Semantics-based Fusion for CityGML and 3D LandXML

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Outline

- Motivation and Objectives
- Background
  - 3D National Topographic Mapping project - CityGML
  - Cadastral Survey Management System project – 3D LandXML
    - ePlan conceptual model
  - Semantic Interoperability - Web Ontology Language (OWL)
- LADM OWL Ontology
- Extending LADM OWL Ontology
- Fusing CityGML and LandXML with LADM OWL
- Conclusions

Motivation

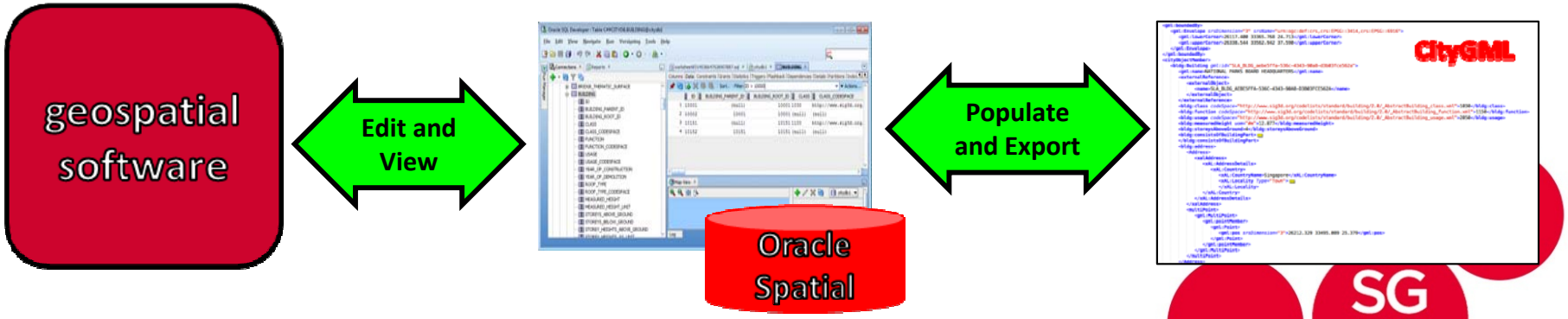
- 3D data are fundamental to support national development and planning, data fusion from varying sources is often unavoidable
- But 3D data are massive and generally diverse in
  - *system* – *e.g. ESRI, Bentley, etc*;
  - *syntax* – *e.g. binary, ASCII*;
  - *schema/structure* – *e.g. CityGML, LandXML*;
    CityGML for city modeling, while LandXML operationally used in automated cadastral processing
  - *semantics* – *e.g. "spot level", "elevation", "height"*
- Differences in *system*, *syntax*, *schema/structure* currently can be resolved by commercial software but not for *semantics*

Objectives

- To semantically fuse Physical Building Data in CityGML and Building Legal Boundary in 3D LandXML with LADM Ontology in OWL
- To provide a useful reference in discussing the future directions and harmonization of the schemas

3D National Topographic Mapping project

- airborne imagery and laser scanning for the whole Singapore
- LOD 0 and 1 modeling for Terrain, Water Body, and Building (in CityGML)
- LOD 2 building modeling
- a national 3D topographic database, which is based on CityGML 2.0 schema



Building Module (CityGML)

- Motivation
- Objectives
- Background
  - CityGML
  - LandXML
  - OWL
- LADM OWL
- Extend LADM OWL
- Fusion
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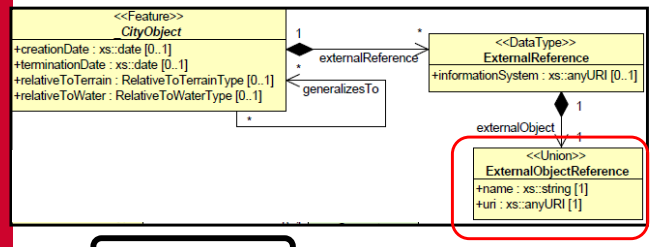

