders. This requires the use of digital equipment in the collection of data about all land parcels and the certification of plans by a registered licensed surveyor and a regional representative of the Director General of the Survey of Ghana. The legal framework being carried out by the Lands Commission of Ghana. The New Lands Commission has been inaugurated since 2009 and this has brought all agencies dealing with land to provide a one-stop service in the issuance of the Land title certificate. This project is a pilot project and at the moment is covering some southern cities of Ghana such as Accra and Kumasi. AutoCAD and Microsoft Excel database is currently being used to implement this, it is hoped that GIS software will be adopted to augment this process in the near future. Current problems include, inadequate archival process, footprints not being included in the cadastral plan for most areas and the process not fully automated. The LTR is being used for taxation and financial transactions.

### Marine Cadastre

The current principle on cadastre is geared towards addressing land and extents to the High Water Marks (HWM) for countries sharing boundaries with water bodies such as the ocean. The marine environment introduces complexities that are not inherent in land based spatial data. The marine space involves rights and responsibilities that are time based. However, often land is being introduced as being in relation to the earth surface which includes the land and sea surface, however, an integrated administrative structure will have to be promulgated to administer and exhaust all the range of rights, restrictions and responsibilities for the land and marine environments. Hence a marine cadastre system can then record all the complexities associated with the determination of the spatial extents, rights, interests, property rights, restrictions and responsibilities within the marine jurisdiction.

Marine cadastre is currently new in Malaysia despite the fact that it is a maritime country. The marine environment in Malaysia consists of activities such as sea navigation, fishing, tourism, oil and gas. The complexities of this environment are yet to be realised in Malaysia. The United Nations Convention of the Law of the Sea (UNCLOS) (UN, 1983) has established various jurisdictions, under which a country can administer, manage and utilize its maritime environment. Malaysia, in conformity with UNCLOS has also enumerated some acts to further enhance its territorial boundaries such as the 1969 ordinance under Article 150(2), No 7 among others stated that the territorial waters of Malaysia (except in the Straits of Malacca, the Sulu Sea and the Celebes Sea) were declared as 12 nautical miles from the base line determined in accordance with UNCLOS. The Continental Shelf Act of 1996 (Act 83) declared the territorial waters and continental shelf limits, the Fisheries Act, Marine Parks Malaysia Order of 1994 was aimed at protecting the Marine Park. Nichols et. al., (2000) described the various rights for the marine cadastre as, Public access, navigation, Fishing, Airspace, Seabed Use, Development, Mineral, Water Column and Riparian (see Figure 2).

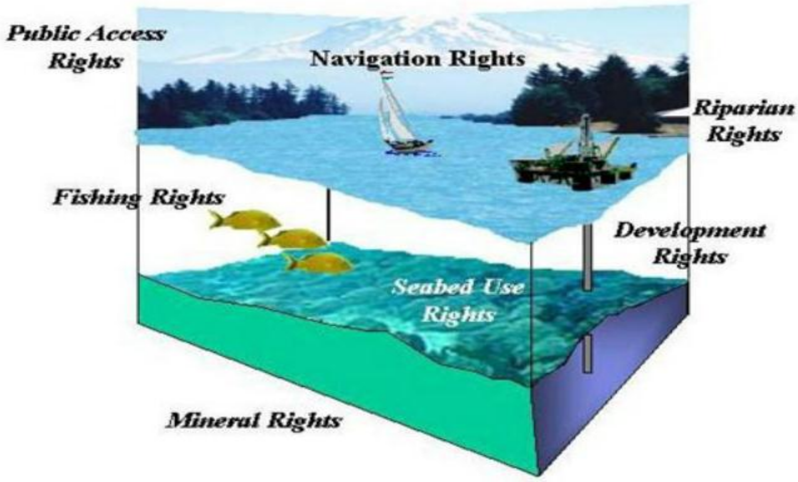


**Fig. 2.** Rights for Marine cadastre (Nichols et al., 2000)

The rights for marine cadastre are overlapping in nature which makes the demarcation of marine parcels a complex issue, the management, exploration and exploitation of marine resources are usually for the benefit of the country and stakeholders up to its Exclusive Economic Zone (EEZ). Hence, most countries adopt similar acts to determine its marine extents and the demarcation of marine 3D volume parcels still a challenge.

