Advanced Principles of 3D Cadastral Data Modelling

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Key words: Data Model, 3D RRRs, Legal Property Object, 3D Cadastral Data Modelling, 3DCDM

SUMMARY

Current cadastral data models use a 2D land-parcel definition and extend it to cover 3D requirements. This approach cannot adequately manage and represent the spatial extent of 3D land rights, restrictions and responsibilities (3D RRRs).

This paper aims to develop a 3D Cadastral Data Model (3DCDM) to configure 3D cadastral frameworks, manage and represent 3D RRRs, and facilitate 3D cadastre implementation.

Three underlying principles have been proposed to develop the 3D Cadastral Data Model (3DCDM). These principles are:

- *Principle 1: The 2D cadastral data model is a sub-set of the 3D cadastral data model,*
- *Principle 2: The 3D cadastral data model should not only accommodate 3D RRRs and their association with physical objects: the data model should also represent the spatial extent of 3D RRRs*, and;
- *Principle 3: The 3D cadastre data model should cater for a broad range of land administration functions including land tenure, land value, land use, and land development with sufficient detail*.

These principles are used to assess and modify the core cadastral data model. Additionally, principles related to the legal property object are also used to modify the 3DCDM. The legal property object combines interests and its spatial dimension into a single entity. This creates more flexibility and enables inclusion of complex commodities and all kinds of RRRs.

The first version of a 3D Cadastral Data Model (3CDM_Version 1.0) is provided at the end of this paper. 3DCDM maintains both legal and physical parts of 3D objects. The data model has wider application than the traditional requirements of cadastral systems: it is also usable in applications such as urban planning and disaster management.

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1. INTRODUCTION

The need for more 'space' resulting from population growth, urbanization and industrialization has increased the pressure on land use planning and development. As a result, space above and below ground level is increasingly used. Examples include underground developments, infrastructure facilities, high-rise buildings, and apartments. To extend the use and functionality of the land, complex infrastructures are being built, both vertically and horizontally, layered and stacked. These three-dimensional (3D) developments affect the interests attached to the underlying land.

A 3D cadastre will assist in managing the effects of 3D development and increase the functionality of a multipurpose cadastre (Stoter & Oosterom, 2006). As the role of cadastre has changed through the development of civilization, cadastral data models have had to develop to meet ever changing demands (Williamson *et al*, 2010).

There have been different cadastral data models since cadastral mechanization. Many jurisdictions, organizations and software developers have developed their own cadastral data model. Examples of data modelling developments are the Core cadastral data model (Henssen, 1995), FGDC Cadastral Data Content Standard for the National Spatial Data Infrastructure (FGDC, 1996), ArcGIS Parcel Data Model (Meyer, 2001), DM.01. (Steudler, 2005), CCDM (Oosterom *et al*, 2006), ICSM Harmonised Data Model (ICSM, 2009), ePlan (ICSM, 2009), Legal Property Object (Kalantari *et al*, 2008), Ubiquitous 3D Cadastre (Park *et al*, 2010), LADM (Lemmen *et al*, 2010a; Lemmen *et al*, 2010b), 5D Data Modelling (Oosterom & Stoter, 2010), and ISO 19152- LADM (ISO, 2011).

The variation between these data models is the result of the author's different attitudes towards cadastres. They are evidence of the varying expectations of a 3D cadastre. However, there is a basic common thread among them all. Current cadastral data models have been developed based on the definition of a 2D land-parcel, and most of the existing data models only cover 2D land-parcels (Kalantari *et al*, 2008). However, some have 3D objects as components of the data model. 3D cadastres are currently being developed in the context of 2D cadastres, yet it is argued that it is the 2D cadastre that should be accommodated within the context of a 3D cadastre (Aien *et al*, 2011a). The research problem underpinning this paper is therefore: *Current cadastral data models use a 2D land-parcel concept and extend it to support 3D requirements. These data models cannot adequately manage and represent the spatial extent of 3D RRRs.*

This paper aims to develop a 3D Cadastral Data Model (3DCDM) based on three proposed principles of 3D cadastral data modelling. The first principle and concept of the legal property object are described in Section 2. Section 3 addresses the second principle and the legal property object package. The third principle is described in Section 4. The 3D Cadastral Data Model (3DCDM_Version 1.0) and its components are presented in Section 5. The paper ends with conclusions in Section 6.

2. FIRST PRINCIPLE OF 3D CADASTRAL DATA MODELLING

The first principle is:

The 2D cadastral data model is a sub-set of 3D cadastral data model.

This principle reverses the current practice of extending the 2D model to include the 3D model. Most current initiatives are arguably utilising 2D cadastral concepts for the development of 3D cadastres.

The core cadastral data model has been developed based on three main components: InterestHolder (who has interests in a particular land parcel); Rights, Restrictions, and Responsibilities (RRRs); and Land (2D land parcel where RRRs are applied on/under that). Figure 1 shows the relationships between these components of the core cadastral data model.

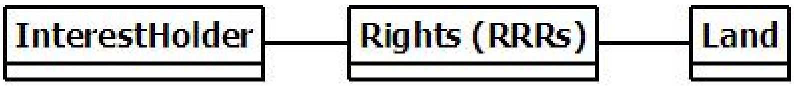

Figure 1. Core Cadastral Data Model (Oosterom et al, 2006)

Obviously, the use of land involves multiple dimensions. However, traditional land administration systems focus on organizing 2D land parcels. A number of reasons current cadastral data models still rely on these 2D parcels for accommodating 3D data. They are: the lack of 3D data collection methods and equipment (lack of information in subdivision plans and architectural maps), and limited 3D storage and representation technologies (3D DBMS, 3D topology, and 3D visualisation specifications). However, 3D developments changed the characteristics of land parcels. Adding to this complexity were an increasing number of different RRRs (e.g. ownership, easements, noise restriction area, mining lease, planning zone, heritage protection area) are associated with one 2D land parcel (Figure 2).

The 2D land parcel is no longer the appropriate basic spatial component of cadastral models for managing and modelling 3D information: 2D land parcels have been superseded by 3D spatial places. People now own and use volumes of space that can be determined in a 3D coordinate system (Aien et al, 2011a).

