Semantics-based Fusion for CityGML and 3D LandXML

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Key words: Semantics-based Data Fusion, CityGML, LandXML, OWL, LADM Ontology

SUMMARY

For any developments that require spatial data, often the fusion of diverse spatial datasets is unavoidable. For instance in developing a 3D cadastral database serving various purposes, data may need to be sourced from different spatial datasets such as: building design models in BIM (Building Information Model) format, topographic and built environment information in CityGML, and cadastral legal boundaries in LandXML. Syntactically and systematically this is not difficult provided the formats of datasets involved are open and are XML-based, but the fusion becomes non trivial when semantic heterogeneity occurs between schemas for example between LandXML and CityGML.

This paper proposes a semantics-based fusion framework to integrate CityGML and 3D LandXML. The paper adopts the ePlan conceptual model, which is implemented in LandXML in Australia and New Zealand. Compared with the standard LandXML schema, the ePlan model is comprehensive to represent specifically cadastral survey information. The ePlan model is integrated with the Building module of CityGML through the LADM OWL Ontology. In previous research, ISO 19152 Land Administration Domain Model (LADM) has been formalized in Web Ontology Language (OWL). To integrate 3D LandXML and CityGML, this LADM OWL ontology is extended with new concepts: *Physical Space Building Unit* and *Physical Space Utility Network* and new relation: *hasLegalSpace*. Every concept in OWL ontology has a unique URI (Uniform Resource Identifier). The URIs of Physical Space Building Unit and Legal Space Building Unit from the LADM OWL ontology are respectively referenced by CityGML's *ExternalReference* element and LandXML's *DocFileRef* element.

The proposed framework attempts to integrate not only the semantic models inherent in the schemas but also the geometries from CityGML and LandXML. Through this semantics-based fusion, it is expected that a computer system will be able to do reasoning and inference in the OWL ontology. The computer system will also be able to retrieve the geometries of building unit's legal space or physical construct, or both, through the ExternalReference and DocFileRef elements. The objective of the framework is to preserve the best of all worlds without changing the existing schemas. Although the framework is a preliminary study and no operational implementation has been done so far, this paper hopes to provide a useful reference in discussing the future directions and harmonization of the schemas.

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1. INTRODUCTION

For any developments that require spatial data, often the fusion of diverse spatial datasets is unavoidable. For instance in developing a 3D cadastral database serving various purposes, data may need to be sourced from different spatial datasets such as: building design models in BIM (Building Information Model) format, topographic and built environment information in CityGML, and cadastral legal boundaries in LandXML.

Syntactically and systematically this is not difficult provided the formats of datasets involved are open and are XML-based, because computer systems are able to parse and process such datasets in any platform. In addition, commercial software such as FME has also been able to support the export and import of a number of 3D standards. The fusion becomes non trivial when semantic heterogeneity occurs between schemas for example between LandXML and CityGML.

This paper proposes a semantics-based fusion framework to integrate CityGML and 3D LandXML. As commonly known currently most projects are using LandXML for 2D applications as far as modeling of parcel is concerned. The paper extends LandXML to model 3D parcels and introduces the Nested Parcels Approach, which makes use of the element of PntList3D of LandXML, to store 3D coordinates.

The paper adopts the ePlan conceptual model in the framework. To support digital lodgment and automated processing in cadastral survey, the ePlan conceptual model is implemented in LandXML in Australia and New Zealand (and a similar model is being developed in Singapore). Compared with the standard LandXML schema, the ePlan model is chosen because the model is comprehensive to represent specifically cadastral survey information.

The ePlan model is integrated with the Building module of CityGML through the LADM OWL Ontology. In previous research, ISO 19152 Land Administration Domain Model (LADM) has been formalized in Web Ontology Language (OWL) (Soon, 2013). To integrate 3D LandXML and CityGML, this LADM OWL ontology is extended with new concepts *Physical Space Building Unit* and *Physical Space Utility Network* and new relation *hasLegalSpace*. Every concept in OWL ontology has a unique URI (Uniform Resource Identifier). The URIs of Physical Space Building Unit and Legal Space Building Unit from the LADM OWL ontology are respectively referenced by CityGML's *ExternalReference* element and LandXML's *DocFileRef* element.

The proposed framework attempts to integrate not only the semantic models inherent in the schemas but also the geometries from CityGML and 3D LandXML. Through this semantics-based fusion, it is expected that a computer system will be able to do reasoning and inference in the OWL ontology. The computer system will also be able to retrieve the geometries of building unit's legal space or physical construct, or both, through the ExternalReference and DocFileRef elements. The objective of the framework is to preserve the best of all worlds without changing the existing schemas, that is, by utilizing OWL ontology for reasoning and inference, using CityGML for topographic information like the physical construct of buildings, and 3D LandXML for legal boundaries in 3D. Overall, although the framework is a preliminary study and no operational implementation has been done so far, this paper hopes to provide a useful reference in discussing the future directions and harmonization of these schemas.

In what follows, Section 2 discusses the background context, which includes CityGML, 3D LandXML and OWL. Section 3 focuses on LADM OWL ontology and the extension to facilitate the fusion. Section 4 elaborates on the semantics-based fusion framework. Section 5 concludes the paper.

