A gentle introduction to CityGML as open standard for semantic 3D city modelling

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Agripolis, Legnaro, 17 November 2017

Overview

- **Part 1: Semantic 3D city modelling & a first look at CityGML**
- Part 2: A second look at CityGML and the 3D City Database
- Part 3: Experiences from Trento and Vienna
- Part 4: Extending CityGML
- Part 5: Energy & cities

Part 1: Semantic 3D city modelling & CityGML

- Semantic 3D city modelling (a short story)

- A gentle introduction to CityGML
  - Main characteristics
  - Brief overview of current applications
  - Working with CityGML: (some) existing tools
  - Online resources

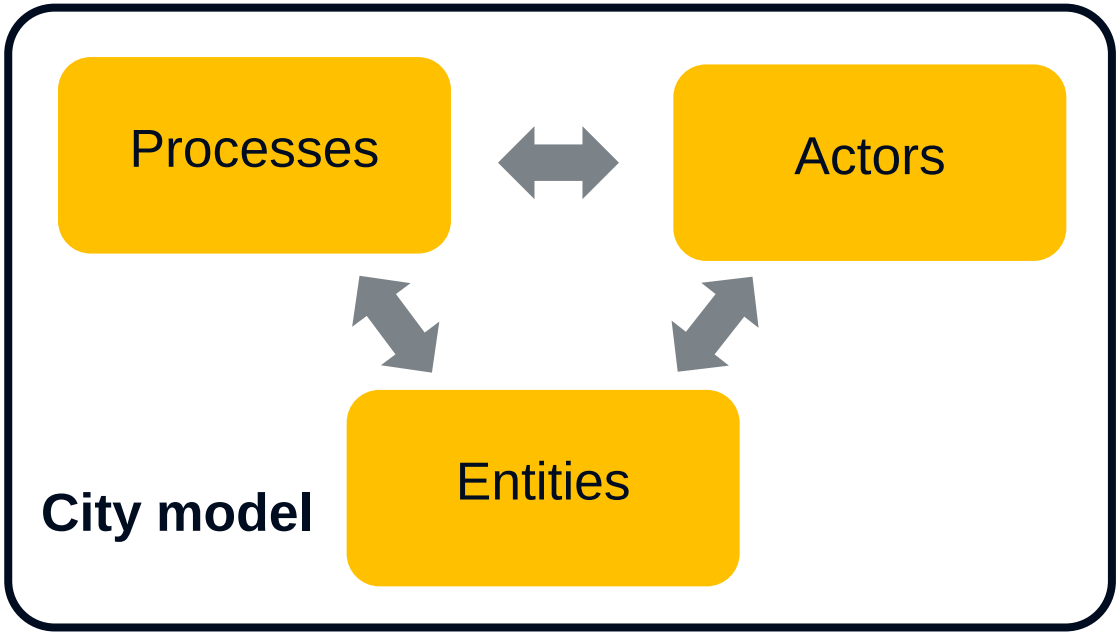
City modelling

Real city

http://media.gettyimages.com/vectors/city-drawing-vector-id523441181?s=170667a

represented by

"Digital twin"



City modelling: today

- Separate modelling, generally by specific sectors
  - Energy
  - Mobility
  - Ecology
  - Economy
  - …
- Each one having its community, models, indicators, stakeholders, etc.

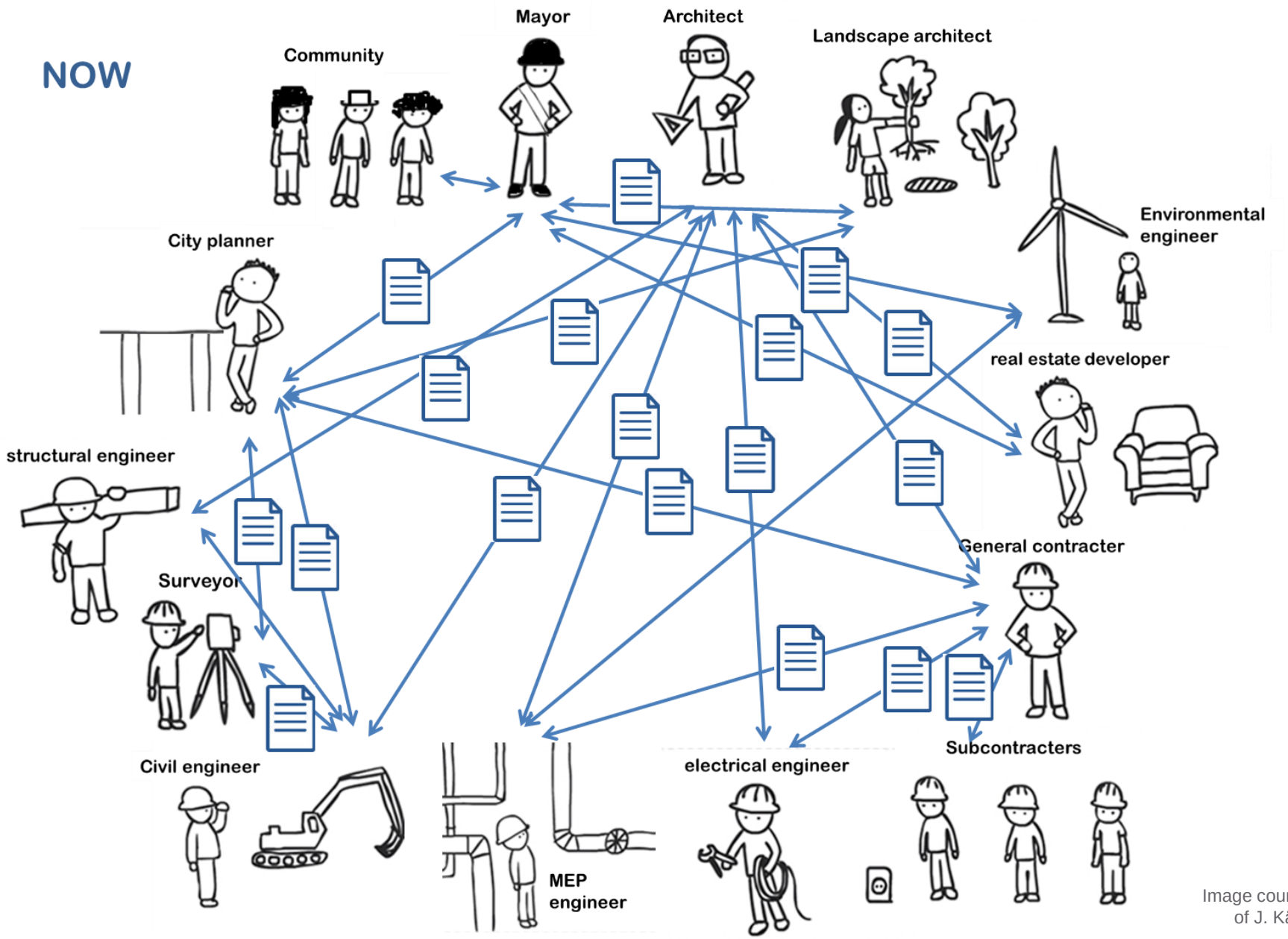


Image courtesy of J. Kämpf

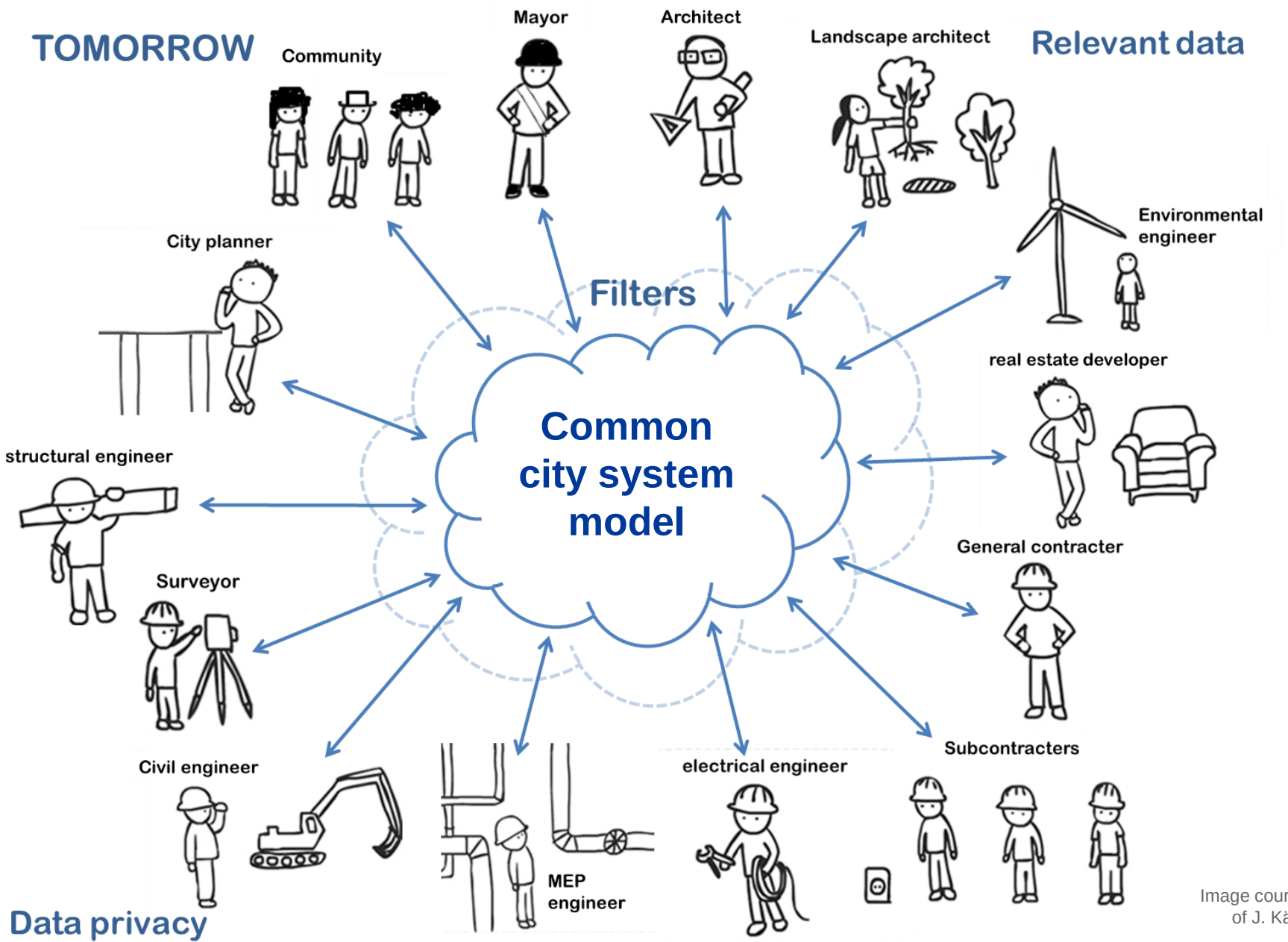
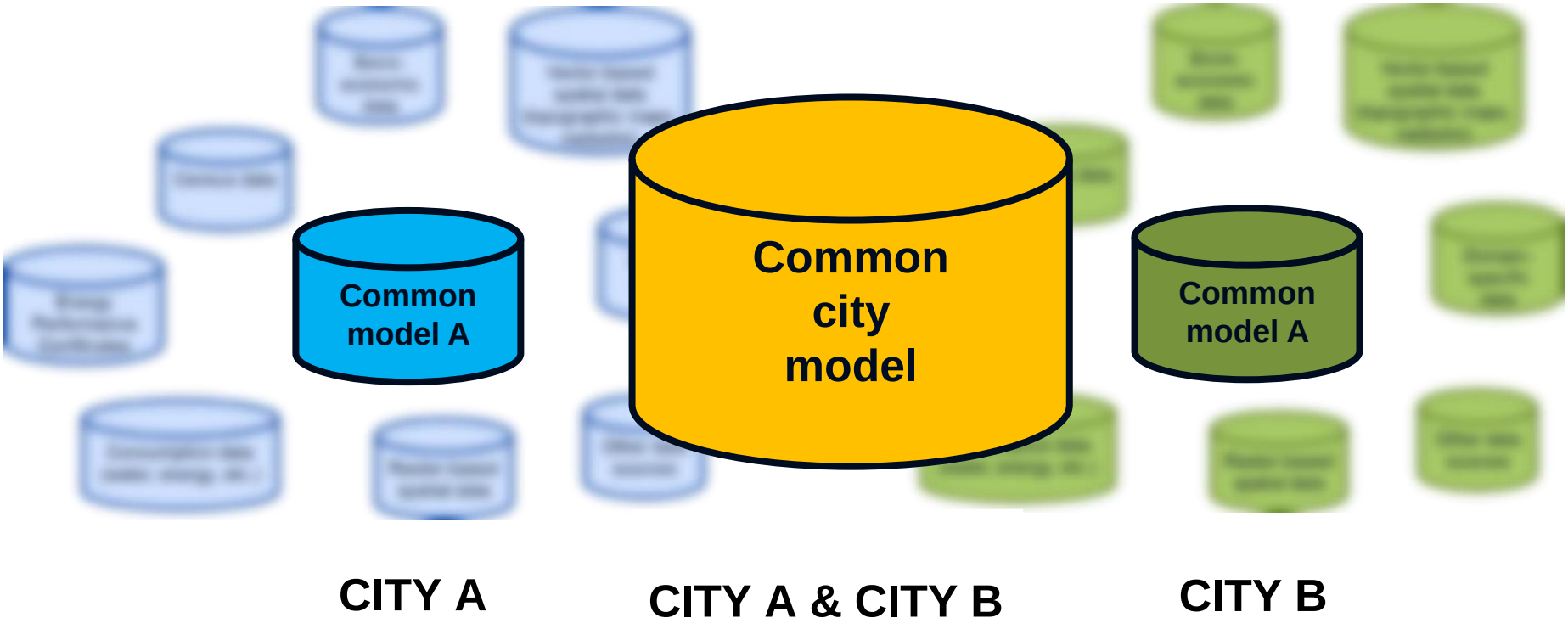


Image courtesy of J. Kämpf

Which common city model?



Spatio-semantic modelling of our world

- Many urban entities are physical objects…
- …and they occupy space in the real world
- Partitioning of occupied real space → discrete objects
  - spatial aspects: location, shape, extent
  - criteria for subdivision: thematic classification into different topographic elements like buildings, streets, trees etc.
- Different, discrete levels of detail (LODs)
- Real world is 3D → semantic 3D city models

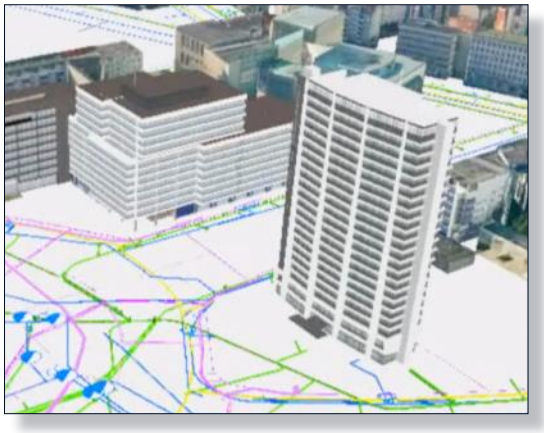


Image: Thomas Becker (2012)

Semantic 3D city modelling

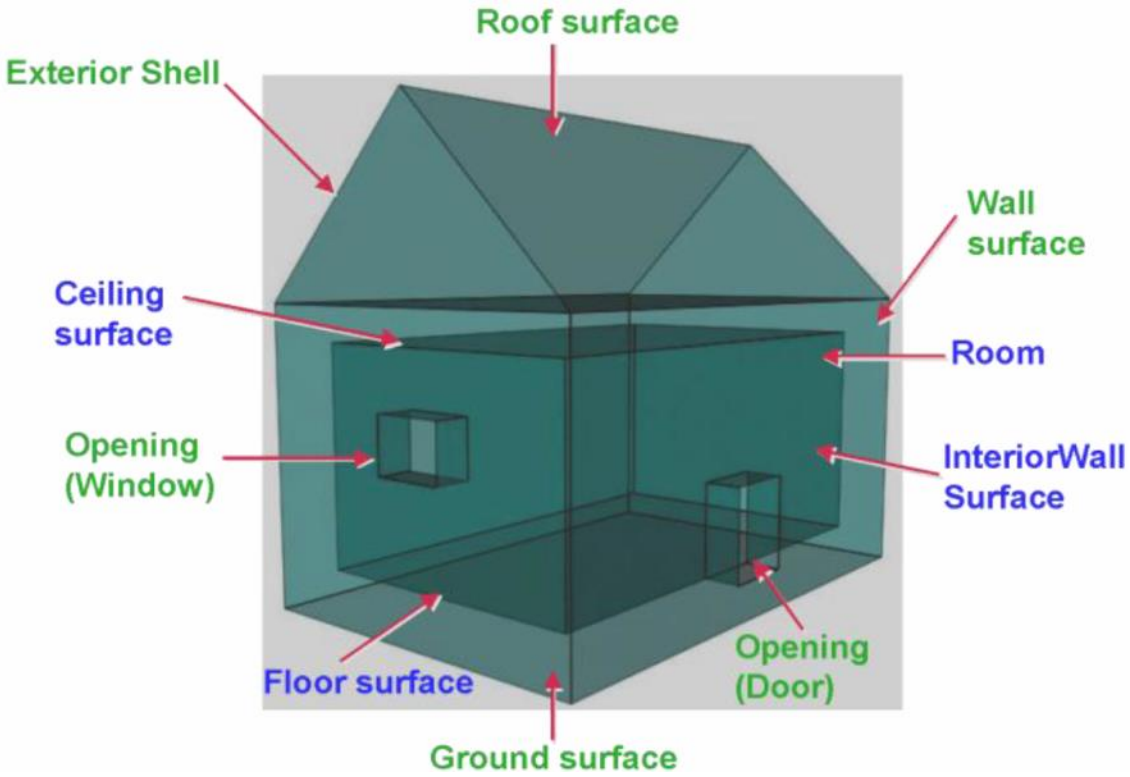
We need a model which is:

- urban
- three-dimensional
- virtual
- reality-based
- metric
- vector-based
- spatio-semantically coherent

Model: urban, 3D, virtual, reality-based, metric, **vector-based AND spatio-semantically coherent**

Vector-based building models

Source: www.geores.de

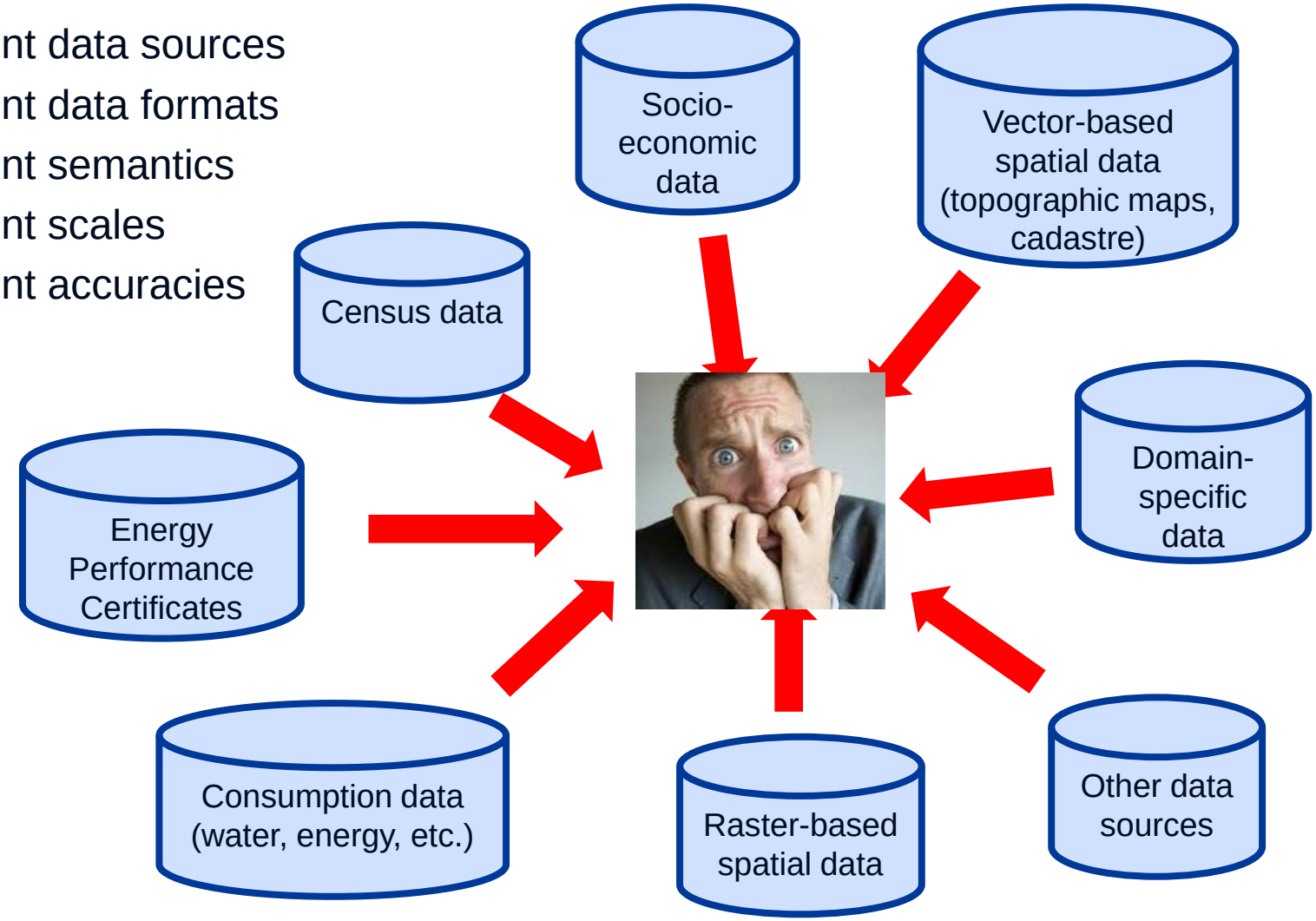


Semantic decomposition of a building (according to CityGML)

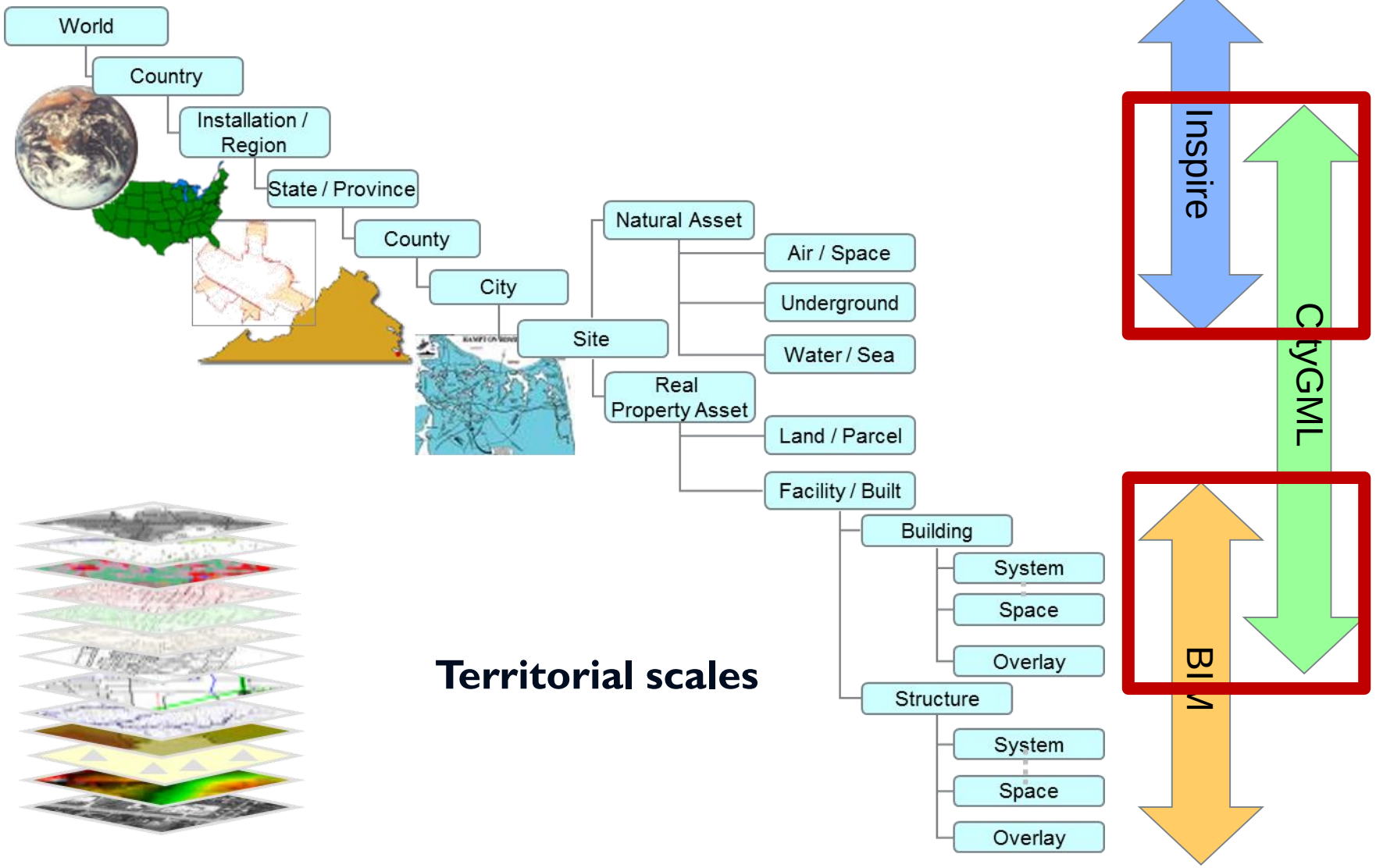
Source: CityGML Encoding Standard, www.opengeospatial.org

Which data model for cities?

- Different data sources
- Different data formats
- Different semantics
- Different scales
- Different accuracies
- …



Which data model for cities?



Territorial scales

Which data model for cities?

- CityGML: City Geography Markup Language
- **Information model** for 3D city models at urban and regional scale (**OGC standard**)
- Comprises **thematic areas** for buildings, terrain, traffic, tunnel, bridges, vegetation, etc.
- Includes multi **level-of-detail 3D geometry**, topology, semantics and appearance
- **Extendible** to other application domains

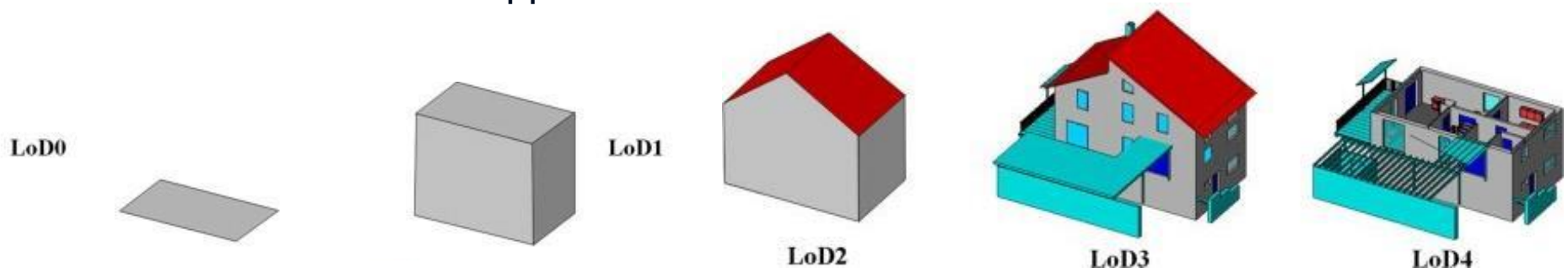


Image source: Karlsruhe Institue of Technology

Which data model for cities?

