A Conceptual Framework of Representing Semantics for 3D Cadastre in Singapore

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SUMMARY

The Land Survey Division of Singapore Land Authority (SLA) has recently embarked on LandXML to replace the existing in-house cadastral submission format for cadastral job processing. The rationale of adopting LandXML is to support automated job processing for cadastral job submissions from registered surveyors. LandXML is capable of capturing surveying data, such as traverses, parcels, and geometries; however, it falls short when representing the semantics of what is captured for automated job processing. This paper discusses a conceptual framework on how to support the semantic representation for LandXML using ontology in 3D cadastres.

Ontology is not novel in the geospatial domain. It has been proven useful in many applications. Ontology is used to explicitly describe semantics by using a formal language, Web Ontology Language (OWL). OWL is a World Wide Web Consortium standard and a variant of XML (eXtensible Markup Language), but different from a standard XML, OWL is enriched with axioms for semantic definitions to build ontology. By interpreting the knowledge in the ontology, a system is able to perform certain operations automatically.

In this paper, a 3D cadastral ontology is engineered to describe the concepts used in 3D cadastre for the context of Singapore. Important concepts such as land lots, airspace lots, subterranean lots, and strata lots are formalized in OWL. Using the axioms from OWL, such as `ObjectAllValuesFrom` and `ObjectIntersectionOf`, the paper demonstrates how these concepts can be described and represented more explicitly. In addition, each concept in OWL is referred with a unique URI (Uniform Resource Identifier). To support semantic representation for LandXML, the *DocFileRef* element in LandXML is linked with the corresponding URI in the OWL. When a LandXML is processed, the respective data can be reasoned with respect to the associated ontology in OWL. This eventually forms a two-tier framework, which consists of the Data Tier and the Knowledge Tier. The Data Tier stores the surveying data, while the Knowledge Tier captures the ontological knowledge. With this conceptual framework in place, it logically sets an important step to achieve the vision of "Smart Cadastre", which also emphasizes the semantic aspect of 3D cadastres.

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1. INTRODUCTION

The Land Survey Division (LSVY) of Singapore Land Authority (SLA, http://www.sla.gov.sg/) is committed to achieve the vision of "Smart Cadastre" (Khoo 2012). Two key objectives to realize this vision are to automate cadastral job processing and to support 3D cadastre (Khoo 2011). In order to automate cadastral job processing, LSVY has recently embarked on LandXML (http://www.landxml.org/), and has planned to implement LandXML as a cadastral job submission standard for registered surveyors in Singapore in 2015.

LandXML is capable of capturing surveying data, such as traverses, parcels, geometries (Karki et al. 2011); however, it falls short when representing the semantics of what is captured for automated job processing. This paper discusses a conceptual framework on how to support the semantic representation of 3D cadastral concepts in LandXML using ontology.

The rationale of supporting LandXML with ontology is twofold. First, the ontology can be used as the integrity constraints (Smart et al. 2007) to check for data integrity and consistency. When exchanging or maintaining LandXML documents, the ontology can ensure that the data captured in the LandXML is always logical according to the rules and knowledge described in the ontology.

The second rationale is to use ontology for semantic data integration. LandXML can also be treated as a legal document for property transactions and field surveys. Parties that are involved can range from various disciplines, such as the legal domain (e.g. lawyers), cadastral domain (e.g. surveyors) and the title registry domain (e.g. registrars). To achieve a common understanding on certain terminology across different domains is difficult (Paasch and Paulsson 2011), not to say if one attempts to integrate different information sources automatically. With the ontology available, it helps to explicitly define the semantics of what is captured in LandXML. This in turn facilitates the integration of information from different sources (Fonseca et al. 2002).

To develop the ontology for 3D cadastre, legislative documents such as the Land Titles Act, are referred. The notion of building ontology from legal texts is not novel. Past research has been done for example on the German traffic code (Kuhn 2001) and the European Water Framework Directive (Soon and Kuhn 2004). This past research is based on linguistics analysis, such as the Entailment Theory from Fellbaum (1990). Diverging from the past research, the paper develops the ontology based on the legislative documents with the domain knowledge, which is derived from author's communications with others in the domain.

The resulting ontology is represented in Web Ontology Language (OWL) (W3C Working Group 2009)and describes concepts related to 3D cadastre, which includes 2D and 3D spatial relationships. The paper is different from Stubkjae and Stuckenschmidt (2000), which focuses on cadastral domain in general and uses Ontology Interchange Language (OIL), which has less expressive power than OWL.

To ensure respective terms in the LandXML are semantically specified, the LandXML document is linked with the ontology in OWL through a unique Uniform Resource Identifier (URI). When a LandXML document is processed, the ontology, which is linked with the LandXML document, can be used to mitigate the conceptual differences that may exist or to facilitate reasoning on the data in LandXML.

There are two main objectives of this paper. The first objective is to provide the framework of supporting semantics for LandXML by linking LandXML with OWL. The second is to layout a first step towards constructing three-dimensional cadastral ontology for Singapore. This step is a significant step in realizing the vision of Smart Cadastre.

In what follows, Section 2 describes the background notions LandXML, Ontology and Web Ontology Language. Section 3 demonstrates a way in which the ontology for 3D cadastre can be engineered from legislative documents. Section 4 proposes the two-tier framework that integrates data and knowledge. Section 5 concludes the paper and offers outlook for future research.