### Underground utility

3D underground utility themes have been identified as one of the important layers that requires to be integrated in a cadastre database (Abdul Rahman et al., 2011). A central utility database will enhance knowledge about underground utilities (Chong 2006, He et al., 2002, Penninga and Oosterom 2006). Such a database will create knowledge about the location and exact utility rights that need to be promulgated, this will serve as a basis for the city authority to establish exact locations for the various utility networks in a city. Three main problems have been identified by Abdul Rahman et. al., (2011):

- Cadastre databases not integrated with underground databases and other databases such as taxation, insurance etc.
- Available software (eg. GIS, CAD, AM/FM)) are currently in 2D.
- Visualization of utility networks difficult to display in 2D maps, due to inadequate information on height (Z).

Currently underground utility networks are developed in 2D thereby creating several difficulties in terms of height, type, width and colour on a 2D plan. 2D plans are inaccurate in terms of location due to some cartographic challenges and other overlay difficulties on a 2D plan. Hence the 2D plans cannot indicate real world events, the 3D situation can represent real world and a more accurate location when it comes to underground utility. Thus, underground pipeline can be handled in a more efficient way in a 3D environment. But the problem to handle pipelines in 3D is unsupported or lacks geometry type in a spatial database. Spatial database offers several basic 3D geometry types but not all 3D geometries are available, volumetric shapes and complex objects are difficult to achieve. Figure 3 shows underground 3D pipelines within a city model environment. More efforts are required to fully integrate underground utility networks into the Malaysian MPC.

**Fig. 3.** 3D surface and subsurface objects with utility network (Abdul Rahman et al., 2012)

In Malaysia, the Department of Survey and Mapping, Malaysia (DSMM) has the ultimate responsibility of maintaining the database of all underground utility data in Malaysia (Abdul Rahman *et. al*., 2011). To ensure this, a National Underground Utility Database has been created, research, in collaboration with the Universiti Teknologi Malaysia (UTM) is on going, and the integration of the underground utility networks with current 3D city models are being explored, initial results is shown in Figure 3.

### Cadastral data models

Current cadastre data models are 2D, this consists of the landowner (InterestHolder), Rights, Restrictions and Responsibilities (RRRs) and land (Figure 4). The landowner is any individual, organisation or group with an interest and rights over a specific extent of land within a planning scheme in a district, within a region in a country (Oosterom et al., 2006; Aien et al., 2011).

**Fig. 4.** 2D cadastral model

Land parcels are displayed as polygons, the concept of 3D volumes (Abdul Rahman *et al*., 2011) has been suggested. 3D volume parcels with a standard height (e.g. 2 – 5 m) can be adopted to describe a 3D volume, the adoption of a standardised height for all 3D parcels will introduce some uniformity when it comes to the description of 3D parcels. The problem with the standard height will be the height for complex and high rise buildings, this, introduces complexities which requires attention. Currently, most 3D cadastre models are using the hybrid approach and most researchers support this concept, the land parcel is 2D, then with the footprints within the 2D land parcel being extruded to create the 3D model of say a building or man-made construction on the parcel. The idea of a fully integrated 3D cadastre model should deal with 3D volumes for all objects found on, above and below the city surface. The current Spatial Unit which has been defined to support the 3D concept, has the parcel as 2D and the buildings and Utility Network are in 3D. The Rights inherent in a 2D parcel are clearer when stated or established, in the case of 3D the Rights (RRRs) inherent are complex, multidimensional and can best be established in 3D (see Figure 5).

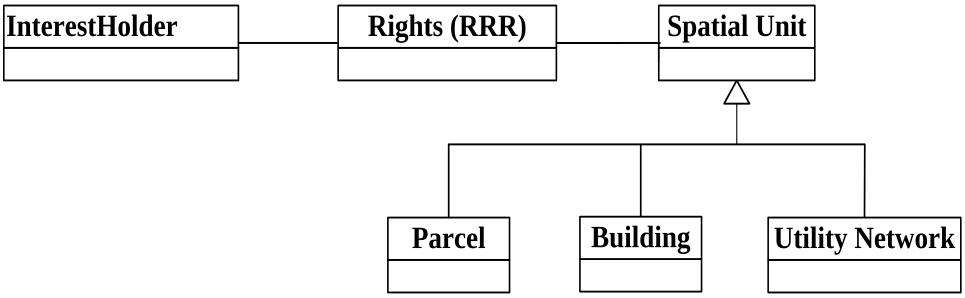


**Fig. 5.** Spatial package in current cadastral data models (ISO/DIS, 2011)

3D objects such as buildings will also have to be visualised at different level of details to provide pertinent answers to some functionality to the LADM. Some expectations of the 3D cadastre is to visualise the RRR's, determine their storage and management of such data in a database management system. The prototype for 3D cadastre attempts to solve some of the challenges enumerated. Section 4 will discuss the concepts for a Unified Cadastre data Model (UCDM) and present experimental results for the 3D volume parcel.