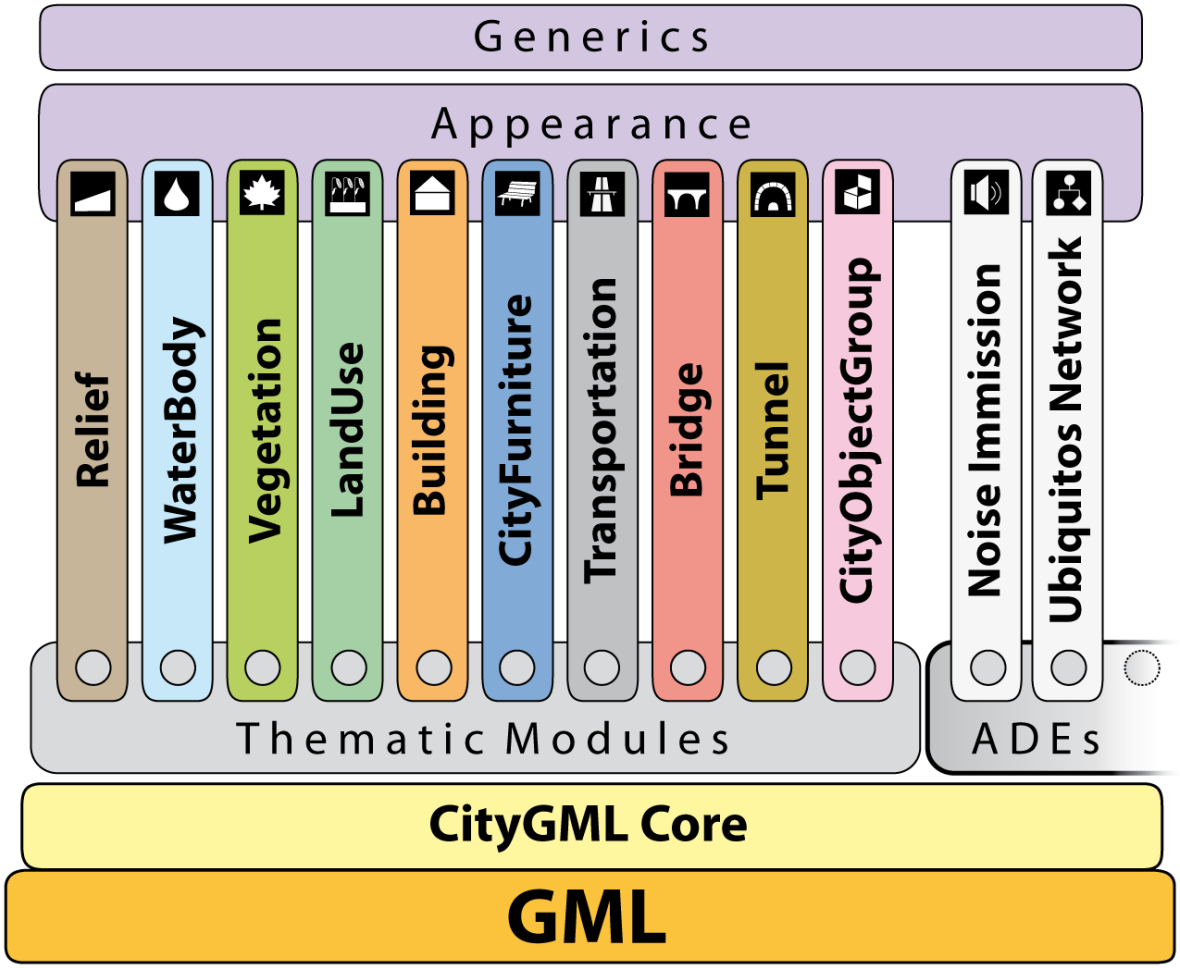


Image source: virtualcitySYSTEMS

Image source: Kolbe et al., 2009

CityGML: building model

NOTA BENE: all images in this and the following slides are taken from the CityGML 2.0 specification document

CityGML: tunnel model

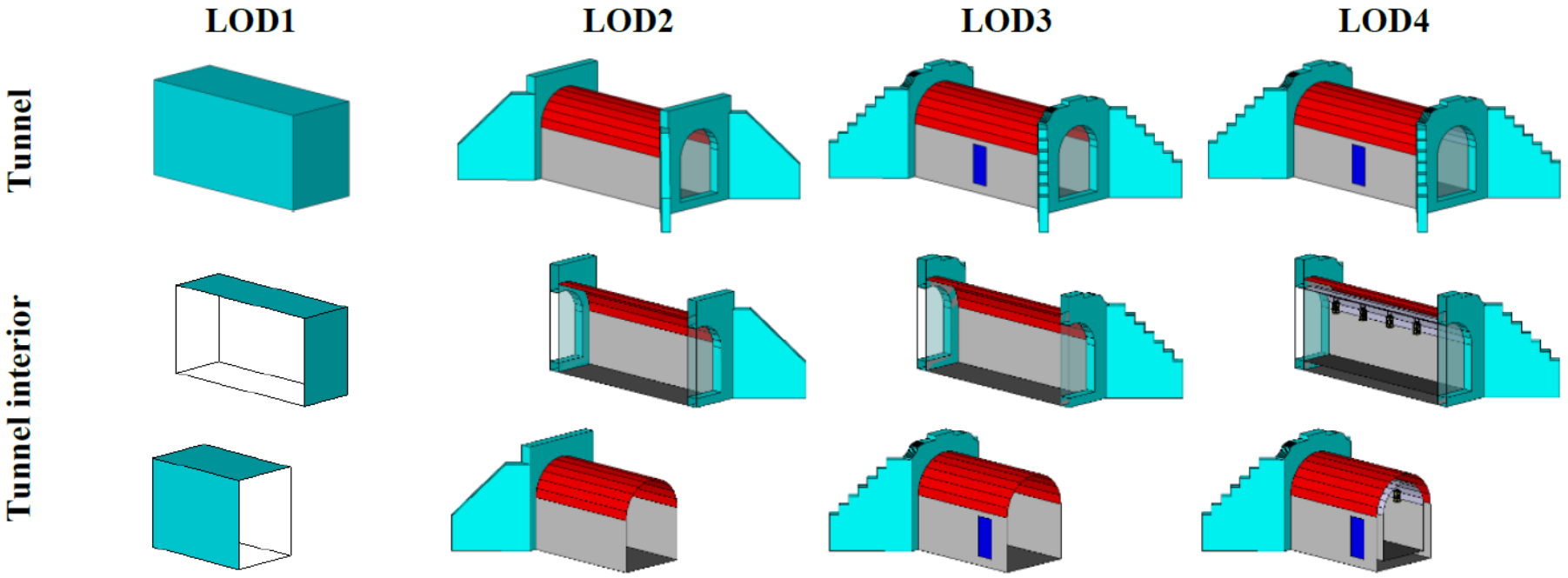


Fig. 40: Tunnel model in LOD1 – LOD4 (source: Karlsruhe Institute of Technology (KIT)).

CityGML: bridge model

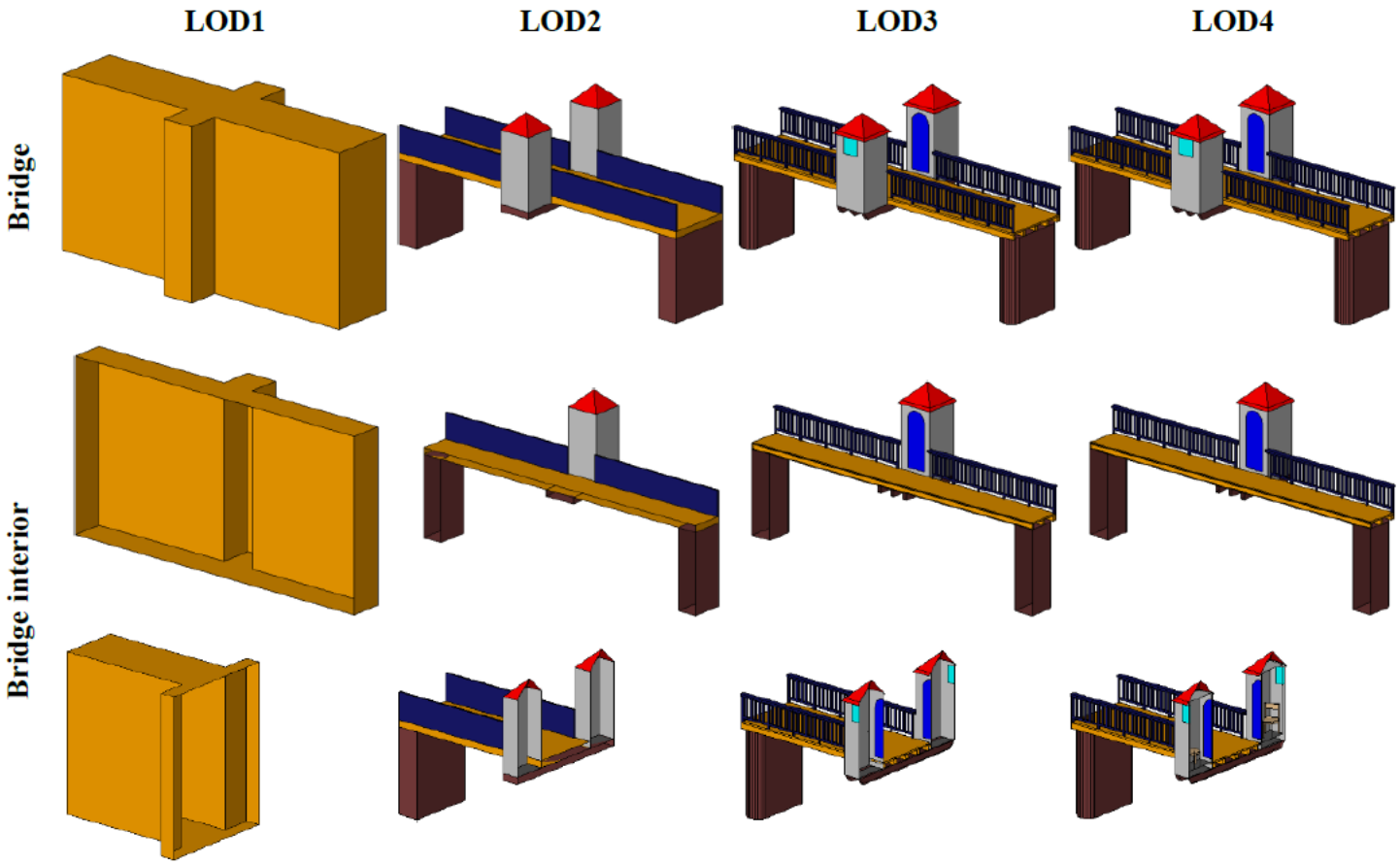


Fig. 46: Bridge model in LOD1 – LOD4. (source: Karlsruhe Institute of Technology (KIT))

CityGML: city furniture model

- Immovable objects like street lanterns, bus stops, street signs, etc.

- Can be represented also as implicit geometries

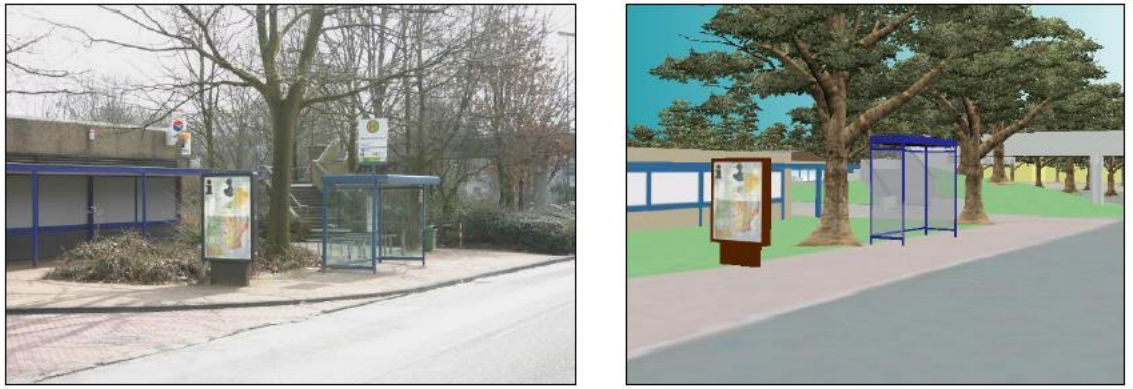


Fig. 67: Real situation showing a bus stop (left). The advertising billboard and the refuge are modelled as *CityFurniture* objects in the right image (source: 3D city model of Barkenberg).

Fig. 68: Real situation showing lanterns and delimitation stakes (left). In the right image they are modelled as *CityFurniture* objects with *ImplicitGeometry* representations (source: 3D city model of Barkenberg).

CityGML: vegetation model

- Solitary vegetation object can be represented in multiple LoDs with any geometry

- Plant cover can be represented only as MultiSurface or MultiSolid

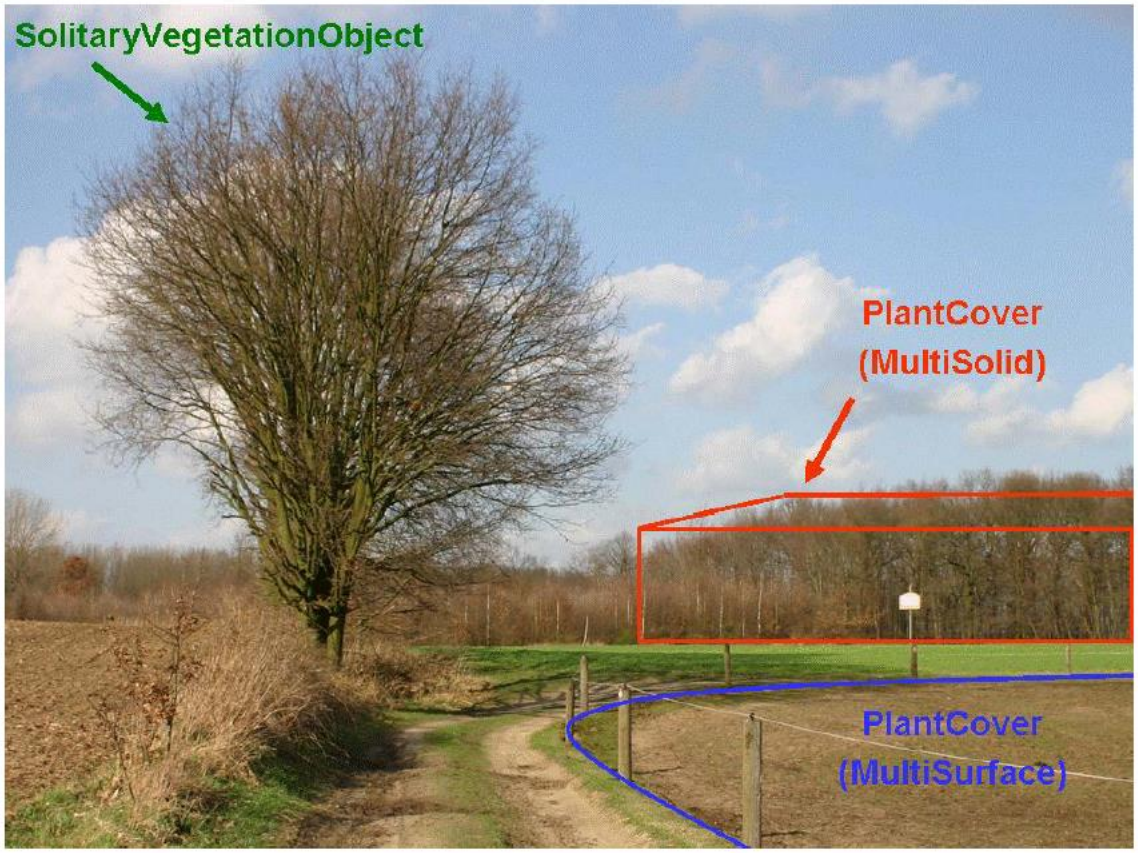
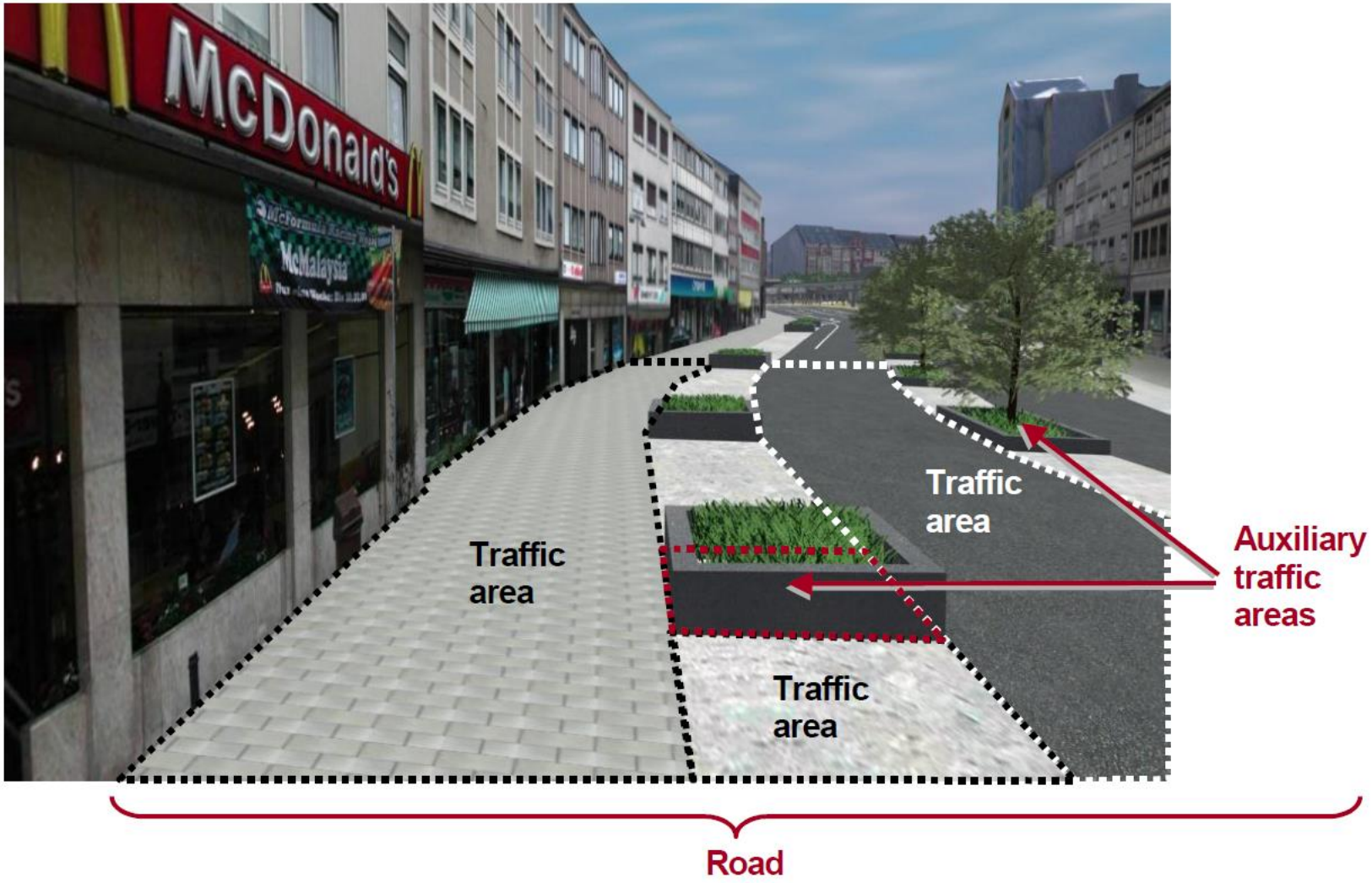
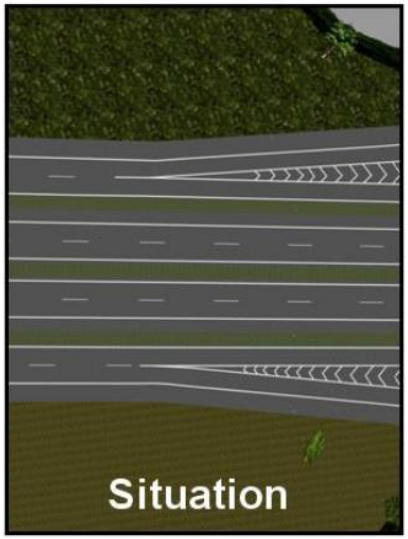


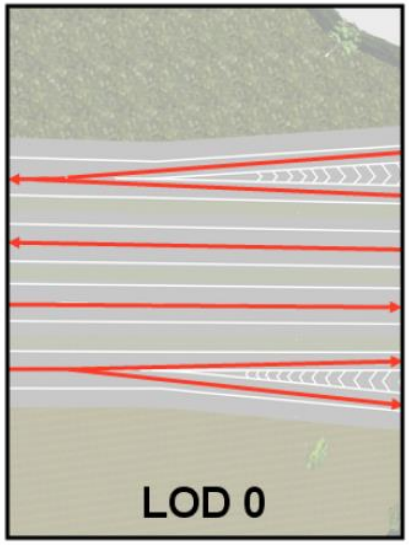
Fig. 63: Example for vegetation objects of the classes *SolitaryVegetationObject* and *PlantCover* (graphic: District of Recklinghausen).

CityGML: transportation model



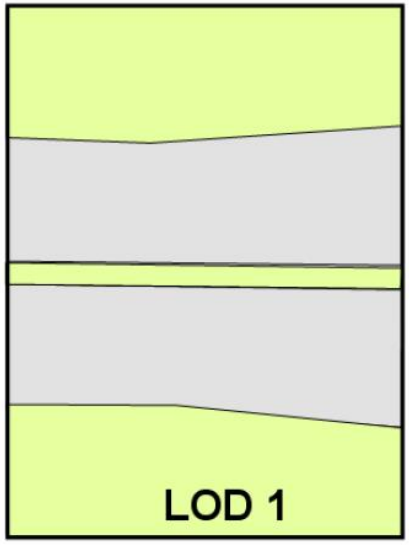
CityGML: transportation model





TransportationComplex provides linear network with line objects

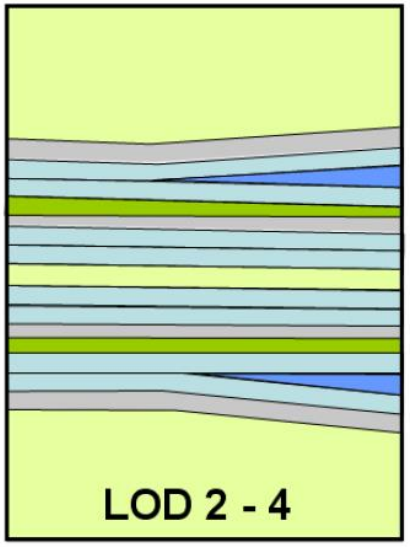
line objects



TransportationComplex provides surface geometry describing the actual shape of the object

TransportationComplex (Surface geometry)

Terrain surface



Surface geometry is devided thematically into TrafficAreas, like:

- Traffic – cars
- Traffic – emergency lane
- Traffic – restricted area
- Auxiliary - grass

CityGML: land use model

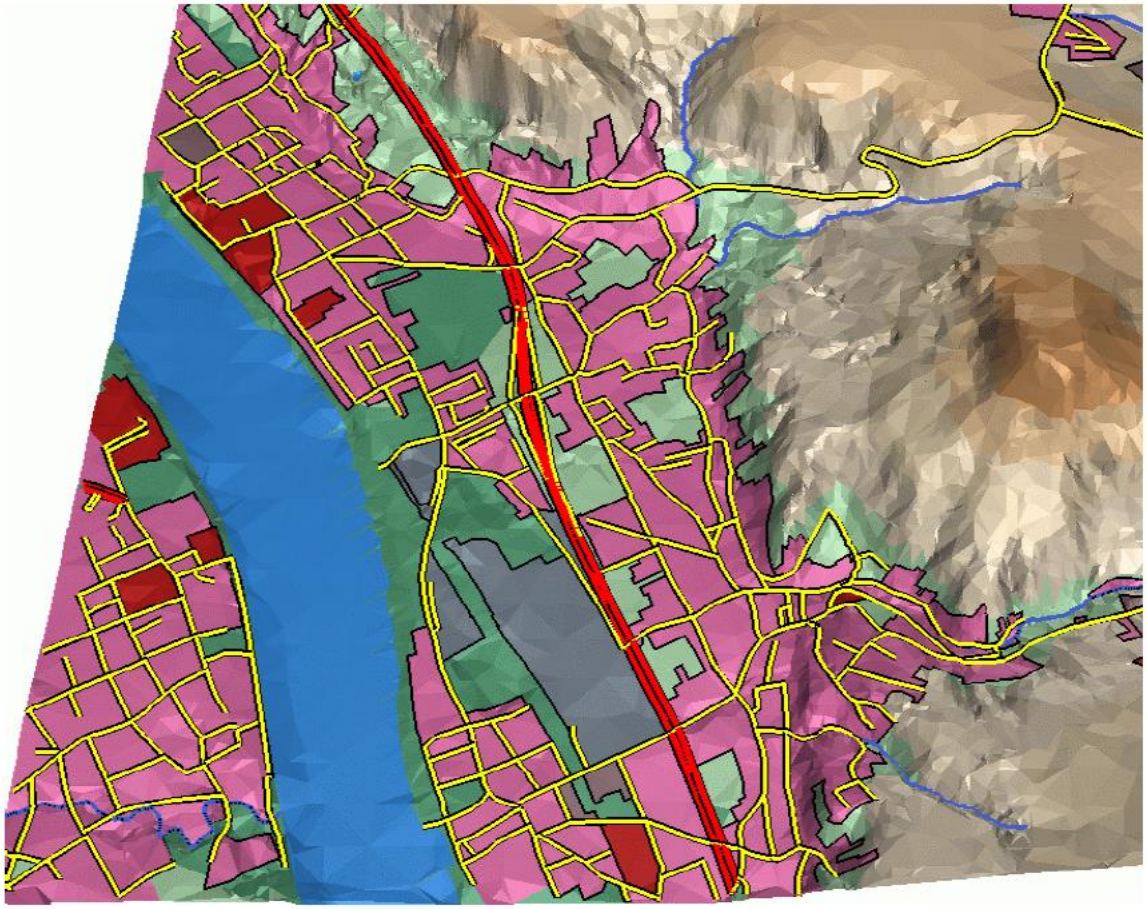


Fig. 72: LOD0 regional model consisting of land use objects in CityGML (source: IGG Uni Bonn).

CityGML: Waterbody model

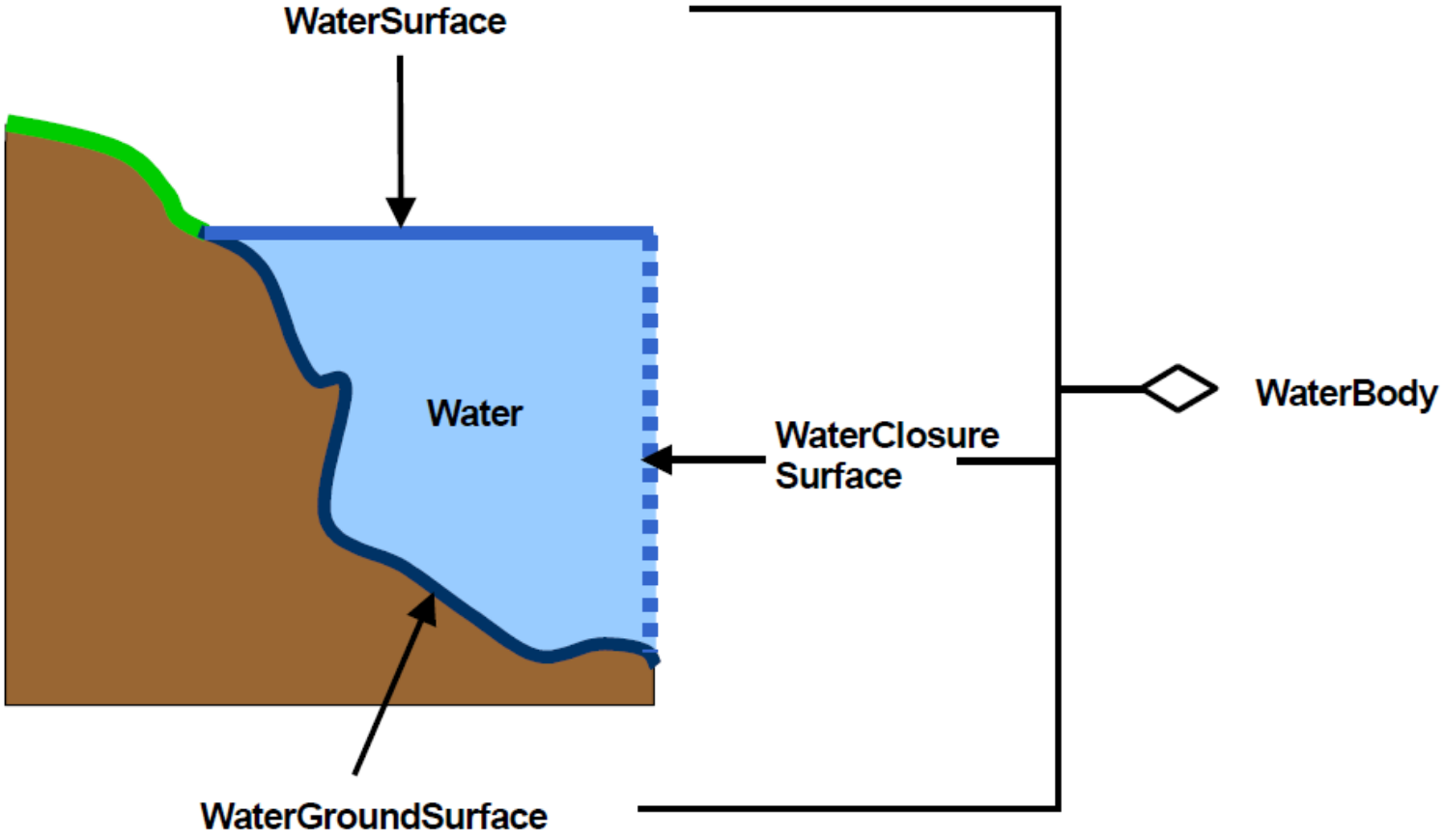
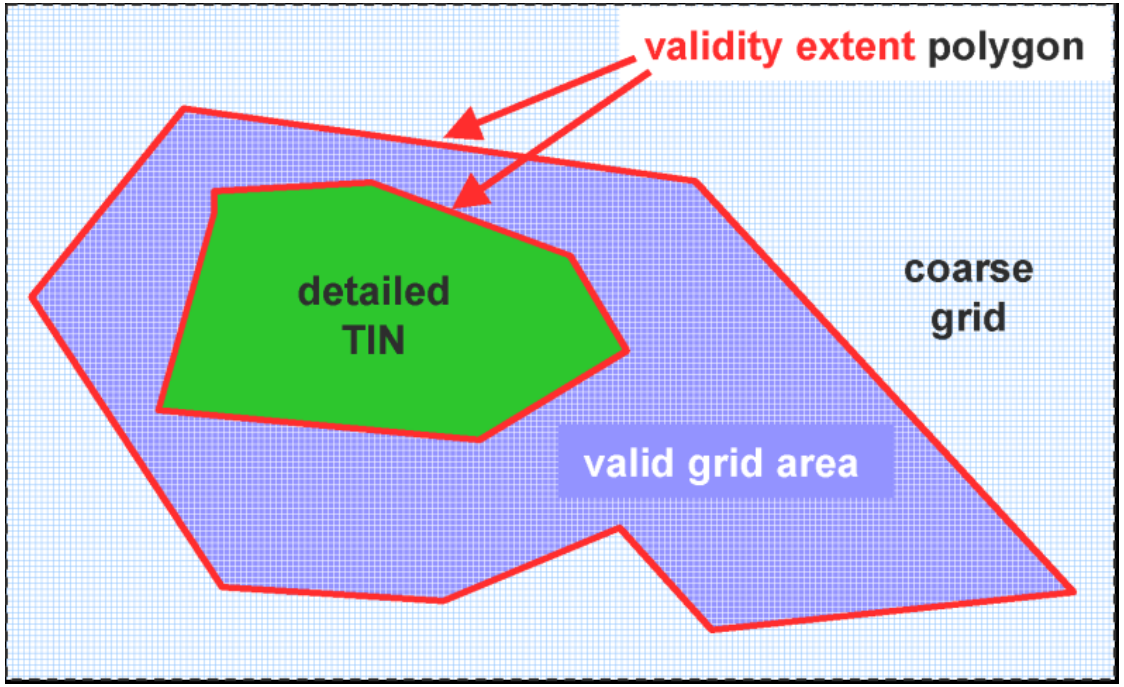


Fig. 55: Illustration of a water body defined in CityGML (graphic: IGG Uni Bonn).