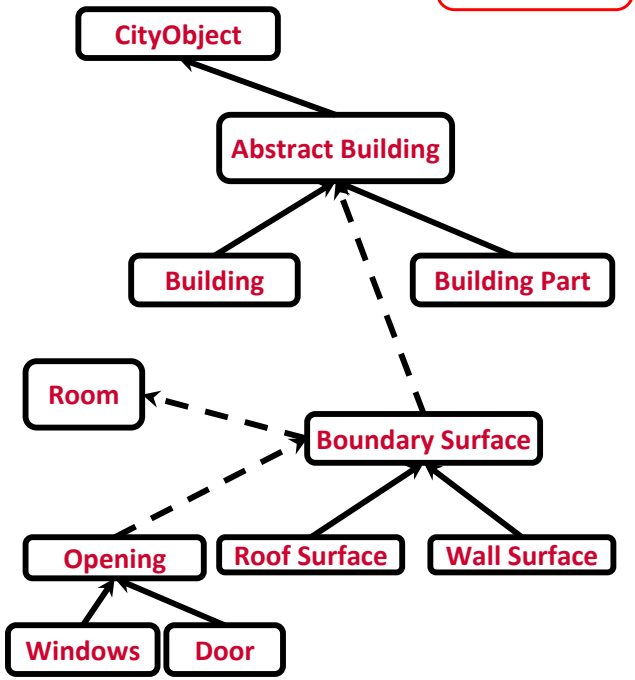


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    <gml:name>NATIONAL UNIVERSITY OF SINGAPORE (BUKIT TIMAH CAMPUS)</gml:name>
    <externalReference>
      <informationSystem>singapore 3D national topographic mapping</informationSystem>
      <externalObject>
        <name>SLA_BLDG_90D36B63-7F79-486C-BA7D-E07787A2F199</name>
      </externalObject>
    </externalReference>
    <bldg:class codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_class.xml">1100</bldg:class>
    <bldg:function codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_function.xml">2100</bldg:function>
    <bldg:measuredHeight uom="#m">12.436</bldg:measuredHeight>
    <bldg:storeysAboveGround>4</bldg:storeysAboveGround>
    <bldg:consistsOfBuildingPart>
      <bldg:BuildingPart gml:id="PT55A0001_0">
        <bldg:roofType codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_roofType.xml">1000</bldg:roofType>
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        </bldg:lod2Solid>
        <bldg:boundedBy>
          <bldg:RoofSurface gml:id="roof_T55A0001_p0_0">
          <bldg:lod2MultiSurface>
          <gml:MultiSurface>
          <gml:surfaceMember>
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          <gml:baseSurface>
          <gml:Polygon gml:id="poly_T55A0001_p0_0">
          <gml:exterior>
          <gml:LinearRing gml:id="line_T55A0001_p0_0">
          <gml:posList srsDimension="3">26063.730 33082.798 40.988 26074.894 33080.928 40.988 26125.811 33096.957 40.987 26125.119 33099.19
          987 26129.645 33100.593 40.986 26126.012 33112.311 40.986 26113.012 33110.719 40.986 26110.144 33119.905 40.986 26116.465 33123.3
          .986 26113.045 33135.611 40.985 26107.601 33134.090 40.985 26106.870 33136.703 40.985 26084.418 33130.428 40.986 26084.982 33128.
          40.986 26081.101 33127.329 40.986 26079.698 33132.350 40.986 26080.922 33132.692 40.986 26079.037 33139.435 40.986 26071.958 3313
          456 40.986 26073.678 33131.304 40.986 26075.617 33131.846 40.986 26077.067 33126.662 40.986 26074.048 33125.818 40.986 26073.535
          .652 40.986 26047.135 33118.414 40.987 26050.498 33106.383 40.987 26064.015 33107.011 40.987 26066.333 33099.471 40.987 26053.251
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          730 33082.798 40.988 </gml:posList>
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          </gml:surfaceMember>
          </gml:MultiSurface>
          </bldg:lod2MultiSurface>
          </bldg:RoofSurface>
        </bldg:boundedBy>
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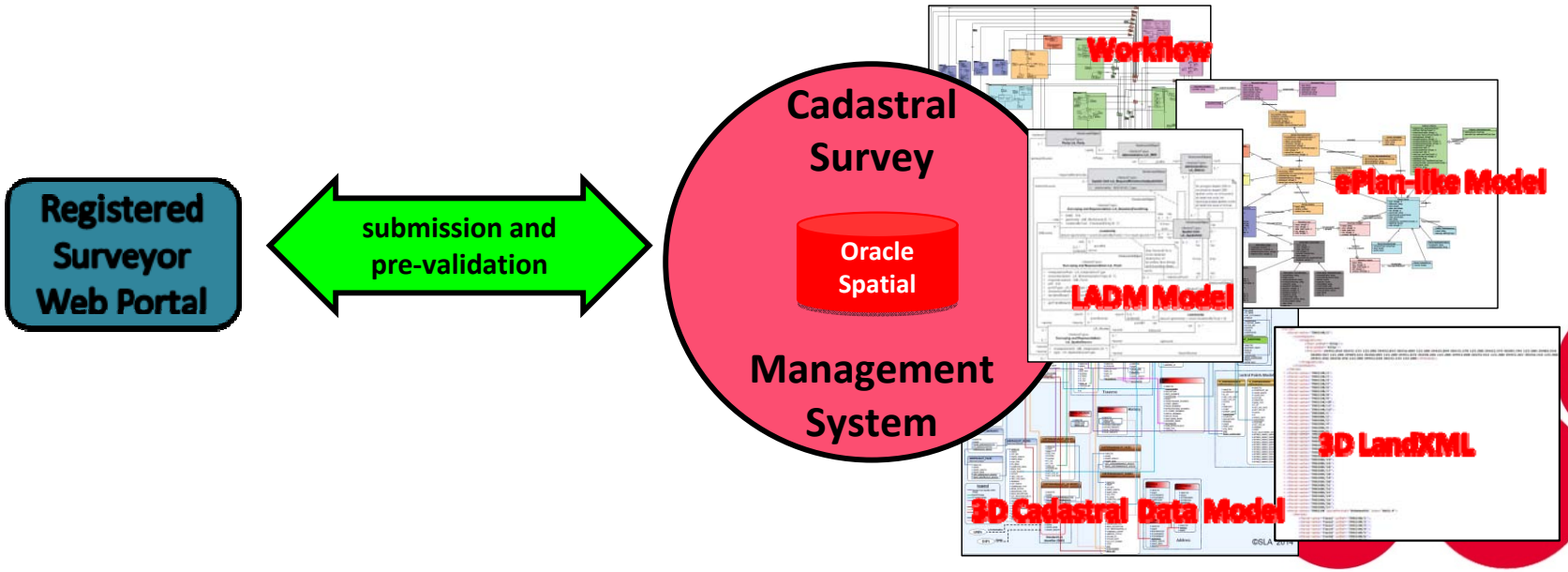
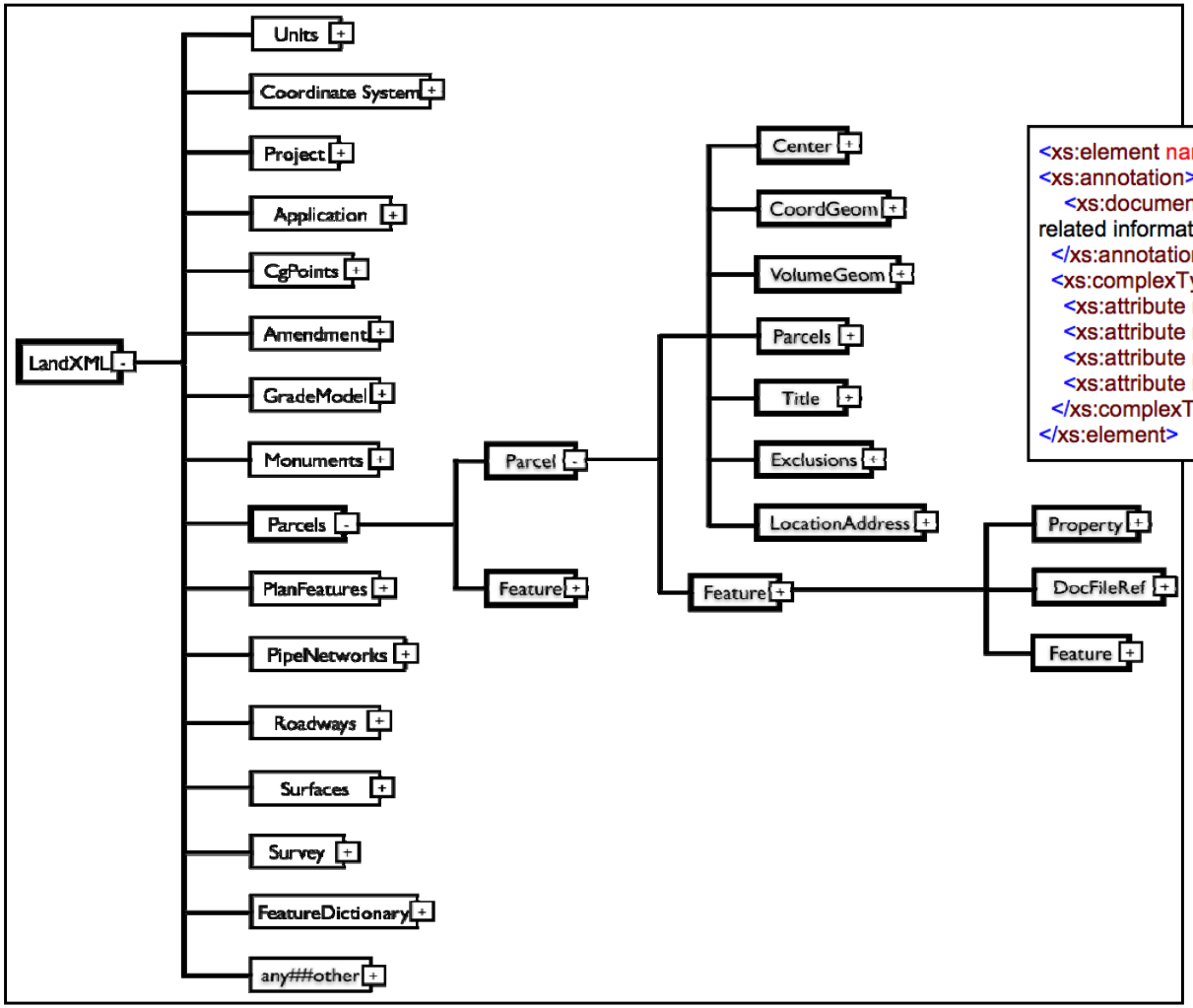
          <bldg:lod2MultiSurface>
          <gml:MultiSurface>
          <gml:surfaceMember>
          <gml:OrientableSurface gml:id="os_T55A0001_p0_1" orientation="+">
```

Cadastral Survey Management System project

- To support 3D Cadastre and automation for Cadastral Survey in Singapore
- Currently at the requirement study with vendor
- To adopt Land Administration Domain Model (LADM) & ePlan model
- Formulating 3D LandXML as submission format



LandXML 1.2 Schema

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<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>
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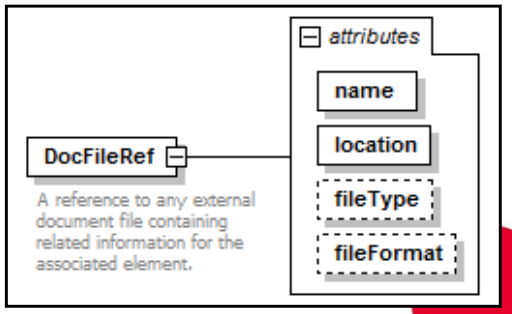

ePlan Model (Parcel) with LandXML

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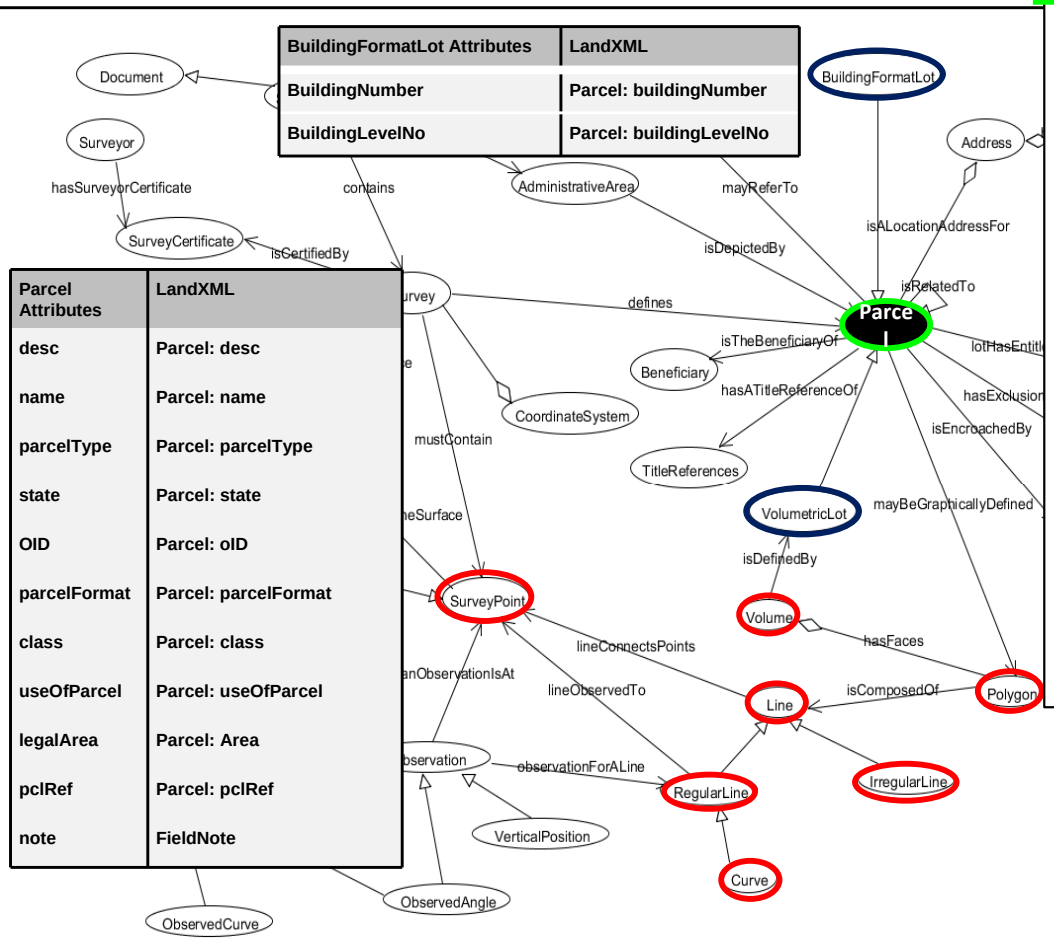
BuildingFormatLot Attributes	LandXML
BuildingNumber	Parcel: buildingNumber
BuildingLevelNo	Parcel: buildingLevelNo

Parcel Attributes	LandXML
desc	Parcel: desc
name	Parcel: name
parcelType	Parcel: parcelType
state	Parcel: state
OID	Parcel: oID
parcelFormat	Parcel: parcelFormat
class	Parcel: class
useOfParcel	Parcel: useOfParcel
legalArea	Parcel: Area
pclRef	Parcel: pclRef
note	FieldNote

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- <xs:element name="Parcel">
  - <xs:complexType>
    - <xs:sequence>
      - <xs:choice maxOccurs="unbounded">
          <xs:element ref="Center" minOccurs="0"/>
          <xs:element ref="CoordGeom"/>
          <xs:element maxOccurs="unbounded" ref="VolumeGeom" minOccurs="0"/>
          <xs:element maxOccurs="unbounded" ref="Parcels" minOccurs="0"/>
          <xs:element maxOccurs="unbounded" ref="Title" minOccurs="0"/>
          <xs:element maxOccurs="unbounded" ref="Exclusions" minOccurs="0"/>
          <xs:element maxOccurs="unbounded" ref="LocationAddress" minOccurs="0"/>
        </xs:choice>
        <xs:element maxOccurs="unbounded" ref="Feature" minOccur
      </xs:sequence>
      <xs:attribute type="xs:string" name="name" use="required"/>
      <xs:attribute type="xs:string" name="oID"/>
      <xs:attribute type="xs:double" name="area"/>
      <xs:attribute type="xs:string" name="desc"/>
      <xs:attribute type="xs:direction" name="dirClosure"/>
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      <xs:attribute type="xs:string" name="parcelType"/>
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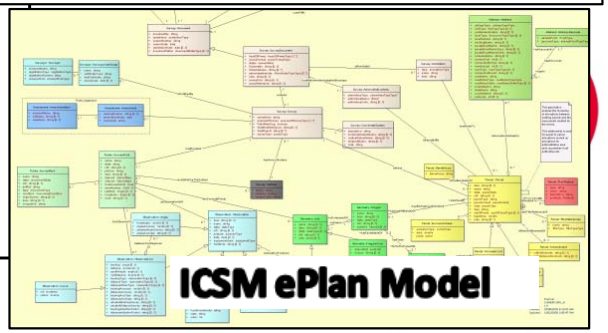
      <xs:attribute type="xs:double" name="setbackRear"/>
      <xs:attribute type="xs:double" name="setbackSide"/>
      <xs:attribute type="parcelStateType" name="state"/>
      <xs:attribute type="xs:string" name="taxId"/>
      <xs:attribute type="parcelClass" name="class"/>
      <xs:attribute type="useOfParcelType" name="useOfParcel"/>
      <xs:attribute type="parcelFormat" name="parcelFormat"/>
      <xs:attribute type="xs:string" name="buildingNo"/>
      <xs:attribute type="xs:string" name="buildingLevelNo"/>
      <xs:attribute type="xs:string" name="volume"/>
      <xs:attribute type="parcelNameRef" name="pclRef"/>
      <xs:attribute type="xs:string" name="lotEntitlements"/>
      <xs:attribute type="xs:string" name="liabilityApportionment"/>
    </xs:complexType>
  </xs:element>
```