2. BACKGROUND

2.1 CityGML

Open Geospatial Consortium (OGC) has defined CityGML (City Geography Markup Language) for modeling 3D city models. The current version of CityGML is 2.0 and contains modules like Relief, Building, City Furniture, Water Body, Bridge, Tunnel, Vegetation, Land Use, and Transportation. CityGML defines classes, attributes and relations for topographic features with aspects of geometrical, topological, semantic and appearance. Different level of details can be captured from LOD (Level of Details) 0 to LOD 4. LOD 0 represents the earth surface (i.e. the terrain) be it as Digital Terrain Model (DTM) or Digital Surface Model (DSM). LOD 1 represents topographic and constructed features as simple 3D blocks (i.e. no texturing or appearance). LOD 2 shows topographic features with texturing and refined top structure. As the case of building for example, instead of a flat roof surface in LOD 1, LOD 2 models the actual shape of a rooftop. LOD 3 models more detailed topographic features and includes other external installations for example windows and doors. LOD 4 includes internal installation modeling (van den Brink, et. al., 2013).

In the Building module of CityGML, Abstract Building is an important class, which has two subclasses called Building and Building Part as depicted in Figure 1. The attributes for Abstract Building class include Class, Function, Usage, RoofType, MeasuredHeight, etc. Abstract Building class also has geometries, which support for the level of details from LOD 0 to LOD 4. As Abstract Building class' specializations, Building and Building Part inherit all attributes and relations of Abstract Building.

Abstract Building class has a part called Boundary Surface class, which consists of two specialization classes called Roof Surface and Wall Surface. Boundary Surface class has a part Opening, which has two subclasses Window and Door. Boundary Surface itself is also part of the class, Room.

At the higher level, Abstract Building class is a subclass of CityObject. CityObject has attributes like creationDate, terminationDate and externalReference. Particularly related to this paper is the ExternalReference element. Through this element, one can relate a city object like a building to an external reference, such as a concept in OWL ontology, using URI (Uniform Resource Identifier).

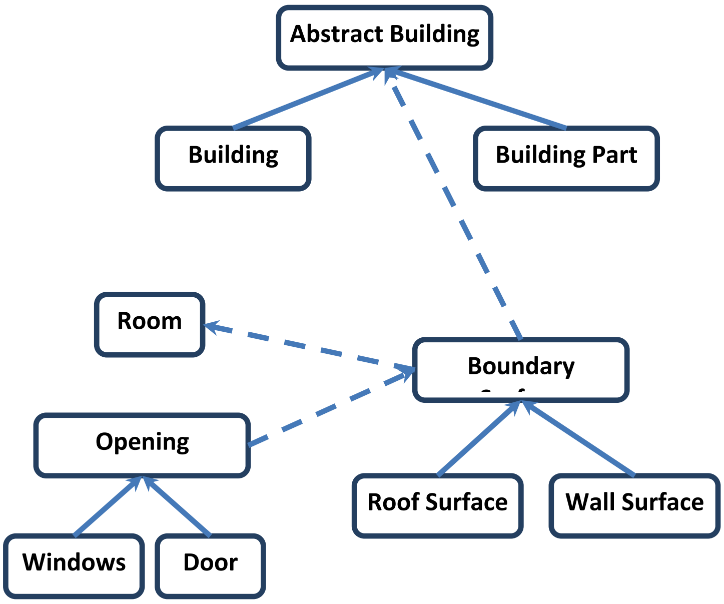


Figure 1. Building conceptual model of CityGML

As an example, a snapshot of CityGML for LOD 1 buildings is shown in Figure 2. As shown in the figure, using the ExternalReference element, CityGML can be linked to external sources using URI. In addition to other attributes such as usage, measuredHeight (e.g. reduced level from a vertical datum) and external address, a LOD 1 building also has geometries, which can be defined as solid (e.g. lod1Solid).

```
▼<cityObjectMember>
 ▼<bldg:Building gml:id="GML_7b1a5a6f-ddad-4c3d-a507-3eb9ee0a8e68">
  ▼<externalReference>
   ▼<externalObject>
    ▼<uri>
      http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#PhysicalSpaceBuildingUnit
     </uri>
    </externalObject>
   </externalReference>
   <gml:name>HDB</gml:name>
   <bldg:class codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_class.xml">1000</bldg:class>
   <bldg:function codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_function.xml">1000</bldg:function>
   <bldg:roofType codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_roofType.xml">1000</bldg:roofType>
   <bldg:measuredHeight uom="#m">26.687</bldg:measuredHeight>
  ▶<bldg:lod1Solid>...</bldg:lod1Solid>
  ▶<bldg:address>...</bldg:address>
  </bldg:Building>
</cityObjectMember>
```

Figure 2. A snapshot of CityGML Building LOD 1

The CityGML schema can be extended to have additional modules such as Cadastre using the Application Domain Extension (ADE) (Stoter, et. al (2011); van den Brink, et. al. (2013)). However, instead of extending the CityGML schema using ADE for Cadastre, the framework considers the ePlan model which is implemented in LandXML. The rationale is that as far as cadastral survey is concerned, the ePlan model is stable and it has operationally been implemented in Australia and New Zealand over the years. In Singapore, a model similar to ePlan is also being developed in LandXML.