CityGML: Digital Terrain Model

- Supports raster and vector DTMs
- Multiple, heterogeneous DTM can be nested
- Each DTM is delimited by a **validity extend polygon**



CityGML: Other modules

- **CityObjectGroup**
  - allows for arbitrary grouping of city objects

- **Generics**
  - allows to define generic city objects, which are not already defined
  - Allows to define generic attributes, which are not already defined

- **Appearance**
  - Allows to define one or multiple appearances for each city object
    - Styling with "colours"
    - Texturing

Working with CityGML, city model generation

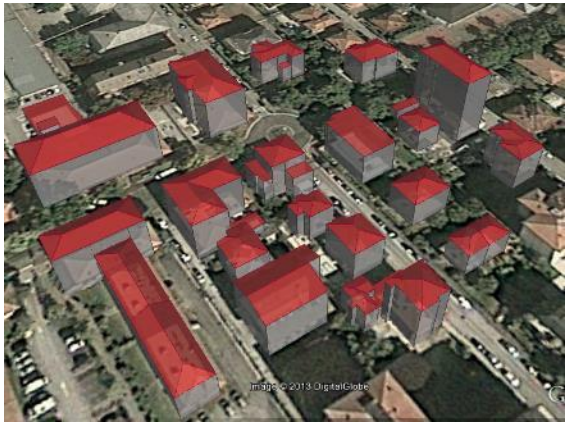
1) Input data

- DSM (min 4, better 10 to 15 pt/m²)
- Building footprints

2) 3D modelling software

3) Import/export tools

4) Spatial RDBMS



5) Output

Brief overview of CityGML tools

- **citygml4j**
  - FOSS Java-based API to read and write CityGML documents (+ ADEs) https://github.com/citygml4j

- **3D City Database ("3DCityDB")**
  - FOSS implementation (Postgres / Oracle) of the CityGML data model
  - Comes with SQL scripts to generate tables and (some) stored procedures

- **Documentation + Installer**: http://www.3dcitydb.org

- **GitHub**: https://github.com/3dcitydb

Brief overview of CityGML-related tools

- **3DCityDB Importer / Exporter**
  - FOSS interface (+ GUI) based on citygml4j
  - Validate & import CityGML data into the 3DCityDB
  - Export data from the 3D city DB into
    - CityGML
    - KML (for Google Earth) + Balloons
    - Gltf (for Cesium WebGL Virtual Globe)
  - Export attributes as spreadsheet/csv

- **3DCityDB-Web-Map-Client**
  - FOSS, web-based front-end of the 3DCityDB for 3D visualisation and interactive exploration of 3D city models
  - Builds on & extends the Cesium library
  - (More details later on)
  - Shipped (also) with the 3DCityDB software package

Welcome

The award winning 3D City Database is a free geo database to store, represent, and manage virtual 3D city models on top of a standard spatial relational database. The database schema implements the CityGML standard with semantically rich and multi-scale urban objects facilitating complex analysis tasks, far beyond visualization. 3DCityDB is in productive and commercial use for more than 10 years in many places around the world. It is also employed in numerous research projects related to 3D city models.

The 3D City Database comes with tools for easy data exchange and coupling with cloud services. The 3D City Database content can be directly exported in KML, COLLADA, and glTF formats for the visualisation in a broad range of applications like Google Earth, ArcGIS, and the WebGL-based Cesium Virtual Globe.

About CityGML

View Demos

New Release

22.11.2016: A bug fix release of the Importer/Exporter **v3.3.1** for Oracle and PostGIS **available now!**

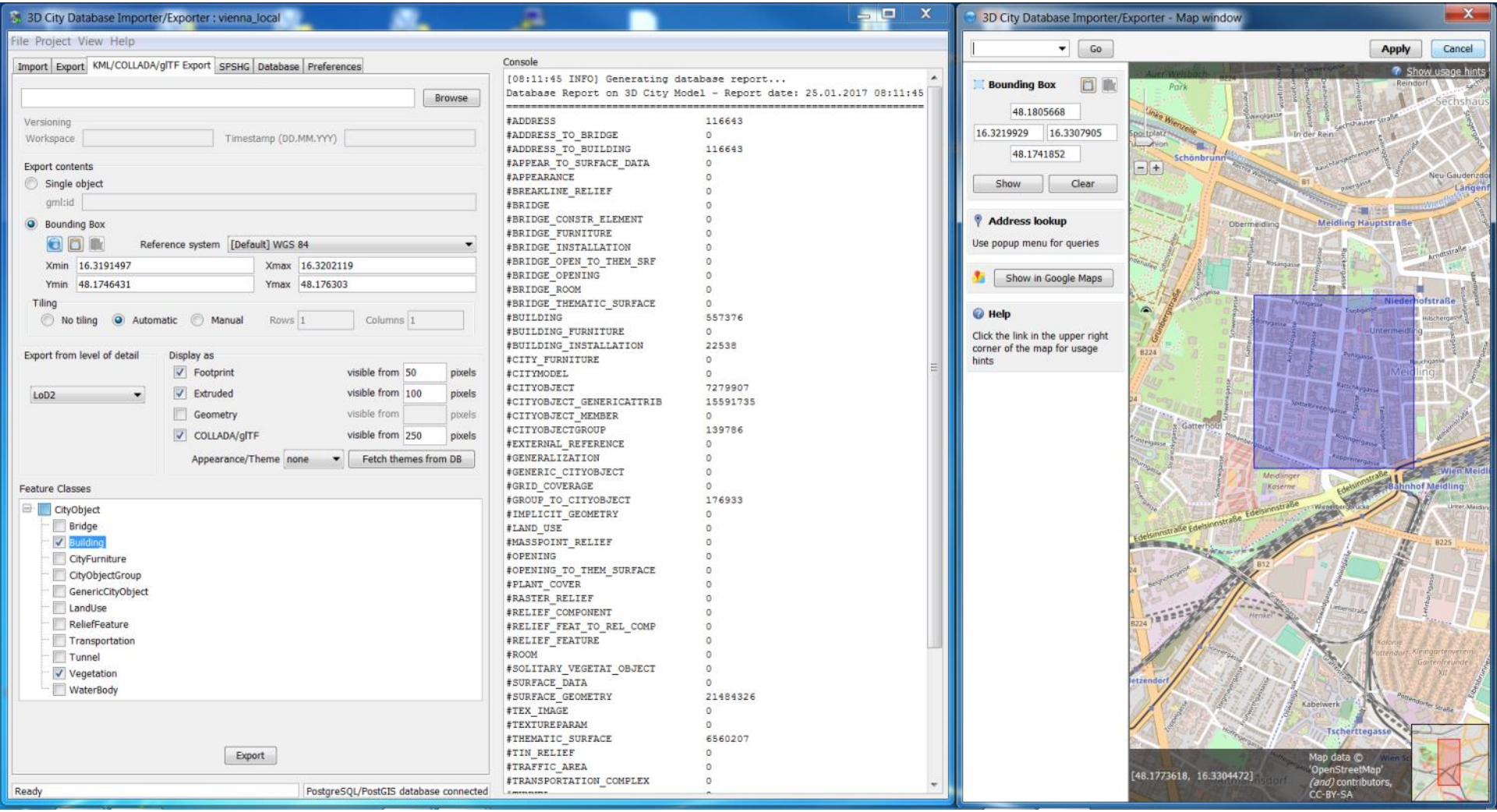
New Major Release

01.09.2016: 3D City Database **v3.3** and Importer/Exporter **v3.3** for Oracle and PostGIS **available now!**

NEW!

Flyer on 3DCityDB v3.3

Download a **two-page flyer** on the new release 3.3.


3D City Database Importer/Exporter : vienna_local
File Project View Help
Import Export KML/COLLADA/glTF Export SPSHG Database Preferences
Browse
Versioning
Workspace
Timestamp (DD.MM.YYY)
Export contents
Single object
gml:id
Bounding Box
Reference system [Default] WGS 84
Xmin 16.3191497
Xmax 16.3202119
Ymin 48.1746431
Ymax 48.176303
Tiling
No tiling Automatic Manual Rows 1 Columns 1
Export from level of detail
LoD2
Display as
Footprint visible from 50 pixels
Extruded visible from 100 pixels
Geometry visible from pixels
COLLADA/glTF visible from 250 pixels
Appearance/Theme none
Fetch themes from DB
Feature Classes
CityObject
Bridge
Building
CityFurniture
CityObjectGroup
GenericCityObject
LandUse
ReliefFeature
Transportation
Tunnel
Vegetation
WaterBody
Export
Ready
PostgreSQL/PostGIS database connected
Console
[08:11:45 INFO] Generating database report...
Database Report on 3D City Model - Report date: 25.01.2017 08:11:45
#ADDRESS 116643
#ADDRESS_TO_BRIDGE 0
#ADDRESS_TO_BUILDING 116643
#APPEAR_TO_SURFACE_DATA 0
#APPEARANCE 0
#BREAKLINE_RELIEF 0
#BRIDGE 0
#BRIDGE_CONSTR_ELEMENT 0
#BRIDGE_FURNITURE 0
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#BRIDGE_OPEN_TO_THEM_SRF 0
#BRIDGE_OPENING 0
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#BRIDGE_THEMATIC_SURFACE 0
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#PLANT_COVER 0
#RASTER_RELIEF 0
#RELIEF_COMPONENT 0
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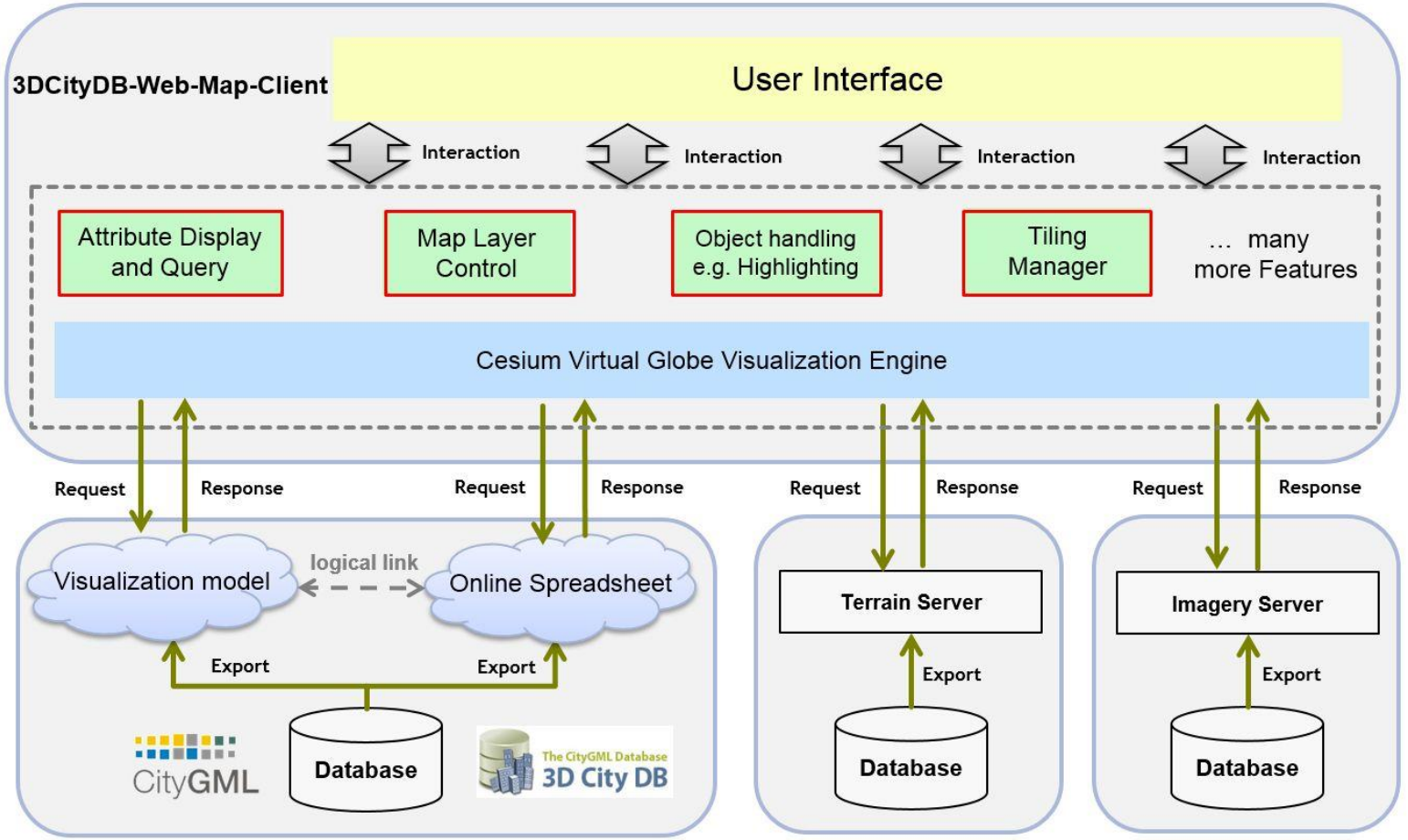
#RELIEF_FEATURE 0
#ROOM 0
#SOLITARY_VEGETAT_OBJECT 0
#SURFACE_DATA 0
#SURFACE_GEOMETRY 21484326
#TEX_IMAGE 0
#TEXTUREPARAM 0
#THEMATIC_SURFACE 6560207
#TIN_RELIEF 0
#TRAFFIC_AREA 0
#TRANSPORTATION_COMPLEX 0
3D City Database Importer/Exporter - Map window
Go
Apply
Cancel
Bounding Box
48.1805668
16.3219929
16.3307905
48.1741852
Show
Clear
Address lookup
Use popup menu for queries
Show in Google Maps
Help
Click the link in the upper right corner of the map for usage hints
Show usage hints
[48.1773618, 16.3304472]
Map data © 'OpenStreetMap' (and) contributors, CC-BY-SA

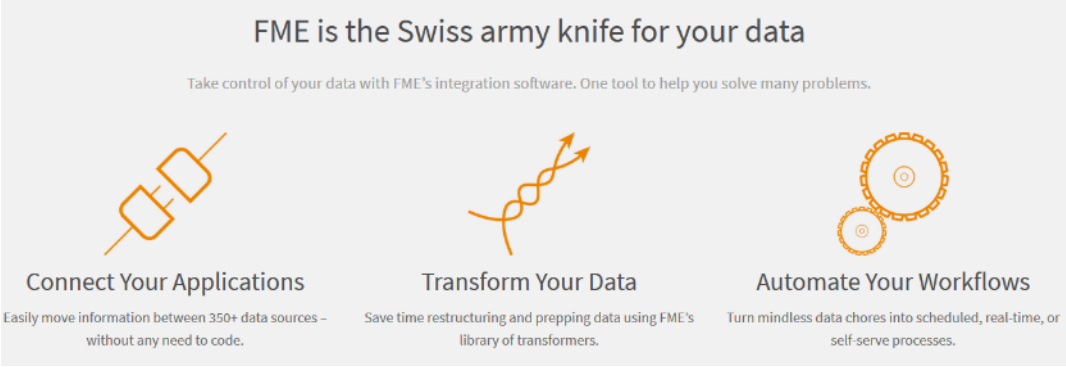
3DCityDB-Web-Map-Client



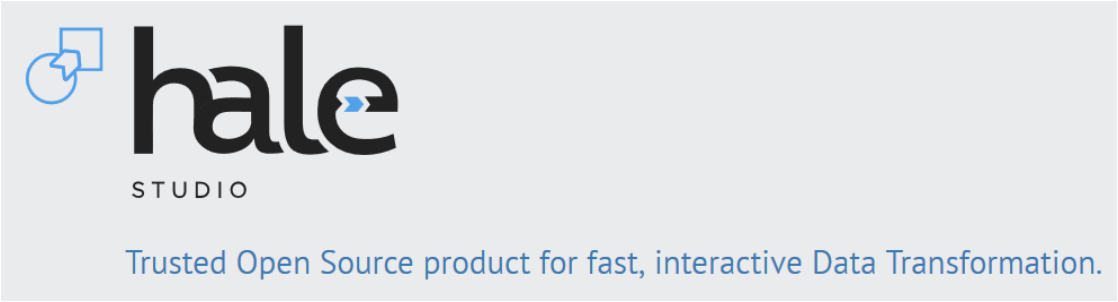
https://github.com/3dcitydb/3dcitydb-web-map

Brief overview of CityGML-related tools

- **Spatial ETL tools with CityGML support**
  - Feature Manipulation Engine (FME) by Safe Software
  - https://www.safe.com/

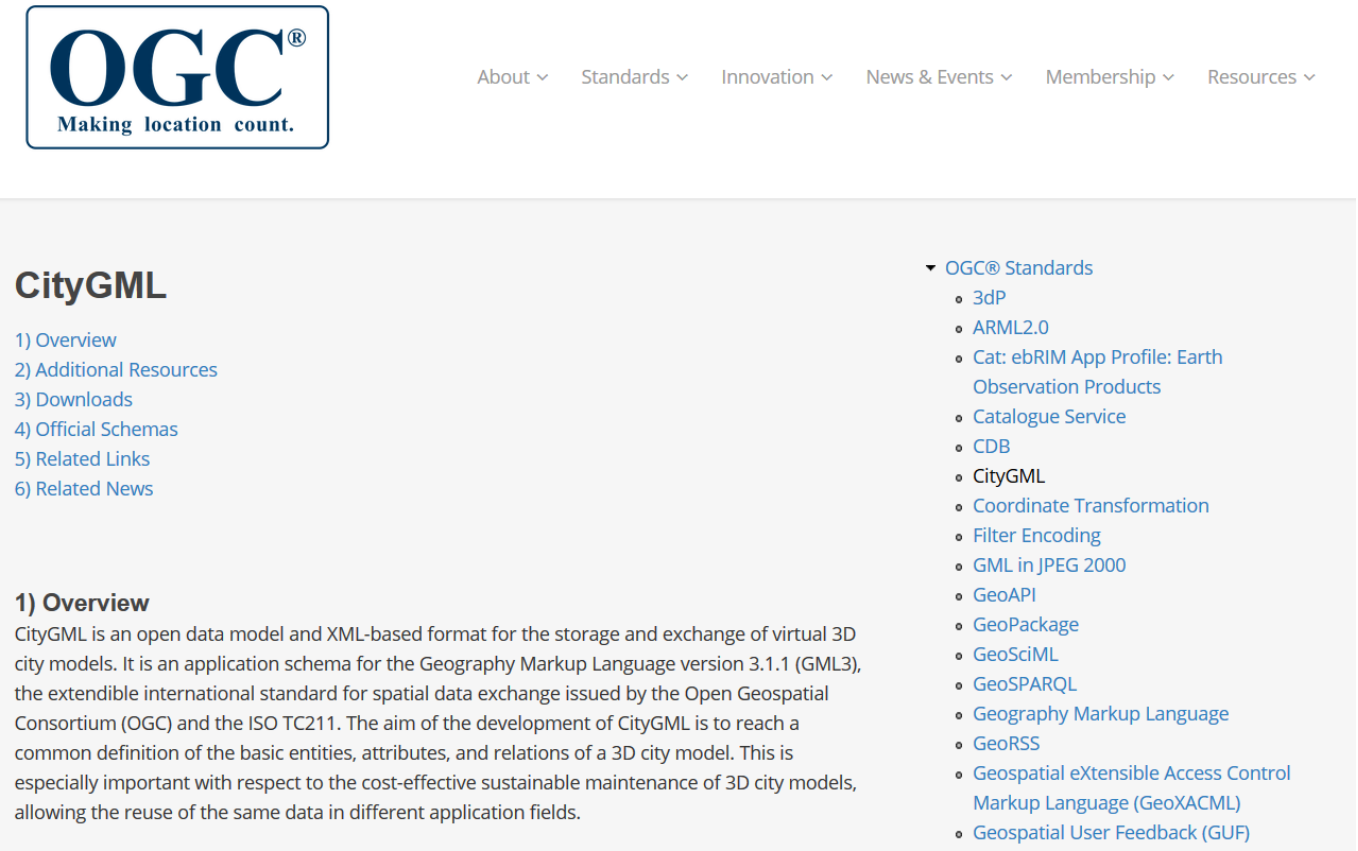


  - Hale Studio by WeTransform
  - https://www.wetransform.to/products/halestudio

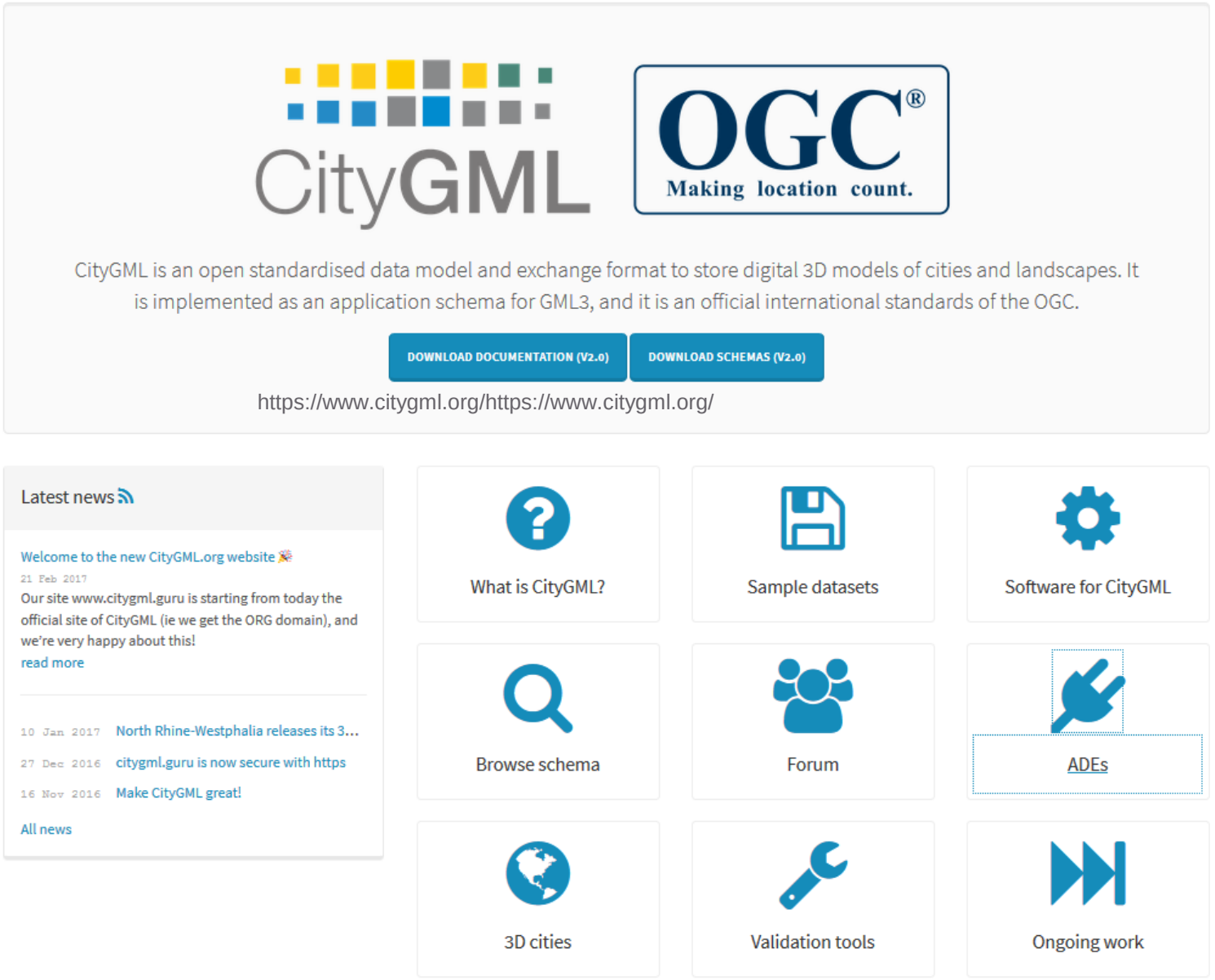


Where to get more information?