spatial

Referencing

non-spatial



Simplified ePlan Model (just Concepts w/o Attributes)

LandXML for 3D (Nested Parcels Approach)

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- <Parcels>
  - <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 29
            30284.567 123.280 29484.221 30260.005 123.280 29451.876 30258.266 123.280 29452.008 30255.922
            29451.056 30250.256 123.280 29452.018 30232.133 123.280</PntList3D>
        </IrregularLine>
      </CoordGeom>
    </Parcel>
  + <Parcel name="70021N/2">
  + <Parcel name="70021N/3">
  + <Parcel name="70021N/4">
  + <Parcel name="70021N/5">
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  + <Parcel name="70020K/26">
  + <Parcel name="70020K/27">
  - <Parcel name="70021N" parcelFormat="Volumetric" area="2621.4">
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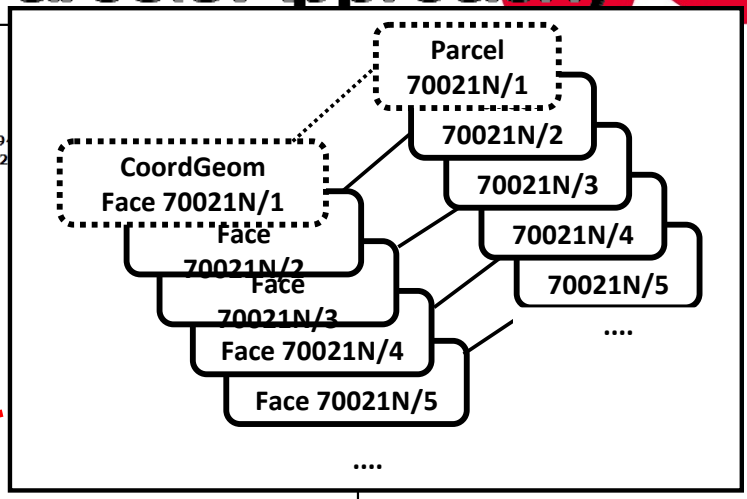
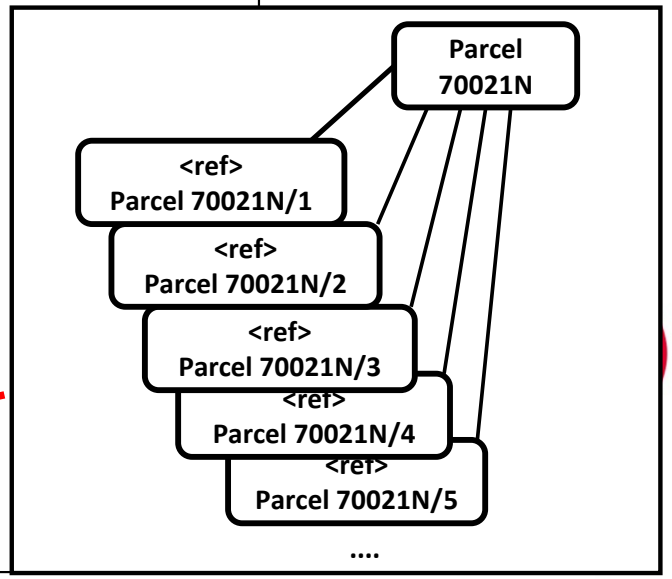
        <Parcel name="Face2" pclRef="70021N/2"/>
        <Parcel name="Face3" pclRef="70021N/3"/>
        <Parcel name="Face4" pclRef="70021N/4"/>
        <Parcel name="Face5" pclRef="70021N/5"/>
        <Parcel name="Face6" pclRef="70021N/6"/>
        <Parcel name="Face7" pclRef="70021N/7"/>
```

Every face is defined with coordinates thru PntList3D



all related faces are referenced to form a Volumetric 3D Parcel



From 3D LandXML to Other Formats

3D LandXML