## A UNIFIED CADASTRE MODEL

3D modelling involves the usage of 2D maps or digital orthophotos displaying cadastre parcels. Footprints of buildings or other features within a specific parcel are then either extruded or using implicit geometry (OGC, 2012) to create the appropriate wireframe from which the facades of such buildings can be created and textured to give such buildings a level of realism. In this research the 3D TIN is used to generate the basic cube using the tetrahedron which can be used to represent volume parcels for buildings or any other features on a parcel of land. The LADM is a concept which consists of the Party Package, Administrtaive package and the Spatial Unit package which includes the surveying and representation subpackage. For the purpose of this research, the concern is the Spatial Unit Package with emphasis on the representation subpackage. The Surveying package has been well covered by Lemmen and Oosterom (2011). The LA_SpatialUnit has spatial properties such as LA_AreaValue, LA_DimensionType, referencepoint and LA_VolumeValue for geometric properties. LA_LegalSpaceNetwork and LA_LegalSpaceBuilding unit are in association to LA_SpatialUnit by legal connotations. Other feature types such as LA_level, LA_RequiredRelationshipSpatialUnit and LA_SpatialUnitgroup established relationships such as height (Level), topology and database criteria for the LA_SpatialUnit. The UML concept for the creation of a prototype Unified Cadastre Data Model (UCDM) with geometric qualities within the LA-SpatialUnit of the LADM (ISO/TC211, 2012**)** is presented (Figure 6). The LA_Non Spatial is related to the land administration part of the LADM which covers LA_Party, LA_RRR and LA_BAUnit are not the focus of this paper.

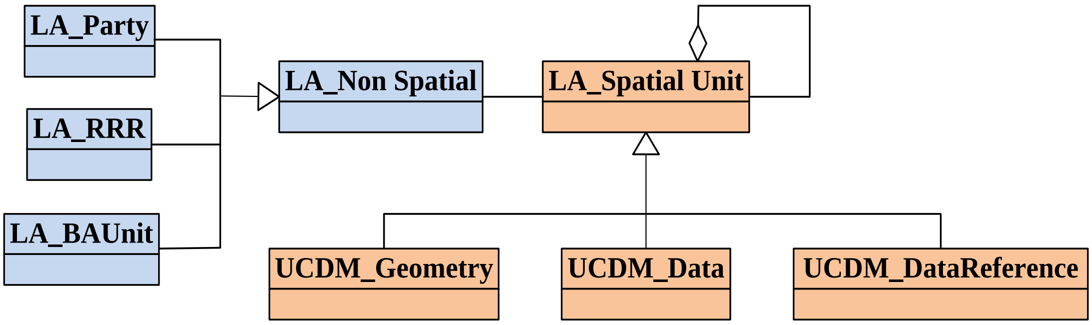


**Fig. 6.** Unified Cadastre Data Model (UCDM)

The UCDM_Geometry is the geometric model adopted for this research which uses the 3D TIN using the concept for volume parcels. UCDM_Data relates to the ways by which data was collected, techniques and other information required to obtain 3D volumes for the unified object, this is adopted from the surveying package. Currently 3D data for feature objects are not readily obtained and other data has to be referenced such as Computer Aided Design (CAD), Building Information Models (BIM) and Light Detection and Ranging (LIDAR) data may be referenced to complement previously collected data. This is a generic model which is representative of the situation in most city centres for 3D cadastre. The parcel identification (ID) for the on surface is linked to parcel ID's for the strata and stratum for the 3D cadastre. The above surface object identifies buildings, complex buildings such as mosques and city landmarks, city furniture and utility networks (Figure 7). Figure 8 shows the association of the above, on and below volume parcels with LA_SpatialUnit. Below surface classes considers man- made constructions, utility, rock type and geology for the subsurface (Figure 9).