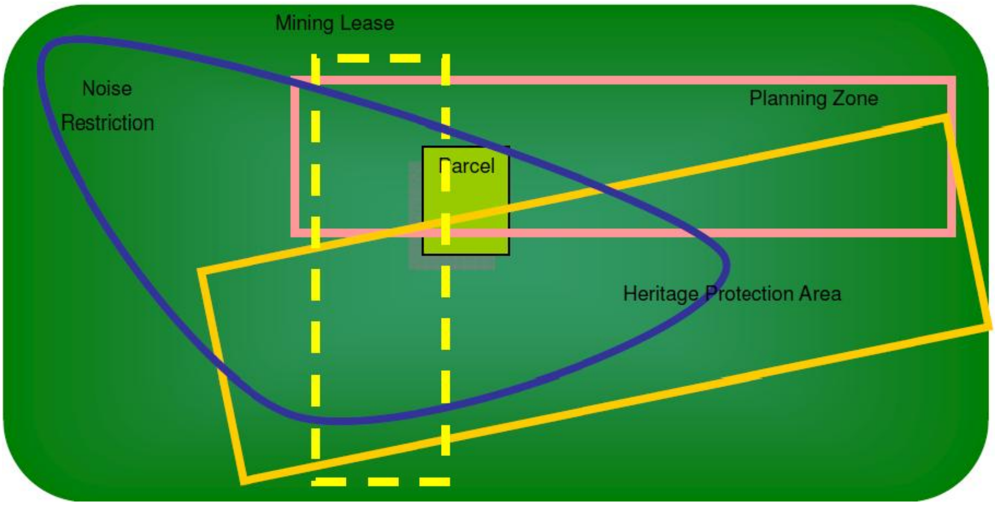

Figure 2. An example of non parcel based interests (Kalantari et al, 2008)

While cadastral data models have been developed to support the 3D cadastre, most initiatives are based upon the 2D cadastral paradigm. In the most cases, a generic spatial unit has been defined to support 3D requirements. This object maintains, for example, 2D land parcels, buildings, and utility network objects (Figure 3). The 2D land parcel object is being used when the model deals with a land parcel, and the Building object is being used when a building is being modelled.

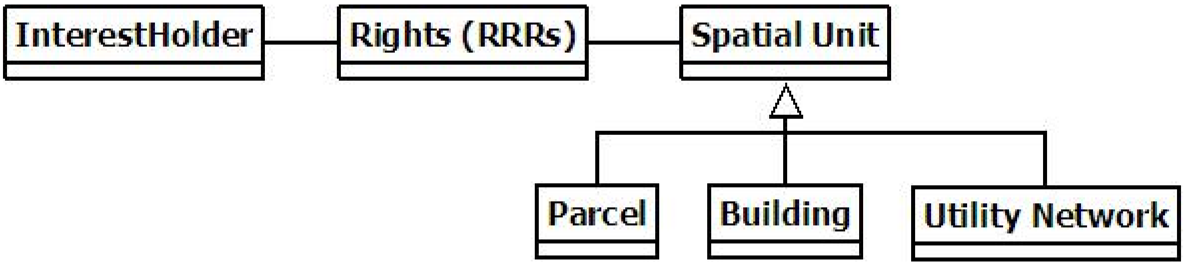

Figure 3. Spatial package in current cadastral data models (ISO, 2011)

In this model, the Building object is treated as if it is dependent on a land parcel and inherits the land parcel's RRRs. In other words, in this data model the 3D cadastral data model is an extension of 2D cadastral data model. In the 3D cadastral data model, the Spatial Unit could be changed to 3D Spatial Space which is no longer dependant on the land parcel as it has its own associated RRRs. An initial 3D Cadastral Data Model is proposed by this reform (Figure 4).

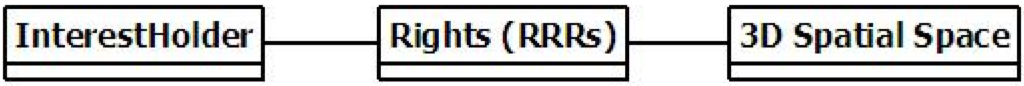

Figure 4. Initial 3D Cadastral Data Model

This data model upgrades the spatial component of the core cadastral data model from a 2D object to 3D object. However, further changes are required. Spatial Component (land or 3D Spatial Space) and legal component (RRRs) are not conceptually separated objects. All RRRs are associated with a particular 3D spatial extent. This means that RRRs and 3D spatial extends can be combined and maintained together. The initial 3D Cadastre Data Model can use the advantages of this concept, which is called the ‘legal property object’, or simply ‘property object’, to simplify its structure and maximise its efficiency.

2.1 Legal property object

In 2008, Kalantari et al proposed the legal property object concept. The aim was to re-engineer the current core cadastral data model. An underlying principle was that land could not be considered a legal entity until an interest was attached to it. There is always a relationship between each interest and its spatial dimension. Therefore, they can be maintained together as a unique entity (legal property object) in a cadastral information system. The legal property object combines an interest and its spatial dimension into an entity: an entity defined by law or regulation which relates to a physical space on, below or above the surface (Kalantari *et al*, 2008).

The concept of the legal property object changes the current core data model from three components into two components. Figure 5 shows a new core cadastral data model based on the legal property object concept.

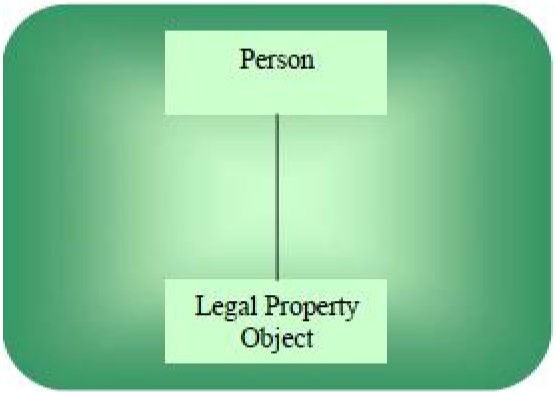

Figure 5. New core Cadastral Data Model (Kalantari et al, 2008)

The advantage of this model is the comprehensive inclusion of all interests in land. It also facilitates the land administration system to be more extensible and scalable in terms of new legislation and land related laws (Kalantari, 2008).

There are some challenges to incorporate the legal property object within a cadastral model. They involve converting RRRs into their corresponding spatial dimensions (the legal property object might be a polygon, network, or a 3D object) and also defining relationships among legal property object layers using identifiers, such as addresses, parcel and property maps, and coordinates.

2.2 Incorporation of legal property object with 3D cadastral data model

Since the legal property object concept changes the core cadastral data model, it would affect the initial 3D Cadastral Data Model. In this model the 3D Spatial Space object and RRRs object are combined together (Figure 6).

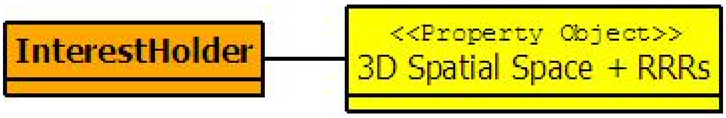

Figure 6. Initial 3D Cadastral Data Model based on the first principle and the concept of legal property object

This data model will use the advantages of the legal property object by using identifiers to connect RRRs with their spatial components.