2.2 3D LandXML

2.2.1 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, 2010b) and Land Information New Zealand (LINZ)'s LandOnline (Haanen and Sutherland, 2002) have been using LandXML as a national standard for cadastral electronic lodgment. The Land Survey Division of Singapore Land Authority (SLA) has embarked on 3D LandXML to replace the existing in-house cadastral submission format for cadastral job processing and 3D Cadastres.

Figure 3 illustrates an overview of the LandXML schema, which is modeled after the LandXML 1.2 diagram publicly available at LandXML.org (http://www.landxml.org/). As described in Figure 3, LandXML can also be used for capturing other types of engineering data, such as pipe networks and roadways. In this paper, we primary focus on the Parcels element and its sub elements.

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 or labeling point of the parcel), 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 (sub)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 (for additional information that is not explicitly defined by the schema).

As a sub-element of the Feature element, the DocFileRef element contains the attributes, name, location, fileType and fileFormat, with the first two attributes defined as required and the rest as optional (see Figure 4). The name can be referred to the name of the document file being linked or a specific concept. Location is referred to any URIs. Like the ExternalReference element in the CityGML schema, the Parcel element can be linked to the concept in OWL through the location attribute in the DocFileRef element.

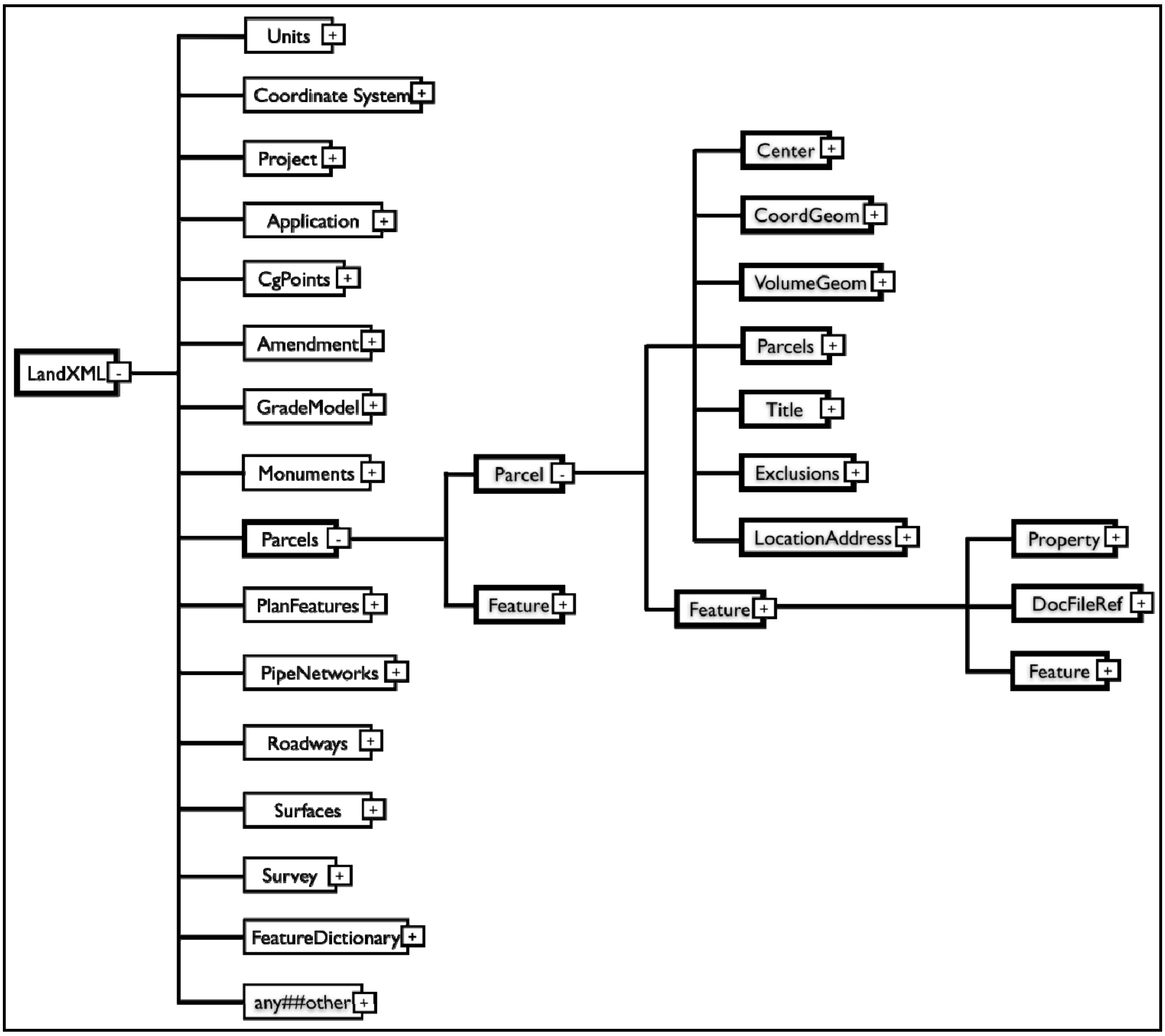
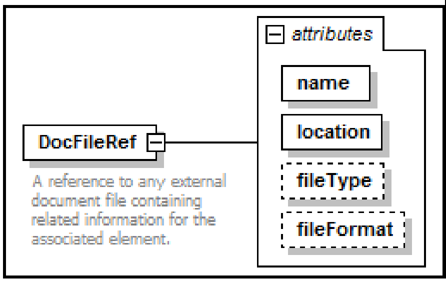