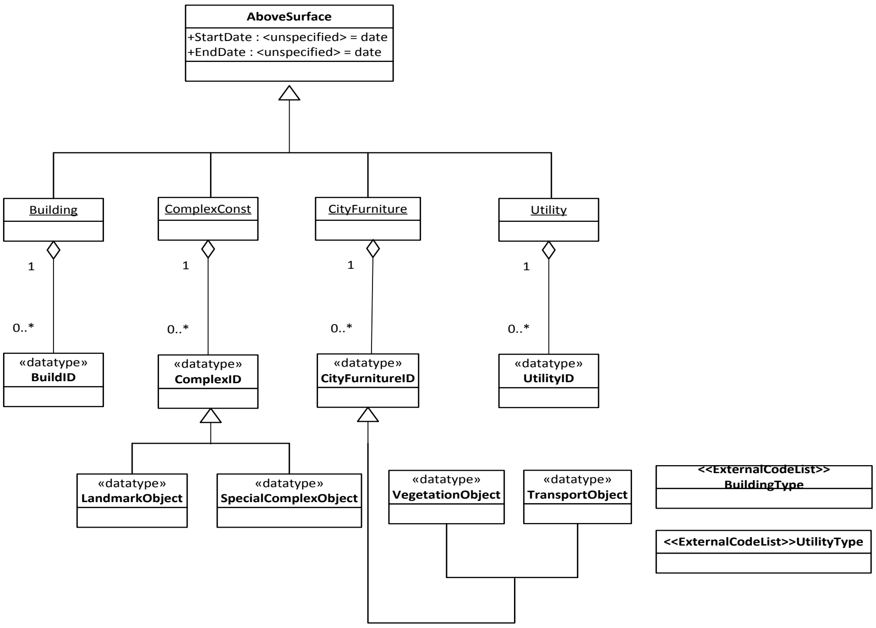


**Fig. 7.** AboveSurface features and datatypes

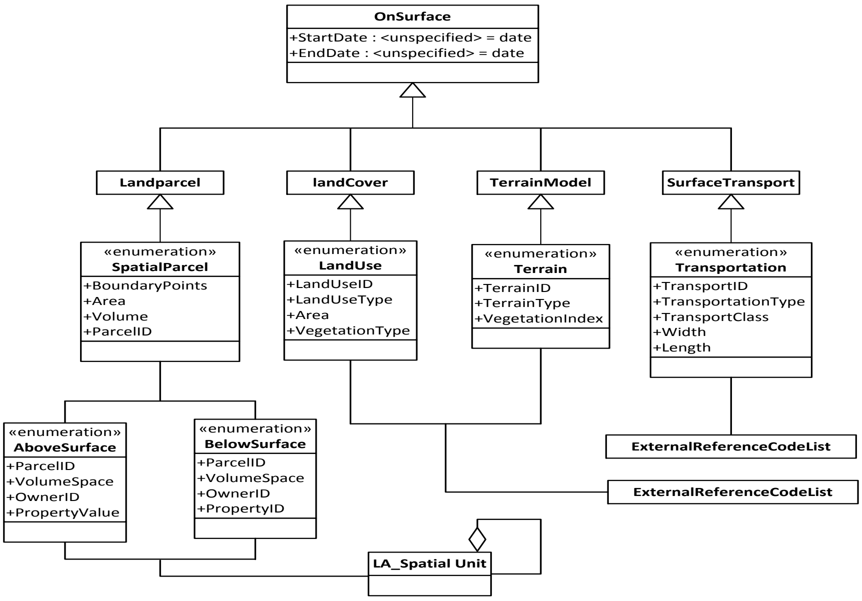


**Fig. 8.** OnSurface classes and data enumerations

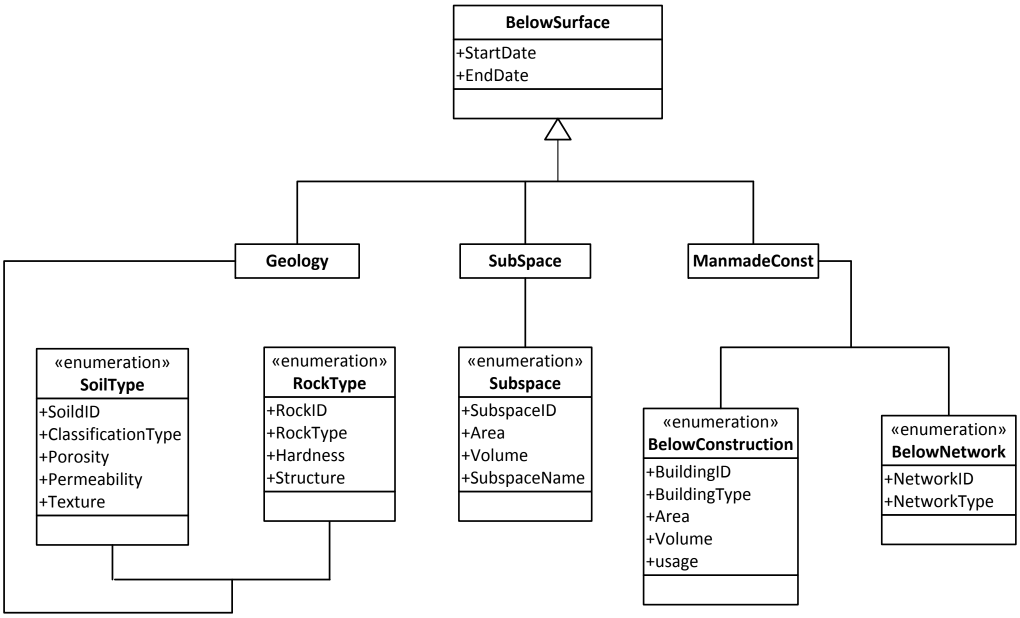


**Fig. 9.** BelowSurface classes and data enumerations

The identification and naming of such unique parcels for Malaysia has been discussed by Hassan and Abdul Rahman (2010). The Land Parcel Identification System (LPIS) standard will have to be adhered to introduce consistency in parcel identification in any country.

## Implementations

According to Lemmen (2012), 3D geometry volume can be defined by a minimum of 4 non-planar SurveyPoints to form a tetrahedron to form the simplest 3D volume object. The advantage of this is the condition of no gaps or overlaps in the partition, hence, 3D or 3D topological relationships are valid. The concept for using 3D TIN in the representation of volume parcels in 3D for land parcels for the 3D cadastre is also represented in Figure 10. The concept uses implicit geometry as defined by CityGML (OGC, 2012) to illustrate the concept, however explicit geometry can also be employed. The Tetrahedral mesh is derived using the 3D piecewise linear complex (Si, 2008) within a graphical user interface. Appropriate simulated attribute information is incorporated to query the system.

The 3D TIN with geometric primitives, node, line, triangle and tetrahedrons are used in this research, connections between the nodes and tetrahedrons are established topologically. The centre of mass of a tetrahedron can be determined on the following