```
- <Parcels>
    + <Parcel name="70021N/1">
    + <Parcel name="70021N/2" area="2621.4">
    + <Parcel name="70021N/3">
    + <Parcel name="70021N/4">
    + <Parcel name="70021N/5">
    + <Parcel name="70021N/6">
    + <Parcel name="70021N/7">
    + <Parcel name="70021N/8">
    + <Parcel name="70021N/9">
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    + <Parcel name="70021N/11">
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    + <Parcel name="70020K/22">
    + <Parcel name="70020K/23">
    + <Parcel name="70020K/24">
    + <Parcel name="70020K/25">
    + <Parcel name="70020K/26">
    + <Parcel name="70020K/27">
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        - <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"/>
            <Parcel name="Face5" pclRef="70021N/5"/>
            <Parcel name="Face6" pclRef="70021N/6"/>
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            <Parcel name="Face8" pclRef="70021N/8"/>
            <Parcel name="Face9" pclRef="70021N/9"/>
            <Parcel name="Face10" pclRef="70021N/10"/>
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            <Parcel name="Face12" pclRef="70021N/12"/>
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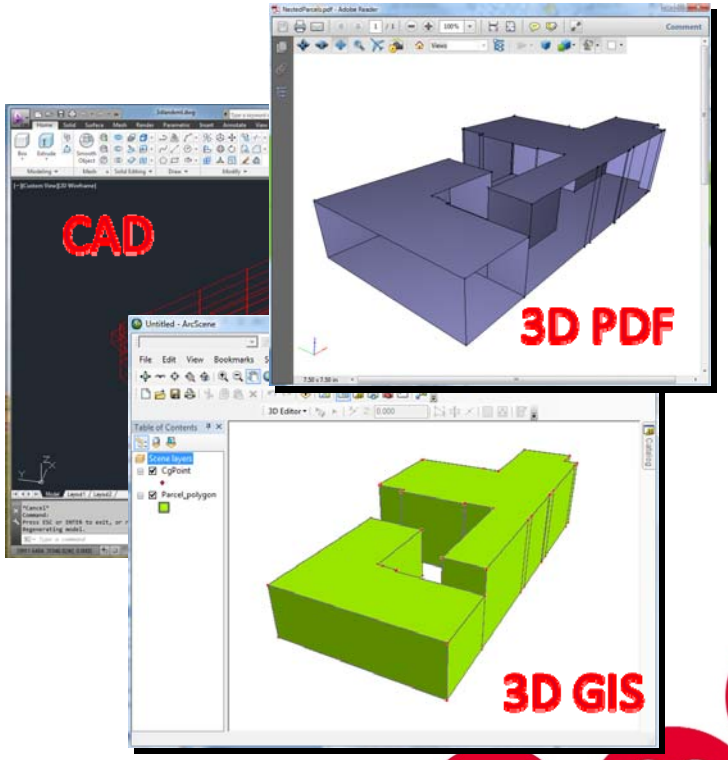
    + <Parcel name="70020K" parcelFormat="Volumetric">
</Parcels>
```

Conversion using FME



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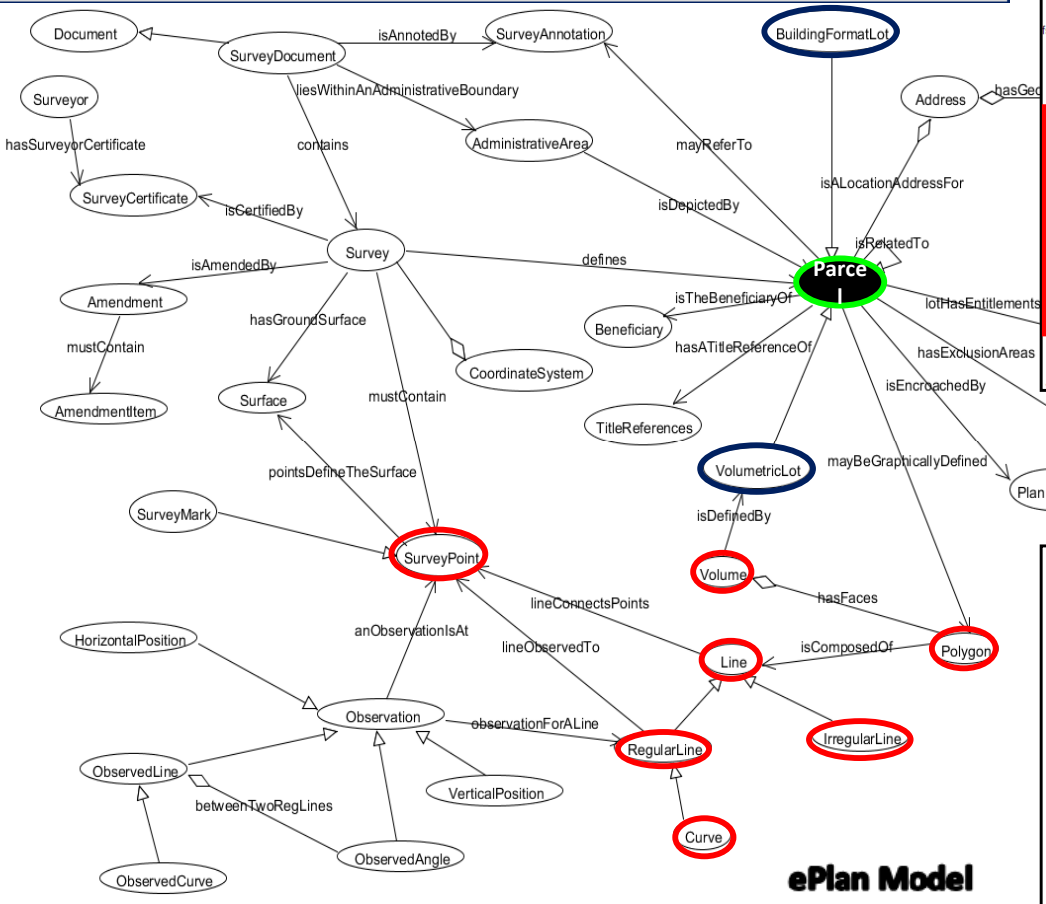
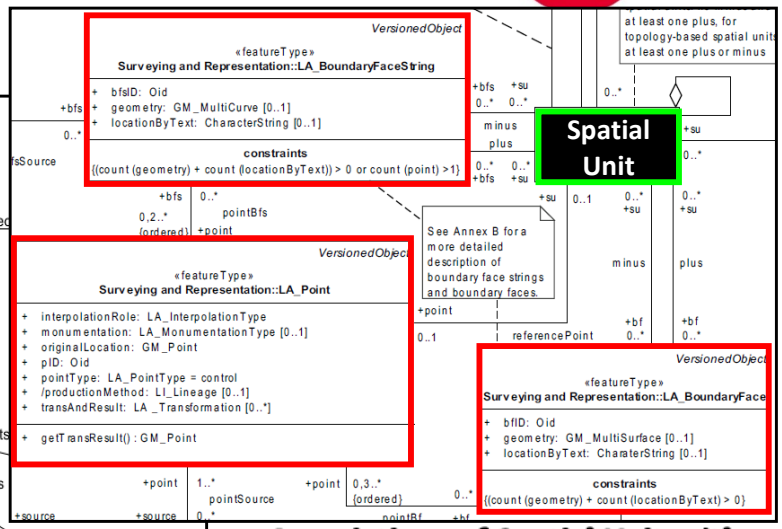
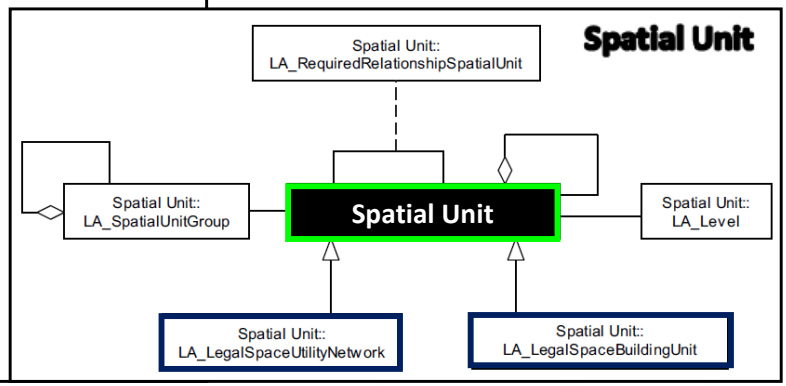
ePlan Model (Parcel) – LADM (Spatial Unit)

Spatial Unit (LADM) and Parcel (ePlan) both connect spatial and non-spatial attributes of property unit

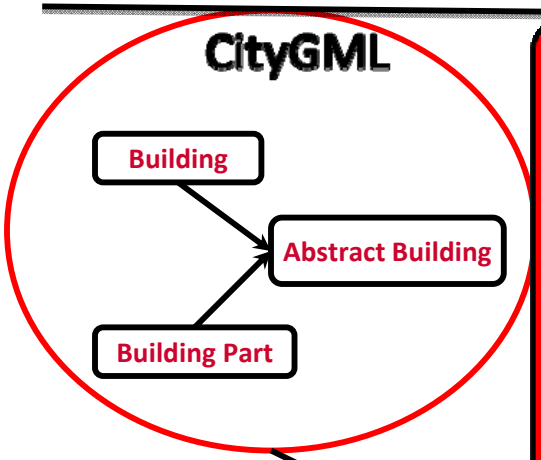




Associations of Spatial Unit with Surveying and Representation



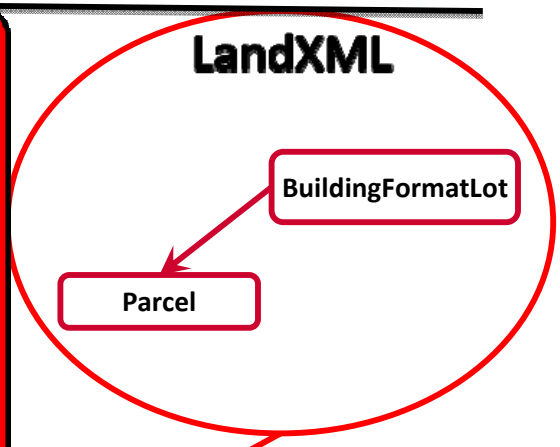
CityGML vs. LandXML



Different usages result in different "Building" interpretations

CityGML:
Physical Building

LandXML:
Legal Building

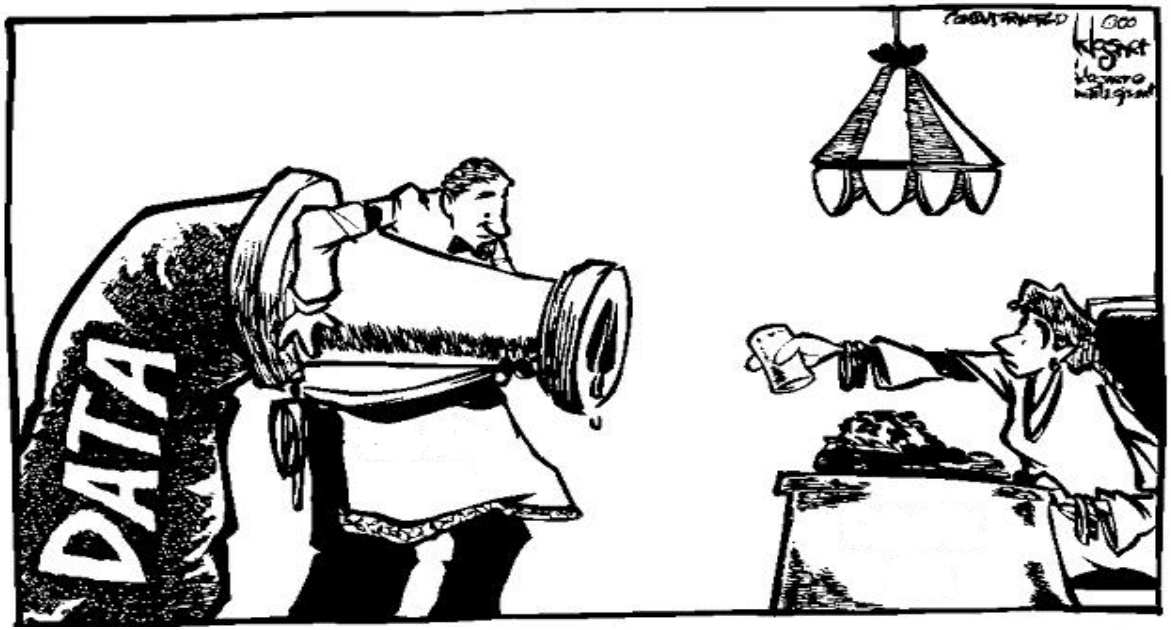


Geometry represents Physical Construct

Geometry represents Legal Space

Why Semantics

- Semantics is the Study of Meaning
- Meaning is implicit and context-dependent
- Precise meaning of exchanged information should be well-understood by all parties, otherwise resulting in low recall and precision



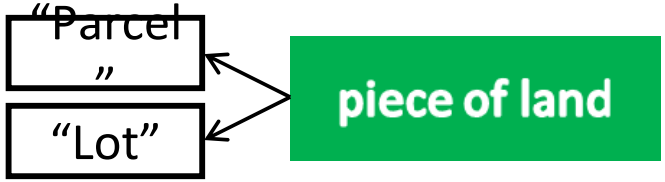
Semantic Ambiguity

- The same term can mean different things

Outlet:
- electronic device points
- retail store
- channel

Parcel:
- package
- land boundary

- Different terms can mean the same thing



A classic example: BoatHouse vs. HouseBoat

Formal Ontology

- **Need an explicit knowledge structure, which should consist of common definitions and semantic relationships for pieces of data used in the domain;**
- **The structure should be represented in a formal language, where computer systems are able to process and understand the meaning;**
- **The structure is called Ontology, which enables computer systems to do reasoning and make inference**

OWL (Web Ontology Language)

- OWL is a formal language to describe ontology
- different from CityGML and LandXML, it supports formal semantics and rules