Figure 3. Overview of the LandXML schema with expansion of the *Parcels* element (source: LandXML.org)




```
<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>
```

(a) **(b)**

Figure 4. (a) The *DocFileRef* element with attributes and (b) the XSD (XML Schema Definition) of the *DocFileRef* element (source: LandXML.org)

2.2.2 Nested parcels approach

To support 3D Cadastres, the existing LandXML schema is utilized to model 3D parcels. Figure 5 illustrates an approach of using the element of PntList3D, which is a sub-element of IrregularLine in the LandXML schema. As shown in Figure 5, to model 3D parcels in Coordinated Cadastre system, a CoordGeom represents a face that contains 3D coordinates (Northing, Easting, and Height) in PntList3D. A series of faces forms a volumetric parcel (i.e. Parcel "70021N"). The volumetric parcel can be referenced to an external resource as a URI. (Alternatively to model 3D parcels in LandXML, one can also use VolumeGeom element, as discussed previously in Shojaei, et. al. (2012).

```xml
▼<Parcel name="70021N/1">
  ▼<CoordGeom>
    ▼<IrregularLine>
       <Start pntRef="433a"/>
       <End pntRef="433a"/>
      ▼<PntList3D>
         29452.018 30232.133 123.280 29452.832 30216.800 123.280 29425.899 30215.278 123.280 29422.375 30281.345
         123.280 29482.916 30284.567 123.280 29484.221 30260.005 123.280 29451.876 30258.266 123.280 29452.008
         30255.922 123.280 29452.207 30250.316 123.280 29451.056 30250.256 123.280 29452.018 30232.133 123.280
       </PntList3D>
     </IrregularLine>
   </CoordGeom>
 </Parcel>
▶<Parcel name="70021N/2">...</Parcel>
▶<Parcel name="70021N/3">...</Parcel>
▶<Parcel name="70021N/4">...</Parcel>
▼<Parcel name="70021N" area="2621.4" parcelFormat="Volumetric">
  ▼<Feature>
     <DocFileRef name="Parcel"
     location="http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#SpatialUnit"/>
   </Feature>
  ▼<Parcels>
     <Parcel name="Face1" pclRef="70021N/1"/>
     <Parcel name="Face2" pclRef="70021N/2"/>
     <Parcel name="Face3" pclRef="70021N/3"/>
     <Parcel name="Face4" pclRef="70021N/4"/>
```

Figure 5. The geometries of 3D parcels are captured using the PntList3D element in LandXML. A volumetric parcel can be referenced to an external resource as a URI

2.2.3 ePlan model

Under the ICSM's ePlan Working Group, a conceptual model called ePlan Model was developed to represent all elements in cadastral survey plans for Australia (Cumerford, 2010a) (see Figure 6 which is derived from Cumerford (2010a)). To support digital lodgment and automated processing, the ePlan model has been adopted as the model for ePlan protocol (Cumerford, 2010b). In Queensland, an instance of the ePlan protocol is called Cadastral Information File (CIF), which contains information that appears in survey plans for registration. The Cadastral Information File is aligned with LandXML and classes in the ePlan model are mapped directly to the elements in LandXML (ICSM (2010); Kalantari, et. al (2013)). This paper adopts the ePlan model in the semantics-based fusion with CityGML as LandXML itself does not define a comprehensive model that represents cadastral survey in particular.