2. LANDXML, ONTOLOGY AND WEB ONTOLOGY LANGUAGE (OWL)

2.1 LandXML Schema
LandXML (http://www.landxml.org) has been used for exchanging surveying data in land development applications (Crews 2003). Government agencies, such as Intergovernmental Committee on Surveying and Mapping (ICSM, http://www.icsm.gov.au) in Australia (Cumerford 2010) and Land Information New Zealand (LINZ)'s LandOnline(Haanen and Sutherland 2002) have been using LandXML as a national standard for cadastral electronic lodgment.

Figure 1 illustrates the overview ofLandXML schema, which is modeled after the LandXML 1.2 diagram publicly available at LandXML.org (http://www.landxml.org/). As described in Figure 1, LandXML can also be used for capturing other types of engineering data, such as pipe networks and roadways. In this paper, we only focus on the Parcels element and its sub elements. (There are other elements that are related to cadastral survey, such as the Survey element. But the Survey element describes the survey-related information, such as observations and surveyor information. Elements as such are not relevant to our discussion here, which focuses on parcels.)

The Parcels element itself can be expanded into 2 elements: Parcel and Feature. The Parcel element can be further subdivided into 8 elements: Center (represents a 2D/3D center point, e.g. center of a curve), CoordGeom (e.g. a sequential list of line and/or curve elements), VolumeGeom (defines the properties of a collection of 3D coordinate geometries), Parcels (a

collection of parcels), Title (the name and type of the title relating to the parcel), Exclusions (e.g. a reserved area), LocationAddress (the address associated to the parcel), and Feature (additional information that is not explicitly defined by the schema).

Among these 8 elements, of particular interest to this paper is the Feature element. As mentioned, the Feature element can describe additional information that is not explicitly defined. One example of the additional information is a document that is related to a specific parcel. As the Parcel element and the Parcels element individually have the Feature element, one can link this additional information to either a specific parcel or a collection of parcels.
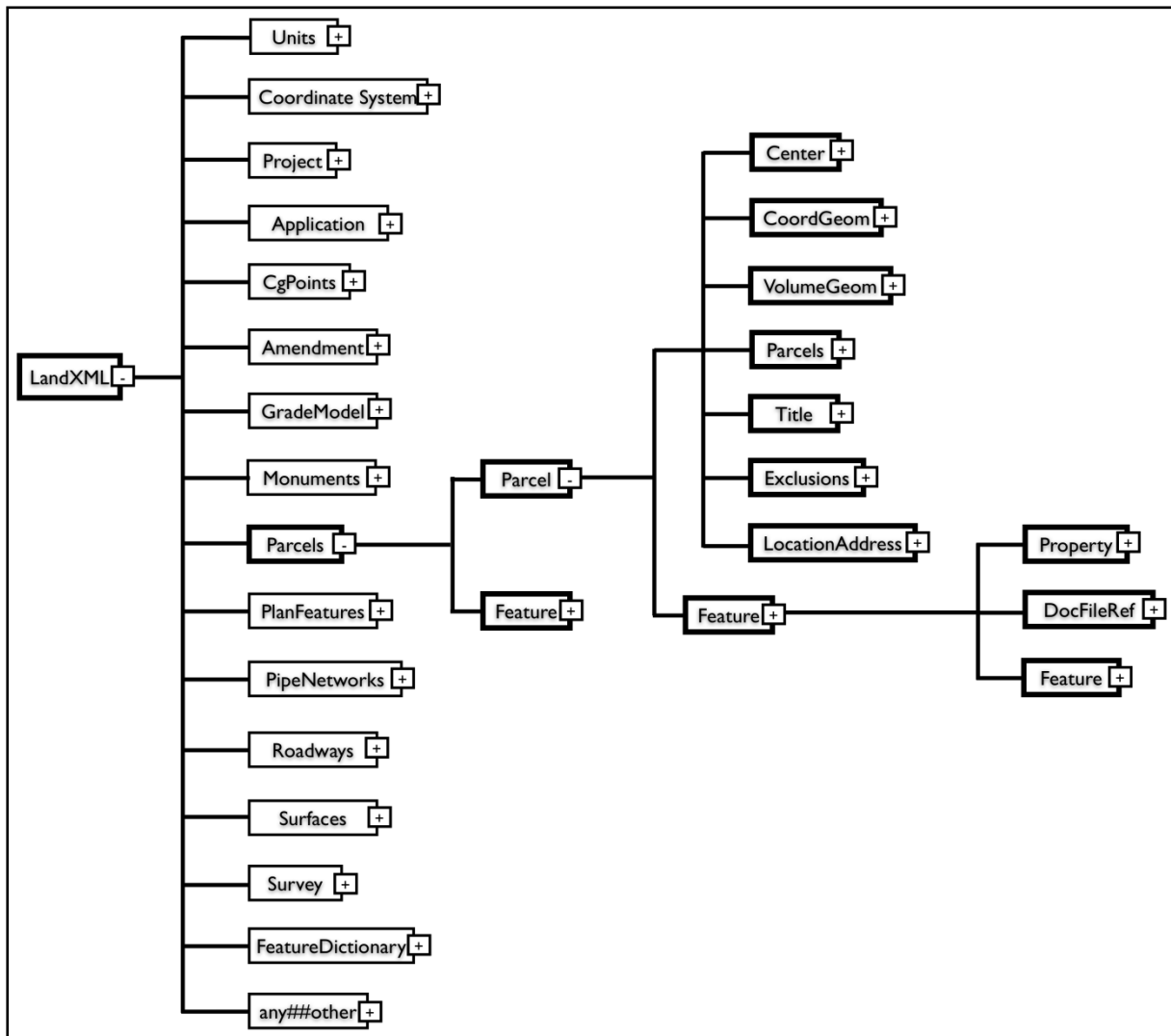