3. SECOND PRINCIPLE OF 3D Cadastral Data Modelling

The second principle is:

The 3D Cadastral Data Model should not only accommodate 3D RRRs and their association with physical objects: the data model should represent the spatial extent of 3D RRRs.

This principle challenges the original definition of the cadastre where land parcels are kept as an attachment to land titles. This principle requires a higher degree of integration between RRRs and their spatial extent.

While a few simple RRRs (such as an easement of way) may be represented on 2D (planar) cadastral paper maps, the diversity and complexity of 3D RRRs requires more than a 2D cadastral paper map (where 3D features are often incorporated by accompanying descriptive text). That is, 3D RRRs require more than merely grafting of the 3rd dimension information onto a 2D planar representation. 2D land parcels are not flexible enough to accommodate an increasing number of non-parcel based interests (Bennett *et al*, 2008; Kalantari *et al*, 2008). Even after recent advances in storage (database) and visualisation systems, current cadastral systems do not attempt to represent RRRs in digital cadastral databases (DCDB). Consequently, the DCDB does not contain all RRRs (Oosterom *et al*, 2011).

User expectations are for 3D RRRs to be visualised in a 3D cadastre. However, visualising 3D RRRs alone would not adequately assist management of 3D RRRs (Aien *et al*, 2011b). Figure 7(d) is an example of a 3D depiction of the RRRs associated with the University of Melbourne’s underground car park (UMP). Figure 7(a) and 7(b) show the location of the UMP on Google Map and Land Victoria’s DCDB respectively (the corresponding parcels are identified by the same symbols). Figure 7(c) is a cross-sectional view of UMP.

Figure 7(a): Orthogonal view of Melbourne University's underground car park (Google, 2010)

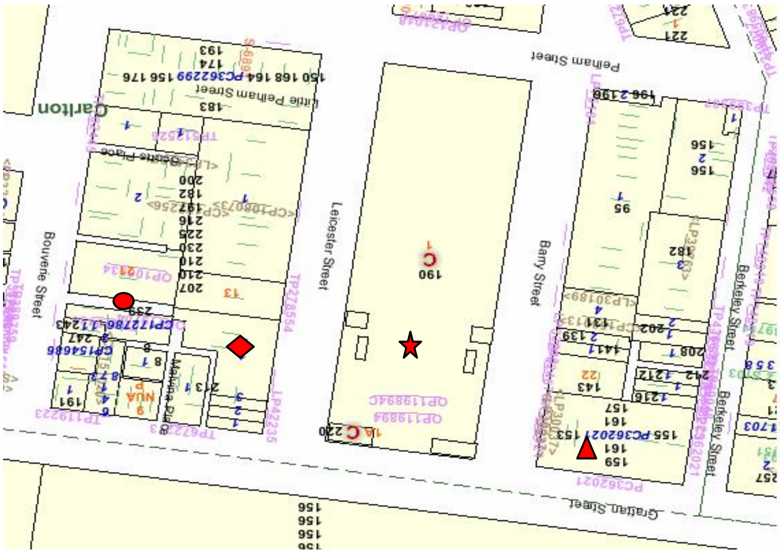

Figure 7(b): LandVictoria's DCDB of this area (LandVictoria, 2010)

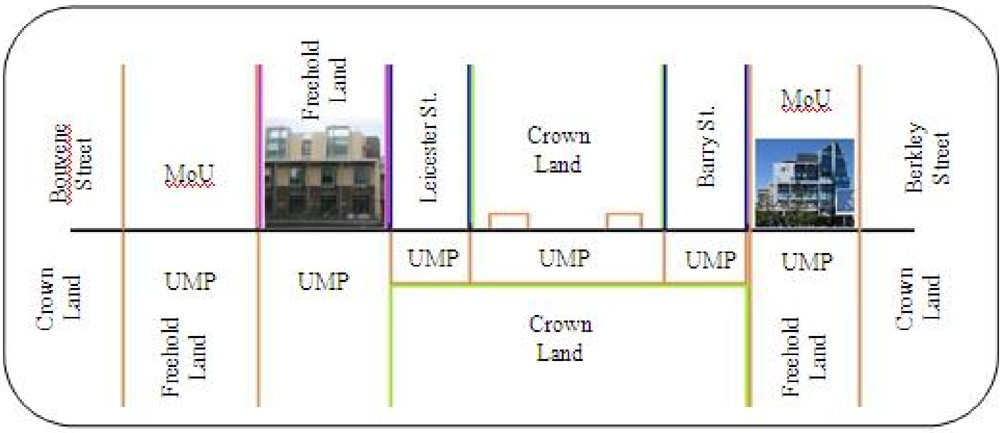

Figure 7(c): Cross-sectional view of University of Melbourne underground car park (UMP)

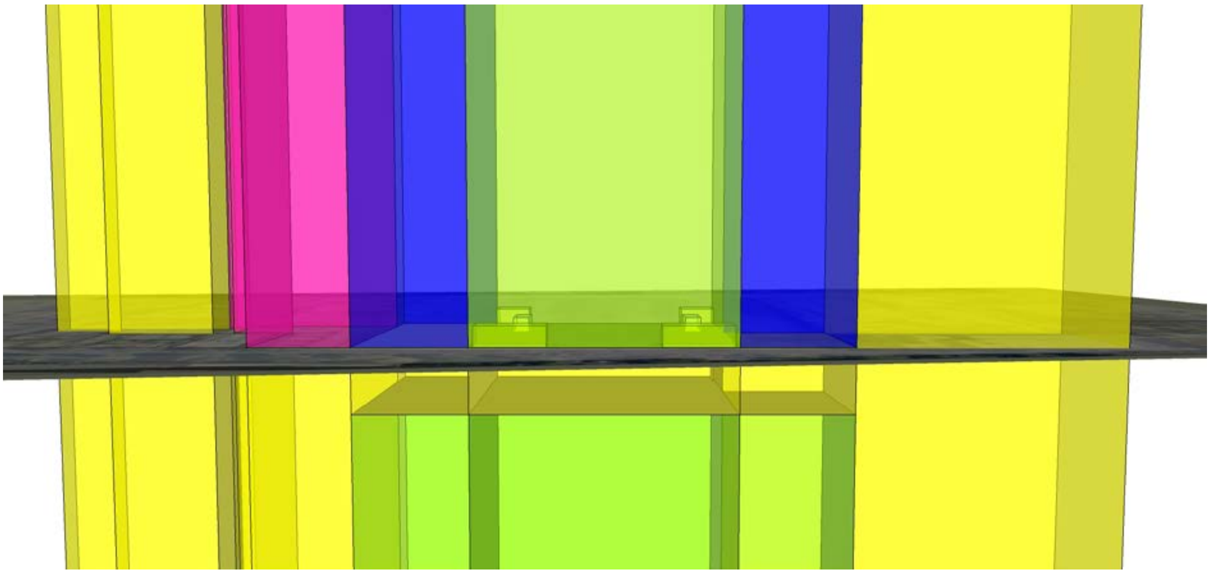

Figure 7(d). Visualisation of 3D RRRs (green and blue spaces are Crown (government) land, the pink space is privately owned, and the University of Melbourne has a right of use over the yellow spaces)

3D objects which represent 3D RRRs are not suitable to manage 3D RRRs. The actual construction of the buildings should be visualised in different details for different land administration functions (Figure 8).