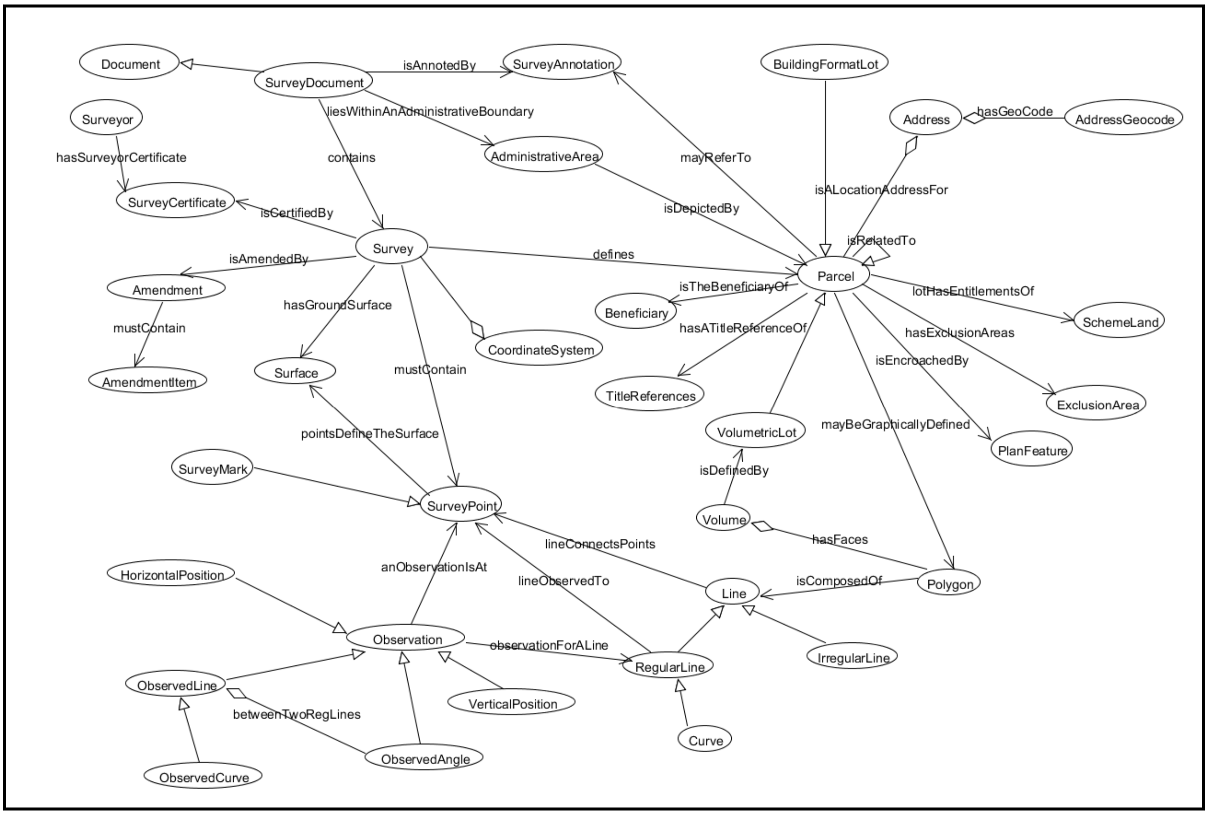


Figure 6. ePlan conceptual model (derived from Cumerford (2010a))

2.3 Web Ontology Language (OWL)

OWL is a World Wide Web Consortium standard and a "knowledge representation language, designed to formulate, exchange and reason with knowledge about a domain of interest" (W3C OWL Working Group, 2012). This section introduces some basic notions of OWL 2 to provide fundamental background. 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.

2.3.1 Basic notions

OWL[1] has three basic entities to represent knowledge. These entities are *classes*, *properties*, and *individuals*. *Classes* refer to categories, such as Party. *Properties* refer to relationships or attributes, such as `hasPartyName,` which relates a party to a name. In this case, Party is the *domain* of the property `hasPartyName` or `DataPropertyDomain (:hasPartyName :Party)`, and string is the *range* or `DataPropertyRange (:hasPartyName xsd:string)`. There are two types of properties: ObjectProperty and DataProperty. ObjectProperty refers to the relationship between classes or between individuals. For instance, `hasPartyMembers` is an ObjectProperty, which can relate GroupParty to PartyMember which both are classes. DataProperty is used to relate a class (or individual) to a value (e.g. number). `HasPartyName`, as mentioned previously is a DataProperty. Different from OWL 1, OWL 2 supports user-defined DataProperty in addition to the existing built-ins such as integer and string.

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

Individuals are instances of classes. An example of individuals is *Kean*, which can be an instance of class Party.

Classes and properties can have hierarchy. To form a hierarchy, classes and properties can respectively use `subClassOf` and `subObjectPropertyOf`. For example, `subObject-PropertyOf (:hasRight :hasRRR)` means that whenever A has `hasRight` relationship with a basic administration unit, A also has `hasRRR` relationship.

`SubClassOf` and `subObjectPropertyOf` are called axioms. An axiom is a truth statement or proposition. For example, `subClassOf (:GroupParty :Party)` is a statement that says GroupParty is a Party. All necessary statements should be explicitly defined to ensure the completeness of the ontology.

There are more complex axioms supported in OWL. Examples are `EquivalentClasses`, `FunctionalObjectProperty`, `FunctionalDataProperty`, `ObjectIntersectionOf`, `ObjectUnionOf`, `ObjectAllValuesFrom` and `ObjectSomeValuesFrom`. `Equivalent-Classes` 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/attribute. For example, `FunctionalDataProperty (:hasPartyName)` means Party can have one and only one name.

All classes, properties and individuals are called *resources* in OWL. Every resource has a unique Uniform Resource Identifier (URI)[2]. An example of URI for the LADM ontology is: http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl.

3. LADM OWL ONTOLOGY

With the current ISO 19152 - Land Administration Domain Model (LADM) standard (ISO, 2012) that is modeled in Unified Modeling Language (UML) and additional explanatory natural text and tables, it will facilitate the software development and database design for the proper implementation of land administration systems. The use of UML supports generating a database schema or exchange format. To support reasoning and inference, Soon (2013) has formalized LADM in OWL. LADM OWL ontology will also support automated integration for land administration information (Boskovic, et. al. (2010); Sladic, et al (2013)). As an overview, Figure 7 demonstrates the classes in the LADM OWL ontology. The OWL ontology is made available at www.isoladm.org (hosted under the ImplementationMaterial link).