basis: if a physical object has uniform density, then its centre of mass is the same as the centroid of the body, a solid object such as the tetrahedron has a uniform density. Then for a n-dimensional simplex, if a set of vertices of a simplex is $V_o$, $V_1$……$V_n$ then the centre of mass (centroid) is given by Equation 1.

$$C = \frac{1}{n+1}\sum_{i=o}^{n} Vi \qquad (1)$$

Where I = 0, 1, 2,……n. For a tetrahedron n=3.

To ensure an optimal quality for the tetrahedrons, two tests were performed: the normalisation factor and the radius-edge ratio quality measure. The quality (Q) of a tetrahedron is given by Equations 2 (Du and Wang, 2003) and 3 (Si, 2008).

$$Q = \alpha \frac{\rho}{\ell_{\max}} \qquad (2)$$

Where $\alpha = 2\sqrt{6}$ is the normalisation factor, $\rho$ is the radius of the circumscribed sphere and $\ell_{max}$ the length of the longest edge.

$$Q = \frac{R}{L} \tag{3}$$

Where R is the radius of the circumscribed sphere and L is the length of the shortest edge.

The methodology for this research is as shown in Figure 10. Microsoft visual c++ version 2008 programming software was used in conjunction with OpenGL and Qt libraries was used to create a prototype for the unified model. Implicit data using the Boundary representation (b-rep) was used to create a tetrahedral wireframe, which is then degenerated to form the basic volume, within a graphical user interface (GUI) capable of displaying the data structure and the attributes. The integrity of the tetrahedrons formed are checked using a quality check, the volume and centre of mass of the basic volume spaces determined