Figure 1. Overview of theLandXML schema with expansion on the *Parcels* element

In this paper, the Feature element is used to link to the ontology in OWL through the *DocFileRef* element (see Figure 2). Depending upon the type of the parcel lots (e.g. airspace lots) defined in the LandXML document, if all parcel lots are referred to the same type, the Feature element of the *Parcels* element will only be used. Otherwise, each Parcel element will have its Feature element that links to the ontology.

The DocFileRef element contains the attributes name, location, fileType and fileFormat, with the first two attributes as required and the other two optional. The name can be referred to the name of the document file being linked or the specific concept in the ontology, such as "StrataLot". Location is referred to any Uniform Resource Identifier (URI). As each concept in OWL contains a unique URI, the Parcel element can be linked to the concept in OWL through the location attribute in the DocFileRef element.
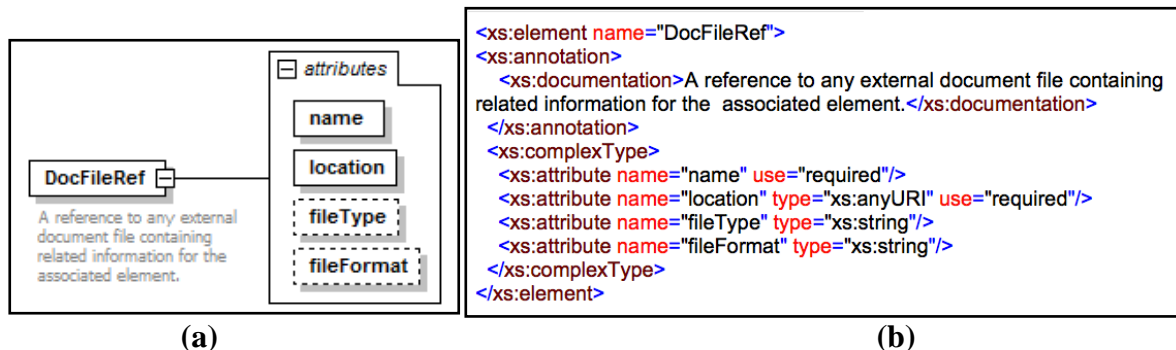

(a)

```
<xs:element name="DocFileRef">
<xs:annotation>
   <xs:documentation>A reference to any external document file containing
related information for the  associated element.</xs:documentation>
 </xs:annotation>
 <xs:complexType>
   <xs:attribute name="name" use="required"/>
   <xs:attribute name="location" type="xs:anyURI" use="required"/>
   <xs:attribute name="fileType" type="xs:string"/>
   <xs:attribute name="fileFormat" type="xs:string"/>
 </xs:complexType>
</xs:element>
```

(b)

Figure 2. (a) The *DocFileRef* element with attributes and (b) the XSD (XML Schema Definition) of the *DocFileRef* element (source: LandXML.org)

2.2 Ontology

The term *ontology* is originated in philosophy to refer to the science of what is, i.e. the kinds and structures of objects, properties, events, processes, and relations in every area of reality (Agarwal 2005; Smith 2003; Mark et al. 2004). From a philosophical perspective, ontology describes the constituents of reality, and the relationships among these constituents. Referring to the geographic domain, which includes cadastre, ontology describes human-made and natural features, categories, relations, and processes at different scales or spatial granularities (Smith 2003). To construct an ontology, therefore the understanding for the ontological foundations of geographic data (Soon 2010) is crucial.

Ontology has also been used in the information sciences community. Slightly diverging from its meaning in philosophy, ontology in the information sciences is a logical theory about how information systems operate. This type of ontology is defined as an explicit specification of a conceptualization (with conceptualizationoften referring to the perspective of the software developers who build the systems).

The ontology in this paper can be treated as a hybrid of the two definitions mentioned above. To be specific, the 3D cadastral ontology in this paper is developed from legislative documents. Legislative documents describe the constituents of reality and the relationships between these constituents, these documents do not explain the logical theory about how information systems operate. Having said that, the paperalso considers the 3D cadastral ontology as an explicit specification of conceptualization (i.e. the definition from the information sciences community). As we know, what is described in legislative documents is often hidden. By representing the hidden knowledge as ontology in OWL, it allows machines to process more intelligently.

2.3 Web Ontology Language (OWL)

Ontology has been proven useful in many applications, such as schema integration (Sheth and Larson 1990), information integration (Fonseca et al. 2002) and intelligent search (Soon et al. 2010). Ontology is used to explicitly describe semantics by using a formal language, Web Ontology Language (OWL)(W3C Working Group 2009). OWL is a World Wide Web Consortium standard and a variant of XML (eXtensible Markup Language), but different from a standard XML, OWL is enriched with axioms for semantic definitions to build ontology. By interpreting the knowledge in the ontology, a reasoner with Description Logics for instance, is able to perform certain operations automatically. As an example, OWL can describe the properties of and the semantic relationships between concepts. The concepts of airspace lots and subterranean lots can be described as subclasses of 3DParcel, and 3DParcel should have a certain height. When a system (supported with a reasoner) is encoded with this knowledge in OWL, and encounters a subterranean lot, the system can straightforwardly consider the respective lot as a 3DParcel, whichrequires certain height.