Figure 8. 3D thematic view of the underground car park - different levels of this car park can be visualised for different purposes (different details)

Based on the second 3D Cadastral Data Modelling principle, the 3D Cadastre Data Model should support both legal and physical objects of a building. Therefore, a 3DCDM_PropertyObject (PO) class has been defined with its two specifications: PO_LegalPropertyObject and PO_PhysicalPropertyObject (Figure 9).

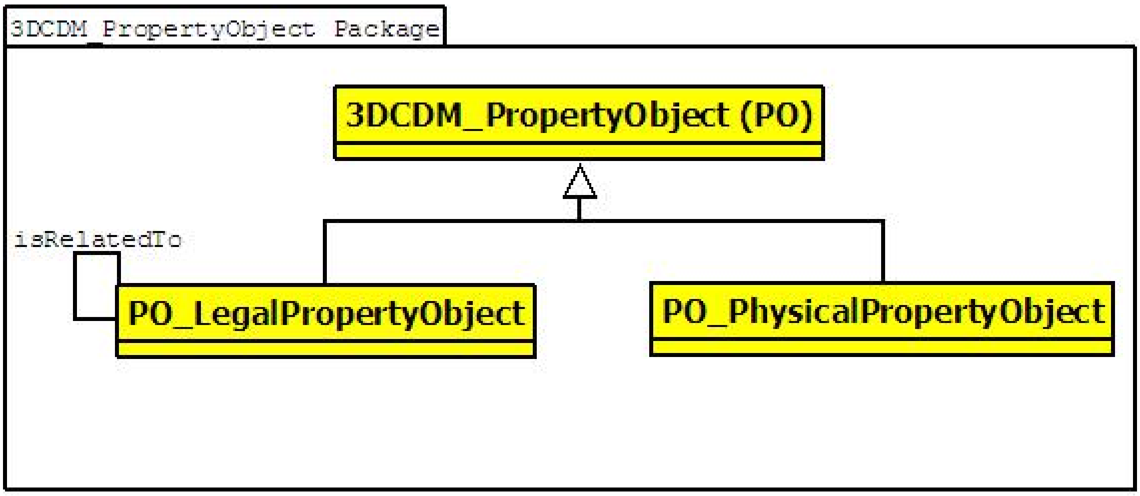

Figure 9. 3DCDM_PropertyObject (PO) package

PO_LegalPropertyObject contains associations to support the legal objects of a building (Figure 10). The PO_LegalPropertyObject has an association with itself to enable the modelling of allocations between existing property objects and the new property objects. All associations are a kind of legal property object (LPO). Different LPOs can create the whole legal object.

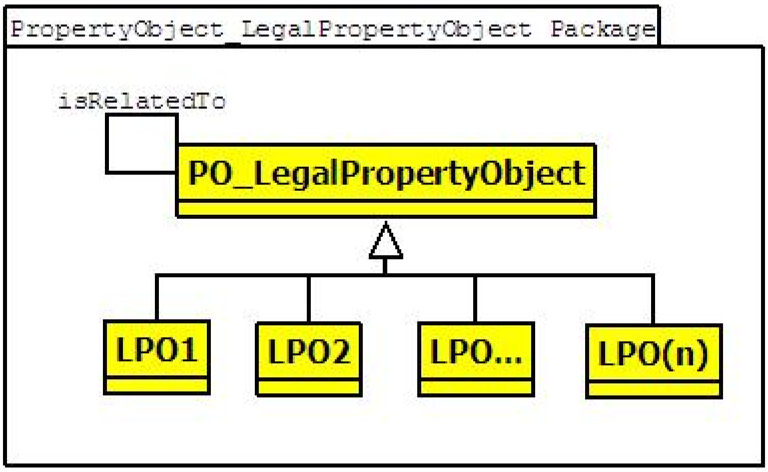

Figure 10. PO_LegalPropertyObject Package

LPO1 can be a lot. Lot is the name given to a separate piece of land, airspace or building that come into existence when a plan of subdivision is registered in the Australian context (Figure 11). LPO2 can be a common property which is the area of a plan of subdivision which is not included in one of the lots but is owned and used in common by those lot owners who are members of the body corporate. It can consist of land, building, air space or an area below the ground (Libbis, 2006).

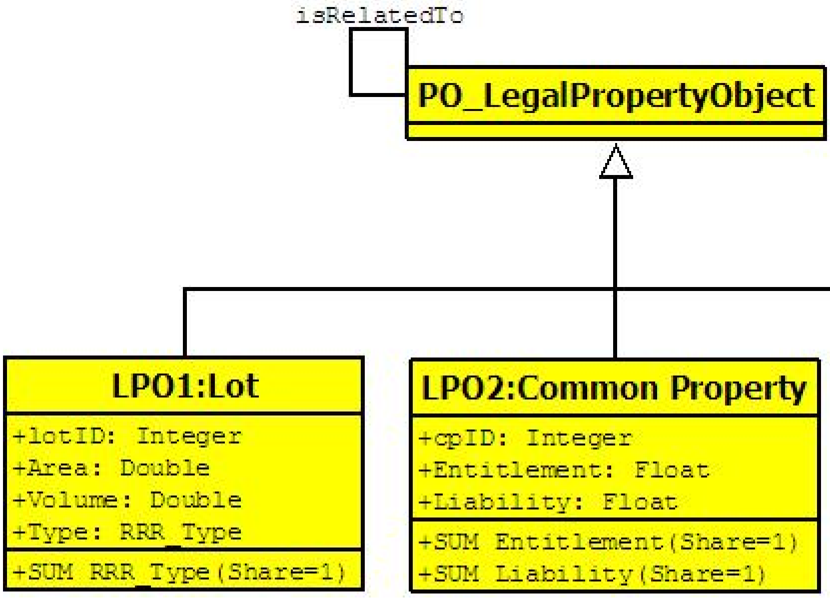

Figure 11. Attributes of PO_LegalPropertyObject

Storey is any level part of a building that has a permanent roof and could be used by people for different purposes. Each storey may contain a unit, its accessories and a utility network. The PO_PhysicalPropertyObject package consists of these objects to model the physical part of a building (Figure 12). Figure 13 describes attributes of LOP_PhysicalObject class.