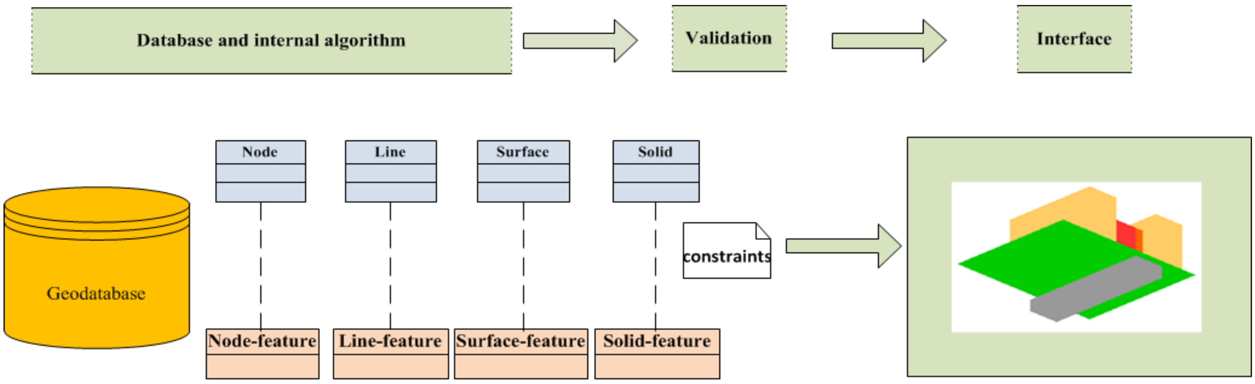


**Fig. 10.** Methodology

The solid form of the 3D TIN is employed to form a wireframe, from which any solid figure such as a flat or 3D volume space can be determined and the centre of mass determined for internal navigation purposes (Figure 11).

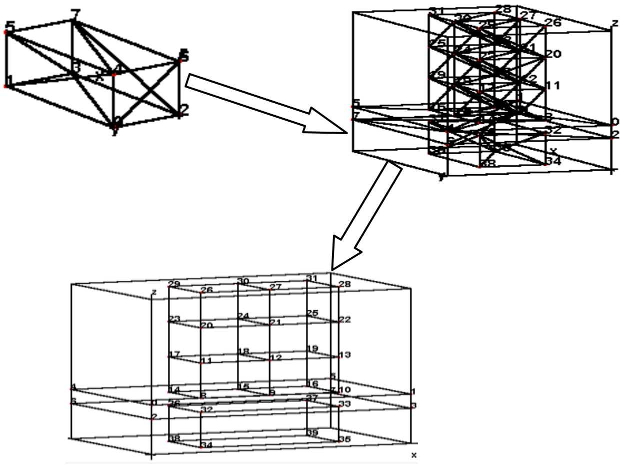
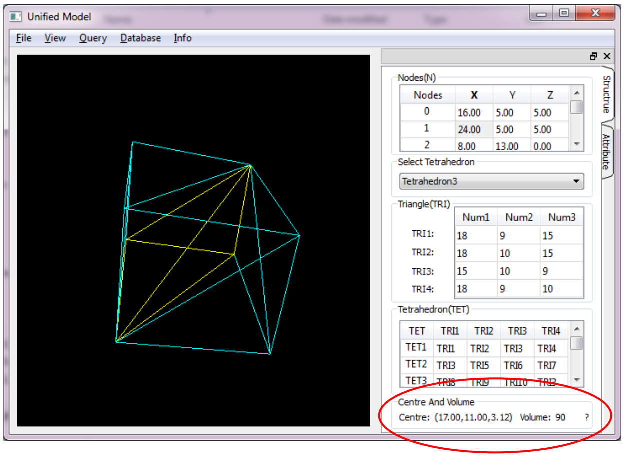


**Fig. 11.** 3D TIN for unified volume parcels

The six tetrahedrons used to form a basic cube and the database within the GUI is displayed in Figure 12.

The interface then uses the data to compute the centre of mass (C) and volume is also computed.



Nodes(N)

| Nodes | X | Y | Z |
|---|---|---|---|
| 0 | 16.00 | 5.00 | 5.00 |
| 1 | 24.00 | 5.00 | 5.00 |
| 2 | 8.00 | 13.00 | 0.00 |

Select Tetrahedron: Tetrahedron3

Triangle(TRI)

| | Num1 | Num2 | Num3 |
|---|---|---|---|
| TRI1: | 18 | 9 | 15 |
| TRI2: | 18 | 10 | 15 |
| TRI3: | 15 | 10 | 9 |
| TRI4: | 18 | 9 | 10 |

Tetrahedron(TET)