2.3.1 Some Basic Notions

OWL is a "knowledge representation language, designed to formulate, exchange and reason with knowledge about a domain of interest"(W3C Working Group 2009). OWL has been evolved from OWL 1 to OWL 2 with some significant improvements. This section introduces some basic notions of OWL 2 to provide fundamental background for the sections that follow. For more details of OWL 2, the readers are referred to OWL 2 Web Ontology Language (http://www.w3.org/TR/owl2-overview/) and subsequent links from the web site.

OWL[1] has three basic entities to represent knowledge. These entities are *classes*, *properties*, and *individuals*. *Classes* refer to categories, such as Parcel. *Properties* refer to relationships, such as `hasLotNumber`, which relates a parcel to a number. In this case, Parcel is the *domain* of the property `hasLotNumber` or `DataPropertyDomain (:hasLotNumber :Parcel)`, and number is the *range* or `DataPropertyRange (:hasLotNumberxsd:long)`. There are two types of properties: ObjectProperty and DataProperty. ObjectProperty refers to the relationship between classes or between individuals. For instance, `hasOwnership` is an ObjectProperty, which can relate Person to Parcel which both are classes. DataProperty is used to relate a class (or individual) to a value (e.g. number). `HasLotNumber`, as mentioned previously is a DataProperty. *Individuals* are instances of classes. An example of individuals is *lot1*, which is an instance of class Parcel. In this paper, the ontology describes classes and properties, andindividuals are captured in LandXML.

Classes and properties can have hierarchy. To form a hierarchy, classes and properties can respectively use `subClassOf` and `subPropertyOf`. For example, `subClassOf (:3DParcel :Parcel)` means that 3DParcel is a specification of Parcel (i.e. Parcel is more general than 3DParcel because Parcel can also be referred to SurfaceParcel).

`SubClassOf` and `subPropertyOf` are called axioms. An axiom is a truth statement or proposition. For example, `subClassOf (:3DParcel:Parcel)` is a statement that says 3Parcel

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[1] For the sake of simplicity, OWL 2 is simply referred as OWL in the paper.

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is a Parcel. All necessary statements should be explicitly defined to ensure the completeness ofthe ontology.

There are more complex axioms supported in OWL. Examples are `EquivalentClasses`, `FunctionalObjectProperty`, `ObjectIntersectionOf`,`ObjectUnionOf`,`ObjectAllValuesFrom`and`ObjectSomeValuesFrom`. `EquivalentClasses`is to state that two classes are equivalent, e.g.`EquivalentClasses (:Human:Person)`. `FunctionalObjectProperty`or`FunctionalDataProperty`refers to one and no more than one relationship. For example,`FunctionalDataProperty (:hasLotNumber)` means Parcel can have one and only one lot number.

`ObjectIntersectionOf`and`ObjectUnionOf`respectively refer to *intersection* and *union* in Set Theory or Boolean operators *AND*and*OR*. For example, being father means he is a man and a parent or in OWL,`ObjectIntersectionOf (:Man :Parent)`. For`ObjectUnionOf`, one can use it to specify for instance being parent, it is`ObjectUnionOf (:Mother :Father)`.

`ObjectAllValuesFrom`and`ObjectSomeValuesFrom`are treated as *universal quantification* (literally means "only" or "all") and *existential quantification* (literally means "at least one" or "some") respectively. For example being a disjoint parcel, *all* instances of the class DisjointParcel should be disjoint from (apart from) any Parcels or `ObjectAllValuesFrom (:disjoint :Parcel)`. But for being stratum, only some instances of the class Stratum are necessary to be disjoint or `ObjectSomeValuesFrom (:disjoint :Parcel)`.

Last but not least, all classes, properties and individuals are called *resources* in OWL. Each of the resources has a unique Uniform Resource Identifier (URI)[2]. For example, if the URI for the 3D cadastral ontology is http://www.sla.gov.sg/ontology/3DCadastralOntology.owl, the URIs for concepts Parcel and StrataLot are respectively http://www.sla.gov.sg/ontology/3DCadastralOntology.owl#Parcel and http://www.sla.gov.sg/ontology/3DCadastralOntology.owl#StrataLot.

3. ENGINEERING 3D CADASTRAL ONTOLOGY FROM LEGISLATIVE DOCUMENTS TO OWL

As mentioned previously, the 3D cadastral ontology is developed from the legislative documents that outline the regulations of governing the lands in Singapore. In this paper, notably three source documents are considered. These documents are Boundaries and Survey Maps Act (in short BSMA), Land Titles Act (LTA) and Land Titles (Strata) Act (in short LTSA), with the former describes all types of parcel lots, and the latter two describe in particular land parcel lots and strata lots. For readers who are interested to acquire the full documents of the Acts can refer to the Singapore Statutes Online at http://statutes.agc.gov.sg/.

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[2] Strictly speaking, OWL supports Internationalized Resource Identifier (IRI), which can contain universal character set including Chineseand Japanese in addition to the ASCII character set (e.g. A-Z Latin alphabets), which URI can only contain. Owing to the paper does not involve universal character set like Chinese, we simply use URI here.