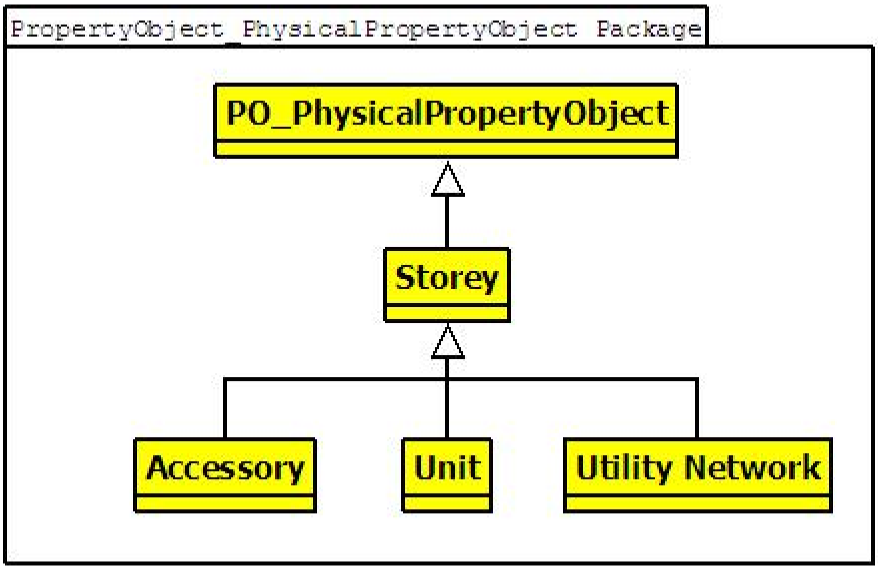

Figure 12. PO_PhysicalPropertyObject Package

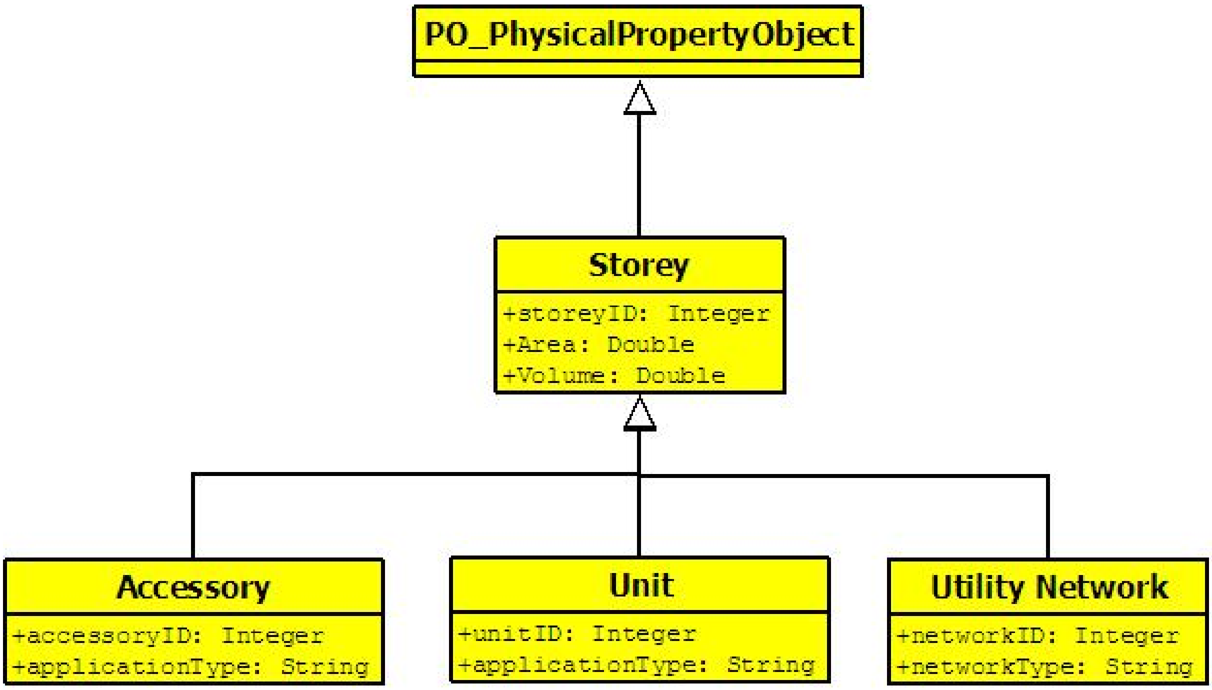

Figure 13. Attributes of PO_PhysicalPropertyObject

4. THIRD PRINCIPLE OF 3D CADASTRAL DATA MODELLING

The third principle is:

The 3D Cadastral Data Model should cater for a broad range of land administration functions including land tenure, land value, land use, and land development with sufficient detail.

Land administration includes diverse but related functions such as Land Tenure, Land Value, Land Use, and Land Development. Traditionally land administration functions have been founded on land parcels.

Although cadastral systems were mainly established to serve a legal or a fiscal purpose, the data of the cadastral systems are also used for facilities management, base mapping, value assessment, land use planning, and environmental impact assessment. A legal basis, however, does not exist everywhere for all of these other purposes (Kaufmann & Steudler, 1998).

The multipurpose 3D cadastres would provide better and more efficient service to the public and private clients. However, 3D cadastres need considerable investment. A 3D cadastre cost/benefit analysis would be needed to demonstrate that the detailed 3D information can serve as a multipurpose 3D cadastre in different domains.

Applications of 3D cadastre are different and they require a different detail and scale of information. For example, land registrars need parcel scale information, meaning that they need to register and visualise subdivided 3D spatial objects and their associated rights. By contrast, city planning organisations need large scale and more detailed information in every unit and storey of a building.

For example, consider a building with two storeys and four units where each unit has one balcony and one access way area (Figure 14). If both units 1 and 2 are owned by person (P1) and the units 3 and 4 are owned by another person (P2), what is registered and represented in a land registry office are subdivided lots and their associated rights, as illustrated in Figure 15. For planning proposes however, information of each separate unit as well as their legal information is important (Figure 16).