```
<SubClassOf>
  <Class IRI="#BAUnit"/>
▼<ObjectHasSelf>
    <ObjectProperty IRI="#hasRequiredRelationshipBAUnit"/>
  </ObjectHasSelf>
</SubClassOf>
```

```
<DLSafeRule>
▼<Body>
  ▼<ClassAtom>
     <Class IRI="#Father"/>
     <Variable IRI="urn:swrl#x"/>
   </ClassAtom>
 </Body>
▼<Head>
  ▼<ClassAtom>
     <Class IRI="#Husband"/>
     <Variable IRI="urn:swrl#x"/>
   </ClassAtom>
 </Head>
</DLSafeRule>
```

Rule

Other OWL semantic relationships include:

owl:TransitiveProperty, SymmetricProperty, FunctionalProperty, InverseFunctionalProperty, inverseOf
owl:sameAs, differentFrom
owl:disjointWith, complementOf,
owl:hasValue, allValuesFrom, someValuesFrom
owl:equivalentClass, equivalentProperty

OWL as ISO 19150

OWL (Web Ontology Language)

- Classes and Instances
- Class Hierarchies
- Class Disjointness
- Object Properties
- Property Hierarchies
- Domain and Range Restrictions
- Equality and Inequality of Individuals
- Datatypes
- Complex Classes
- Property Restrictions
- Property Cardinality Restrictions
- Enumeration of Individuals
- Property Characteristics, Property Chains

e.g.

```
<DisjointClasses>
    <Class IRI="LandLot"/>
    <Class IRI="StrataLot"/>
</DisjointClasses>
```

LandLot::= ¬ StrataLot

e.g.

```
<EquivalentClasses>
    <Class IRI="Father"/>
    <ObjectIntersectionOf>
        <Class IRI="Man"/>
        <Class IRI="Parent"/>
    </ObjectIntersectionOf>
</EquivalentClasses>
```

Father::= Parent ∩ Man

e.g.

```
<TransitiveObjectProperty>
    <ObjectProperty IRI="locatedIn"/>
</TransitiveObjectProperty>
```

locatedIn as transitive

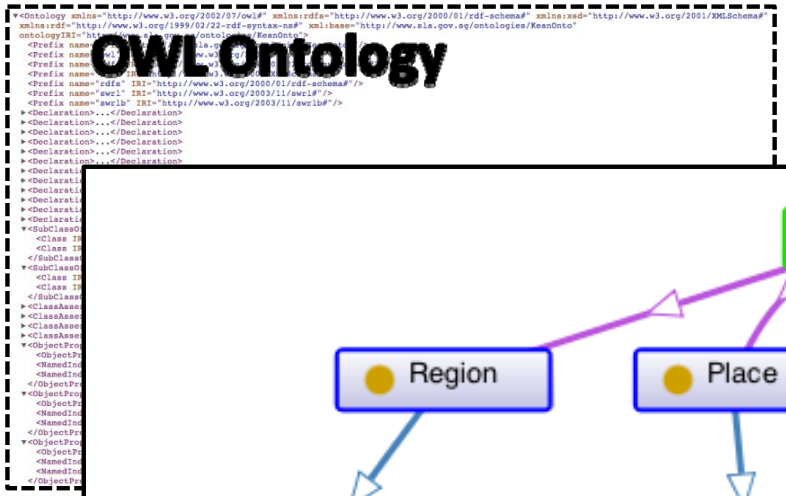
reference: http://www.w3.org/TR/owl2-primer/

- **Every class, instance, property (relationship) has a unique URI (Uniform Resource Identifier), e.g.**

```
<owl:Class rdf:about="http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#BoundaryFace">
```

Reasoning and Inference

OWL Ontology



Ontology about Kean

Rule: Father (?x) -> Husband (?x)