3.1 Relevant Legislative Texts to Build 3D Cadastral Ontology

In this section, the paper will present some relevant texts extracted from the legislative documents. Specifically, in each of the referred documents, there is one section called "Interpretation" which contains the meanings of specific terms that are used in the document. The texts presented here are extracted from this particular section, and the 3D cadastral ontology is developed from these texts.

In Land Titles Act (Chapter 157),
"land" means —
(a) the surface of any defined parcel of the earth, all substances thereunder and so much of the column of airspace above the surface whether or not held apart from the surface as is reasonably necessary for the proprietor's use and enjoyment, and includes any estate or interest[3] therein and all vegetation growing thereon and structures affixed thereto; or
(b) any parcel of airspace or any subterranean space whether or not held apart from the surface of the earth and described with certainty by reference to a plan approved by the Chief Surveyor and filed with the Authority, and includes any estate or interest therein and all vegetation growing thereon and structures affixed thereto,
and where the context so permits, the proprietorship of land includes natural rights to air, light, water and support and the right of access to any highway on which the land abuts;

In Boundaries and Survey Maps Act,
"land" includes —
(a) a parcel of land which is in the actual possession of the owner by himself or other person holding by, through or under him;
(b) land covered by water;
(c) a building or a structure erected on land;
(d) any parcel of airspace or any subterranean space whether or not held apart from the surface of the earth; and
(e) any estate or interest in land;

In Land Title (Strata) Act (Chapter 158),
"lot" means a stratum which is shown as a lot on a strata title plan, and includes a lot specified as an accessory lot on any such plan
and
"stratum" means any part of land consisting of a space of any shape below, on or above the surface of the land, or partly below and partly above the surface of the land, the dimensions of which are delineated;
and
"accessory lot" means a lot intended for separate proprietorship and use with any other specified lot or lots for any purpose;

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[3] According to Land Titles Act, *"interest", in relation to land, means any interest in land recognised as such by law, and includes an estate in land*; therefore this paper considers "interest" and "estate" as equivalences, and the ontology only captures the relationship with "interest" only.

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3.2 Formalizing 3D Cadastral Concepts in OWL

The 3D cadastral concepts are formalized individually according to the source document. The resulting formalized concepts become the 3D cadastral ontology. In the following sub-sections, the formalization is described for concepts in each of the source documents.

3.2.1   Land Titles Act

"Land" as defined in the Land Titles Act can be referred to three types of parcel lots: Land Lot, Airspace Lot and Subterranean Lot. Here the paper considers "land" to be equivalent with Parcel, which is the top concept of the 3D cadastral ontology (i.e. all concepts in the ontology are then subsumed from Parcel).

Land Lot refers to the surface of a lot on earth, while Airspace Lot and Subterranean Lot are located above and under the Land Lot. Although the act currently does not explicitly define Airspace Lot and Subterranean Lot as 3D parcel, this paper sees the need to refer them as such for formalization. Thus there are two types of parcels, one is SurfaceParcel and the other is 3DParcel, and both are generally referred to as Parcel.

```
subClassOf (:LandLot :SurfaceParcel)
subClassOf (:AirspaceLot :3DParcel)
subClassOf (:SubterraneanLot :3DParcel)
subClassOf (:3DParcel :Parcel)
subClassOf (:SurfaceParcel :Parcel)
```

Minimally a parcel has a lot number and is shown on plan, which is approved by the chief surveyor. A plan mainly can be classified into Certified Plan and Strata Title Plan.

```
DataPropertyDomain (:hasLotNumber :Parcel)
DataPropertyRange (:hasLotNumberxsd:long)
FunctionalDataProperty (:hasLotNumber)

ObjectPropertyDomain (:isShownOn :Parcel)
ObjectPropertyRange (:isShownOn :Plan)

ObjectPropertyDomain (:isApprovedBy :Plan)
ObjectPropertyRange (:isApprovedBy :ChiefSurveyor)

subClassOf(:CertifiedPlan :Plan)
subClassOf(:StrataTitlePlan :Plan)
```

All parcels have Height (although sometimes SurfaceParcel can have a zero height).

```
DataPropertyDomain (:hasHeight :Parcel)
DataPropertyRange (:hasHeightxsd:double)
```

3DParcel has 2D Outer Most Boundary

```
ObjectPropertyDomain (:hasOuterMostBoundary :3DParcel)
ObjectPropertyRange (:hasOuterMostBoundary :OuterMostBoundary)
```

SurfaceParcel has SurfaceParcelBoundary.

```
ObjectPropertyDomain(:hasSurfaceParcelBoundary :SurfaceParcel)
ObjectPropertyRange(:hasSurfaceParcelBoundary :SurfaceParcelBoundary)
```

Both OuterMostBoundary and SurfaceParcelBoundary are subclasses of 2DBoundary
```
subClassOf(:OuterMostBoundary :2DBoundary)
subClassOf(:SurfaceParcelBoundary :2DBoundary)
```

andOuterMostBoundaryshould always be located within SurfaceParcelBoundary.
```
ObjectPropertyDomain (:isWithin :OuterMostBoundary)
ObjectPropertyRange (:isWithin :SurfaceParcelBoundary)
```