- CityGML Specifications: http://www.opengeospatial.org/standards/citygml



- CityGML homepage: http://www.citygml.org



- CityGML Wiki: http://www.citygmlwiki.org

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Part 2: A 2nd look at CityGML and the 3DCityDB

- CityGML: A look at the UML model
- The 3D City Database

NOTA BENE: all UML diagrams in the following slides are taken from the CityGML 2.0 specification document

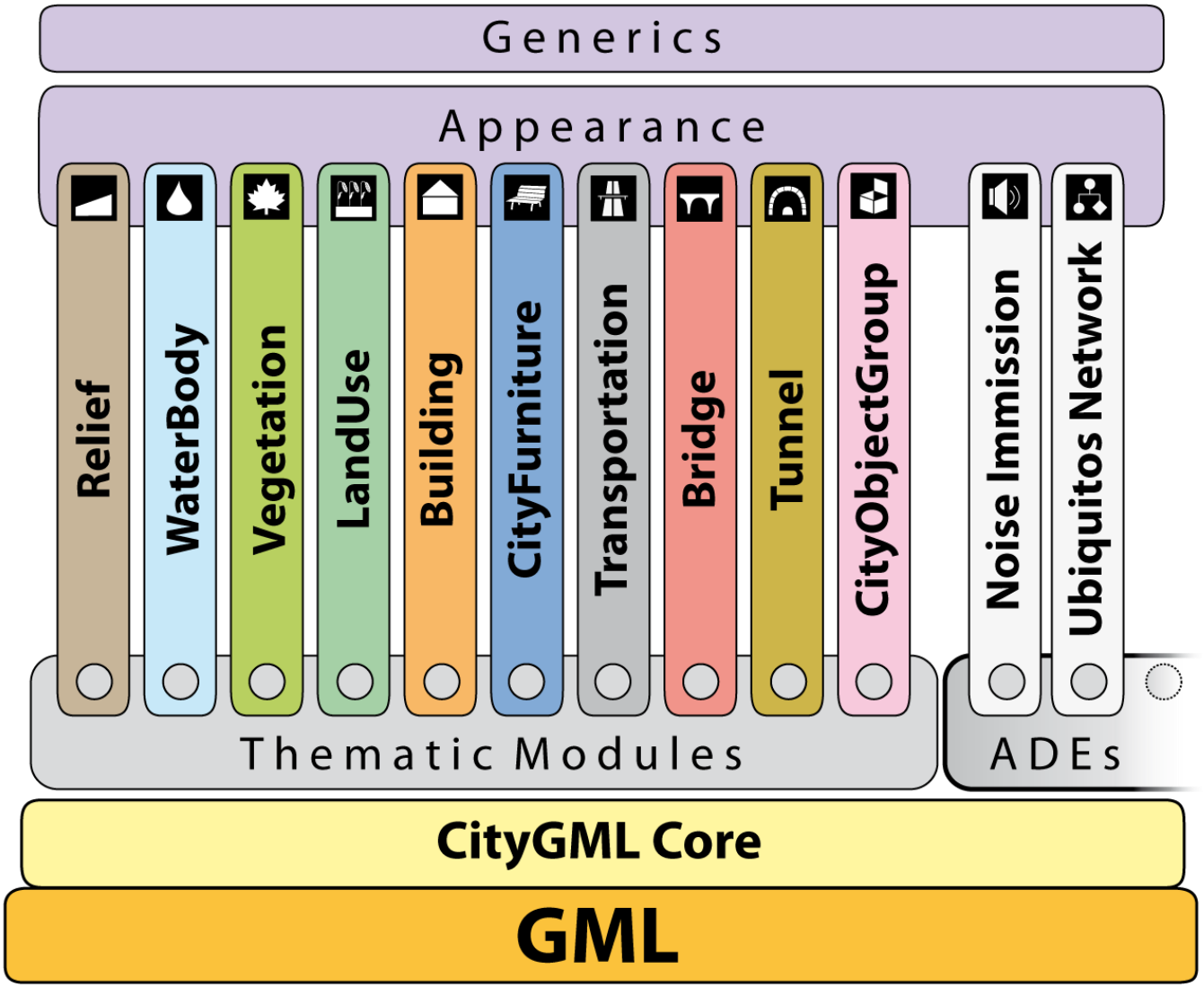
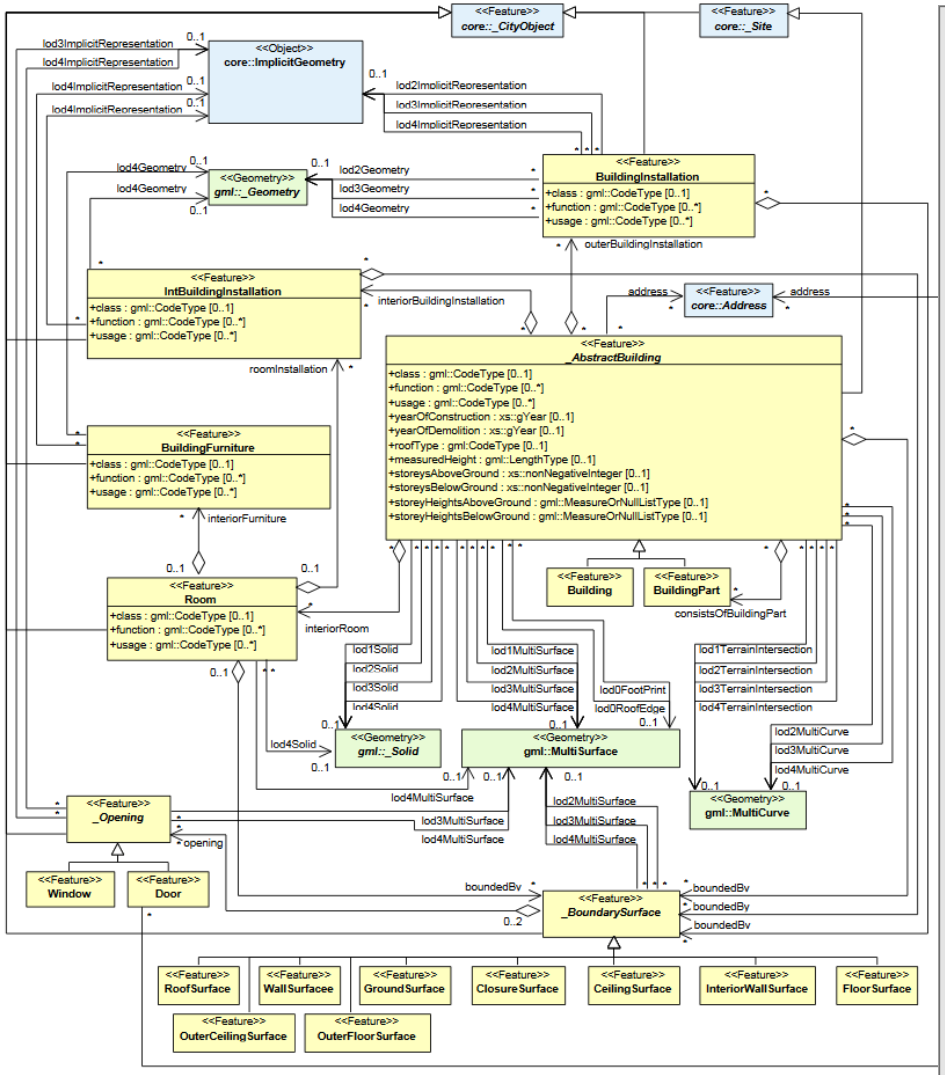


Image source: virtualcitySYSTEMS

CityGML: data model AND XML-based data format

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  <gml:boundedBy>
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      <gml:lowerCorner>-2501.47 335478.41 208.397</gml:lowerCorner>
      <gml:upperCorner>-1972.514 336128.59 235.707</gml:upperCorner>
    </gml:Envelope>
  </gml:boundedBy>
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      <gml:name>028540</gml:name>
      <core:creationDate>2016-04-07</core:creationDate>
      <grp:groupMember>
        <bldg:Building gml:id="UUID_52082618-f668-40da-bf92-3b606057c92c">
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          <core:creationDate>2016-04-07</core:creationDate>
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          <bldg:lod0FootPrint>
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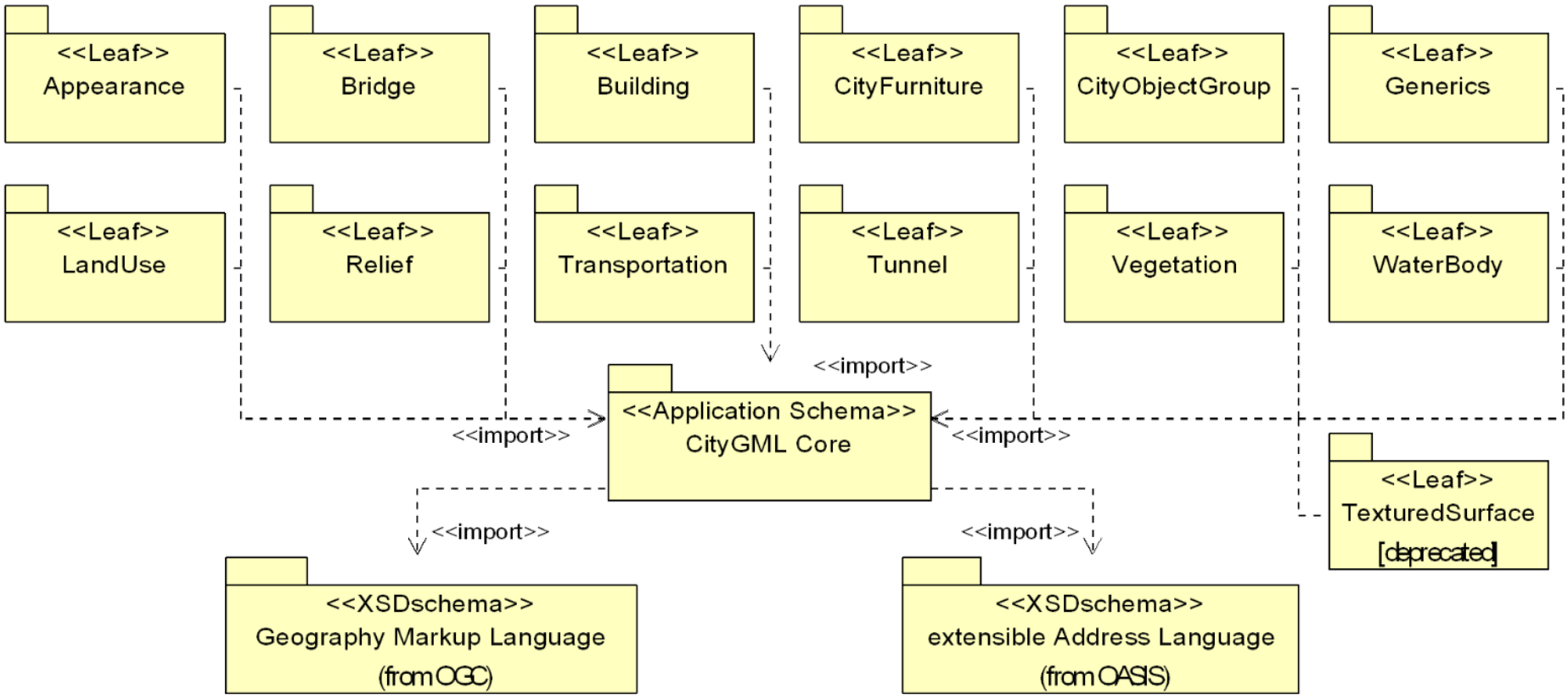
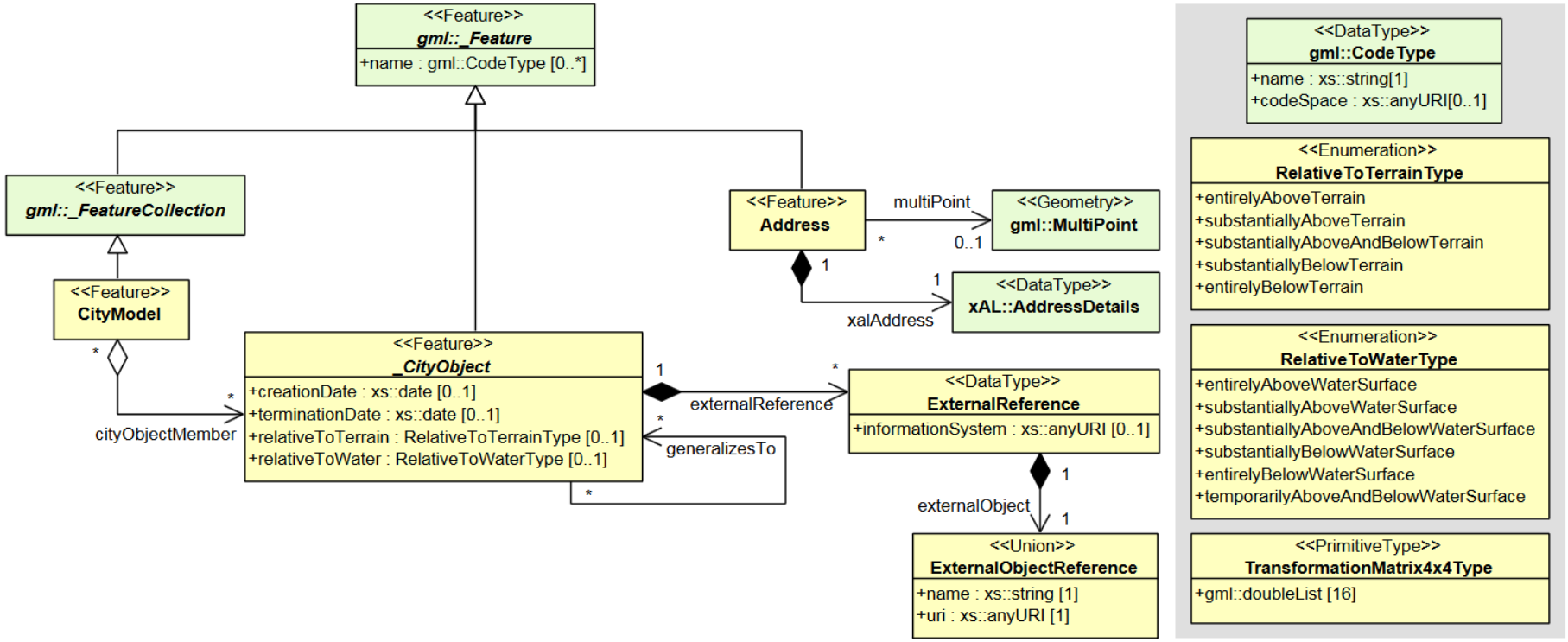
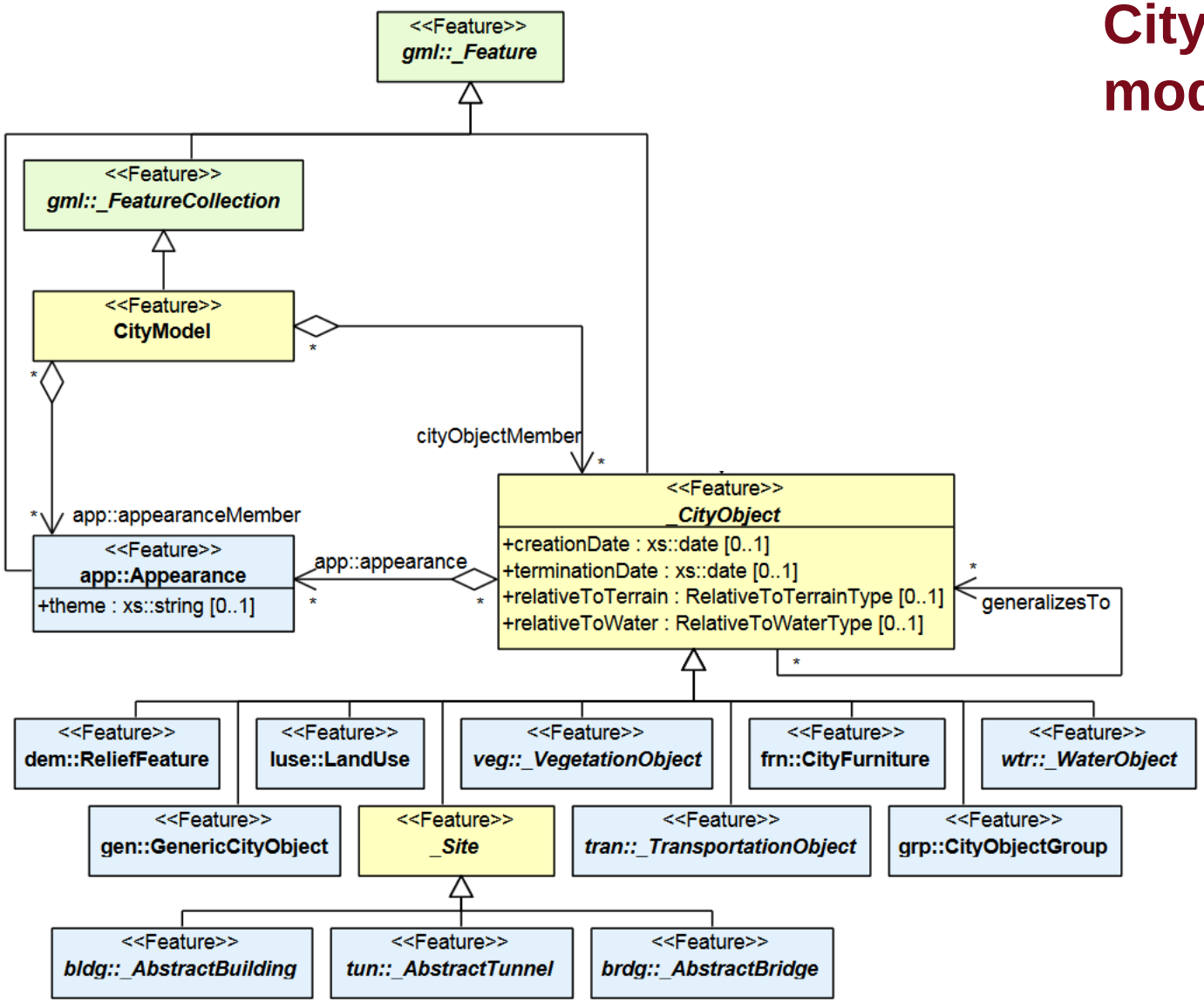
CityGML modules overview

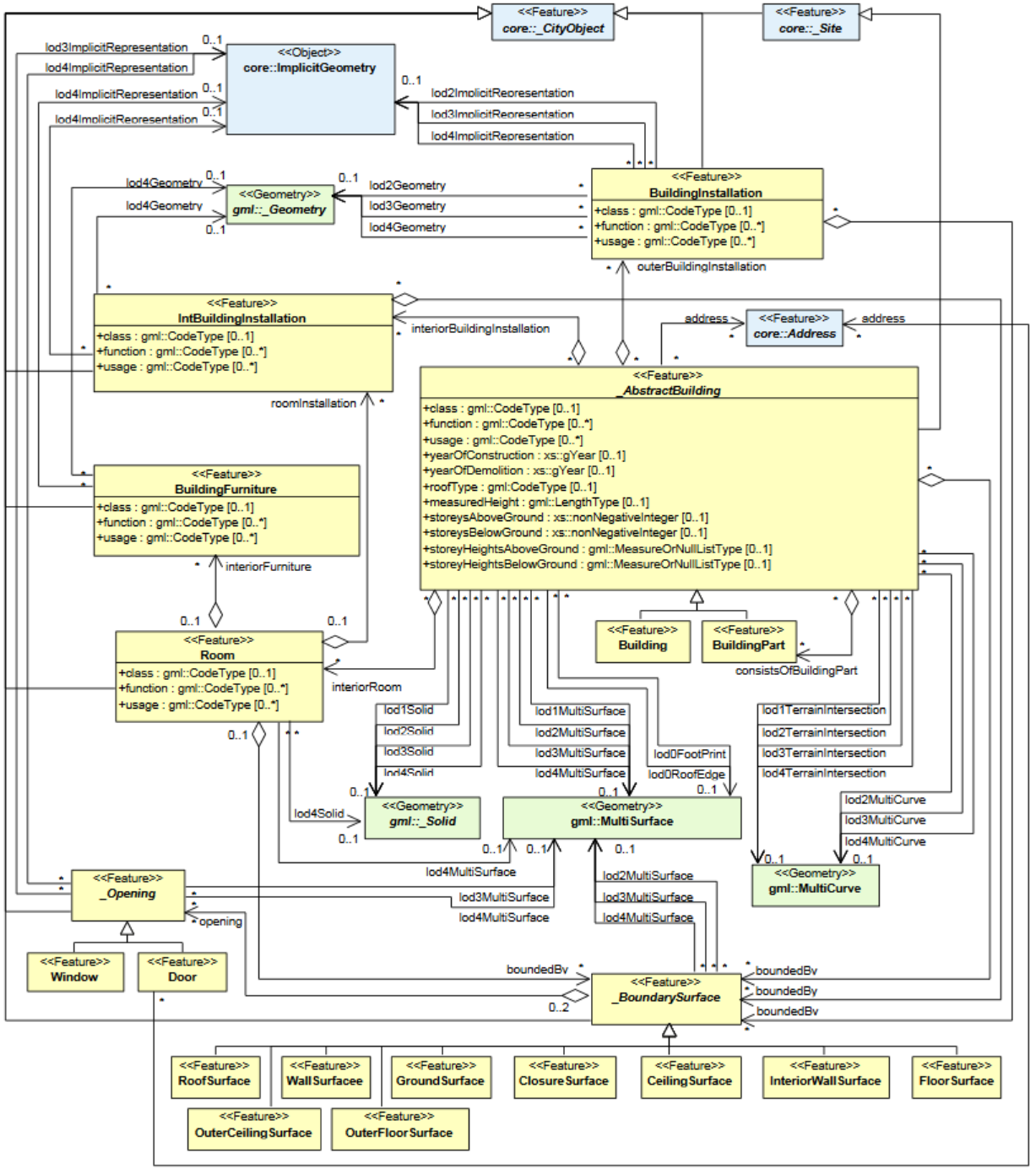


CityGML Core module, part 1

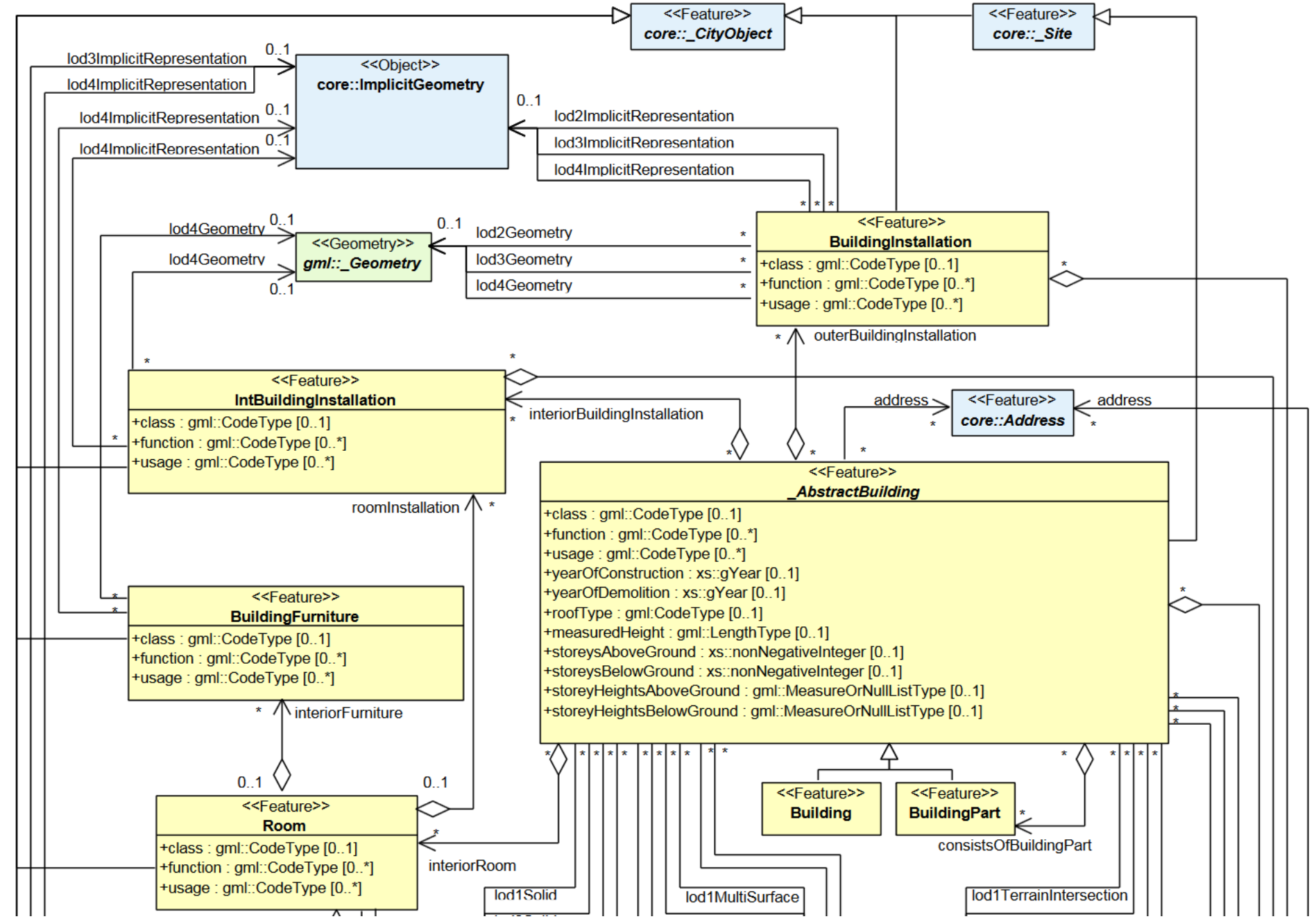


CityGML: core module





CityGML: building module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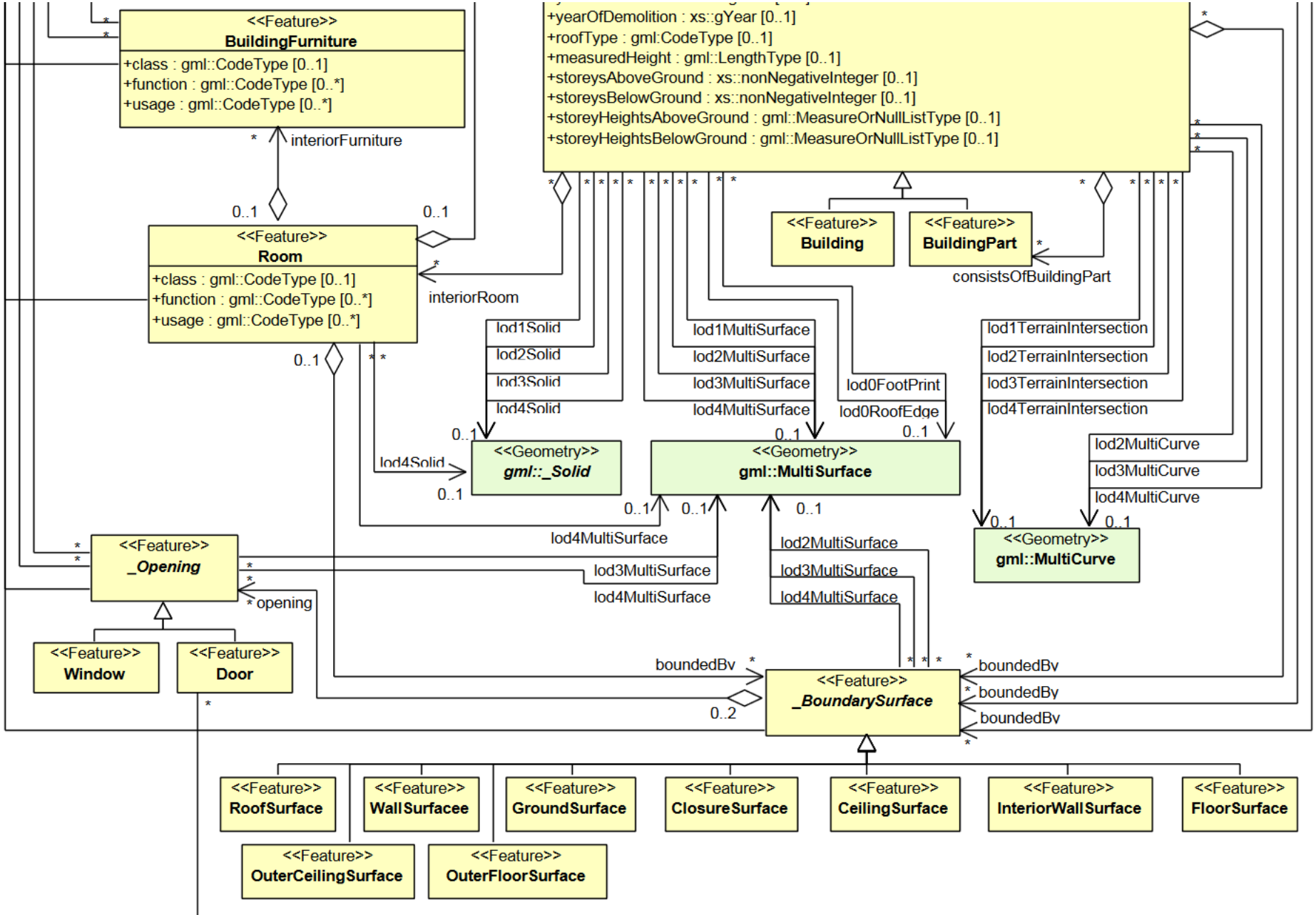
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lod2MultiSurface
lod3MultiSurface
lod4MultiSurface
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lod0RoofEdge
lod1TerrainIntersection
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Door
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FloorSurface
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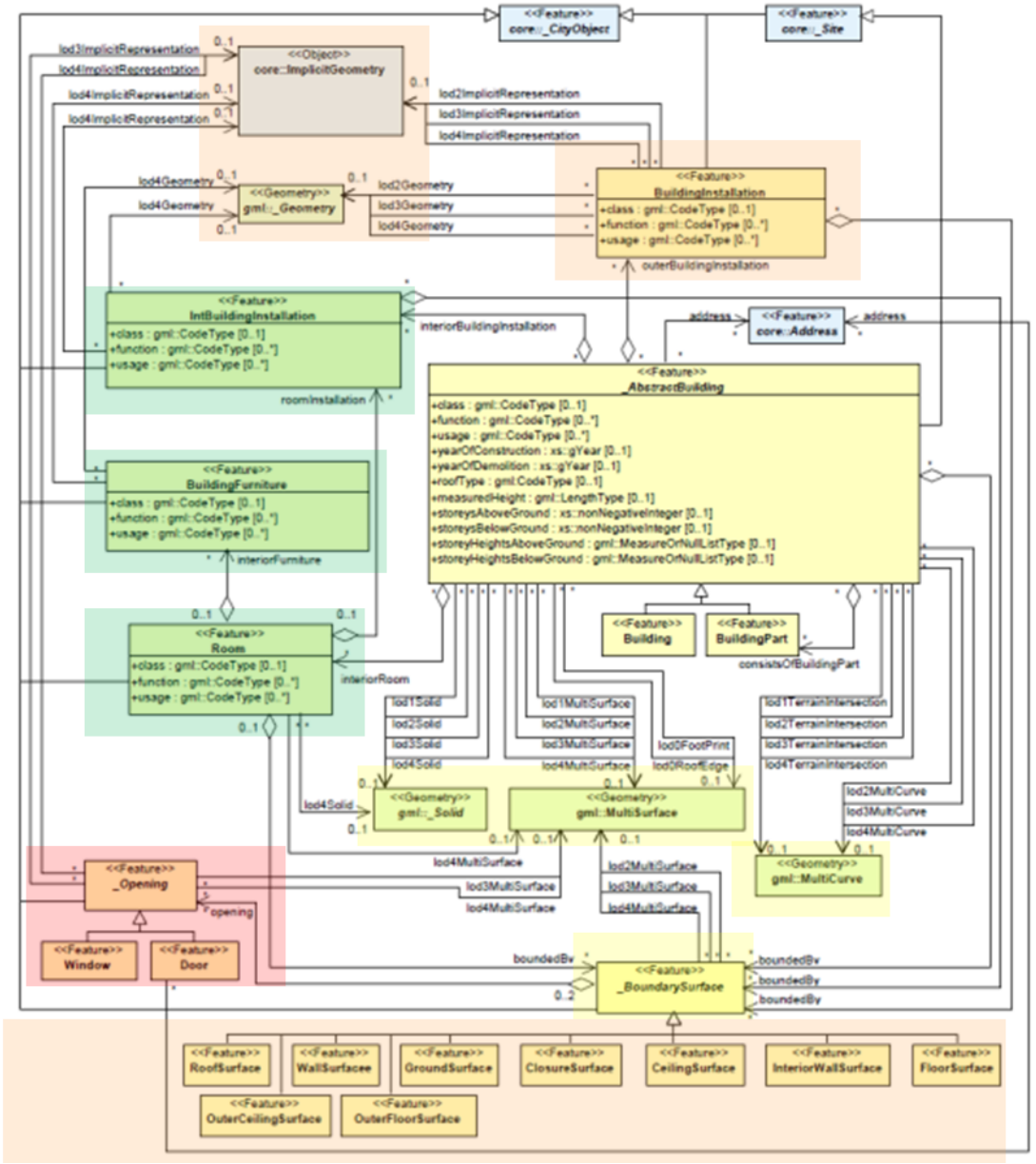
OuterFloorSurface