3.1 Extending the LADM OWL ontology

In the existing LADM OWL ontology, Spatial Unit has two sub-classes, Legal Space Utility Network and Legal Space Building Unit, which represent the legal boundary of a utility

[2] Strictly speaking, OWL supports Internationalized Resource Identifier (IRI), which can contain universal character set characters such as Chinese and Japanese in addition to the ASCII character set (e.g. A-Z Latin alphabets, to which URI is restricted). Because this paper is expressed in the Latin alphabet, we simply use URI here.

network and a building unit respectively. With the intention to use the LADM OWL ontology for automated integration of land administration information, the LADM OWL ontology is augmented with a new concept Physical Space Building Unit (see Figure 8). In addition, as a physical building sometimes can have more than one legal boundary, for example through strata subdivision, a relation is defined as hasLegalSpace between Physical Space Building Unit and Legal Space Building Unit. hasLegalSpace is an ObjectProperty in the LADM OWL ontology.

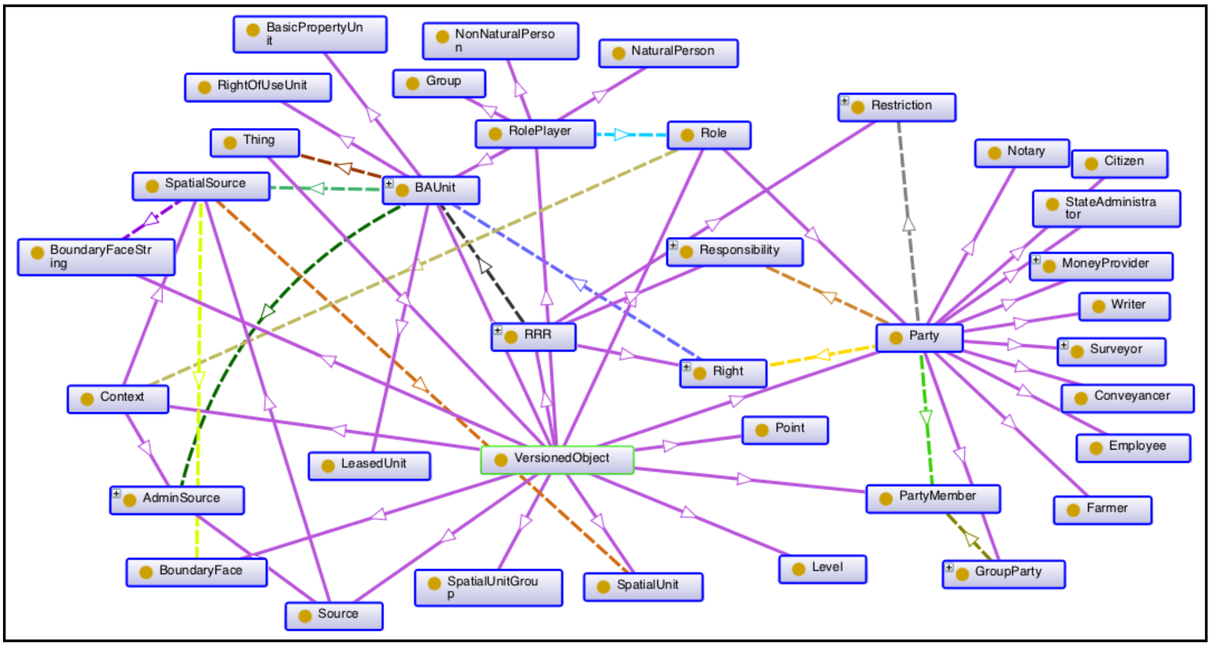


Figure 7. Overview of the existing LADM OWL ontology (Soon, 2013).

The same also applies to utility network where a new concept *Physical Space Utility Network* is added. The relation hasLegalSpace also links Physical Space Utility Network with Legal Space Utility Network (Utility Network will not be further discussed here).

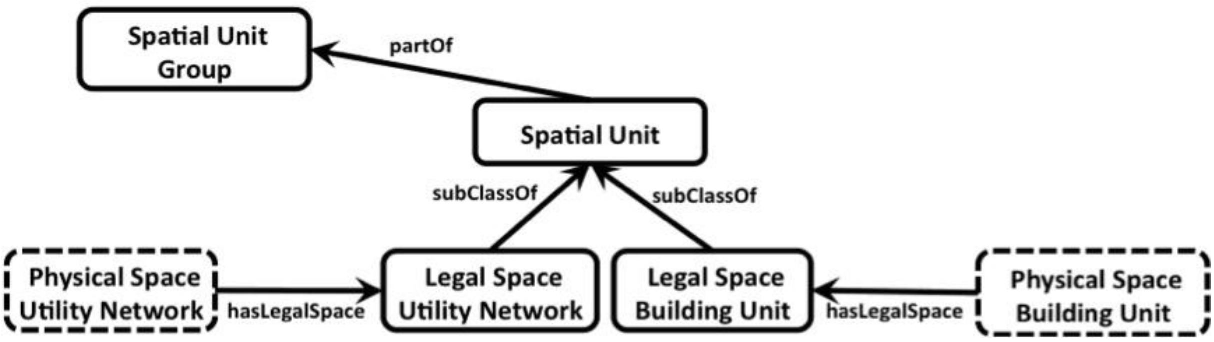


Figure 8. Extension to the existing LADM OWL ontology with new concepts Physical Space Utility Network and Physical Space Building Unit (highlighted in dash-lined boxes) and with a new relation hasLegalSpace

4. SEMANTICS-BASED FUSION FRAMEWORK

With the addition of new concepts in the LADM OWL ontology, it helps to integrate information about building from CityGML and LandXML. The following sub-sections discuss the interconnections between LADM OWL ontology and CityGML, and between LADM OWL ontology and ePlan model respectively. This section also discusses how the interconnections can be syntactically realized.