3DParcel can "meet" (i.e. on) or "disjoint" (i.e. apart from) with SurfaceParcel[4].
```
ObjectPropertyDomain(:disjoint :3DParcel)
ObjectPropertyRange(:disjoint :SurfaceParcel)


ObjectPropertyDomain(:meet :3DParcel)
ObjectPropertyRange(:meet :SurfaceParcel)
```

3DParcel can only be attached with one SurfaceParcel.
```
ObjectPropertyDomain (:hasSurfaceParcel :3DParcel)
ObjectPropertyRange (:hasSurfaceParcel :SurfaceParcel)
FunctionalObjectProperty (:hasSurfaceParcel)
```

Specifically, SubterreanLot is located under SurfaceParcel,
```
ObjectPropertyDomain(:isUnder :SubterraneanLot)
ObjectPropertyRange(:isUnder :SurfaceParcel)
```

andAirspaceLot is located above SurfaceParcel.
```
ObjectPropertyDomain(:isAbove :AirspaceLot)
ObjectPropertyRange(:isAbove :SurfaceParcel)
```

With these spatial relationships defined, more new concepts can be identified as follows.

One of them is the DisjointSubterraneanLot concept. This concept refers to a subterranean lot that is apart from SurfaceParcel.
```
subClassOf (:DisjointSubterraneanLot :SubterraneanLot)
EquivalentClasses(
          :DisjointSubterraneanLot
ObjectIntersectionOf(
ObjectAllValuesFrom(:disjoint :SurfaceParcel)
          :SubterraneanLot
)
```

---

[4] The readers are referred to Zlatanova, S. (2000) for more details on 3D spatial relationships, such as meet, disjoint and overlap.

```
)
```

The other is the MeetSubterraneanLot concept, which refers to subterranean lot that "touches" SurfaceParcel.

```
subClassOf (:MeetSubterraneanLot :SubterraneanLot)
EquivalentClasses(
        :MeetSubterraneanLot
ObjectIntersectionOf(
ObjectAllValuesFrom (:meet :SurfaceParcel)
        :SubterraneanLot
)
)
```

Similarly, two new concepts can also be defined for airspace lot. One is the DisjointAirspaceLot, which refers to an airspace lot that is apart from SurfaceParcel.

```
subClassOf (:DisjointAirspaceLot :AirspaceLot)

EquivalentClasses(
        :DisjointAirspaceLot
ObjectIntersectionOf(
ObjectAllValuesFrom (:disjoint :SurfaceParcel)
        :AirspaceLot
)
)
```

The other is the MeetAirspaceLot concept. This concept refers to an airspace lot that "touches" SurfaceParcel.

```
subClassOf (:MeetAirspaceLot :AirspaceLot)

EquivalentClasses(
        :MeetAirspaceLot
ObjectIntersectionOf(
ObjectAllValuesFrom (:meet :SurfaceParcel)
        :AirspaceLot
)
)
```

Finally, other non-spatial relationships can also be defined.

```
ObjectPropertyDomain (:hasVegetationOn :Vegetation)
ObjectPropertyRange (:hasVegetationOn :Parcel)

ObjectPropertyDomain (:hasAffixedStructureTo :AffixedStructure)
ObjectPropertyRange (:hasAffixedStructureTo :Parcel)

ObjectPropertyDomain (:isOwnedFor :Parcel)
ObjectPropertyRange (:isOwnedFor :Proprietorship)
```

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with Proprietorship refers to natural rights to air, light, water and support and the right of access.

```
subClassOf (:NaturalRightsToAir :Proprietorship)
subClassOf (:NaturalRightsToLight :Proprietorship)
subClassOf (:NaturalRightsToWater :Proprietorship)
subClassOf (:NaturalRightsToSupport :Proprietorship)
subClassOf (:RightOfAccess :Proprietorship)
```

3.2.2   Land Titles (Strata) Act

In Land Titles (Strata) Act, three important concepts are defined. These concepts are StrataLot, which is referred as "lot" in LTSA, Accessory Lot and Stratum.

Let us start with StrataLot. As defined in LTSA, StrataLot is a stratum that is shown as lot on plan, and it includes accessory lot.

In other words, to be considered as a strata lot, the stratum should be a parcel, which has a lot number and is shown on plan.

```
EquivalentClasses(
            :StrataLot
ObjectIntersectionOf(:Stratum :Parcel)
)
```

Logically, a strata lot is also considered as a 3DParcel. (Therefore, like other 3DParcels, StrataLot also has properties like hasOuterMostBoundary and hasHeight.)

```
subClassOf(:StrataLot :3DParcel)
```

A strata lot also has an accessory lot

```
ObjectPropertyDomain (:hasLot :StrataLot)
ObjectPropertyRange (:hasLot :AccessoryLot)
```

which is intended for separate proprietorship, and is also a 3DParcel.

```
ObjectPropertyDomain (:separateProprietorshipFrom :AccessoryLot)
ObjectPropertyRange (:separateProprietorshipFrom :StrataLot)

subClassOf(:AccessoryLot :3DParcel)
```

For stratum, it has shape and dimensions

```
ObjectPropertyDomain (:hasShape :Stratum)
ObjectPropertyRange (:hasShape :Shape)

DataPropertyDomain (:hasDimensions :Stratum)
DataPropertyRange (:hasDimensionsxsd:double)
```