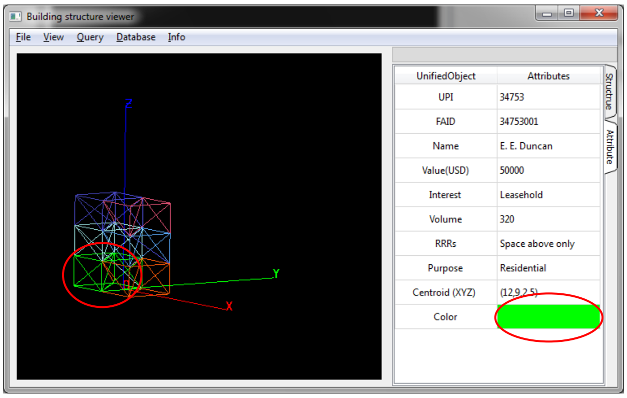
| TET | TRI1 | TRI2 | TRI3 | TRI4 |
|---|---|---|---|---|
| TET1 | TRI1 | TRI2 | TRI3 | TRI4 |
| TET2 | TRI3 | TRI5 | TRI6 | TRI7 |
| TET3 | TRI8 | TRI9 | TRI10 | TRI3 |

Centre And Volume

Centre: (17.00,11.00,3.12) Volume: 90 ?

**Fig. 12.** Cube created from the tetrahedrons

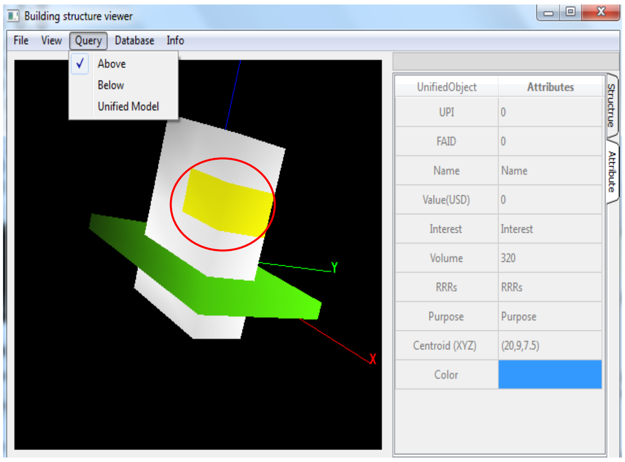
Figure 13 shows a typical wireframe of the above surface object with some attribute information about the queried part (shown green).



| UnifiedObject | Attributes |
|---|---|
| UPI | 34753 |
| FAID | 34753001 |
| Name | E. E. Duncan |
| Value(USD) | 50000 |
| Interest | Leasehold |
| Volume | 320 |
| RRRs | Space above only |
| Purpose | Residential |
| Centroid (XYZ) | (12,9,2.5) |
| Color | 🟩 |

**Fig. 13.** The wireframe is queried with attribute information

Figure 14 shows the unified object, which in this case is a 3D volume parcel with above, on and below 3D objects in LoD 1.Specific apartment blocks can be queried (marked yellow)



| UnifiedObject | Attributes |
|---|---|
| UPI | 0 |
| FAID | 0 |
| Name | Name |
| Value(USD) | 0 |
| Interest | Interest |
| Volume | 320 |
| RRRs | RRRs |
| Purpose | Purpose |
| Centroid (XYZ) | (20,9,7.5) |
| Color | 🟦 |

**Fig. 14.** Unified object

## Benefits of the MPC

A well-structured MPC will be of benefit to most governments, public agencies, private firms, regional bodies, academia and individuals. The MPC will serve as a land information bank, which will contain all available spatial and non-spatial information concerning land volume parcels. Visualization of these parcels in 3D i.e. volume parcels will further enhance the MPC and introduce the concept of 3D modelling. As an integrated land information system it can exhibit data on ownership, rights and all encumbrances associated with the land volume parcel, this promotes transparency and wealth creation in the land market. Inventory of all land parcels together with information for the strata and stratum will strengthen property ownership, project implementation and monitoring. Agencies can identify areas for planning and further development. The tax system can be more efficient and dealings with banks and insurance companies made more transparent. For example the proposed National Underground Utility Database for Malaysia when incorporated in the MPC will streamline the provision of essential services such as electricity, water, sewerage, communication networks. The management of the public utility networks will be more efficiently managed. Other indirect benefits of the MPC can include crime prevention, population control, census mapping, location and management of educational centres. The MPC needs to be adopted by most countries as the benefits of setting up a credible model that conforms to the LADM will bring more efficiency in the land market of all countries, especially Asia and African countries where the existence of the LADM is only in the conceptual stage in some countries and almost non-existent in other countries. Section 5 introduces the conclusions and future works for this research.