4.1 Interconnection between LADM ontology and CityGML building module

In CityGML, Abstract Building class essentially captures the physical construct of a building, or a building part. It is not meant to contain any legal boundary of the building. Conceptually therefore, Abstract Building class from the Building module of CityGML can be considered as an equivalent class with the Physical Space Building Unit concept of the LADM OWL ontology (Figure 9). With this relation, the subclasses of Abstract Building, Building and Building Part are also equivalent with Physical Space Building Unit.

The equivalent class relation between Physical Space Building Unit and Abstract Building can also be inferred that a physical building or a building part in CityGML has a legal space (i.e. the legal boundary) through the hasLegalSpace relation between Physical Space Building Unit and Legal Space Building Unit in the LADM OWL ontology.

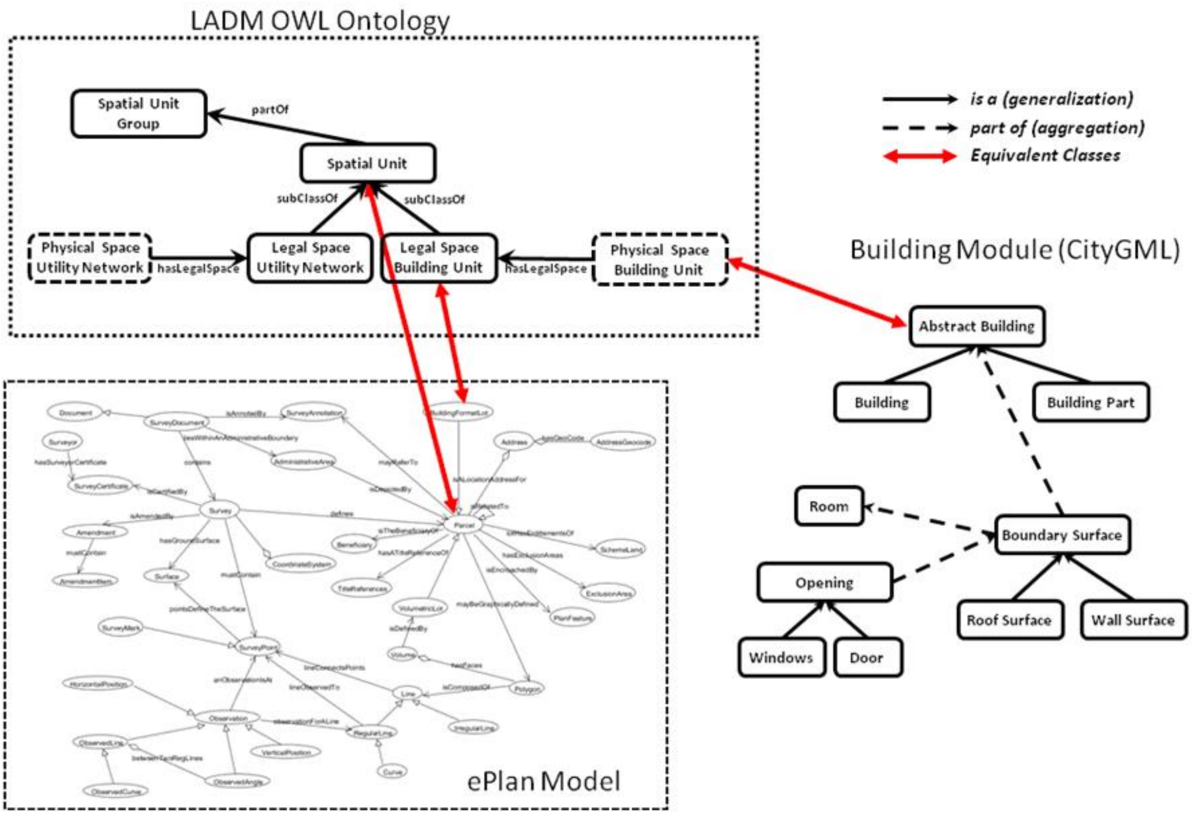


Figure 9. The LADM OWL Ontology and ePlan model are connected through concepts Spatial Unit and Legal Space Building Unit with Parcel and BuildingFormatLot respectively. CityGML's Building module and the LADM OWL ontology are linked by relating Physical Space Building Unit and Abstract Building as equivalent classes

4.2 Interconnection between LADM Ontology and ePlan Model

Compared to the CityGML's Building module, ePlan model is relatively more straightforward to integrate with the LADM OWL ontology as both the ePlan model and the Spatial Unit concept in the LADM OWL ontology were meant to represent cadastral survey.
As depicted in Figure 9, the Spatial Unit and Legal Space Building Unit concepts from the LADM OWL ontology are equivalent classes with the Parcel and BuildingFormatLot classes from the ePlan model respectively. Both Spatial Unit and Parcel play the same role to make the connection between the spatial and non-spatial attributes of a property unit.