UML diagram of the building model in CityGML

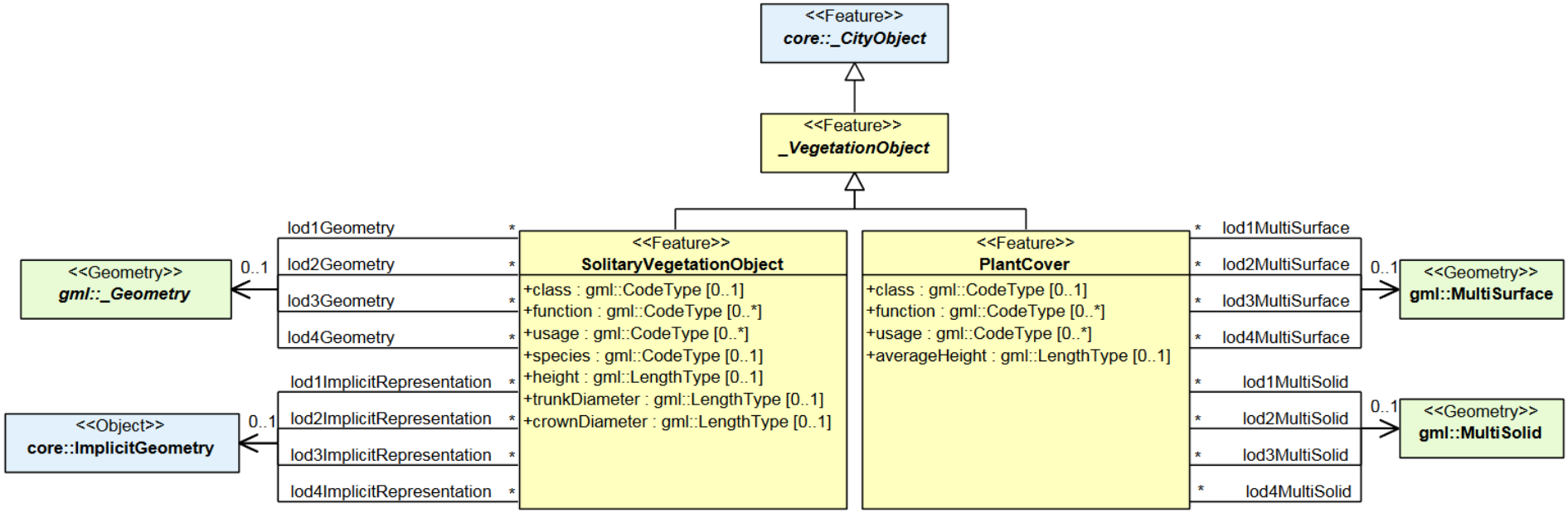
Lod1

Lod2

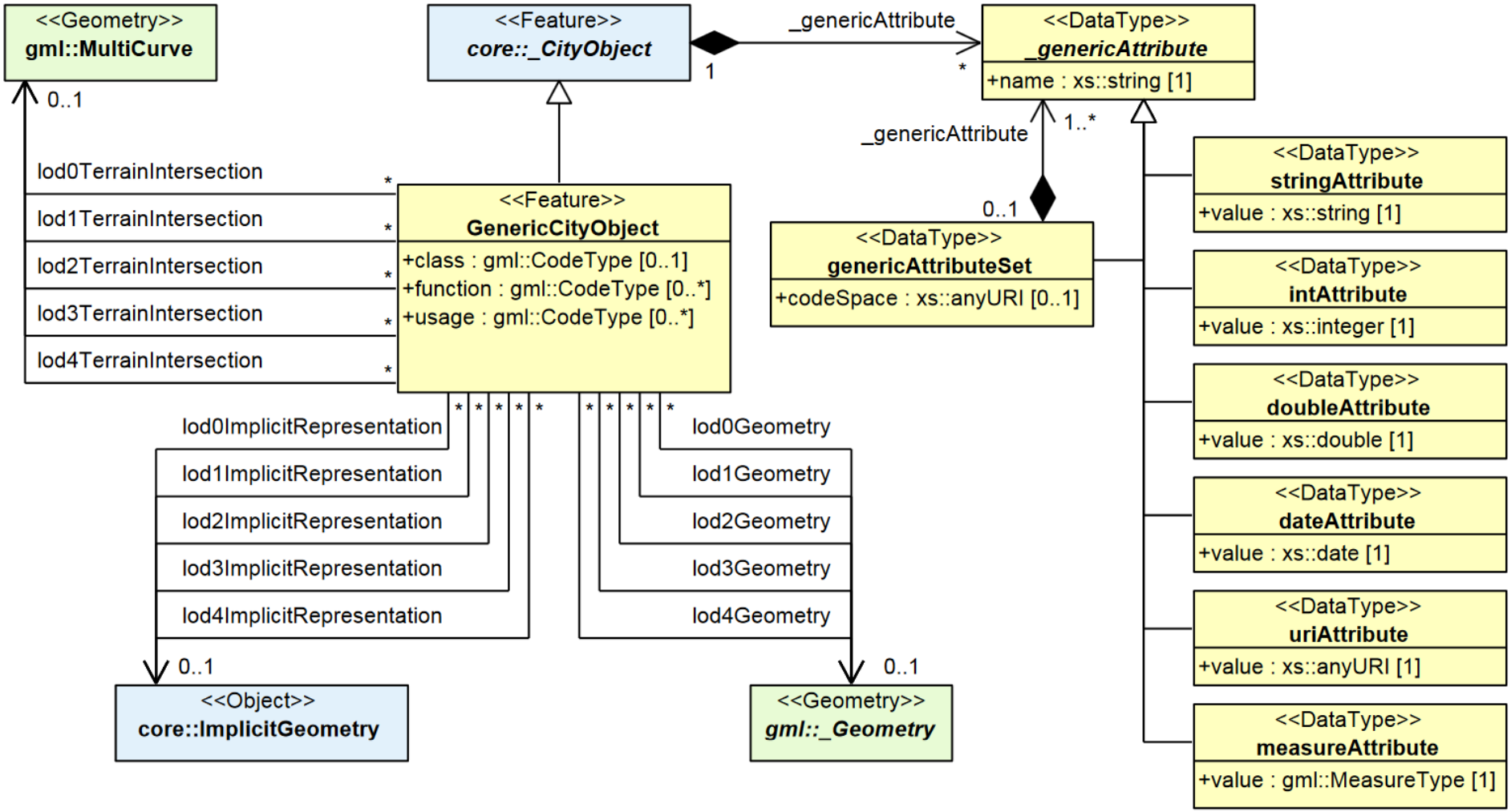
Lod3

Lod4

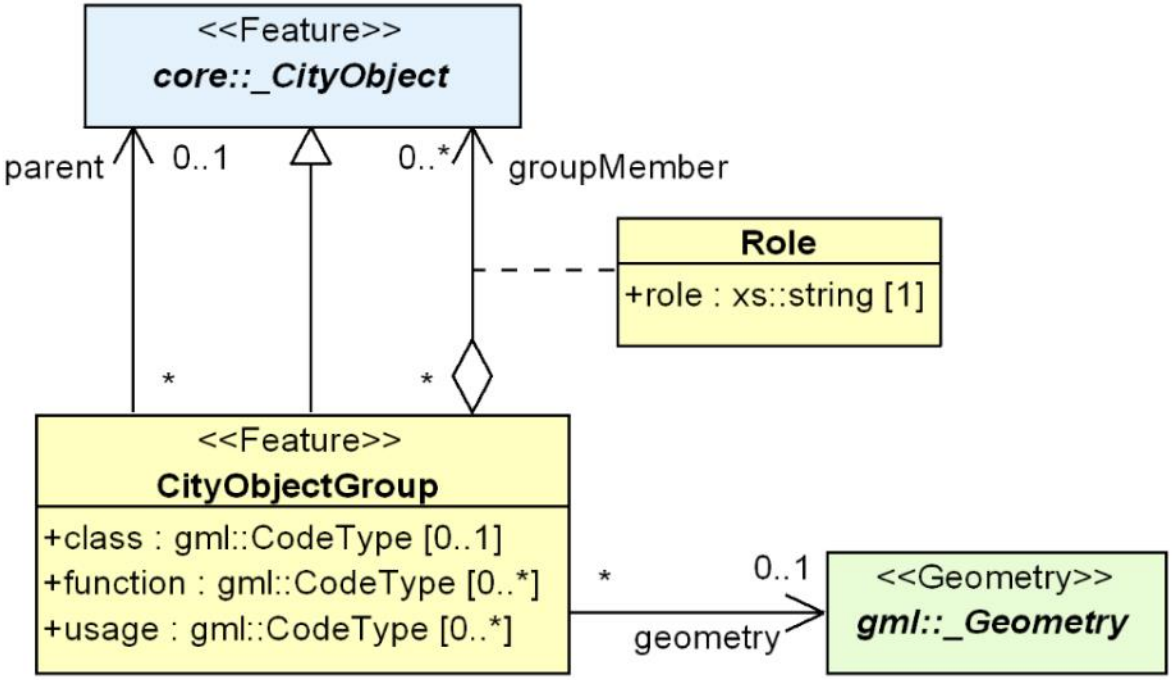
CityGML: vegetation module



CityGML: generics module



CityGML: CityObjectGroup module



3D City Database

- Free and open-source database implementation of the CityGML data model
  - For PostgreSQL / PostGIS and for Oracle
  - Comes with an importer / exporter for ("vanilla") CityGML data from / to the database
  - Consists of 60 predefined tables + a number of functions

- **General mapping rules from OO-model to ER-model**
  - All **NON-CityObjects** (e.g. Features) mapped to own tables
    - E.g. ADDRESS, EXTERNAL_REFERENCE
  - All **CityObjects** mapped to
    - CITYOBJECT table (+ OBJECTCLASS reference table, i.e. "telephone book")
    - Class specific table (e.g. BUILDING)
    - Ancillary tables (GEOMETRY SURFACE, APPEARANCE, etc.)
    - E.g. _AbstractBuilding: CITYOBJECT + BUILDING + anc. tables.

3D City Database

- Tables:
  - CITYOBJECT, OBJECTCLASS
  - BUILDING, VEGETATION
  - SURFACE_GEOMETRY
  - CITYOBJECT_GENERICATTRIB
  - GENERIC_CITYOBJECT
  - CITYOBJECTGROUP

- Stored procedures (functions):
  - DELETE_*(id): DELETE_BUILDING, DELETE_ROOM, DELETE_BRIDGE, …
  - DELETE_CITYOBJECT(id) is a general function dealing with ANY cityobject
  - DELETE_CITYOBJECTGROUP(id)

- The delete functions take care of deleting objects having data spread over multiple tables.

Edit Data - PostgreSQL 9.3 (localhost:5432) - citydb33...

File Edit View Tools Help

No limit

	id [PK] integer	classname character varying(256)	superclass_id integer
71	70	BridgeFloorSurface	67
72	71	BridgeRoofSurface	67
73	72	BridgeWallSurface	67
74	73	BridgeGroundSurface	67
75	74	BridgeClosureSurface	67
76	75	OuterBridgeCeilingSurface	67
77	76	OuterBridgeFloorSurface	67
78	77	BridgeOpening	3
79	78	BridgeWindow	77
80	79	BridgeDoor	77
81	80	BridgeFurniture	3
82	81	BridgeRoom	3
83	82	BridgeConstructionElement	3
84	83	AbstractTunnel	20
85	84	TunnelPart	83
86	85	Tunnel	83
87	86	TunnelInstallation	3
88	87	IntTunnelInstallation	3
89	88	TunnelBoundarySurface	3
90	89	TunnelCeilingSurface	88
91	90	InteriorTunnelWallSurface	88
92	91	TunnelFloorSurface	88
93	92	TunnelRoofSurface	88
94	93	TunnelWallSurface	88
95	94	TunnelGroundSurface	88
96	95	TunnelClosureSurface	88
97	96	OuterTunnelCeilingSurface	88
98	97	OuterTunnelFloorSurface	88
99	98	TunnelOpening	3
100	99	TunnelWindow	98
101	100	TunnelDoor	98
102	101	TunnelFurniture	3
103	102	HollowSpace	3
104	103	TexCoordList	56
105	104	TexCoordGen	56
106	105	WaterObject	3
*			

106 rows.

TABLE "OBJECTCLASS"

AUSTRIAN INSTITUTE OF TECHNOLOGY

TABLE "CITYOBJECT"

AUSTRIAN INSTITUTE OF TECHNOLOGY

Edit Data - PostgreSQL 9.3 (localhost:5432) - energy_db - cityobject

File Edit View Tools Help

No limit

	id [PK] integer	objectclass_id integer	gmlid character varying(256)	gmlid_codespace character varying(1000)	name character varying(1000)
1	1	26	id building 1		Building 1
2	2	33	id roofsurface 1		RoofSurface 1
3	3	38	id window 4rw		Window 4rw
4	4	33	id roofsurface 2		RoofSurface 2
5	5	34	id wallsurface 2		WallSurface 2
6	6	34	id wallsurface 1		WallSurface 1
7	7	38	id window 3bs		Window 3bs
8	8	38	id window 4bs		Window 4bs
9	9	38	id window 4as		Window 4as
10	10	38	id window 3as		Window 3as
11	11	38	id window 1s		Window 1s
12	12	38	id window 2s		Window 2s
13	13	39	id door 1		Door 1
14	14	39	id door 2		Door 2
15	15	34	id wallsurface 4		WallSurface 4
16	16	38	id window 2be		Window 2be
17	17	38	id window 3be		Window 3be
18	18	38	id window 2ae		Window 2ae
19	19	38	id window 3ae		Window 3ae
20	20	34	id wallsurface 3		WallSurface 3
21	21	38	id window 1aw		Window 1aw
22	22	38	id window 3bw		Window 3bw
23	23	38	id window 1bw		Window 1bw
24	24	38	id window 3aw		Window 3aw
25	25	35	id groundsurface 1		GroundSurface 1

141 rows.

Edit Data - PostgreSQL 9.3 (localhost:5432) - energy_db - cityobject

File Edit View Tools Help

No limit

	id [PK] integer	objectclass_id integer	gmlid character varying(256)	gmlid_codespace character varying(1000)	name character varying(1000)	name_codespace character varying(4000)	description character varying(4000)
1	1	26	id building 1		Building 1	''	This is Building 1
2	2	33	id roofsurface 1		RoofSurface 1	''	This is Roofurface 1 (West)
3	3	38	id window 4rw		Window 4rw	''	This is Windows 4r (West)
4	4	33	id roofsurface 2		RoofSurface 2	''	This is Roofurface 2 (East)
5	5	34	id wallsurface 2		WallSurface 2	''	This is WallSurface 2 (North)
6	6	34	id wallsurface 1		WallSurface 1	''	This is WallSurface 1 (South)
7	7	38	id window 3bs		Window 3bs	''	This is Windows 3b (South)
8	8	38	id window 4bs		Window 4bs	''	This is Windows 4b (South)
9	9	38	id window 4as		Window 4as	''	This is Windows 4a (South)
10	10	38	id window 3as		Window 3as	''	This is Windows 3a (South)
11	11	38	id window 1s		Window 1s	''	This is Windows 1 (South)
12	12	38	id window 2s		Window 2s	''	This is Windows 2 (South)
13	13	39	id door 1		Door 1	''	This is Door 1
14	14	39	id door 2		Door 2	''	This is Door 2
15	15	34	id wallsurface 4		WallSurface 4	''	This is WallSurface 4 (East)
16	16	38	id window 2be		Window 2be	''	This is Windows 2b (East)
17	17	38	id window 3be		Window 3be	''	This is Windows 3b (East)
18	18	38	id window 2ae		Window 2ae	''	This is Windows 2a (East)
19	19	38	id window 3ae		Window 3ae	''	This is Windows 3a (East)
20	20	34	id wallsurface 3		WallSurface 3	''	This is WallSurface 1 (West)
21	21	38	id window 1aw		Window 1aw	''	This is Windows 1a (West)
22	22	38	id window 3bw		Window 3bw	''	This is Windows 3b (Wsdest)
23	23	38	id window 1bw		Window 1bw	''	This is Windows 1b (West)
24	24	38	id window 3aw		Window 3aw	''	This is Windows 3a (West)
25	25	35	id groundsurface 1		GroundSurface 1	''	This is GroundSurface 1

141 rows.

Edit Data - PostgreSQL 9.3 (localhost:5432) - energy_db - building

File Edit View Tools Help

No limit

	id [PK] integer	building_parent_id integer	building_root_id integer	class character varying(256)	class_codespace character varying(4000)	function character varying(1000)	function_codespace character varying(4
1	1		1	Residential			
2	100		1000	Office			
3	1001		1001				
4	1002		1002				
5	1003		1003				
6	1010		1010				
*							

6 rows.

TABLE "CITYOBJECT“ + “BUILDING”

Overview

- Part 1: Semantic 3D city modelling & a first look at CityGML
- Part 2: A second look at CityGML and the 3D City Database
- **Part 3: Experiences from Trento and Vienna**
- Part 4: Extending CityGML
- Part 5: Energy & cities

Part 3: Modelling cities in CityGML

Experiences from…

- Italy: Trento – Project **EnerCity**
- Austria: Vienna – Project **Ci-Nergy**
- Conclusions
- Bibliographic references for Trento and Vienna
- Acknowledgements for Trento and Vienna

3D city models and energy

SEMANTIC 3D CITY MODELS AS INFORMATION HUB FOR SMART CITY APPLICATIONS

Yes, cool… BUT:

How easy / hard is the way till a *usable* 3D city model is created?

- Major / typical issues?
- Time / resources required?

TRENTO:
Project EnerCity (2012 – 2015)

- 2012, Conception @ FBK, **Trento**
  3D Optical Metrology unit

- 2013, First implementation @ TUM, **München**
  Department of Geoinformatics

- 2014-15, Refinement @ AIT, **Vienna**
  Sustainable Buildings and Cities unit

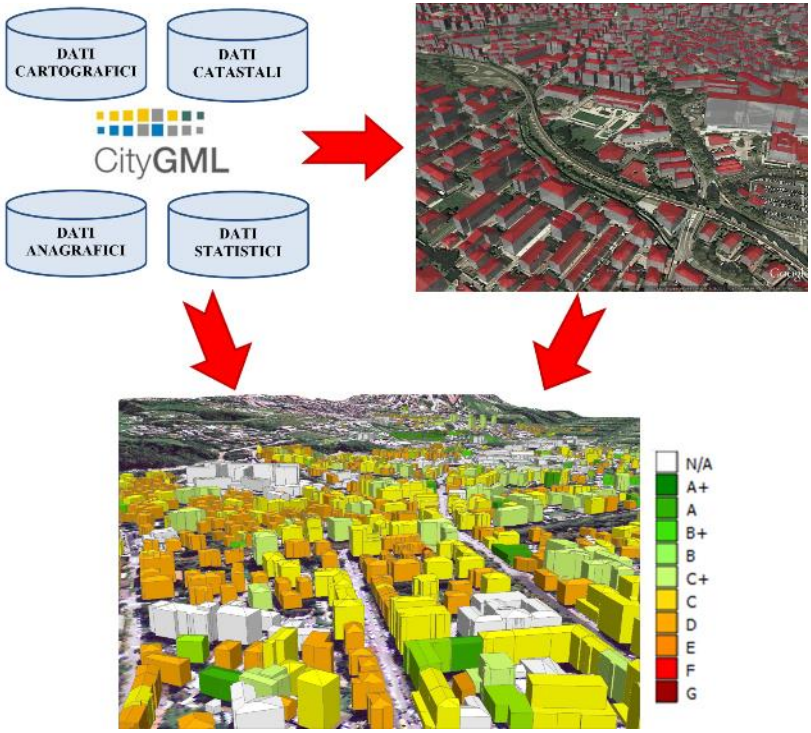
TRENTO: EnerCity

Overall question:

Can a CityGML-compliant 3D city model be created in Trento and used e.g. for energy-related applications? (Using only exiting data!)

Approach:

- **Step 1**: Creation of the 3D city model up to LoD2 (focus on geometries)
- **Step 2**: Enrichment of the 3D city model (focus on attributes)
- **Step 3**: Estimation of buildings' energy performance (not discussed here)



Step 1: Creation of the 3D city model up to LoD2

Semi-automatic generation of a 3D city model (up to LoD2)

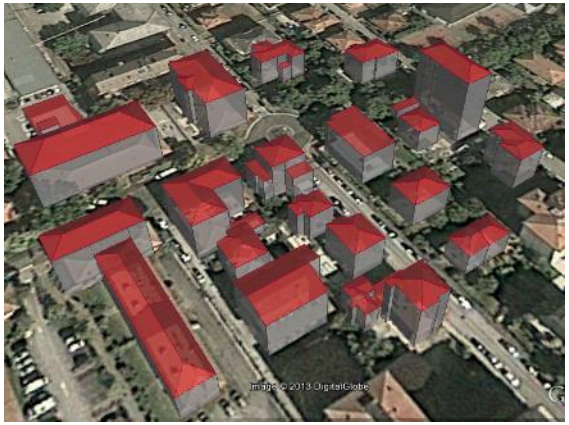
1) Input data

- DSM (min 4, better 10 to 15 pt/m^2)
- Building footprints

2) 3D modelling SW

3) Import/export tools

4) Spatial RDBMS



5) Output

Step 1: Creation of the 3D city model

Trento study area: ca. 2300 heterogeneous buildings (size, usage, age, etc.)

DSM (open data)

- Density **1 pt/m²** (urban areas)
  - Sub-optimal density
- Time **2006/2007**
  - A bit outdated…
    (missing/newer buildings in red)

Step 1: Creation of the 3D city model

Building footprints, data sources:

- Catasto Tavolare (open data)
  - Dates back to the Austrian system, is still valid *only* in the territories annexed to Italy after WWI. For the rest of Italy: Catasto dei Terreni
  - Smallest unit is the „Particella catastale“ (land parcel)
  - Is geo-referenced, but there are *relevant* geometric distortions wrt. DSM
  - Built-up parcels have a unique ID, however multiple footprints may occur in the same parcel and share the same ID

- Topographic map of Trento (CTTN, Carta Tecnica Trento)
  - Aligns better with the DSM, no relevant geometric distortions
  - Is very detailed, contains sometimes building parts, allowing for a more detailed 3D reconstruction
  - Has a general classification of buildings' type/usage, however different from the cadastral one
  - Is missing links to cadastral maps

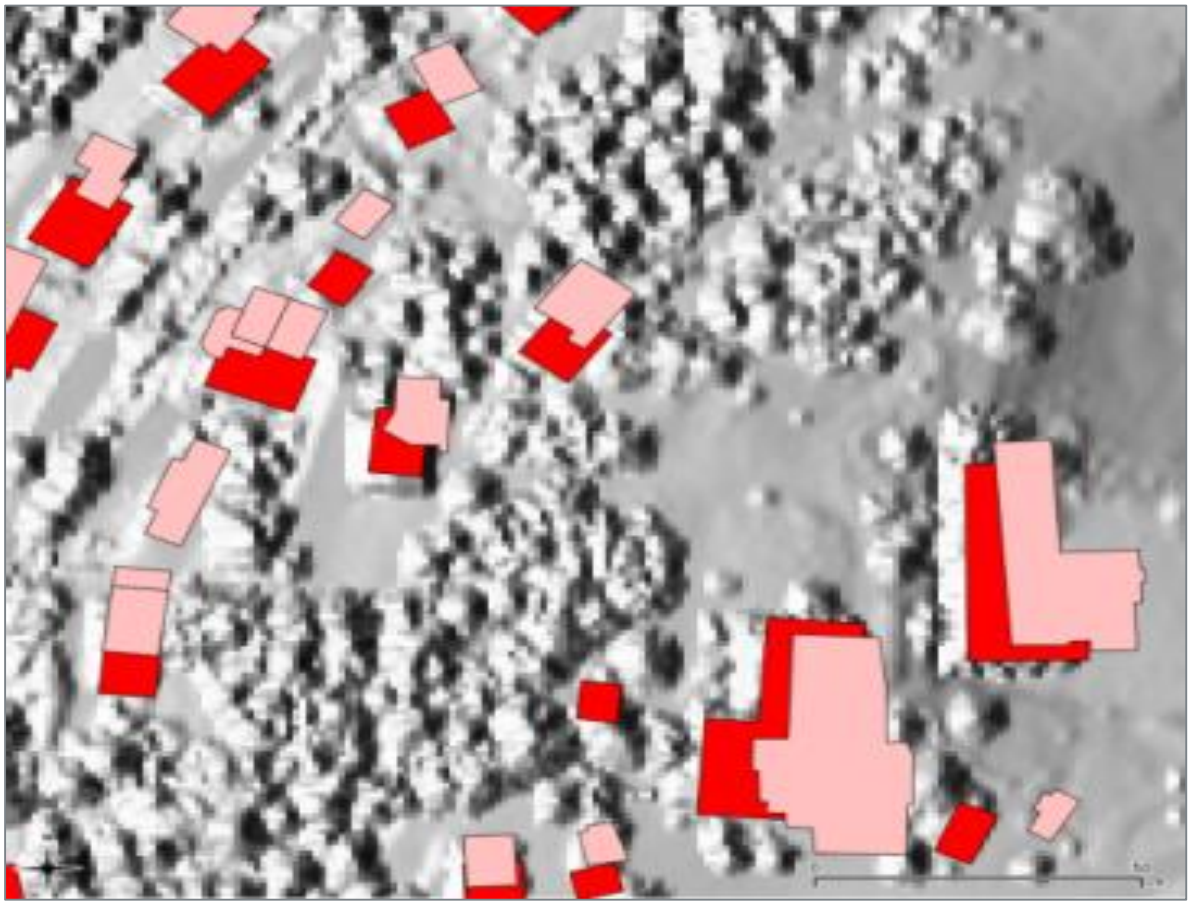
Step 1: Creation of the 3D city model

Catasto Tavolare, example of geometric problems:

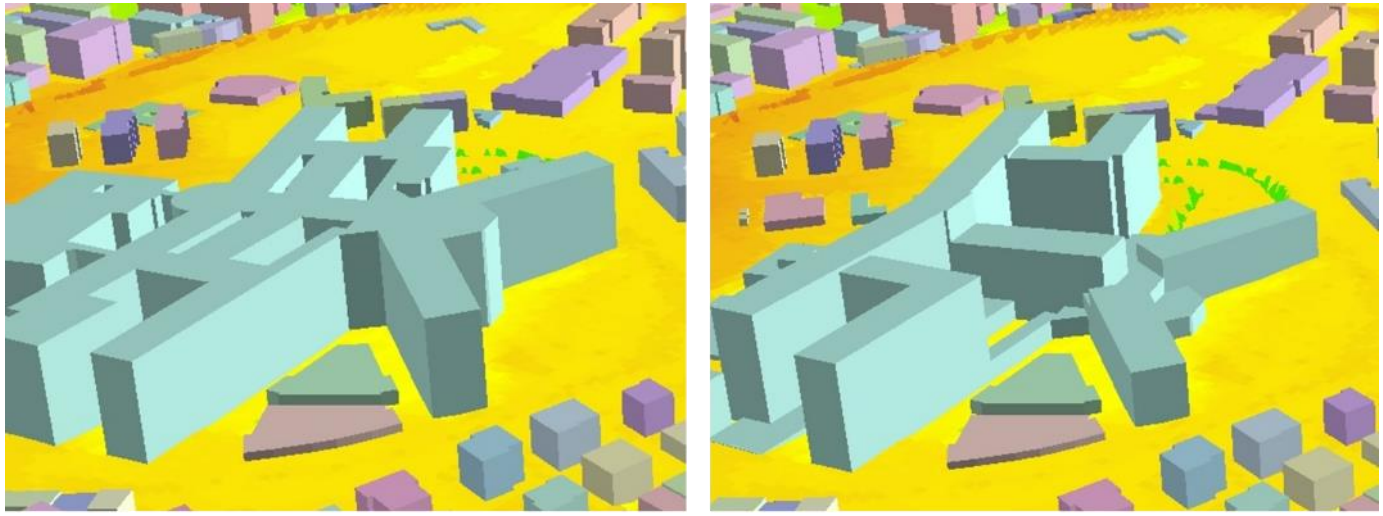
- shifts/distortions: footprints unsuitable to be overlaid onto the DSM
  - Lager distorsions outside the city centre
  - "Acceptable" distortions in the city centre

Pink:
Buildings' footprints in Catasto Tavolare

Red:
Buildings' footprints in Carta Tecnica Trento



Step 1: Creation of the 3D city model



LoD1 single-part building LoD1 multi-part building
obtained by extruding CTTN footprints

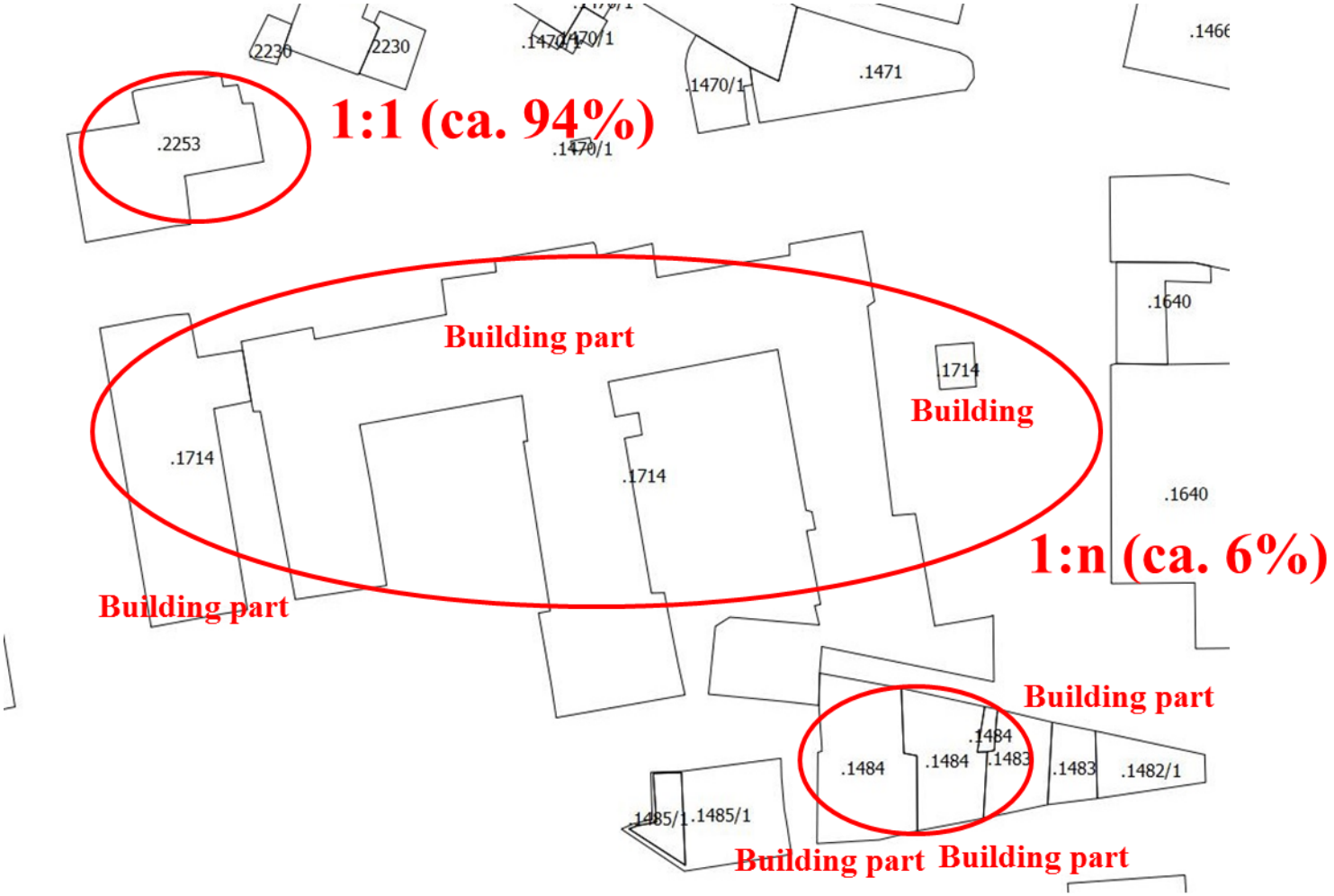
So, why not simply dump the cadastre geometries?