## SUMMARY AND DISCUSSIONS

The 3D TIN spatial model has served as the “union” for most spatial data models and the challenge for adopting a single 3D spatial data model for 3D GIS is still on-going, the authors think the 3D TIN is a sigificant spatial data model that can be used to achieve this goal. We have also demonstrated that this model and the GUI can be used in facilities management and also in creating 3D mining models.

The UML diagrams developed shows how the above, on and below situations can be integrated into the LA_SpatialUnit (Figure 8). The implementations includes additional features, this computes the centre of mass and volume of say, a flat in a condominium. Q including: Has building A has underground construction? What is the volume?, where is Flat D?, Show me all the centres of the unified object, What is the semantic information for Flat C, among others can be answered.

The area of application for the unified model is 3D cadastre. The concept for volume parcels and the wireframe of above, on and below surface objects have been presented within a GUI. Queries to show volume parcels in both graphics and semantics has been implemented. (see Figure 10). Individual volume space representing specific flats for the above surface volume spaces and below volume space is shown when the wireframe is degenerated to show the polygons of each volume which represents a flat.

The paper has also highlighted the need to incorporate marine cadastre and underground utilities database in 3D cadastre and used Malaysia as a test case where research is on-going, initial results have been presented at FIG conference on 3D cadastre in China. Also the 3D modelling concept for 3D parcel volumes using the concept of tetrahedrons has been enumerated. The concept for the unified model will enhance the spatial part of the LADM and bring about some level of conformity and the realization of a fully 3D approach for representing 3D objects. The Land Administration Domain Model (ISO/TC211, 2012; Lemmen et al., 2010) is a conceptual model which can serve as the basis on which other models can be built or referred. A more regional or country specific model using the LADM can be developed with specific attributes and associations. For 3D marine objects, this aspect needs to be developed, this is usually important for countries with the sea or ocean as a boundary, this has been reiterated by Abdul Rahman et al., (2012), marine objects need to be incorporated in a country’s 3D cadastre. There is not yet an existing generic class in the LADM for 3D marine cadastre, so this has to be added in the country profile. It should be noted that this is not a Malaysian specific situation and marine objects are (or will become) in many countries relevant (Nichols et al., 2001).

As pointed out by (Stoter, 2004), in many countries a 2D description should be interpreted as a 3D prismatic volume with no upper and lower bound; The UCDM has been modelled to conform with the conceptual model of the LADM and made more relevant using the Malaysian MPC as a test case. The major signifcance for our model is a full 3D volume parcel using 3D TIN.

The prototype is still in the implementation stage, and the GUI requires further enhancement, this concept using the 3D TIN for volume parcels is still on-going and the interface will have more features to incorporate all the concepts enumerated.

## CONCLUSIONS

3D modelling for 3D cadastre has been initiated and a geometric approach in the form of volume parcels introduced. The multi-purpose cadastre (MPC) must be integrated to include marine parcels and the strata and stratum condition unified. The incorporation of marine cadastre and the concept of a utilities database highlighted. The National Underground Utility Database with 3D City Modelling for the Malaysian MPC is on-going and initial results presented. The Malaysian MPC model is compatible with the LADM (Land Administration Domain Model). The UML details of the model comply with the concept of the LA_SpatialUnit of the LADM for the MPC has been presented. The benefits to be derived from the MPC with the incorporation of 3D modelling and underground utility have been enumerated. We anticipate that the proposed approach for incorporating 3D modelling could be implemented for the MPC by city authorities in the near future. The 3D volumes for feature objects above (multi-level structures) and on (3D land parcel volume) and below (multi-level structures) will be made more user-friendly. This algorithm can easily be adopted as it runs on a readily available programming language and can be easily set up in any computing environment once the database is set up. The cost of such a setup is low and the benefits will be high in situations where some agencies cannot afford sophisticated software’s with its attendant challenges. This paper is advocating the concept of 3D parcel volumes and enumerated the concept of using the 3D TIN to show this concept due to the advantages presented by the data model. The advantage of incorporating some subsurface attributes such as geology and subspace (cavities) and underground constructions has been highlighted. The 3D TIN spatial data model is significant and should be adopted for the full realization of 3D GIS.

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