```
<DLSafeRule>
 <Body>
  <ClassAtom>
   <Class IRI="#Father"/>
   <Variable IRI="urn:swrl#x"/>
  </ClassAtom>
 </Body>
 <Head>
  <ClassAtom>
   <Class IRI="#Husband"/>
   <Variable IRI="urn:swrl#x"/>
  </ClassAtom>
 </Head>
</DLSafeRule>
```

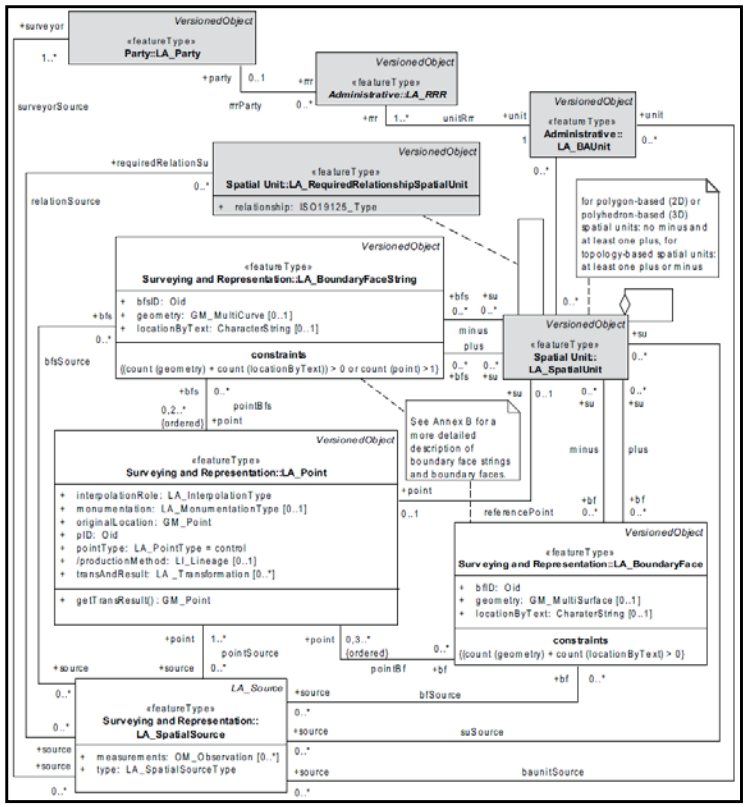
```
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#locatedIn"/>
  <NamedIndividual IRI="#Novena"/>
  <NamedIndividual IRI="#CentralRegion"/>
</ObjectPropertyAssertion>
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#locatedIn"/>
  <NamedIndividual IRI="#RevenueHouse"/>
  <NamedIndividual IRI="#Novena"/>
</ObjectPropertyAssertion>
```

"locatedIn" relation between classes

```
<TransitiveObjectProperty>
  <ObjectProperty IRI="#locatedIn"/>
</TransitiveObjectProperty>
```

"locatedIn"'s characteristic: transitive

ISO 19152 – Land Administration Domain Model

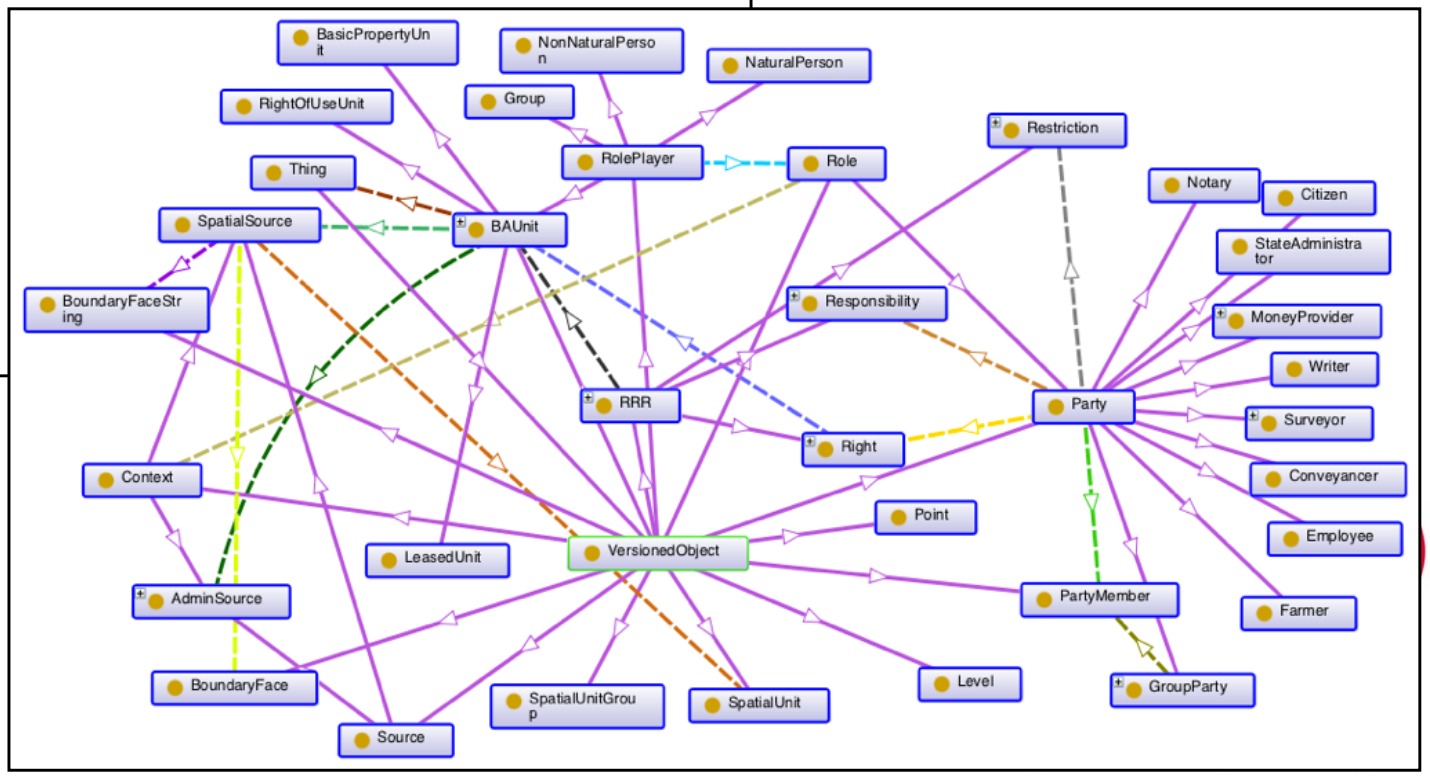


- "enables the combining of land administration information from different sources in a coherent manner." (ISO 19152)
- Currently in UML models, the formalization of LADM in OWL is developed (Soon, 2013)

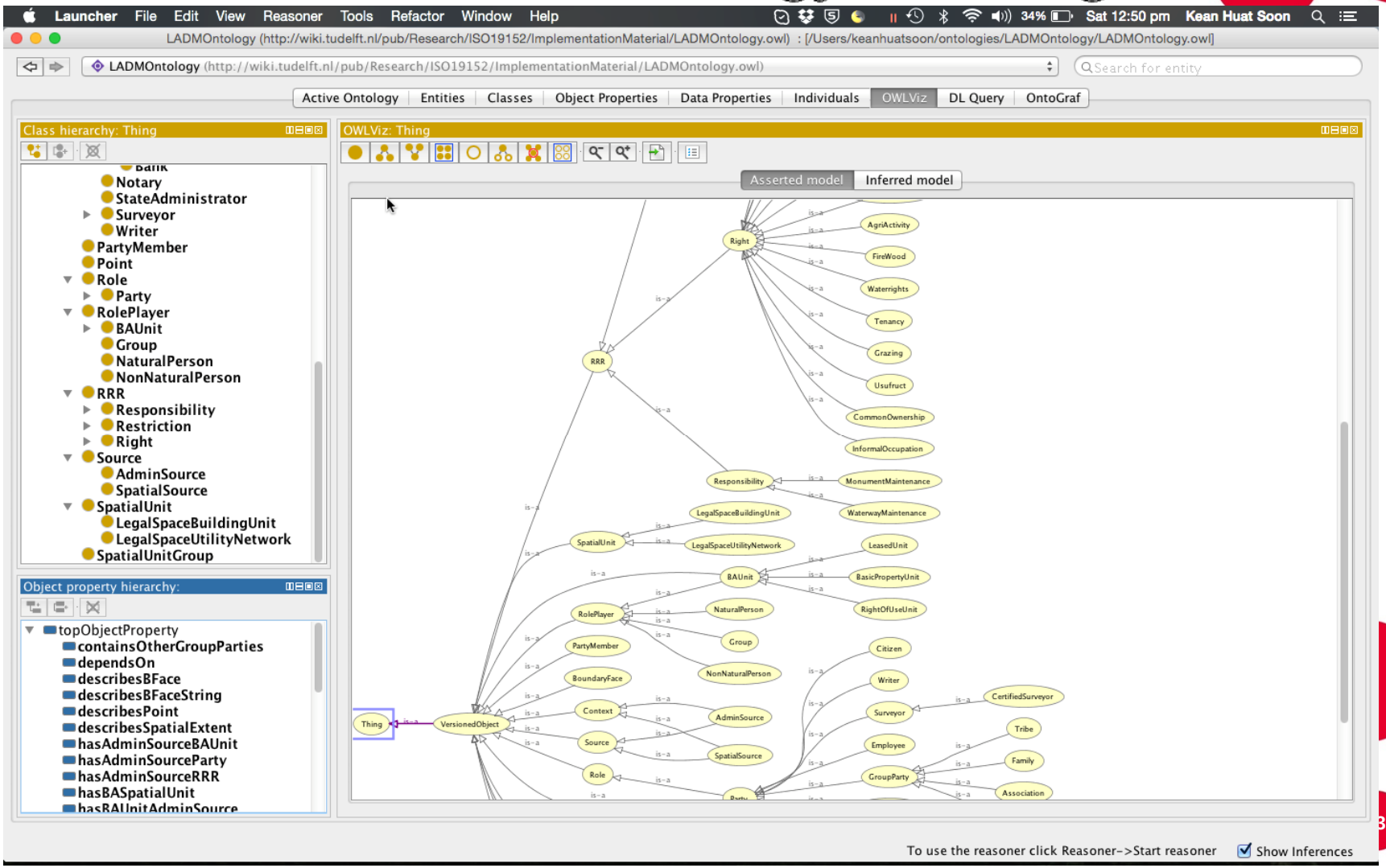
LADM in OWL

- Motivation
- Objectives
- Background
  - CityGML
  - LandXML
  - OWL
- LADM OWL
- Extend LADM OWL
- Fusion
- Conclusions

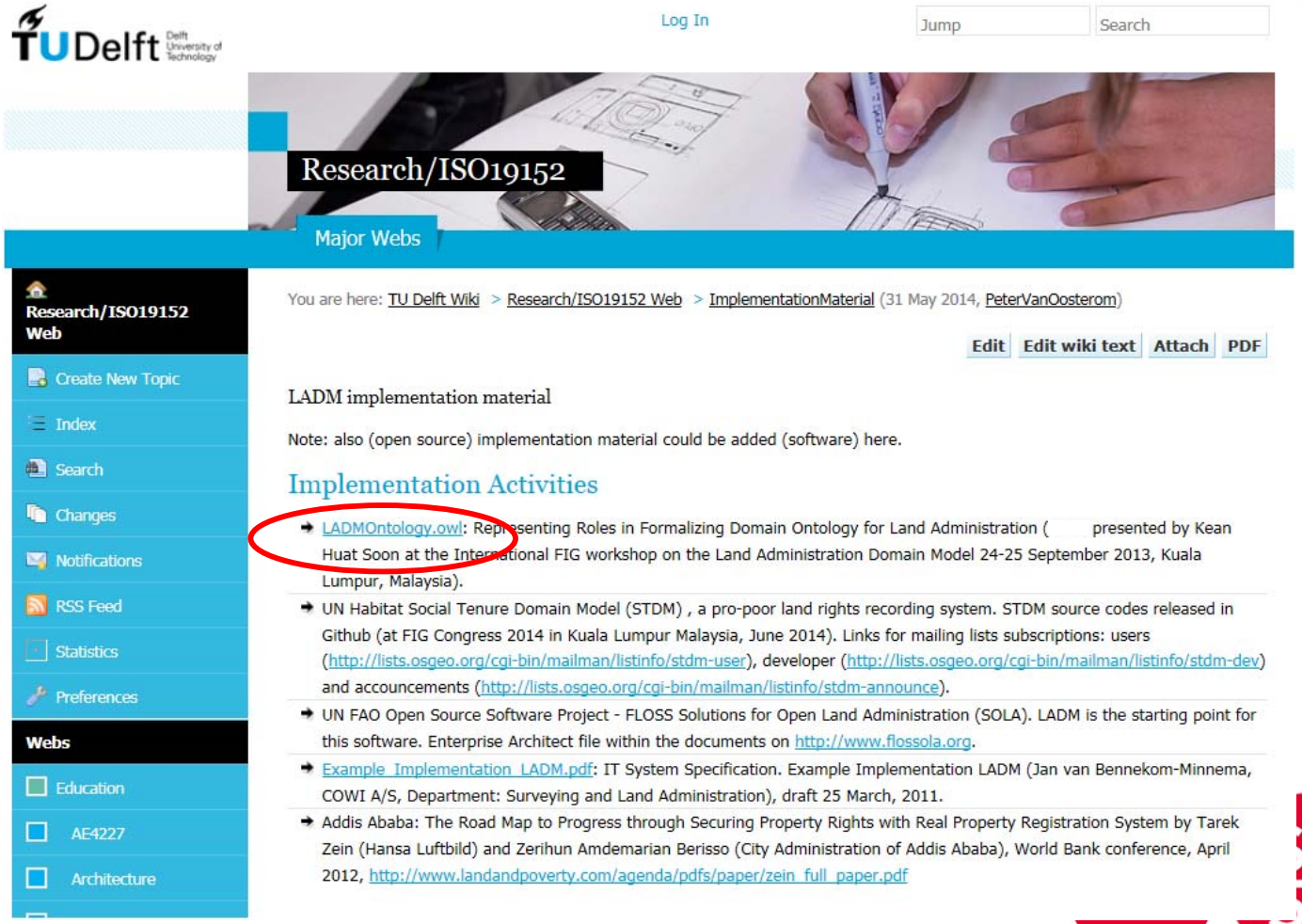