- Catasto dei Fabbricati („Buildings' cadastre“)
  - Same system for whole Italy
  - Smallest unit is the „Unità immobiliare“: a whole building, or a part of it (flat, shop, garage, …)
  - In Trentino: „Unità immobiliari“ have their own codes + a reference to the Catasto Tavolare
  - Floor plans are generally provided as ungeoreferenced tiff/pdf files

Step 1: Creation of the 3D city model

Catasto Tavolare, example of cardinality issues:

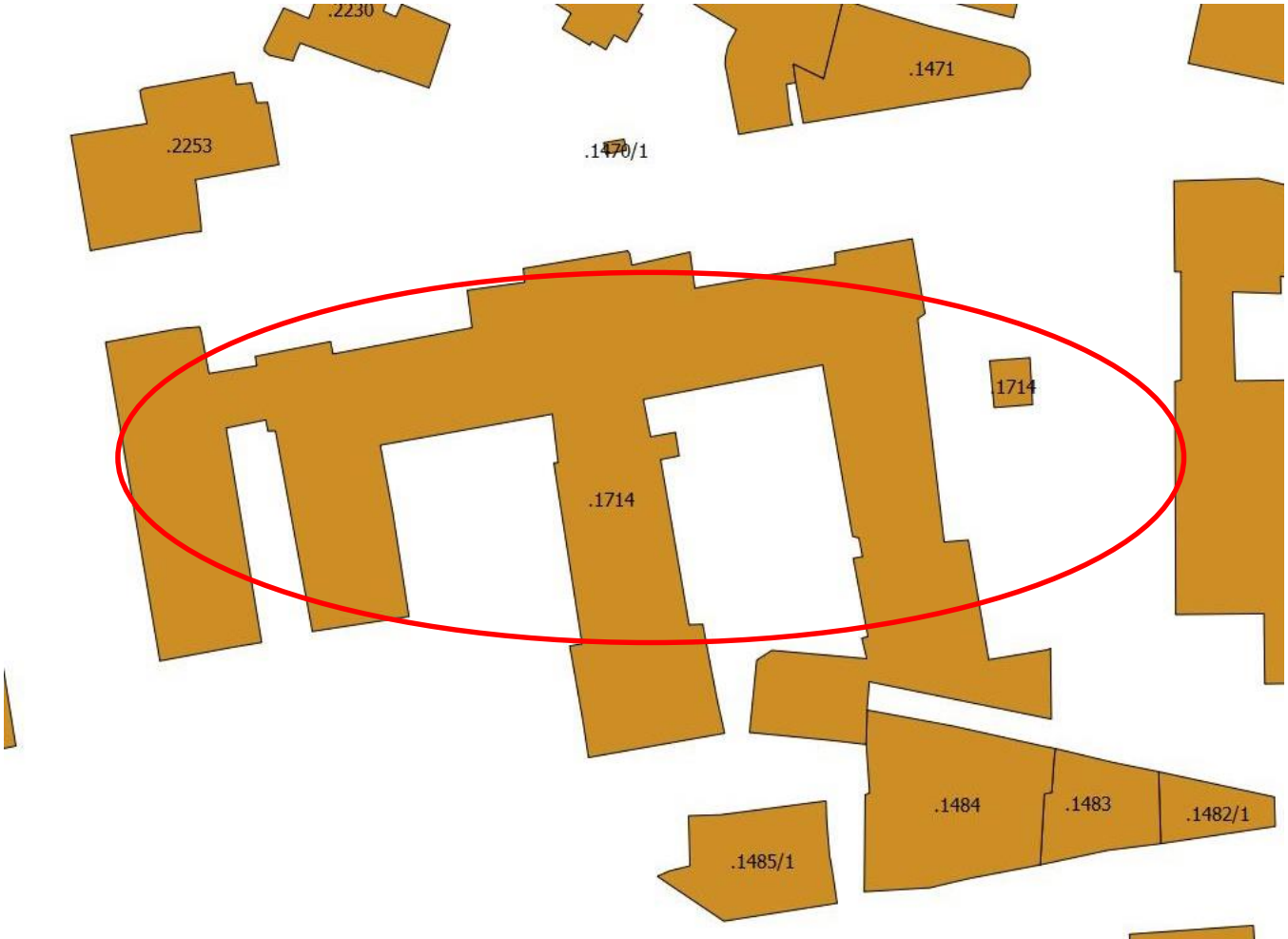
- (Sometimes) no clear identification of a building inside the same parcel: multiple building „parts“ AND/OR multiple buildings



Step 1: Creation of the 3D city model

Catasto Tavolare, example of cardinality problems:

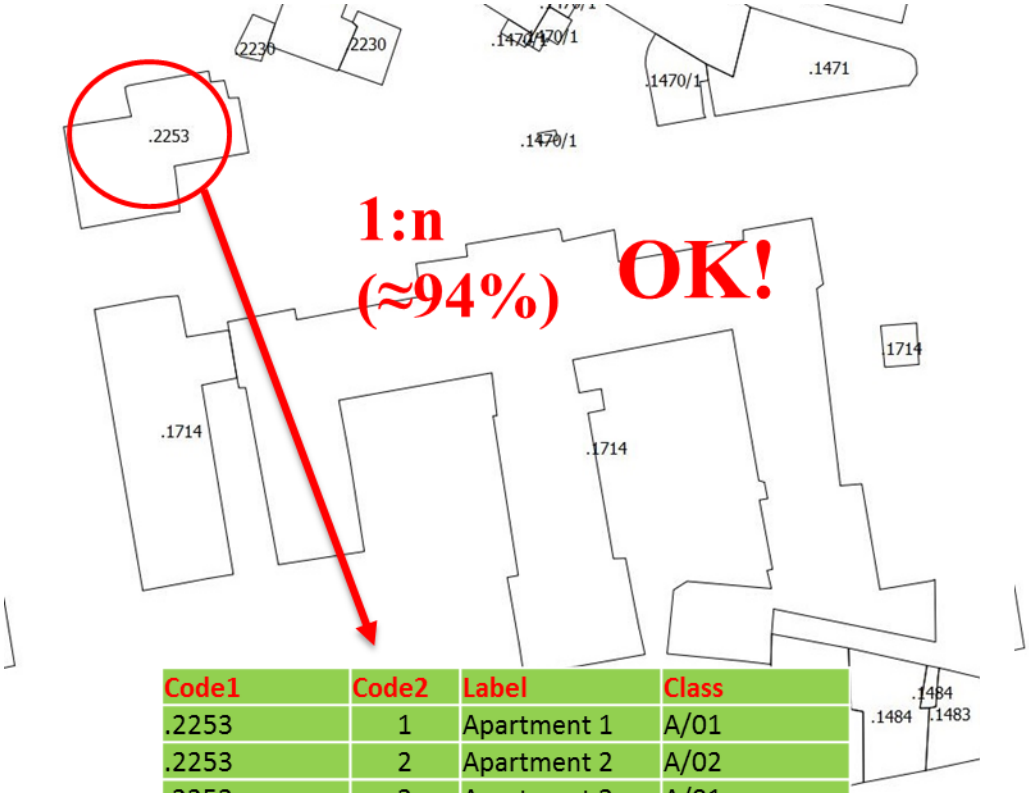
- Successive aggregation AND disaggregation required
- The parcel ID is an attribute, not a primary key

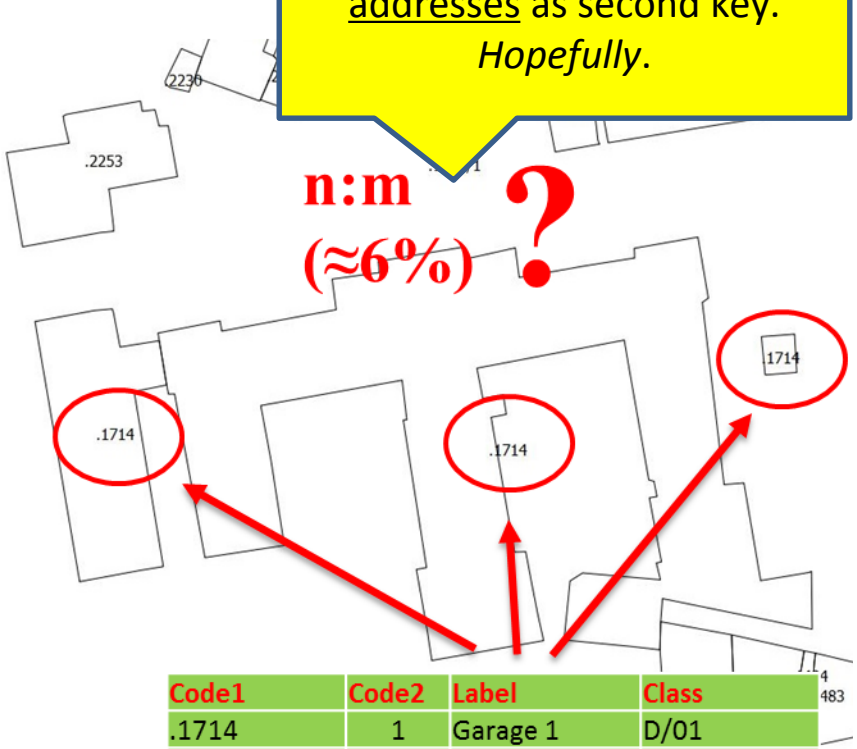


Step 1: Creation of the 3D city model

Catasto Tavolare + Catasto Fabbricati, example of cardina

This can be resolved only *manually* or (partially) using addresses as second key. *Hopefully*.





Code1	Code2	Label	Class
.2253	1	Apartment 1	A/01
.2253	2	Apartment 2	A/02
.2253	3	Apartment 3	A/01
.2253	4	Apartment 4	A/01
.2253	5	Apartment 5	A/02
.2253	6	Apartment 6	A/01
.2253	7	Apartment 7	A/01
.2253	7	Shop 1	C/01
.2253	8	Shop 2	C/01
.2253	9	Garage 1	D/01

Code1	Code2	Label	Class
.1714	1	Garage 1	D/01
.1714	2	Garage 2	D/01
.1714	3	Shop 1	C/01
.1714	4	Shop 2	C/01
.1714	5	Apartment 1	A/02
.1714	6	Apartment 2	A/01
.1714	7	Apartment 3	A/01
.1714	7	Apartment 4	A/01
.1714	8	Apartment 5	A/01
.1714	9	Apartment 6	A/01

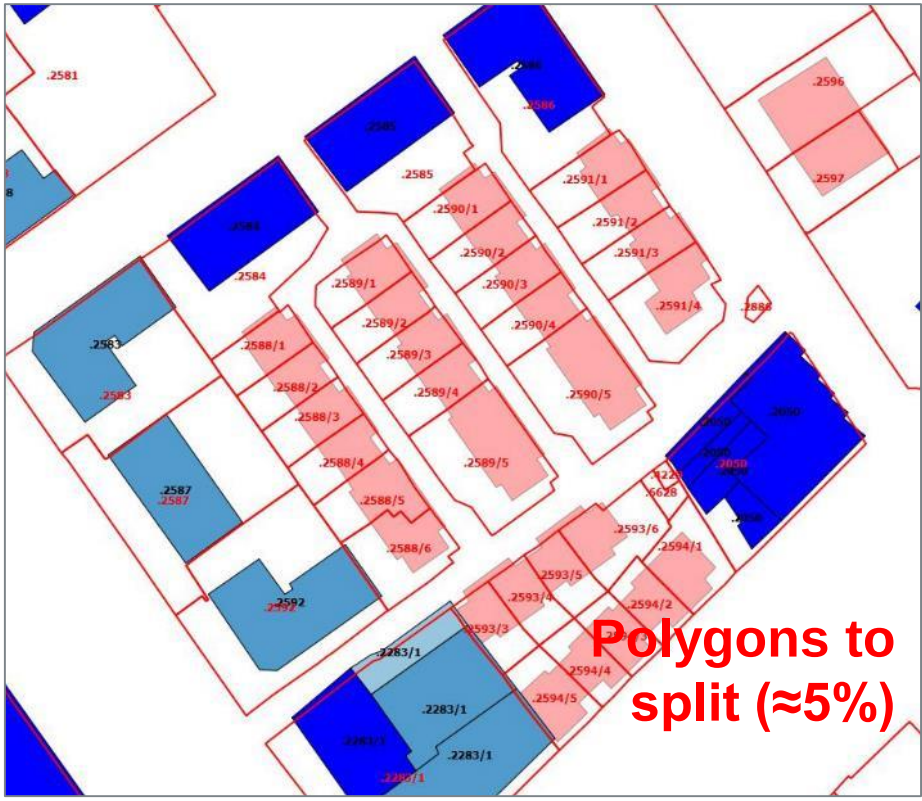
Step 1: Creation of the 3D city model

How to overcome the geometric problems of the cadastral cartography?

HYBRID APPROACH

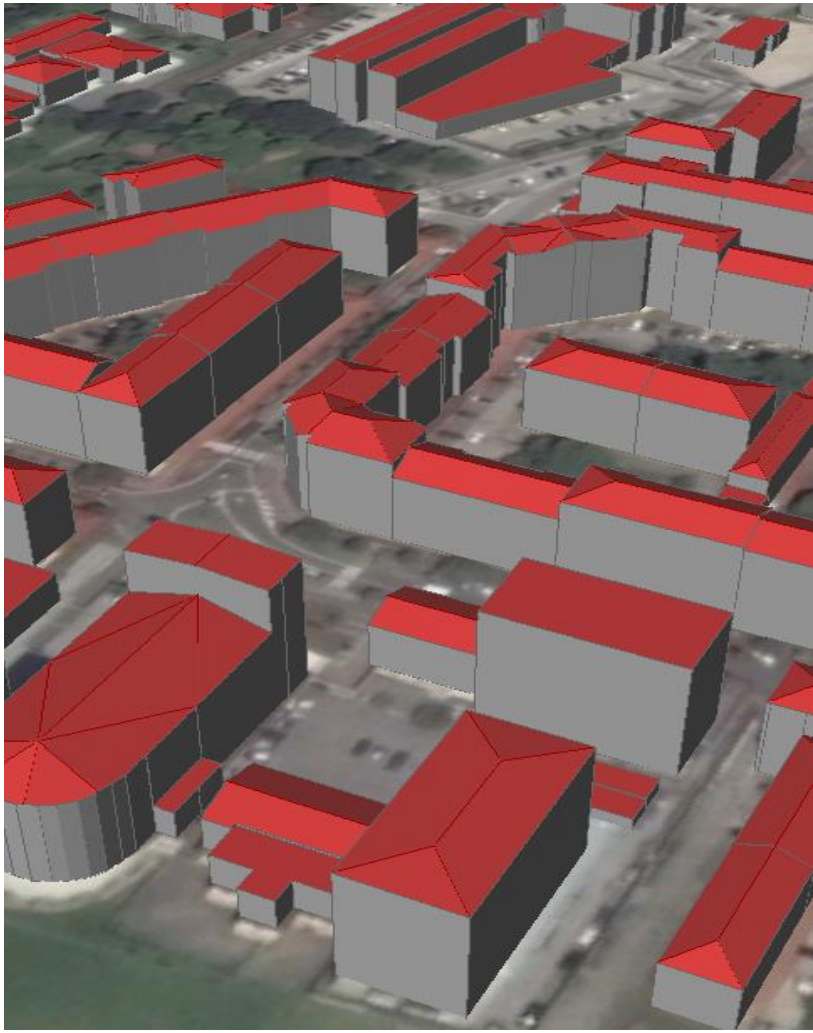
Preserve cadastral information, but use topographic map as source of footprint geometries

1. Segment footprint from topographic map according to cadastral map
   - Take care of further cardinality problems between topographic and cadastral geometries
2. Define unique building IDs
3. Transfer cadastral codes to topographic map (by set of rules to take inexact overlaps into account)



Results

- 3D reconstruction carried out by means of B-REC by virtualCitySystems
- Ca. 2300 buildings, modelled as single-part or multi-part in LoD0, LoD1, LoD2
- Circa 40% of the buildings edited manually due to low density of the DSM
- Global height RMSE of all buildings wrt. DSM circa was 0,7 m.
- Time required: 1 month

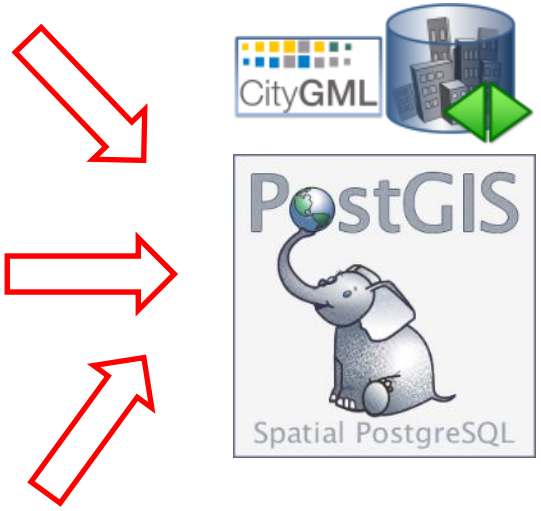


Step 1: Creation of the 3D city model

Step 2: Enrichment of the 3D city model

Integration of heterogeneous datasets at building level:

- Cadastral information (building usage, year of construction, n. units, n. floors, n. rooms, …, etc.)
- Addresses
- Number of residents and families
- List of refurbishments till 1992 and from 1993 till today
- Energy Performance Certificates (at building OR apartment level)
- …

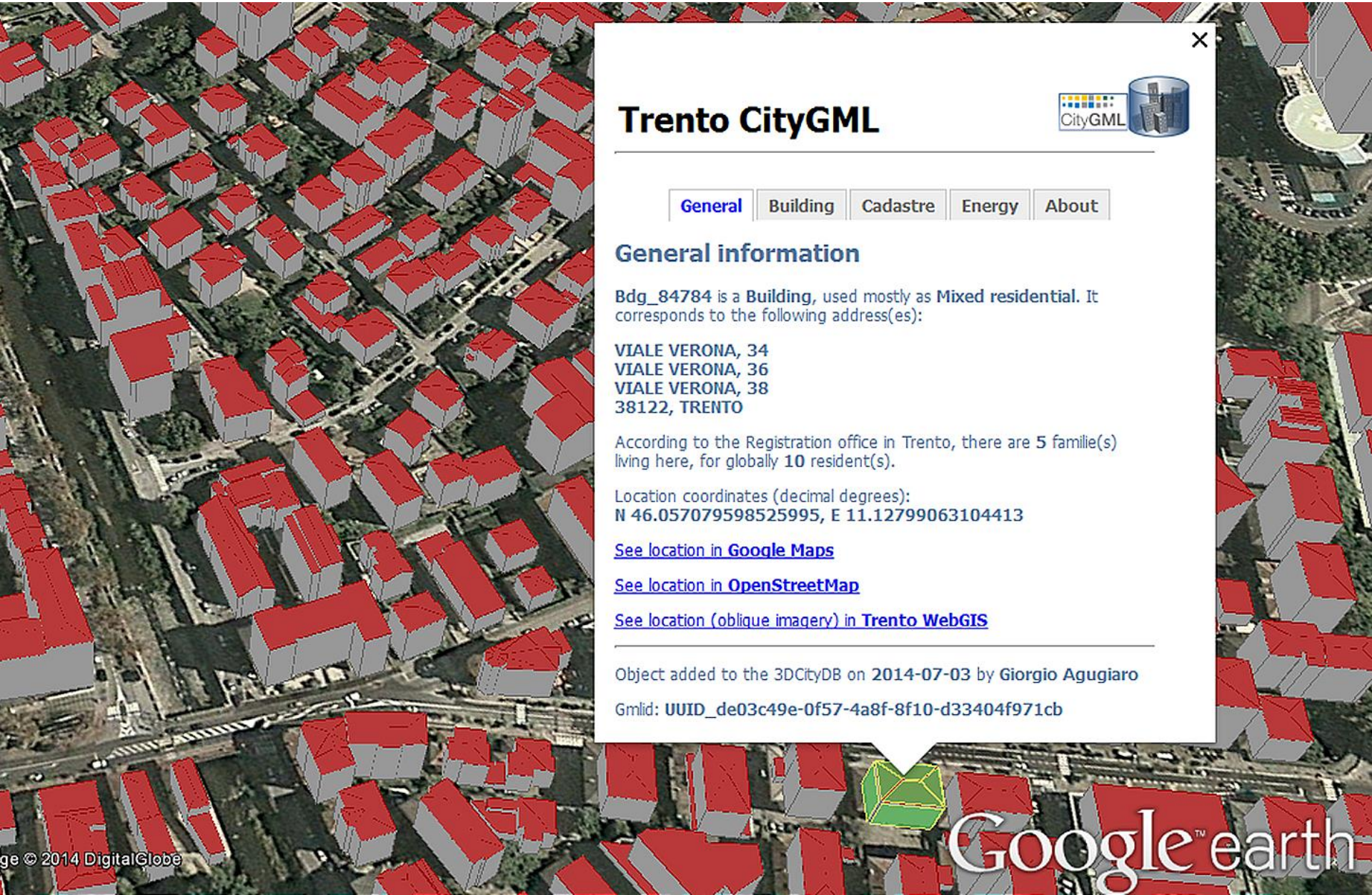


Implementation of automatic & semi-automatic checks for data consistency and error detection

Step 2: Enrichment of the 3D city model

Step 2: Enrichment of the 3D city model

Step 2: Enrichment of the 3D city model



Conclusions TRENTO (Part 1 + 2)

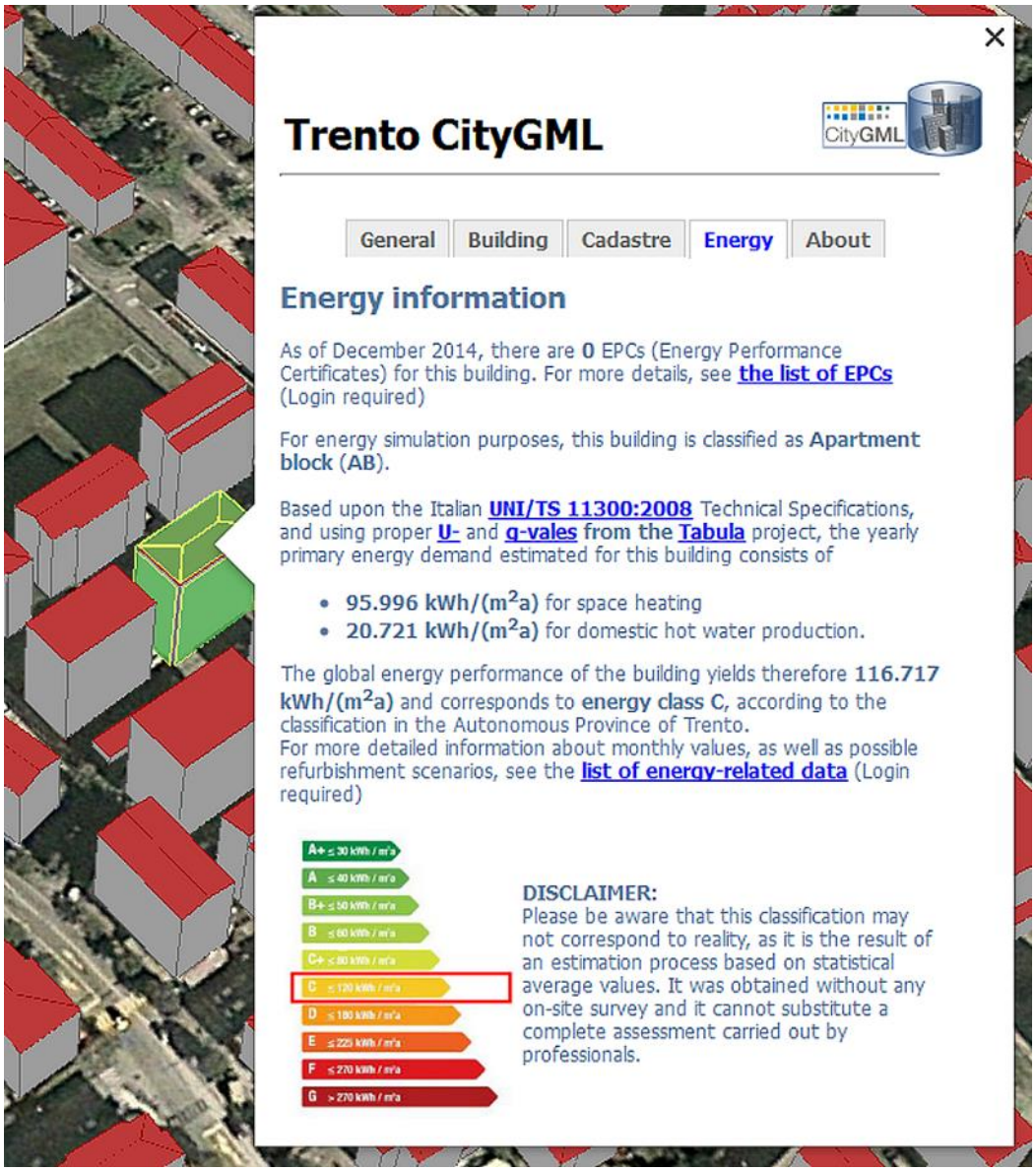
- Creation of a CityGML-based 3D model of Trento IS POSSIBLE

- Approach is extensible to the whole city, but cannot be applied fully automatically
- Some datasets are a bit old and sub-optimal, but they are being updated (e.g. Lidar and Catasto Tavolare)
- Mutual benefit in data integration: no redundancies and greater control on data quality

- Initial effort not negligible, but: "**Do once, use many!**"

- Approx. estimated time effort for completing the whole city:
  - 2 or 3 (experienced and trained) persons for up to one year

Step 3: Estimation of buildings' energy performance



VIENNA:
Project CI-NERGY (2013 – 2017)

- CI-NERGY: **Smart Cities with sustainable energy systems**
- Marie Curie Action, Initial Training Network (ITN) Project
- Multi-disciplinary PhD programme: 11 PhDs, 3 Post-Docs
- Members:
  - HFT (Stuttgart), EPFL (Lausanne), University of Nottingham, Polito (Turin), UCD (Dublin), AIT (Vienna), TUW (Vienna)
  - Siemens, EDF, IES
  - City of Vienna**,** City of Geneva

- http://www.ci-nergy.eu

CINERGY

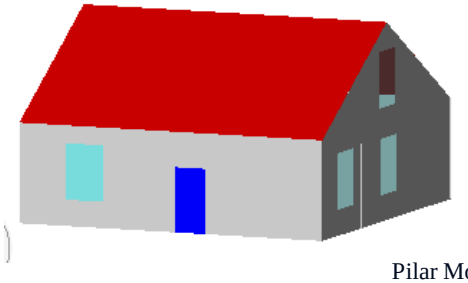
Co-funded by the Intelligent Energy Europe Programme of the European Union

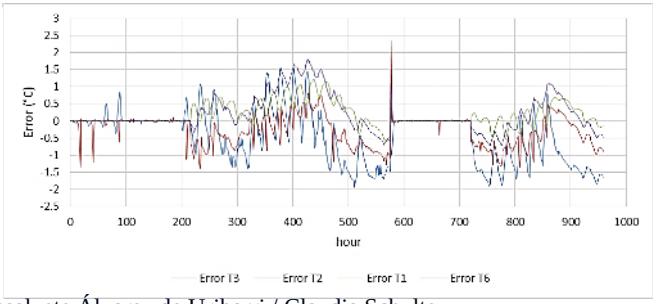
MARIE CURIE ACTIONS

Project CI-NERGY: Goals

- A coherent platform aimed at supporting decisions for urban energy planning
  - Using (also) geo-referenced city data
  - Variable scale: buildings, district, city
  - Model interaction between energy demand, supply, networks and storage

- Use cases
  - Buildings' energy demand prediction
  - Dynamic building simulation
  - District heating network (co)-simulation
  - Service-oriented infrastructure

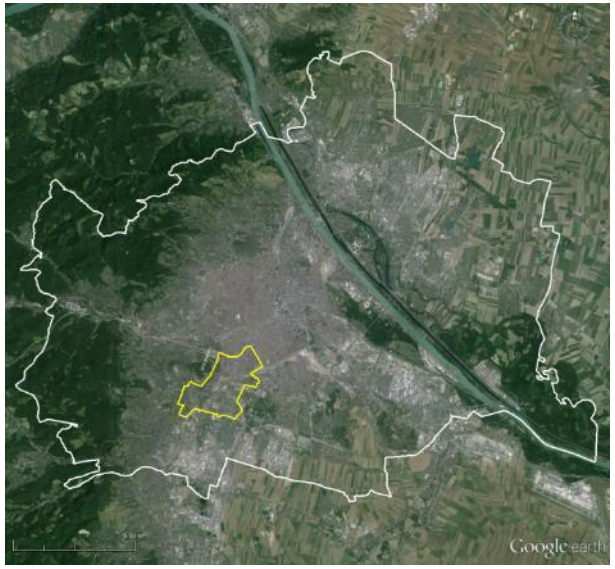




3D city model of Vienna

- CityGML-compliant, since 2015 in development @ AIT
  - Fits CI-NERGY project needs & goals
  - Availability of geometries up to LoD2
  - Lots of data (spatial, non-spatial, energy-related) published recently as Open Government Data (OGD)

- Study area: 12th district (Meidling)
  - ≈ 8.2 km^2, ≈ 90000 inhabitants
  - ≈ 7500 buildings, ≈ 5500 residential buildings
  - Heterogeneity of building types, sizes, functions, etc.