The BuildingFormatLot class of the ePlan model does not contain the spatial element (i.e. geometry) of a parcel. The BuildingFormatLot class is only described by two attributes: BuildingNo and BuildingLevelNo. So the BuildingFormatLot class is equivalent to Legal Space Building Unit of the LADM OWL ontology.

4.3 Syntactic Links between LADM OWL Ontology, CityGML and LandXML

The equivalent class relation that links between the concepts from LADM OWL ontology to CityGML and LandXML can be syntactically realized with the external referencing capability supported in CityGML and LandXML using the ExternalReference and DocFileRef elements respectively. As mentioned previously both CityGML and LandXML can refer to external resources through the ExternalReference and DocFileRef elements via the URIs of concepts in the LADM OWL ontology.

Figure 10 illustrates an example by using the DocFileRef element; a volumetric parcel is referenced with the concept, Spatial Unit in the LADM OWL ontology via the URI of Spatial Unit.

```
▼<Parcel name="70021N" area="2621.4" parcelFormat="Volumetric">
  ▼<Feature>
     <DocFileRef name="Parcel"
     location="http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#SpatialUnit"/>
   </Feature>
  ▼<Parcels>
     <Parcel name="Face1" pclRef="70021N/1"/>
     <Parcel name="Face2" pclRef="70021N/2"/>
     <Parcel name="Face3" pclRef="70021N/3"/>
     <Parcel name="Face4" pclRef="70021N/4"/>
```

Figure 10. A volumetric parcel is referenced with Spatial Unit concept in the LADM OWL ontology via URI, using the DocFileRef element

Similarly, the Building class of CityGML can also be referenced with the URI of Physical Space Building Unit using the ExternalReference element. An example of such external referencing is shown in Figure 11.

```
▼<bldg:Building gml:id="GML_7b1a5a6f-ddad-4c3d-a507-3eb9ee0a8e68">
  ▼<externalReference>
    ▼<externalObject>
      ▼<uri>
         http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#PhysicalSpaceBuildingUnit
       </uri>
     </externalObject>
   </externalReference>
   <gml:name>HDB</gml:name>
   <bldg:class codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_class.xml">1000</bldg:class>
   <bldg:function codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_function.xml">1000</bldg:function>
```

Figure 11. A Building class of CityGML is referenced with the URI of Physical Space Building Unit concept in the LADM OWL ontology using the ExternalReference element

5. CONCLUSIONS

For any developments that require spatial data, often the fusion of diverse spatial datasets is required. This becomes non trivial when semantic heterogeneity occurs between schemas like CityGML and LandXML. The paper introduced a semantics-based fusion framework to integrate CityGML and LandXML using the LADM OWL ontology previously developed. The LADM OWL ontology is augmented with concepts of Physical Space Building Unit and Physical Space Utility Network, which are related to Legal Space Building Unit and Legal Space Utility Network respectively through a new relation hasLegalSpace.

The paper looked into how the extended LADM OWL ontology is linked with CityGML schema and ePlan model through the equivalent Class relation. Syntactically, the equivalent Class relation can be realized using the ExternalReference and DocFileRef elements of CityGML and LandXML respectively.

The framework ultimately attempts to integrate not only the semantic models inherent in the schemas but also the geometries from CityGML and LandXML. Through this semantics-based fusion, it is expected that a computer system will be able to do reasoning and inference in the OWL ontology. The computer system will also be able to retrieve the geometries of building's legal space or physical space, or both, through the ExternalReference and DocFileRef elements. The intention of the framework is to utilize the best of all worlds (i.e. CityGML, LandXML and OWL) without affecting the existing schemas, which have been comprehensively developed for different applications.

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BIOGRAPHICAL NOTES

Kean Huat Soon is a Senior Surveyor at the Land Survey Division of Singapore Land Authority. He is instrumental in the development of the new cadastral system in the Division to support 3D Cadastres and automated cadastral processing using 3D LandXML. He also leads the development of the open system infrastructure, which is primarily based on CityGML schema, to support 3D National Topography. He earned a Msc in Geography from the Pennsylvania State University, a Msc in Geoinformatics and Bachelor of Surveying (Land) from University of Technology Malaysia. His research interests include semantic interoperability, data modeling, cadastral information system and ontology.

Rod Thompson joined the Queensland Government in the Department of Mapping and Surveying in 1985, and was instrumental in the development of the Digital Cadastral Data Base (DCDB). He gained his doctorate in 2007 with a dissertation entitled "Towards a Rigorous Logic for Spatial Data Representation". He remains employed by the same (albeit re-named) government department, is Adjunct Associate Professor with the University of Southern Queensland, and retains a research association with the Delft University of Technology.

Victor Khoo is a Deputy Director at the Land Survey Division of Singapore Land Authority (SLA). He received his Ph.D. and Master of Engineering from the Nanyang Technological University (NTU), Singapore and his Bachelor degree in Land Surveying from the University Technology of Malaysia (UTM). Victor is a Registered Surveyor; a professional surveyor registered under the purview of Singapore's Land Surveyors Act. He works in diverse geospatial related subjects that encompass the collection, management and dissemination of geospatial data. His specific areas of interest include Differential GPS, Cadastral Surveying and Spatial Data Infrastructure.

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