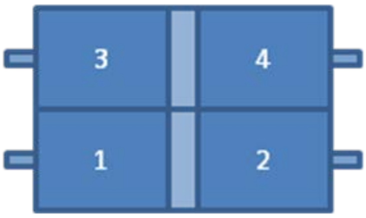

Figure 14. A two storeys building with 4 units (each unit has one balcony) and one access stair

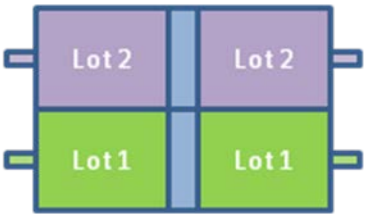

Figure 15. P1 owned Lot 1 and P2 owned Lot 2 (Legal model)

Figure 16. A model which is useful for planning purposes (Physical model)

The third principle also challenges the single building block of the cadastre that is used as the atomic unit of land administration functions. Modern cadastral data models should use 3D objects as the basic building block. This principle supports the proposition that there is no single basic building block for the cadastre: different levels of detail (in terms of accuracy and feature) will be required for the 3D development in different land administration functions.

Based on the three principles described thus far and the 'legal property object' concept, the 3D Cadastral Data Model (3DCDM_Version 1.0) is developed in the next section. This data model accommodates concepts of proposed principles. It maintains both legal and physical parts of 3D objects. The data model has wider application than the traditional requirements of cadastral systems.

5. 3D CADASTRAL DATA MODEL (3DCDM_VERSION 1.0)

The first version of 3D Cadastral Data Model (3DCDM_Version 1.0) is presented in this section. It is based on the principles of 3D Cadastral Data Modelling, and lessons from the legal property object concept. 3DCDM has seven packages to support the 3D cadastres. They are 3DCDM_InterestHolder, 3DCDM_Propertyobject (PO), 3DCDM_Geometry, 3DCDM_Survey, 3DCDM_SurveyPoints, 3DCDM_SurveyObsevation, and 3DCDM_ExternalSources (Figure 17).

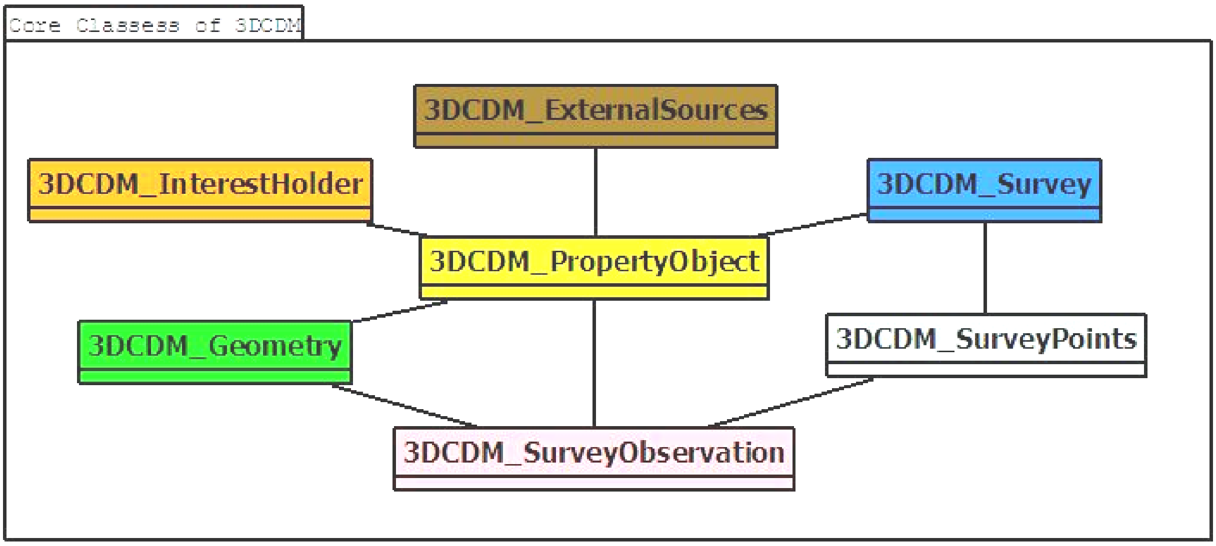

Figure 17. Core classes of 3DCDM

5.1 InterestHolder Package

The only class in this package is 3DCDM_InterestHolder class. InterestHolder can be a person, group, or an organization who has certain rights (RRRs) over a particular 3D spatial space.

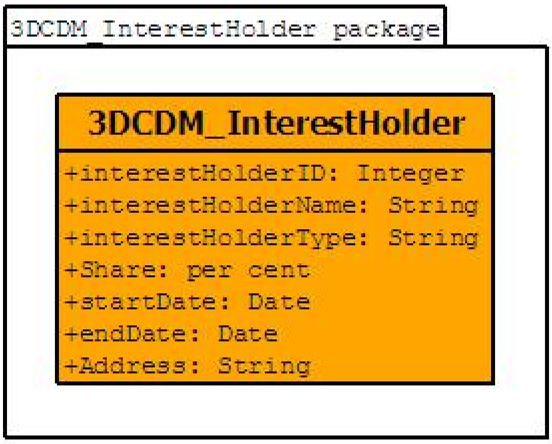

Figure 18. 3DCDM_InterestHolder Package

5.2 LPO (Legal Property Object) Package

As described in section 3, the main class in this package is 3DCDM_PO with its two specializations, PO_LegalPropertyObject and PO_PhysicalPropertyObject. This package supports both legal and physical parts of a 3D object (building) (Figure 19).