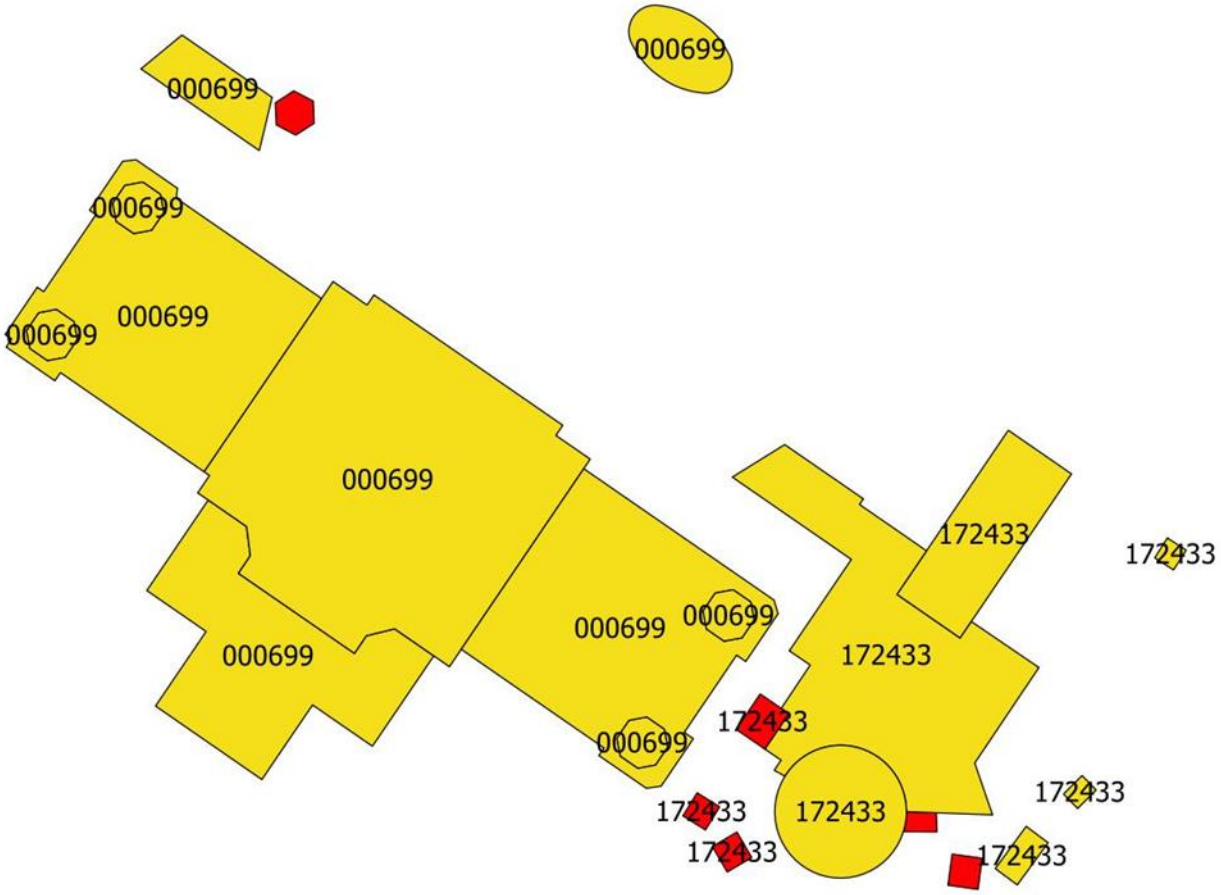


Data sources

- Buildings
  - LoD0: **Flächen-Mehrzweckkarte (F-MZK)** (open data)
    - Polygon-based topographical "multi-purpose" 2D map
    - Reference map for all successive products
    - Objects are classified into 50 classes (buildings, traffic, water bodies, etc.)
  - LoD1: **Baukörpermodell** (open data)
    - Derived by the F-MZK and constantly updated by the city
    - Pure geometry, no semantics
  - LoD2: **CityGML geometries** from 2012 DSM
    - Input Lidar ≈ 4 pt/m^2 + spot wise updates by photogrammetry)

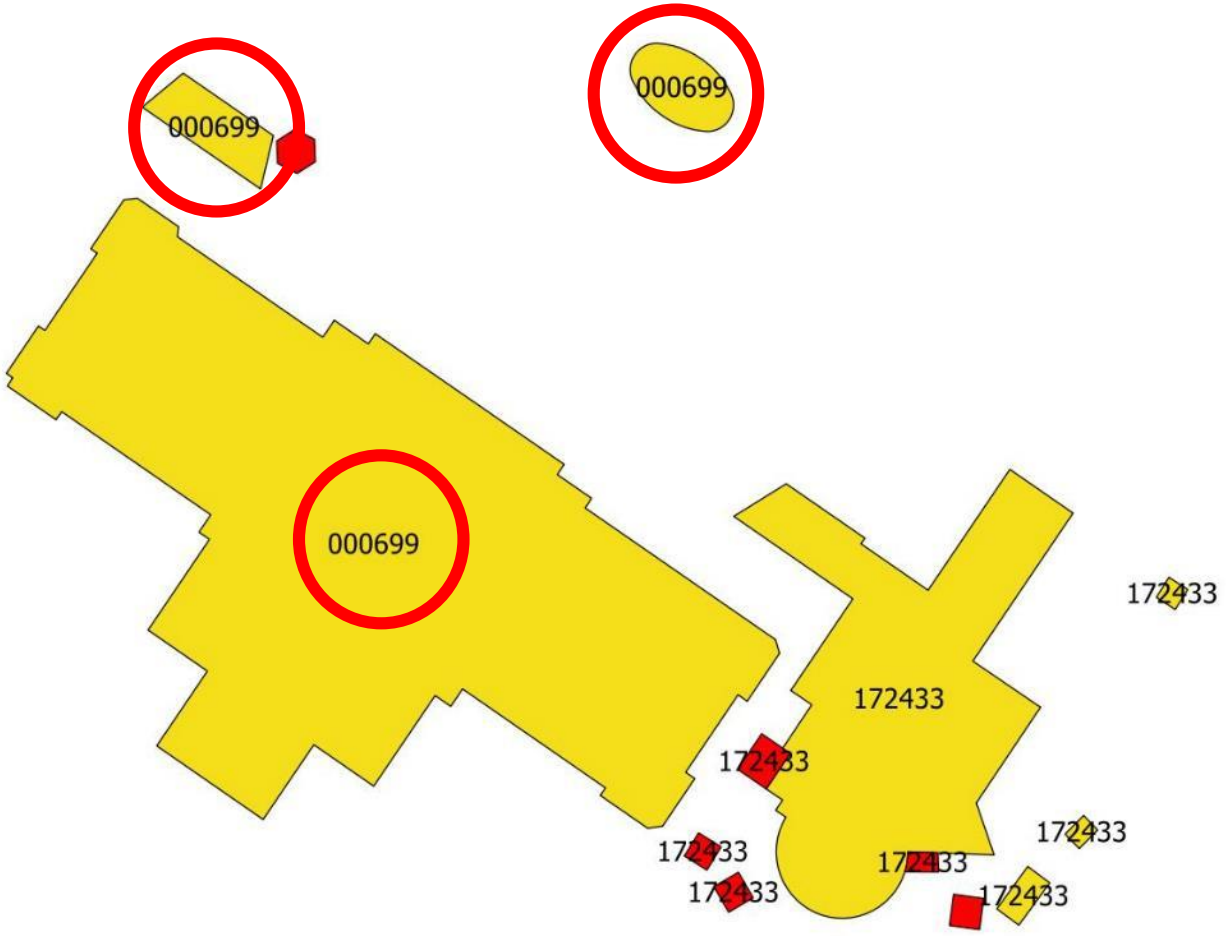
Data integration issues

- Cardinality issues due to absence of a unique building ID



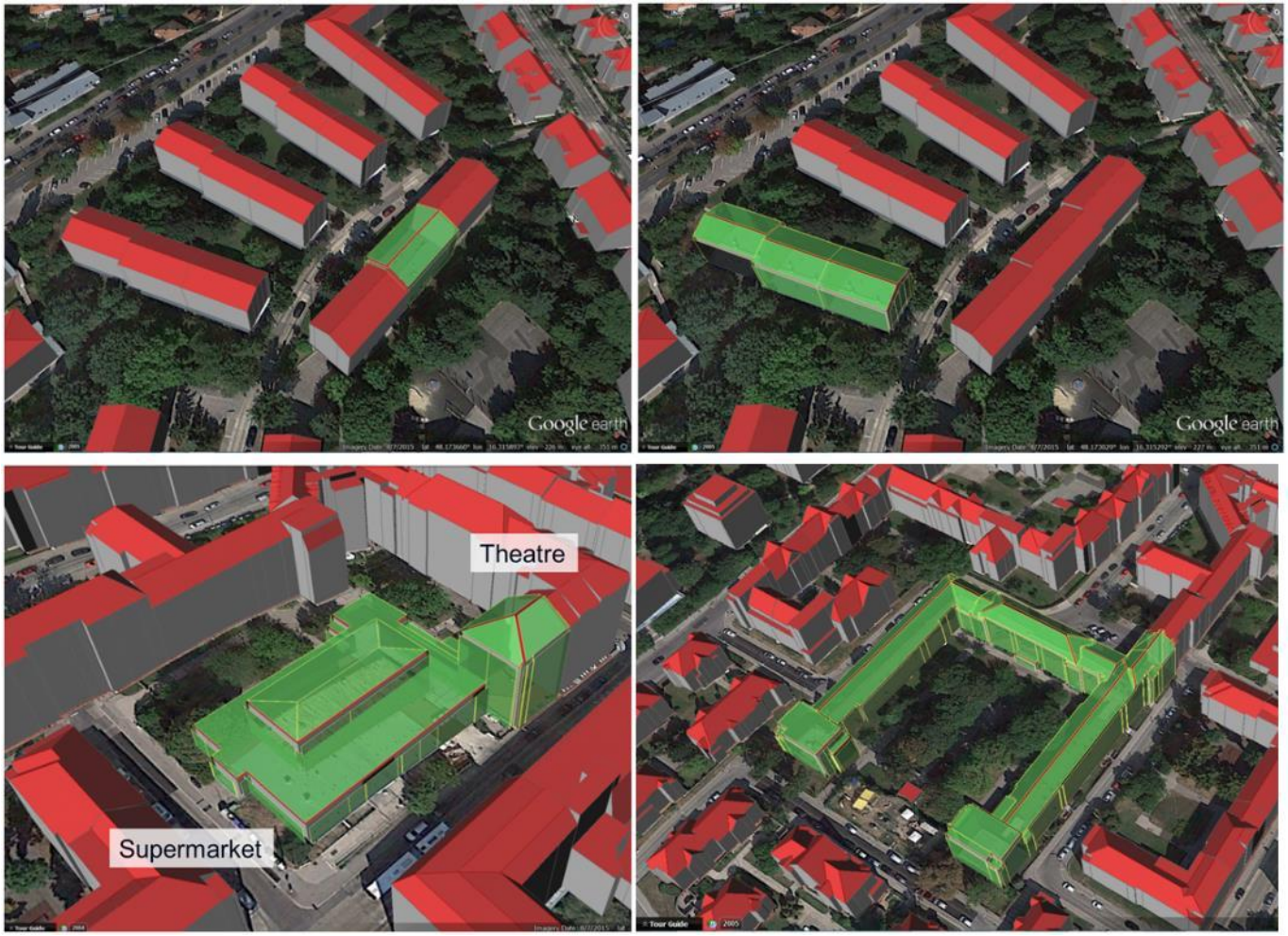
Data integration issues

- Cardinality issues due to absence of a unique building ID



Data integration issues

- Issues with hierarchies and grouping of buildings / building parts



Other data sources

- Addresses (point geometries)
- Buildings' information:
  - Year/period of construction
  - Number of floors above / below ground
  - Building use (residential, commercial, industrial, etc.)
  - Building / site name
  - Number of residents
- Specific info for social housing buildings
  - Number of households
  - Past refurbishment
  - History, architect, etc.
- District heating network, Gas network
- Plenty of other data, mostly open data
  - Solar and PV installed panels
  - 2D Tree cadastre

Other data sources: issues

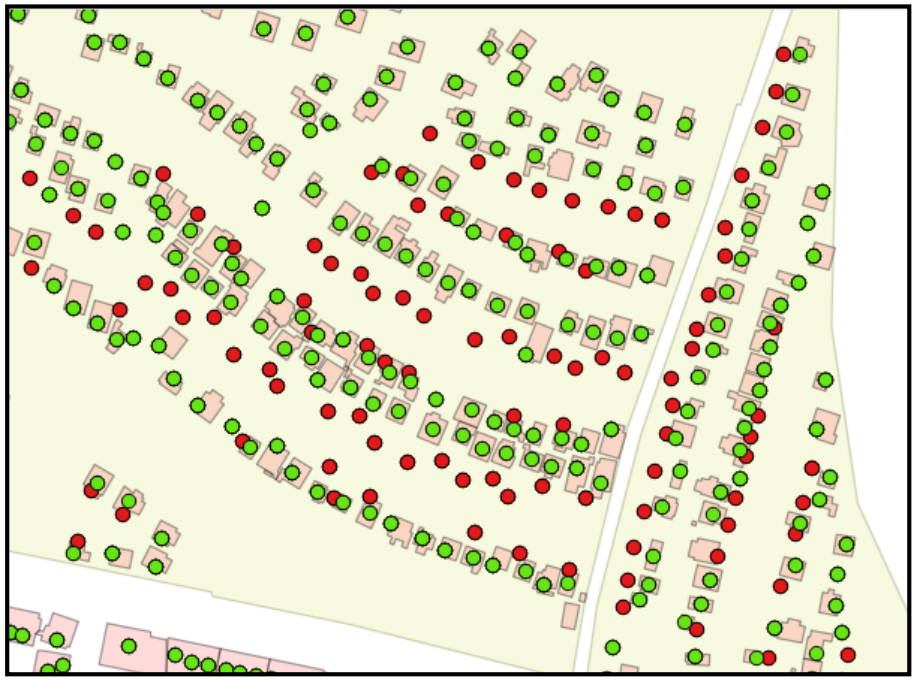
- Due to lack of unique buildings' ID, most datasets are linked to address data
- If no direct reference to address, point geometries are used

- Integration possible only via spatial overlay, but…

Address points:

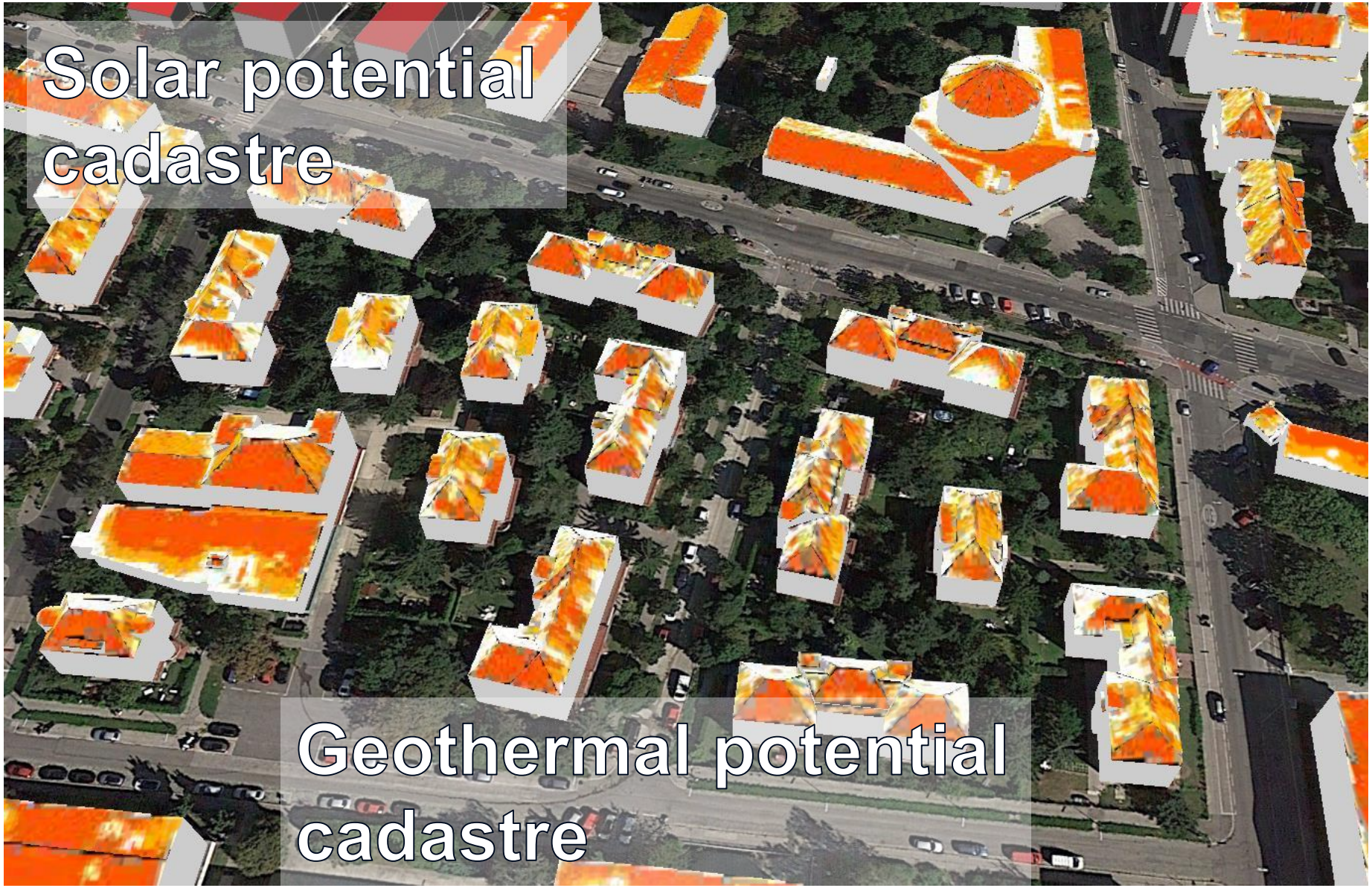
RED: before editing

GREEN: after editing



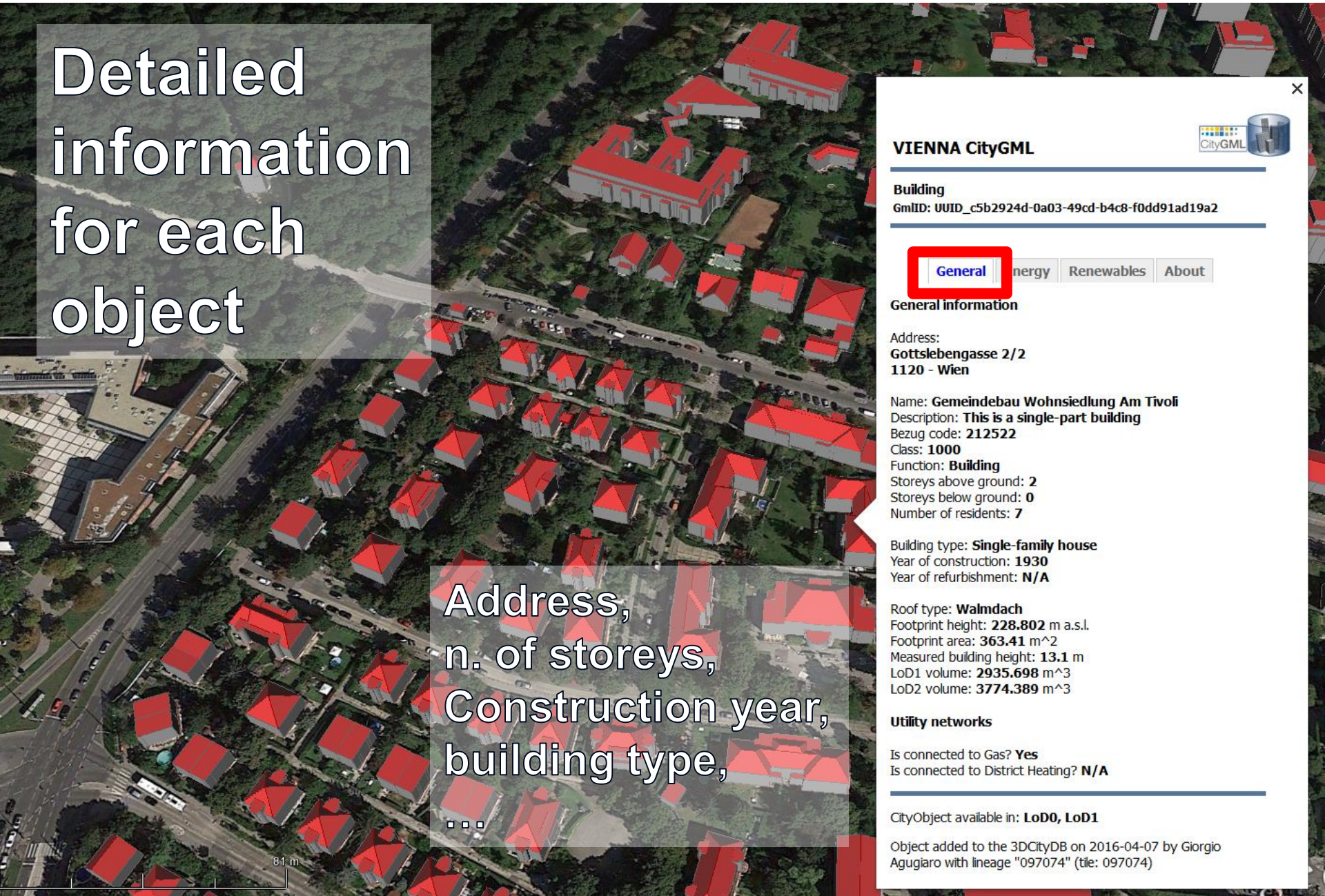
VIENNA 3D CITY MODEL

AUSTRIAN INSTITUTE OF TECHNOLOGY



VIENNA 3D CITY MODEL

AUSTRIAN INSTITUTE OF TECHNOLOGY



VIENNA 3D CITY MODEL

AUSTRIAN INSTITUTE OF TECHNOLOGY

Detailed information for each object

Genera | **Energy** | Renewables | About

Original state:

Space heating demand: **189218.157** kWh/a
DHW demand: **12170.175** kWh/a
Electricity demand: **9884.997** kWh/a
CO2-equivalent emissions: **50.256** t/a

Energy certification:

Heating energy demand: **346.34** kWh/(m^2*a) (**Class G**)
Total energy demand: **437.69** kWh/(m^2*a) (**Class G**)
CO2-equivalent emissions: **86.43** kg/(m^2*a) (**Class G**)

Refurbished state:

Space heating demand: **27367.129** kWh/a
CO2-equivalent emissions: **12.059** t/a

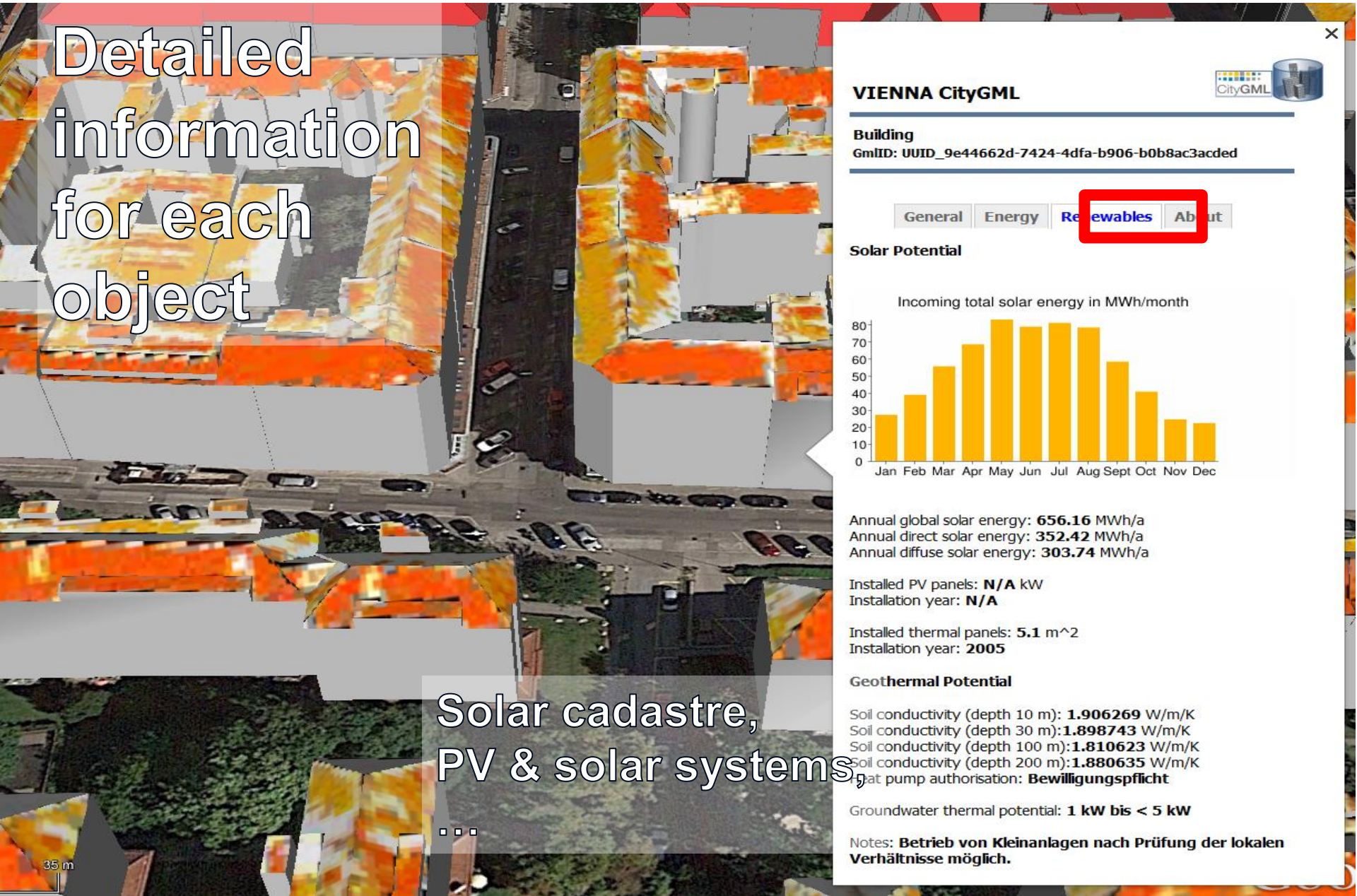
Energy certification:

Heating energy demand: **68.0** kWh/(m^2*a) (**Class C**)
Total energy demand: **112.02** kWh/(m^2*a) (**Class B**)
CO2-equivalent emissions: **20.74** kg/(m^2*a) (**Class B**)

Energy demand, refurbisment scenarios, ...