Stratum also has spatial relationships overlap, meet and disjoint with SurfaceParcel.

```
ObjectPropertyDomain (:overlapStratum :Stratum)
```

```
ObjectPropertyRange (:overlapStratum :SurfaceParcel)

ObjectPropertyDomain (:meetStratum :Stratum)
ObjectPropertyRange (:meetStratum :SurfaceParcel)

ObjectPropertyDomain (:disjointStratum :Stratum)
ObjectPropertyRange (:disjointStratum :SurfaceParcel)
```

Specifically, Stratum can be defined as follows.
```
EquivalentClasses(
          :Stratum
ObjectUnionOf(
ObjectSomeValuesFrom (:overlapStratum :SurfaceParcel)
ObjectSomeValuesFrom (:disjointStratum :SurfaceParcel)
ObjectSomeValuesFrom (:meetStratum :SurfaceParcel)
)
)
```

3.2.3   Boundaries and Survey Maps Act

In addition to the definitions for "land" in LTA, BSMA defines land to include ownership and to be covered by water. Here again the paper considers "land" to be equivalent with Parcel. Therefore,
```
ObjectPropertyDomain (:hasOwnership :Person)
ObjectPropertyRange (:hasOwnership :Parcel)

ObjectPropertyDomain (:hasInterestIn :Person)
ObjectPropertyRange (:hasInterestIn :Parcel)

ObjectPropertyDomain (:isCoveredBy :Parcel)
ObjectPropertyRange (:isCoveredBy :Water)
```

4.   THE TWO-TIER FRAMEWORK

The Parcel element in the LandXML document is linked with the respective concept in OWL through URI. The link forms a two-tier framework as illustrated in Figure 3. In this framework, the lower tier (i.e. the Data Tier) captures all data related to the parcel, while the upper tier (the Knowledge Tier) represents knowledge including rules and semantic relationships of the respective concepts, which were discussed in Section 3.
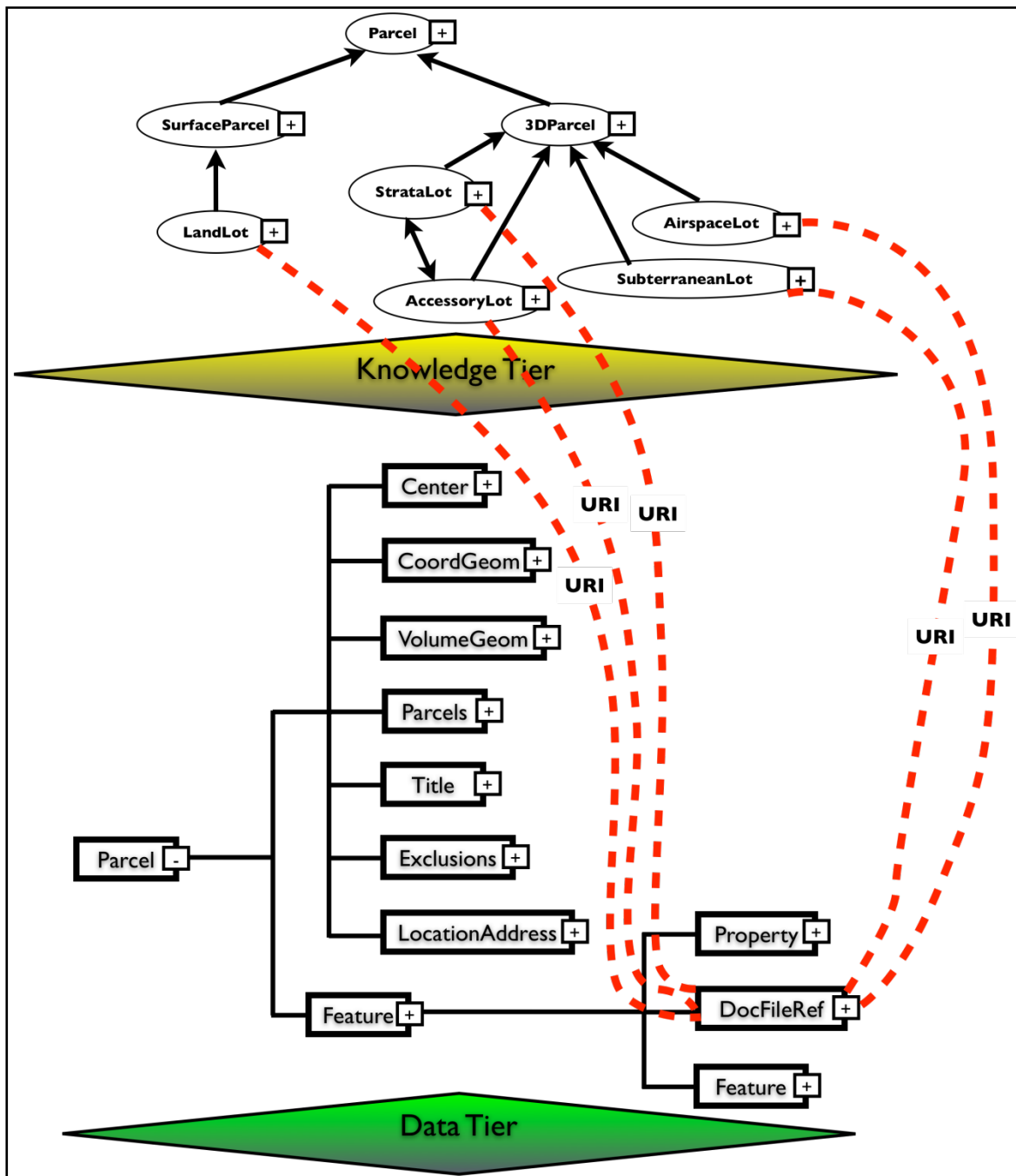
Figure 3. The two-tier framework consists of the Data Tier and the Knowledge Tier

In the following, Section 4.1 describes how the linkage can be made through URI, and Section 4.2 discusses potential applications resulting from the two-tier framework.