```
▼<Ontology xmlns="http://www.w3.org/2002/07/owl#" xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#" xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
 xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xml:base="http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl"
 ontologyIRI="http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl">
  <Prefix name="" IRI="http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#"/>
  <Prefix name="owl" IRI="http://www.w3.org/2002/07/owl#"/>
  <Prefix name="rdf" IRI="http://www.w3.org/1999/02/22-rdf-syntax-ns#"/>
  <Prefix name="xsd" IRI="http://www.w3.org/2001/XMLSchema#"/>
  <Prefix name="rdfs" IRI="http://www.w3.org/2000/01/rdf-schema#"/>
  <Prefix name="swrl" IRI="http://www.w3.org/2003/11/swrl#"/>
  <Prefix name="swrlb" IRI="http://www.w3.org/2003/11/swrlb#"/>
  <Prefix name="owl2xml" IRI="http://www.w3.org/2006/12/owl2-xml#"/>
  <Prefix name="LADMOntology" IRI="http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#"/>
▼<Declaration>
    <Class IRI="#AdminPublicServitude"/>
  </Declaration>
▼<Declaration>
    <Class IRI="#AdminSource"/>
  </Declaration>
▼<Declaration>
    <Class IRI="#AgriActivity"/>
  </Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▼<Declaration>
    <Class IRI="#BoundaryFaceString"/>
  </Declaration>
▼<Declaration>
    <Class IRI="#CertifiedSurveyor"/>
  </Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▼<Declaration>
    <Class IRI="#Conveyancer"/>
  </Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
▶<Declaration>...</Declaration>
```

LADM OWL Ontology in Protege

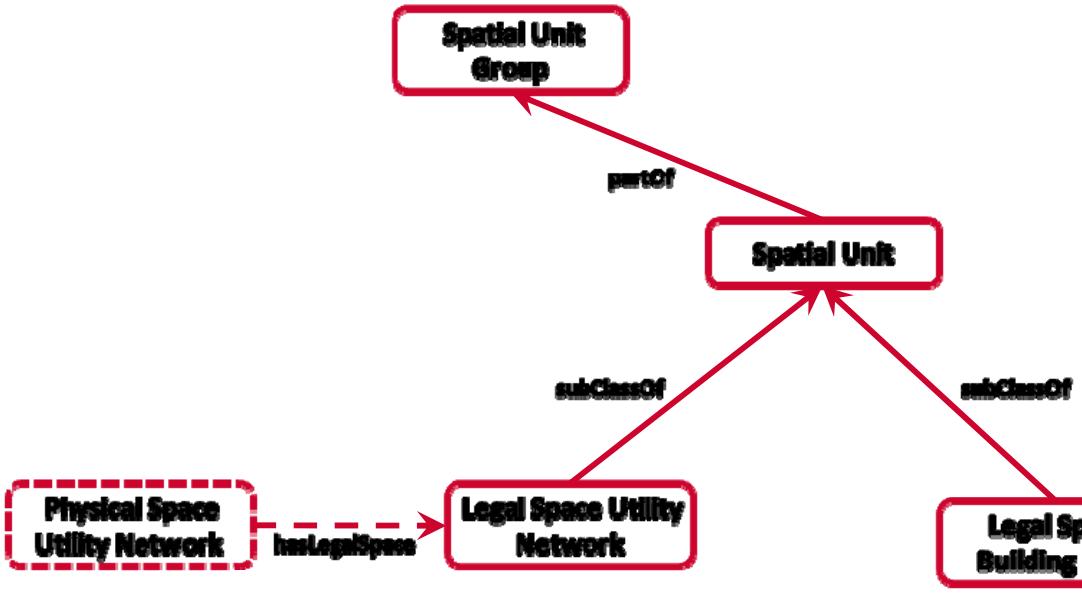


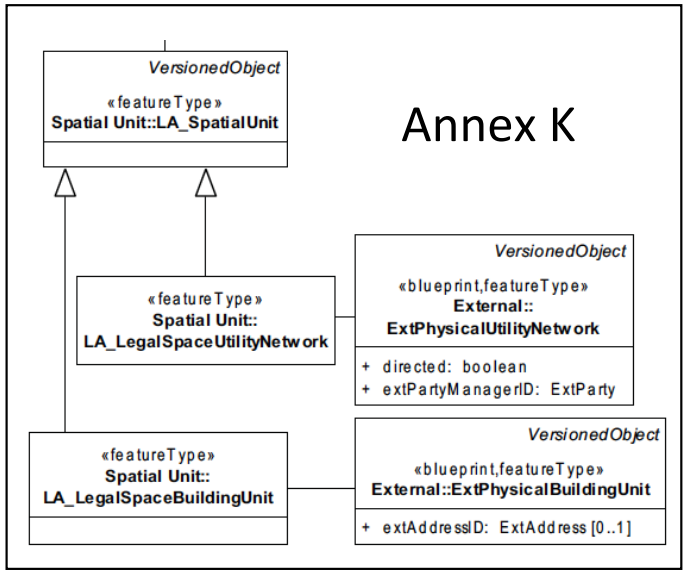
LADM OWL Ontology @ LADM Wiki



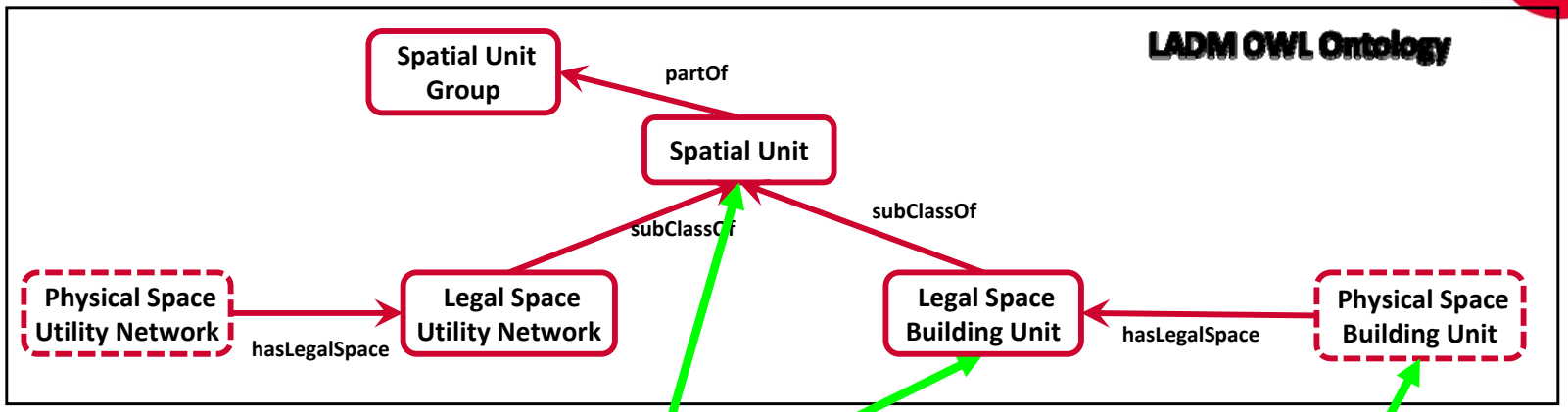
http://wiki.tudelft.nl/bin/view/Research/ISO19152/ImplementationMaterial

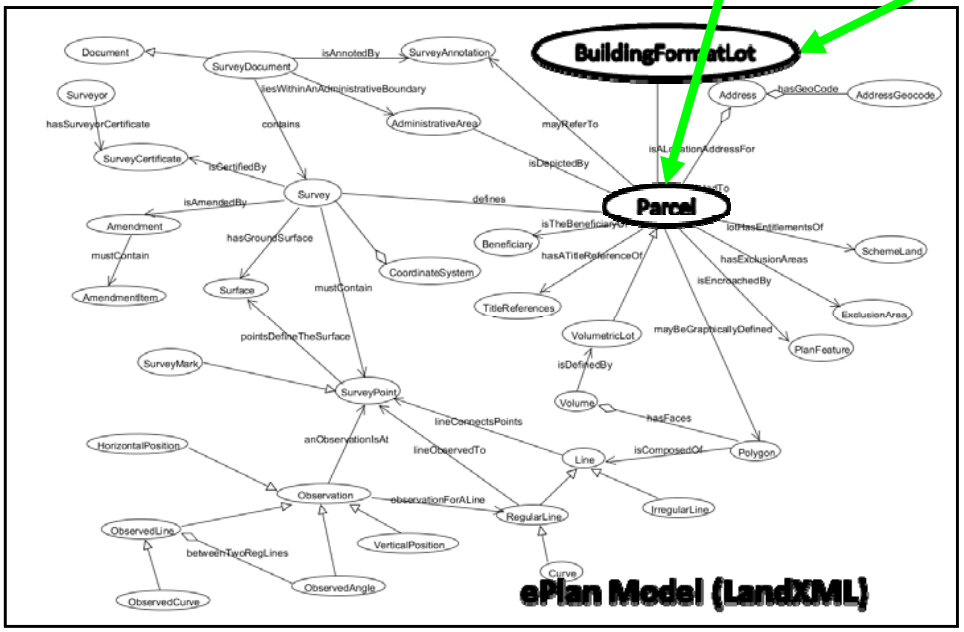
Extending the LADM OWL Ontology

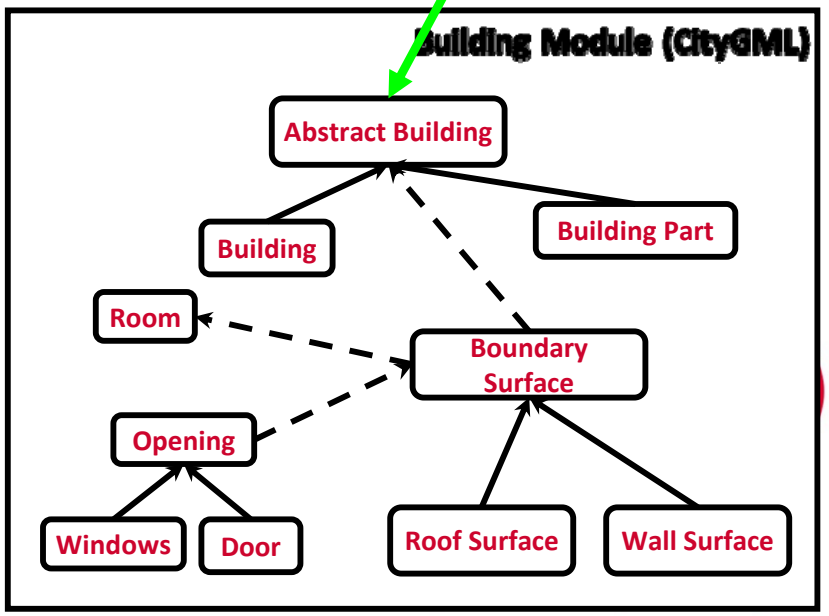




Mapping







Syntactic Links

LandXML and LADM OWL Ontology