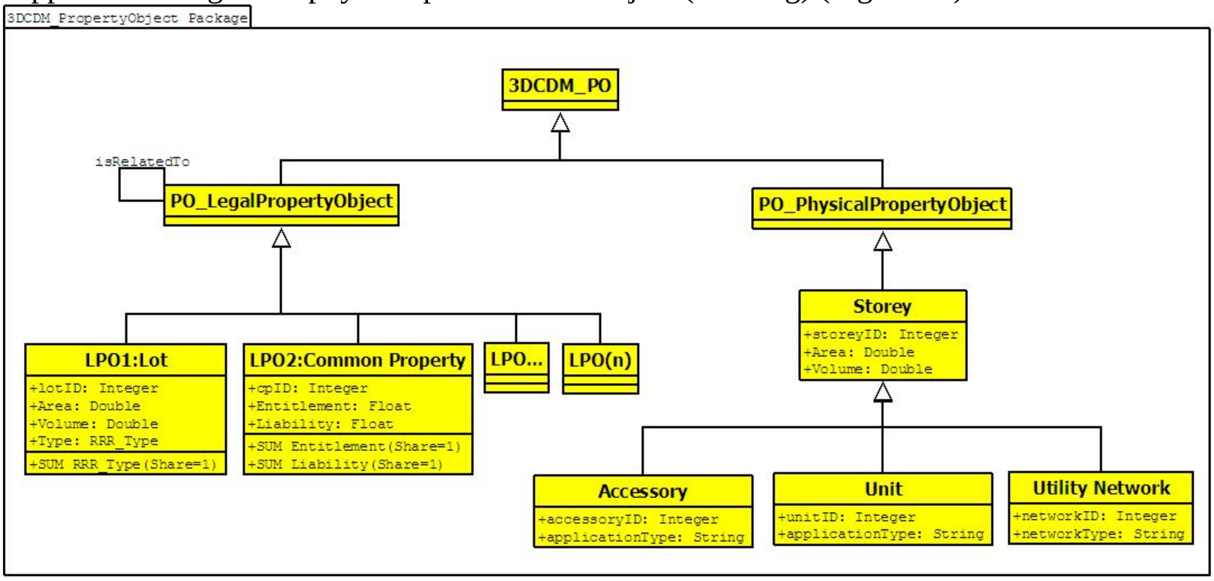

Figure 19. 3DCDM_PO Package

5.3 Geometry Package

This package utilises the geometry model of CityGML to shape the geometry of legal and physical objects. This package consists of primitives to form complexes, composite geometries or aggregates. Point is used for zero-dimensional object, _Curve for one-dimensional, _Surface for two-dimensional, and _Solid for three-dimensional objects (Figure 20). Combination of the primitives (aggregates, complexes or composites) forms more complex objects and provides topology among objects (Gröger et al, 2008).

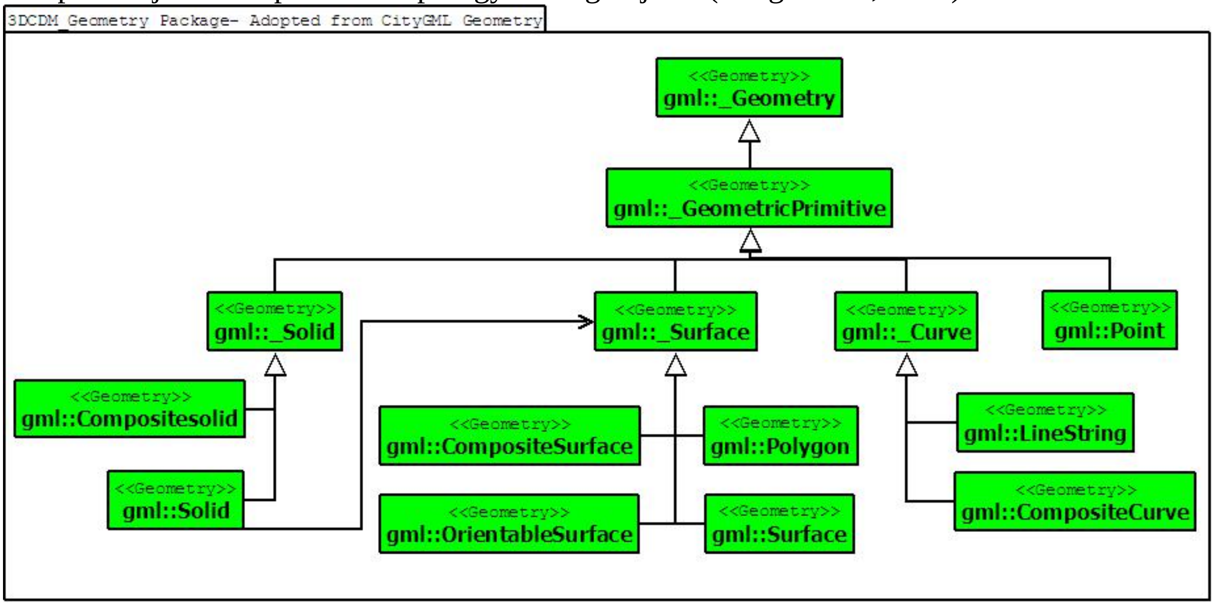

Figure 20. 3DCDM_Geometry Package (adopted from CityGML data model)

5.4 Survey Package

This package contains 4 classes which deal with technical and administrative information of surveying, surveyor, and subdivision plan. They are 3DCDM_Survey, 3DCDM_SurveyMetadata, 3DCDM_CoordinateSystem, and 3DCDM_Surveyor (Figure 21).

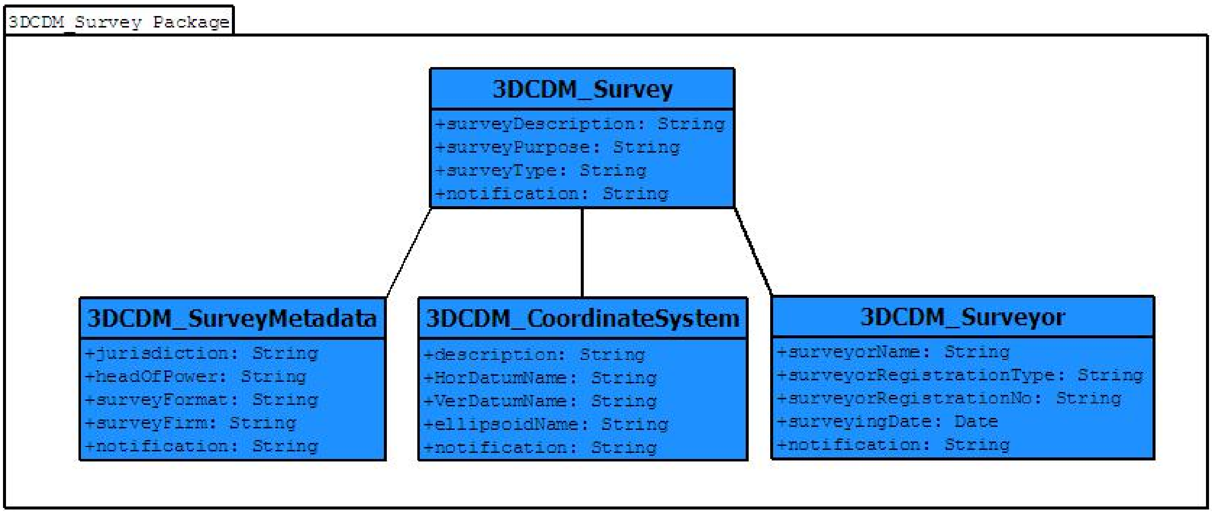

Figure 21. 3DCDM_Survey Package

5.5 SurveyPoints Package

This Package has one 3DCDM_SurveyPoints class to contain the elements related to the survey permanent marks which are placed in the ground by monuments (e.g., pin, peg) for the purpose of being surveyed. Survey points can be 2D or 3D (Figure 22).