4.1 Linking LandXML to OWL

Ontology developed in Section 3 should be linked with the LandXML documents so that data described in the LandXML documents can be reasoned for data integrity and consistency. To enable the reasoningaboutthe data, the Parcel element from LandXMLis linked to the ontology based on the type of parcel (e.g. Strata lot, Airspace Lot). For example, let's say the

parcel described in the LandXML is a strata lot, the *DocFileRef* of the Parcel element should be linked to the StrataLot concept in the ontology as illustrated in Figure 4.

```
<DocFileRef name="StrataLot" location="http://www.sla.gov.sg/ontology/3DCadastralOntology.owl#StrataLot" />
```

Figure 4.Linkage of LandXML to ontology through DocFileRef.

Notethat *DocFileRef* should be linked to a specific concept, not to a more general or more specific concept, the reason being that the necessary knowledge that can be used for reasoning may be lost. For example if the type of parcel is subterranean lot, theDocFileRef should link to SubterraneanLot and not to 3DParcel or MeetSubterraneanLot in the ontology. Linking to 3DParcel concept will not allow thereasoner to infer whether the parcels described in the LandXMLare located above or under the land lot, because 3DParcel also includes other types of parcels such asStrataLot, AirspaceLot and AccessoryLot. In contrast, if the LandXML is linked to the MeetSubterraneanLot concept, the reasoner will infer that the parcels are located on the land lot. Parcels that are apart from the surface will be flagged as an error, although these parcels are subterranean lots.

4.2 Applications
4.2.1 Data Integrity and Consistency
The ontology can serve as rules for checking the integrity and consistency of data (Frank 2001; Duckham et al.2006) in the LandXML. For example, in the ontology, 3DParcel has been specified to have only one SurfaceParcel and each Parcel can only have one lot number. When updating a strata lot in a LandXML, a system will be able to automatically alert the users if the surface parcel associated with the strata lot has a different lot number. Likewise, the ontology has defined that airspace lot is located above land lot. When realized that the height of a parcel, which has been specified as airspace lot in the LandXML, is below the associated land lot, a system can inform the users to check for the inconsistency between the type of parcel and the height in the LandXML.

4.2.2 Semantic Data Integration
Cadastral data is one of the fundamental datasets in Singapore's National Spatial Data Infrastructure (NSDI), SG-SPACE (Singapore Geospace Collaborative Environment) (Khoo 2009). The cadastral dataset is often used to integrate with other datasets, such as the transportation datasets, which include roads, rails (includes the Mass Rapid Transit (MRT)), and these datasets sometimes are meant to be interpreted in three dimensions, such as the flyover bridges/roads, above-surface and below-surface MRTs. In order to integrate these datasets, especially in an automated way, the semantics of the datasets are crucial and should be made explicit and clear (Harvey et al. 1999; Metral et al.2010). With the 3D cadastral ontology in place, it facilitates the automatic integration between the cadastral dataset with other datasets, provided the target dataset also explicitly defines its semantics. For example, a below-surface rail has been defined as a class that has a property of below the earth surface in a transportation ontology. A system will be able to integrate a dataset depicting the below surface rails with subterranean lots from a cadastral dataset because both are referred to as below the earth surface.

5. CONCLUSIONS

The paper has presented a conceptual framework of representing semantics for 3D cadastre in Singapore. There are two main contributions of this paper. One is developing the 3D cadastral ontology; the other is supportingLandXML with semantic representation by linking the LandXML with OWL.

Knowledge presented in legislative documents is often implicit. To make use of the knowledge, it should be made explicit and formalized in a formal language like OWL, so that computers are able to interpret the knowledge for intelligent processing. The paper has taken a first step to formalize the knowledge in legislative documents to ontology in OWL. Also, concepts related to 3D cadastre are ambiguous. Only by making explicit the semantics of what is described in the documents, the gap of conceptual differences can be reduced.

The ontology would not be more useful, if it is not linked with the respective dataset. To utilize the ontology to its fullest extent, corresponding concepts in the ontology should be linked with the related dataset. Only by that, a reasoner is able to reason about the data for integrity and consistency. The paper has shown the two-tier framework that links LandXML with OWL through unique URI. With this linkage, the two-tier frameworkhas merged the semantic and geometrical aspects of 3D cadastre.

5.1 Future Work

Spatial relationships are mainly divided into topological (e.g. meet, disjoint, overlap) (Egenhofer 1989), directional (e.g. right, under, above) (Eschenbach 1999) and proximity (e.g. near, far) (Gahegan 1995). Spatial relationships like under and above are significantly important to define the concepts in 3D cadastre. But in the paper, the definitions of "above" and "under" are relatively weak. To complement this, one way is to consider Semantic Web Rule Language (Horrocks et al. 2004), which can be used to define more complex expressions and rules.

Another limitation is that the paper has only demonstrated the conceptual framework. A running case study is necessary to show the feasibility of the proposed framework.

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BIOGRAPHICAL NOTES

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