```
▼<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"/>
```

CityGML and LADM OWL Ontology

```
▼<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>
```

Conclusions

- fusion of varying spatial datasets is often required in any spatial developments
- proposed augmenting LADM OWL Ontology with Physical Space Building Unit concept to fuse Building module (CityGML) and Parcel in the ePlan model (LandXML)
- linkages are realized via elements ExternalReference and DocFileRef
- linked the schemas, while allowed reasoning and inference in LADM OWL Ontology

thank you!

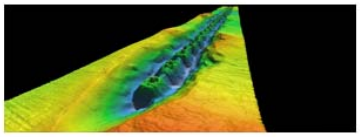
soon_kean_huat@sla.gov.sg or keanhuat.soon@gmail.com

13th South East Asian Survey Congress

28 – 31 July 2015, Marina Bay Sands, Singapore

http://www.seasc2015.org.sg/

Abstract Submission: March 1, 2015



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The congress theme provides a platform for government, industry and academia to discuss opportunities and challenges of geospatial data creation, maintenance and management.

The Congress also provides an unparalleled

Programme

The South East Asian Survey Congress is for Surveyors in all fields to gain knowledge, and new frontier in the applications of advanced technology in Survey. The Congress is also an excellent place and opportunity to network and exchange ideas.

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CALL FOR CONTRIBUTIONS

Workshop on
Life Cycle of Spatial Developments in 3D

Tuesday, 28 July 2015 @ Marina Bay Sands, Singapore

In Conjunction with 13th South East Asia Survey Congress, 28 – 31 July 2015
(http://www.seasc2015.org.sg/)

Organizers

Kean Huat Soon (SLA, Singapore), Alias Abdul Rahman (UTM, Malaysia), and Rod Thompson (Queensland Government, Australia)

Summary

The workshop aims to serve as a platform to present, discuss, and exchange ideas on issues and possible solutions encountered in the life cycle of spatial developments in 3D. The focus of the workshop is on, but not limited to, topics concerning: 3D data management, 3D modelling and 3D data integration. These are three intrinsic aspects in the life cycle of spatial developments in 3D. Efficient 3D data management ensures 3D data are well managed and organized during the life cycle be it in the phase of data collection, processing, presentation or dissemination. 3D modeling concerns the structure of the data as represented; while 3D data integration addresses open standards and conceptual modeling including, for example the ISO 19152 - Land Administration Domain Model (LADM). The workshop will look into LADM and open standards such as 3D LandXML and CityGML. For better integration in the life cycle, the workshop will also discuss issues resulting from differences in syntax, system, schema and semantics between varying datasets, and will study possible solutions to improve the integration.