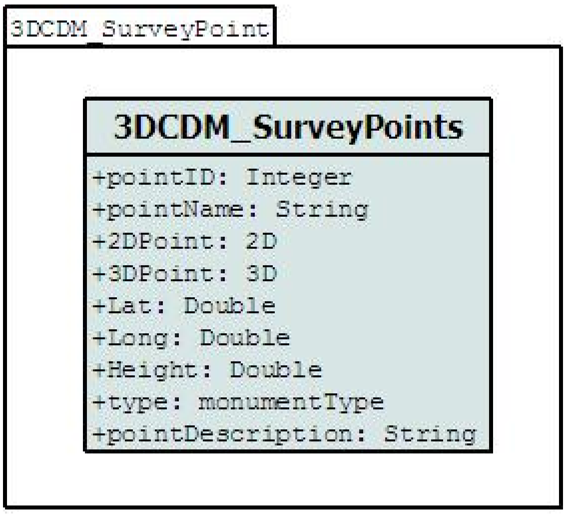

Figure 22. 3DCDM_SurveyPoints Package

5.6 SurveyObservation Package

The 3DCDM_SurveyObservation package contains 3DCDM_SurveyObservedLine, 3DCDM_SurveyAngle, and 3DCDM_SurveyStation classes to maintain observed data which form a spatial component of the 3DCDM (Figure 23).

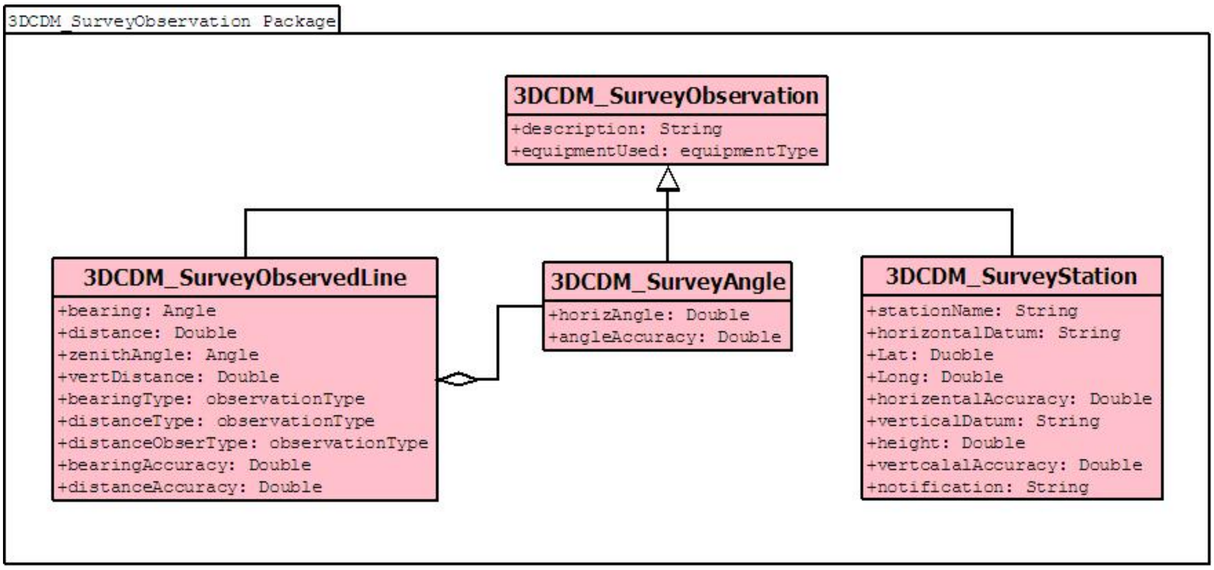

Figure 23. 3DCDM_SurveyObservation Package

5.7 ExternalResource Package

Surveying data and subdivision plans are not detailed enough to guide reconstruction of both legal and physical objects of buildings. In some applications, more detailed information required, which external sources such as architectural and engineering plans can provide. The 3DCDM_ExternalResource package contains only one class to support all different external sources (figure 24).

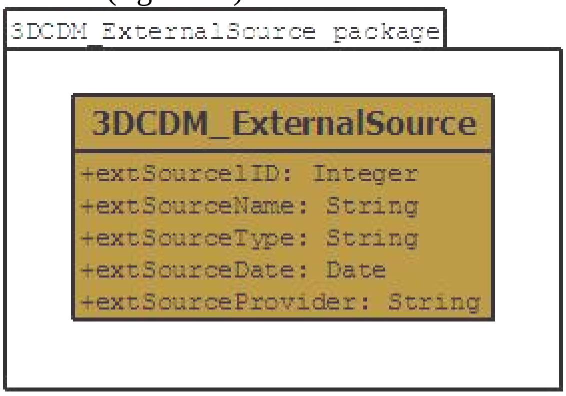

Figure 24. 3DCDM_ExternalSource Package

6. CONCLUSION

Land development and land use are increasingly three-dimensional (high-rise buildings, underground basements and car parks), but, use outdated two-dimensional cadastral systems. This paper advances the proposition that a comprehensive cadastre must be three-dimensional to properly manage, represent and visualise the spatial extent of 3D land rights, restrictions and responsibilities (3D RRRs).

The paper introduces three principles of an adequate 3D Cadastral Data Model. In addition, the concept and advantages of using the 'legal property object' have been addressed. The result of these principles is significant. It will shape the 3D cadastre concept and consequently 3D Cadastral Data Models. Most of the current cadastral data models have been influenced by a very broad understanding of 3D cadastral concepts because clarity in what needs to be represented and analysed cadastre needs to be established.

To this end, the first version of 3D Cadastral Data Model (3DCDM_Version 1.0) has been developed to support the 3D cadastre and more city planning applications. This data model has seven packages which support different parts of a 3D cadastral system. The next phase of this work will involve piloting and testing the model.

Finally, it is also worth noting that in the short to medium term (and potentially the long term), a 3D cadastre will not be required in all contexts (e.g. consider isolated rural areas in Australia). This notion may provide clues as to how 3D cadastres will be implemented in practice. 3D cadastral models will need to take this into account: the development of full 3D cadastre will most likely be staged processed, supported by cost/benefit analyses that demonstrate the value of each stage. Further research should therefore also examine approaches to implementation. In conclusion, the model presented here can be seen as part of the processes of development.

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