81 m

VIENNA 3D CITY MODEL



Conclusions VIENNA

- Similar conclusions as with Trento: approach is extensible to the whole city, but cannot be applied fully automatically
- Nevertheless, the more datasets are integrated, the easier it is to fill the gaps and check for potential errors.
- Initial effort not negligible, but: "**Do once, use many!**"
- Approx. estimated time effort for completing the whole city (180k buildings):
  - Extremely depending on the amount of desired datasets to be added!!
  - Up to five (experienced and trained) persons for one year

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  http://link.springer.com/article/10.1007/s12518-015-0163-2

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  http://atti.asita.it/ASITA2014/Pdf/019.pdf

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ACKNOWLEDGMENTS

- Provincia di Trento
  - Servizio Catasto
  - Agenzia Provinciale per le Risorse Idriche e l'Energia (APRIE)
- Comune di Trento
  - Servizio Sistema Informativo
  - Servizio Urbanistica
  - Ufficio Anagrafe
  - Archivio Storico

- City of Vienna (Stadt Wien)
  - Magistratsdirektion Strategische Energieangelegenheiten
  - Magistratsabteilung 14 Informations- und Kommunikationstechnologie
  - Magistratsabteilung 39 Prüf-, Überwachungs- und Zertifizierungsstelle
  - Magistratsabteilung 41 Stadtvermessung

Overview

- Part 1: Semantic 3D city modelling & a first look at CityGML
- Part 2: A second look at CityGML and the 3D City Database
- Part 3: Experiences from Trento and Vienna
- **Part 4: Extending CityGML**
- Part 5: Energy & cities, experiences from Trento and Vienna (reprise)

Part 4: Extending CityGML

- Generics module (already seen before)
  - Generic CityObject
  - Generic Attribute

- External references

- ADE mechanism

- Extending the 3D City Database to accommodate the ADEs

NOTA BENE: all UML diagrams in the following slides are taken from the Energy ADE or Utility Network ADE GitHub resources (see links later on).

External references

- Every CityObject can store multiple references to external resources (databases, datasets, web resources, etc.)

- Such a reference denotes the external information system and the unique identifier of the object in this system

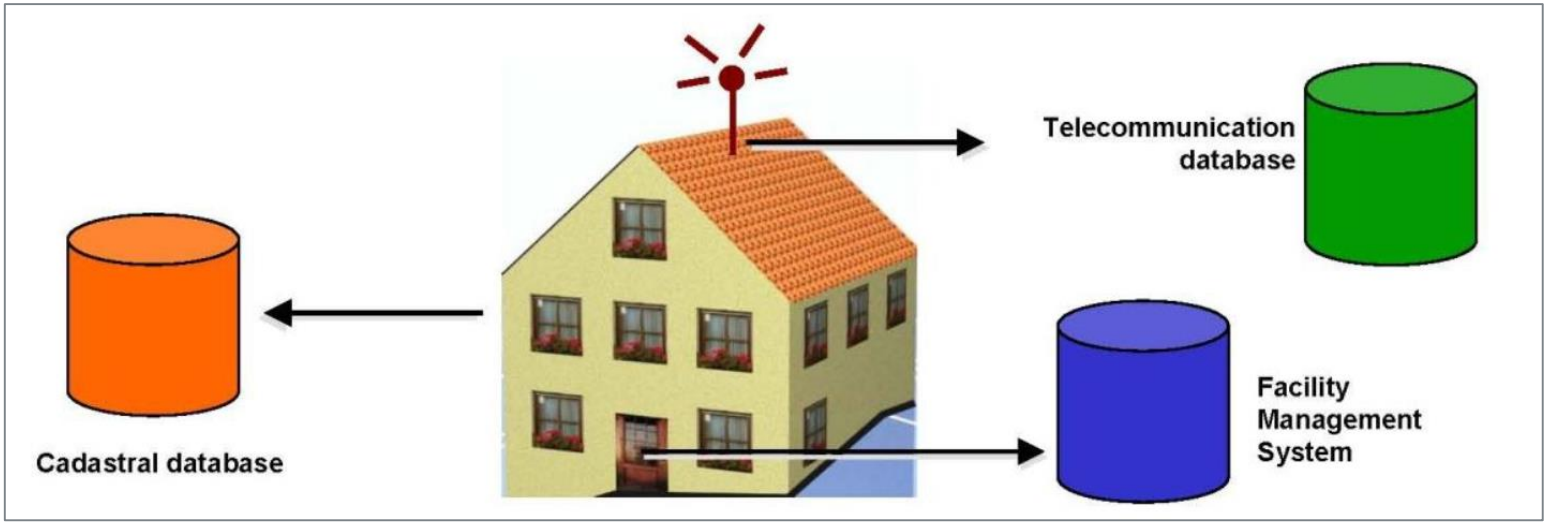


Image source: CityGML 2.0 Specification document

Application Domain Extensions (ADE)

- Starting from the CityGML data model, existing classes are extended and/or new classes and attributes are added.
- They are formalised in a XSD schema which is then referenced in the CityGML instance document.
- It is a more "elegant" way to extend CityGML, but also more complex
  - Allows to better define semantics and relations among classes
- (So far) no support for ADE by the Importer/Exporter
  - But research work is being carried out
  - 3DCityDB support for ADE is also pretty new
- FME already allows to read/write ADE-content
  - using the XSD file of the ADE

Which data energy model for cities?

- CityGML lacks specific features and attributes for energy-related applications (e.g. thermal zones, timeseries, etc.)
- BUT: extendable via **Application Domain Extensions** (ADE)

Energy ADE

Energy ADE

- Extends CityGML and defines standardised entities needed for building energy simulation purposes at city scale (bottom-up and top-down)
- In development since 2014, v.0.9 release September 2017
- Current consortium: 20 institutions, 11 countries (and growing!)
- Intended to be eventually released as OGC best practice document
- Available online https://github.com/cstb/citygml-energy
- Modular structure (5 modules)

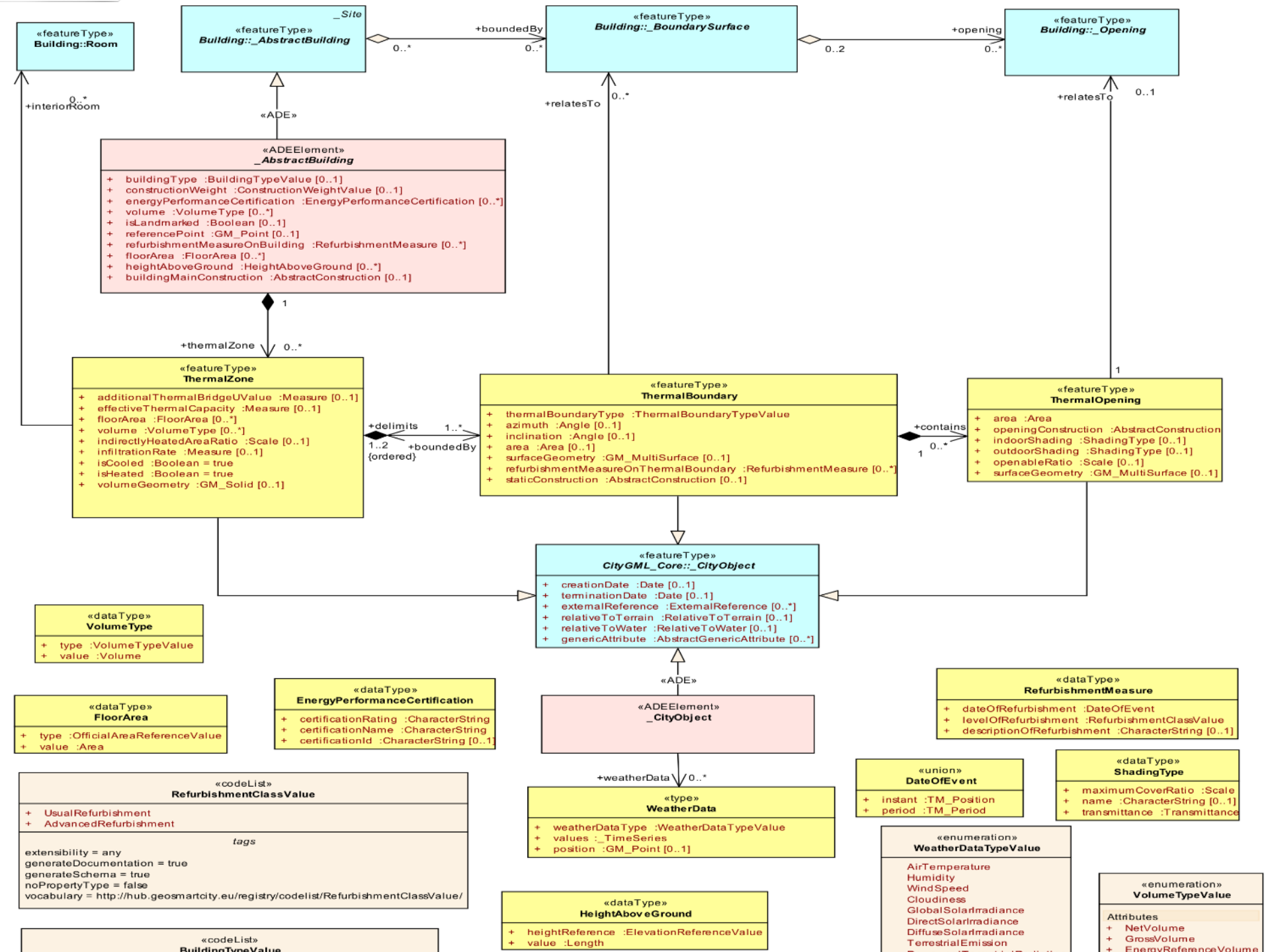
Energy ADE

Module 1: Building physics

- Extends CityGML objects (e.g. Building) and relates them to new thermal entities (ThermalZone, ThermalBoundary, ThermalOpening)

- Central object is the ThermalZone: reference volume for heating/cooling energy demand calculation

- Other useful classes:
  - WeatherStation and WeatherData
  - EnergyPerformanceCertification
  - RefurbishmentMeasure
  - etc.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_Site
«featureType»
Building::_AbstractBuilding
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0..*
0..*
«featureType»
Building::_BoundarySurface
+opening
0..2
0..*
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0..*
«ADE»
+relatesTo
0..*
+relatesTo
0..1
«ADEElement»
_AbstractBuilding
+ buildingType :BuildingTypeValue [0..1]
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+ energyPerformanceCertification :EnergyPerformanceCertification [0..*]
+ volume :VolumeType [0..*]
+ isLandmarked :Boolean [0..1]
+ referencePoint :GM_Point [0..1]
+ refurbishmentMeasureOnBuilding :RefurbishmentMeasure [0..*]
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+ buildingMainConstruction :AbstractConstruction [0..1]
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+ volume :VolumeType [0..*]
+ indirectlyHeatedAreaRatio :Scale [0..1]
+ infiltrationRate :Measure [0..1]
+ isCooled :Boolean = true
+ isHeated :Boolean = true
+ volumeGeometry :GM_Solid [0..1]
+delimits
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{ordered}
1..*
+boundedBy
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+ thermalBoundaryType :ThermalBoundaryTypeValue
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+ staticConstruction :AbstractConstruction [0..1]
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1
0..*
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+ openingConstruction :AbstractConstruction
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+ openableRatio :Scale [0..1]
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+ period :TM_Period
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ShadingType
+ maximumCoverRatio :Scale
+ name :CharacterString [0..1]
+ transmittance :Transmittance
«codeList»
RefurbishmentClassValue
+ UsualRefurbishment
+ AdvancedRefurbishment
tags
extensibility = any
generateDocumentation = true
generateSchema = true
noPropertyType = false
vocabulary = http://hub.geosmartcity.eu/registry/codelist/RefurbishmentClassValue/
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+ weatherDataType :WeatherDataTypeValue
+ values :_TimeSeries
+ position :GM_Point [0..1]
«enumeration»
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Humidity
WindSpeed
Cloudiness
GlobalSolarIrradiance
DirectSolarIrradiance
DiffuseSolarIrradiance
TerrestrialEmission
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+ value :Length
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Attributes
+ NetVolume
+ GrossVolume
+ EnergyReferenceVolume
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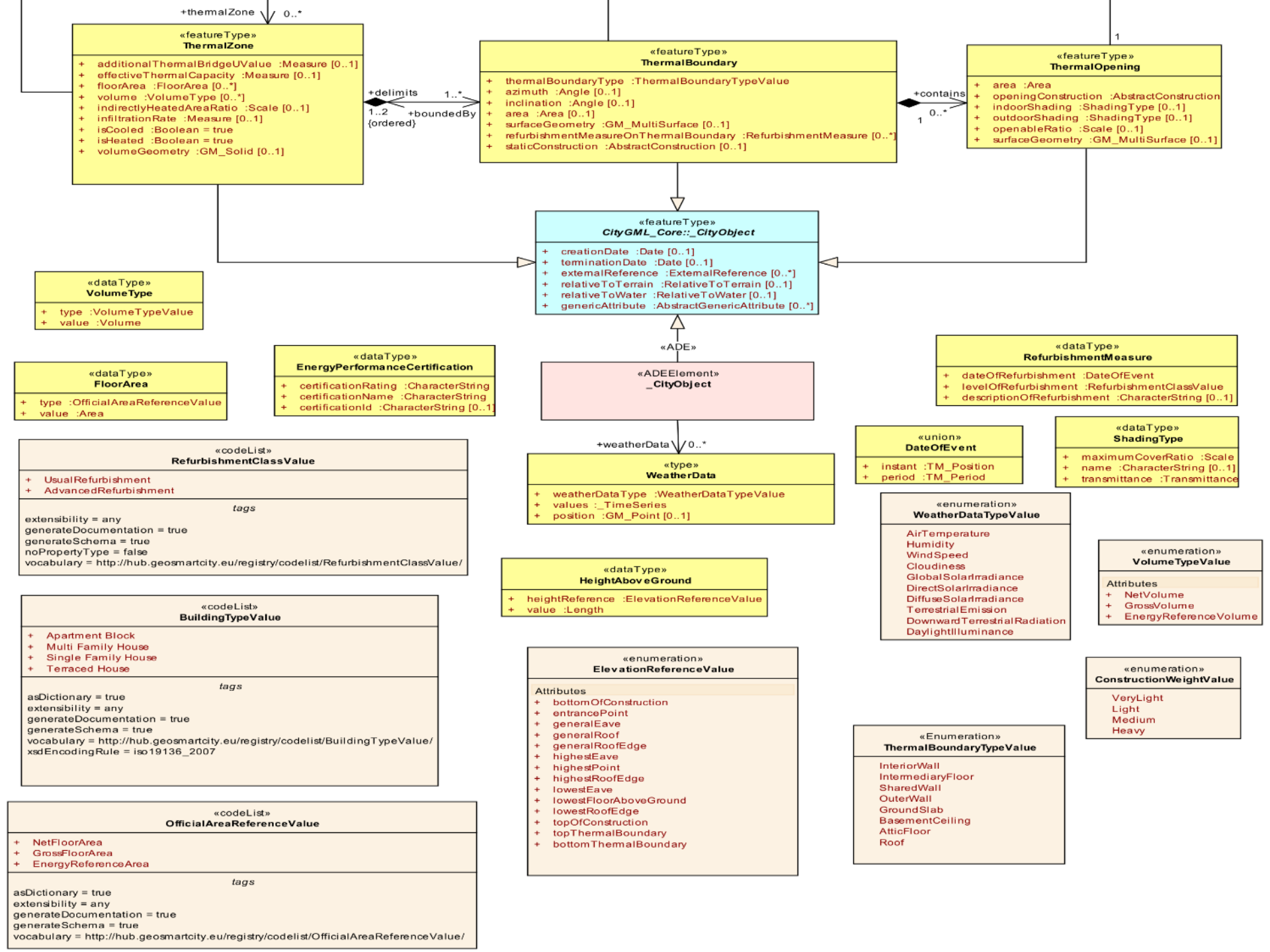
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0..*
1
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+ indoorShading :ShadingType [0..1]
+ outdoorShading :ShadingType [0..1]
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+ values :_TimeSeries
+ position :GM_Point [0..1]
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«dataType»
ShadingType
+ maximumCoverRatio :Scale
+ name :CharacterString [0..1]
+ transmittance :Transmittance
«codeList»
RefurbishmentClassValue
+ UsualRefurbishment
+ AdvancedRefurbishment
tags
extensibility = any
generateDocumentation = true
generateSchema = true
noPropertyType = false
vocabulary = http://hub.geosmartcity.eu/registry/codelist/RefurbishmentClassValue/
«enumeration»
WeatherDataTypeValue
AirTemperature
Humidity
WindSpeed
Cloudiness
GlobalSolarIrradiance
DirectSolarIrradiance
DiffuseSolarIrradiance
TerrestrialEmission
DownwardTerrestrialRadiation
DaylightIlluminance
«dataType»
HeightAboveGround
+ heightReference :ElevationReferenceValue
+ value :Length
«enumeration»
VolumeTypeValue
Attributes
+ NetVolume
+ GrossVolume
+ EnergyReferenceVolume
«codeList»
BuildingTypeValue
+ Apartment Block
+ Multi Family House
+ Single Family House
+ Terraced House
tags
asDictionary = true
extensibility = any
generateDocumentation = true
generateSchema = true
vocabulary = http://hub.geosmartcity.eu/registry/codelist/BuildingTypeValue/
xsdEncodingRule = iso19136_2007
«enumeration»
ElevationReferenceValue
Attributes
+ bottomOfConstruction
+ entrancePoint
+ generalEave
+ generalRoof
+ generalRoofEdge
+ highestEave
+ highestPoint
+ highestRoofEdge
+ lowestEave
+ lowestFloorAboveGround
+ lowestRoofEdge
+ topOfConstruction
+ topThermalBoundary
+ bottomThermalBoundary
«enumeration»
ConstructionWeightValue
VeryLight
Light
Medium
Heavy
«Enumeration»
ThermalBoundaryTypeValue
InteriorWall
IntermediaryFloor
SharedWall
OuterWall
GroundSlab
BasementCeiling
AtticFloor
Roof
«codeList»
OfficialAreaReferenceValue
+ NetFloorArea
+ GrossFloorArea
+ EnergyReferenceArea
tags
asDictionary = true
extensibility = any
generateDocumentation = true
generateSchema = true
vocabulary = http://hub.geosmartcity.eu/registry/codelist/OfficialAreaReferenceValue/

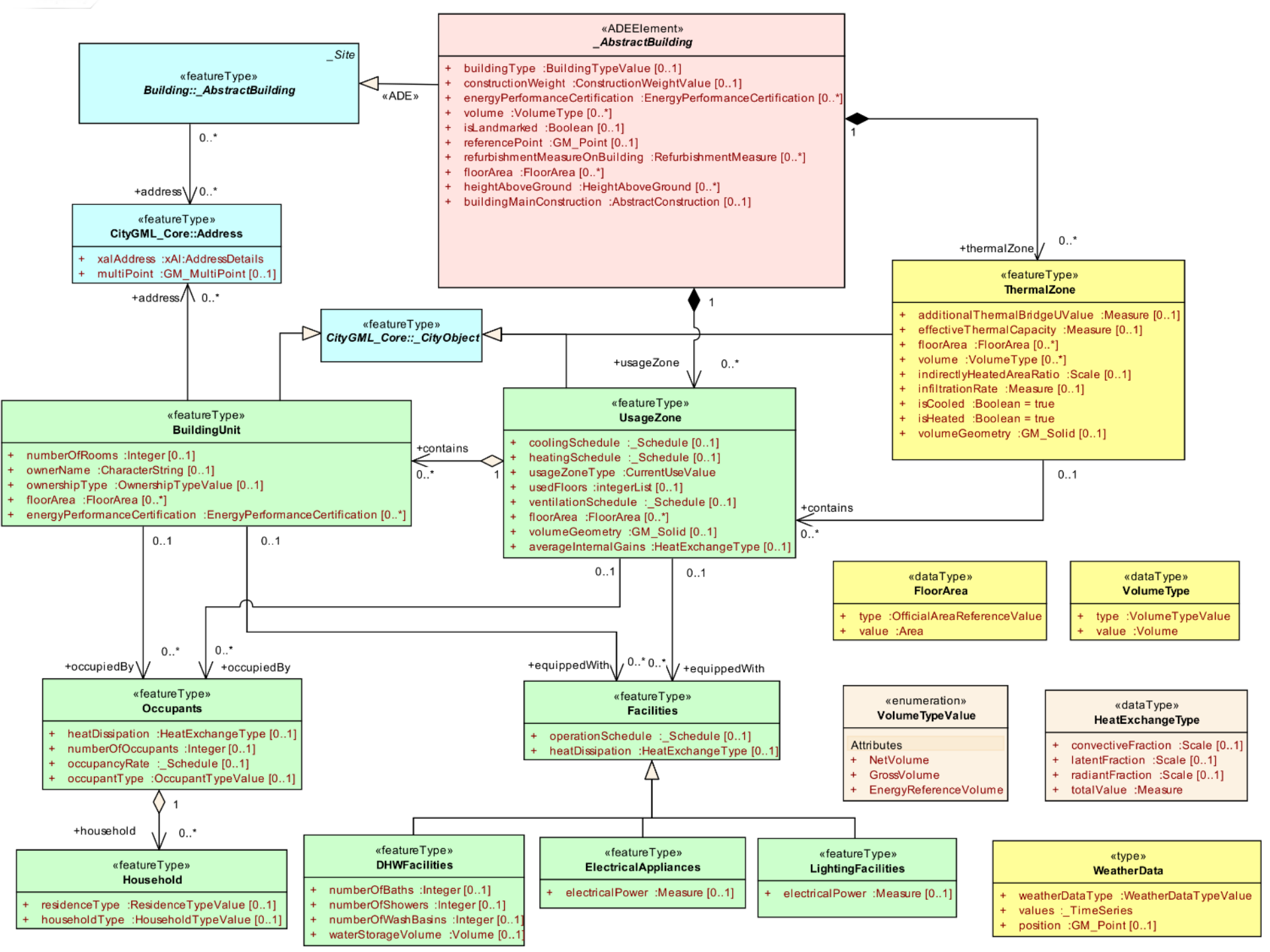
Energy ADE

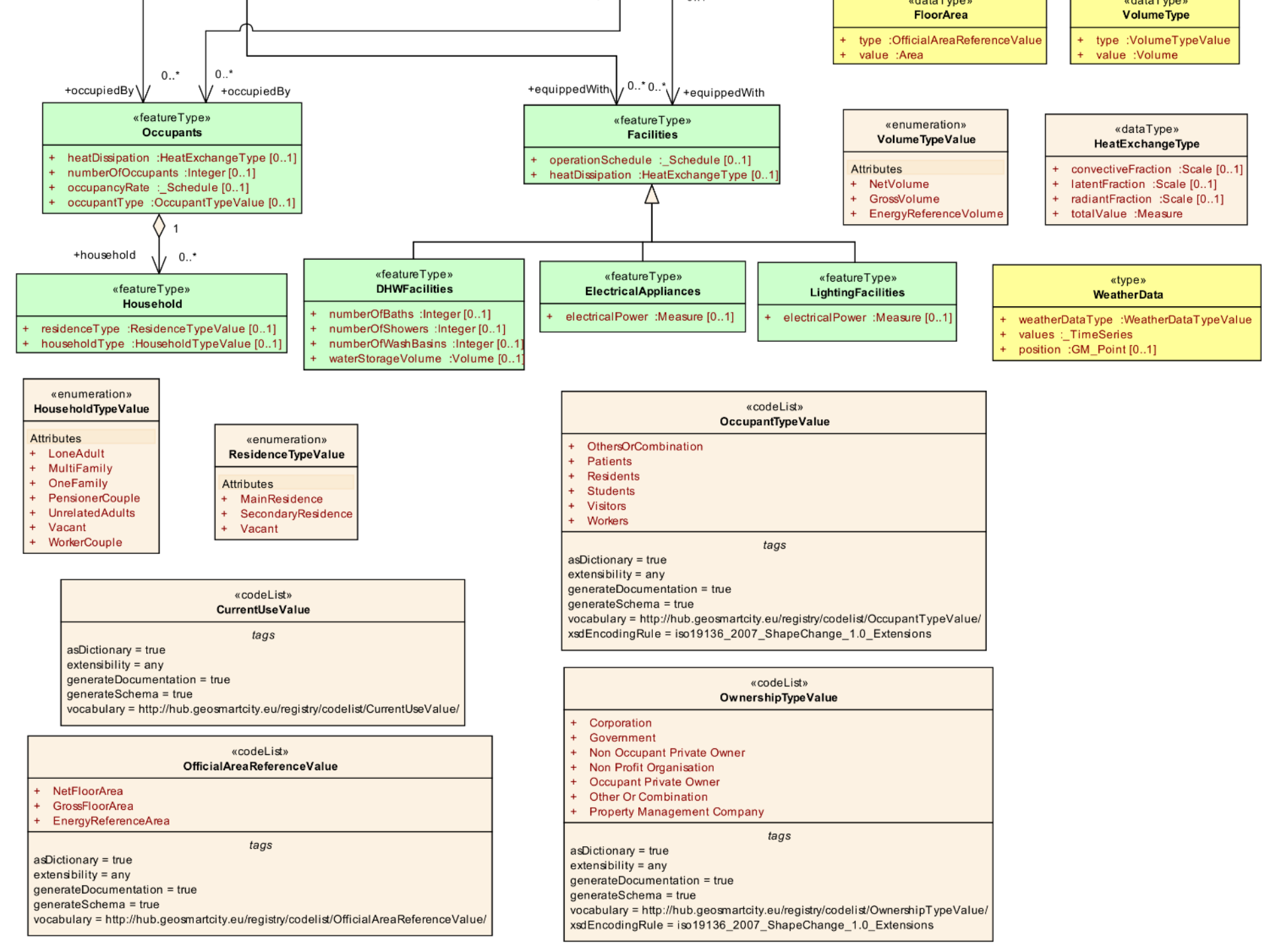
Module 2: Occupancy

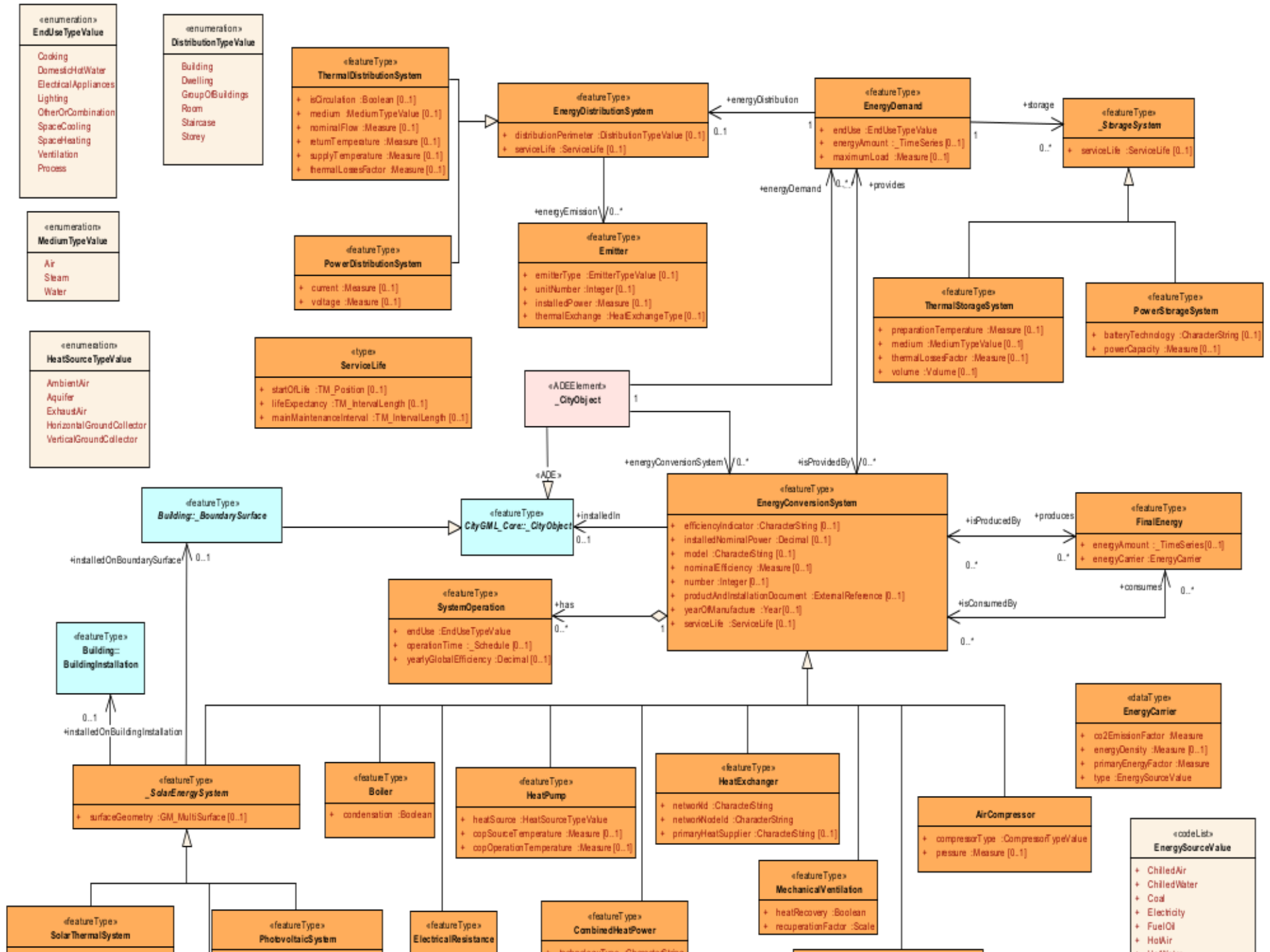
- Contains the characterisation of the building usage, i.e. people and facilities
- Main classes are the UsageZone and the BuildingUnit. A usage zone is contained in a thermal zone and characterises the usage of an homogeneous part of the building in terms of heating, cooling, ventilation

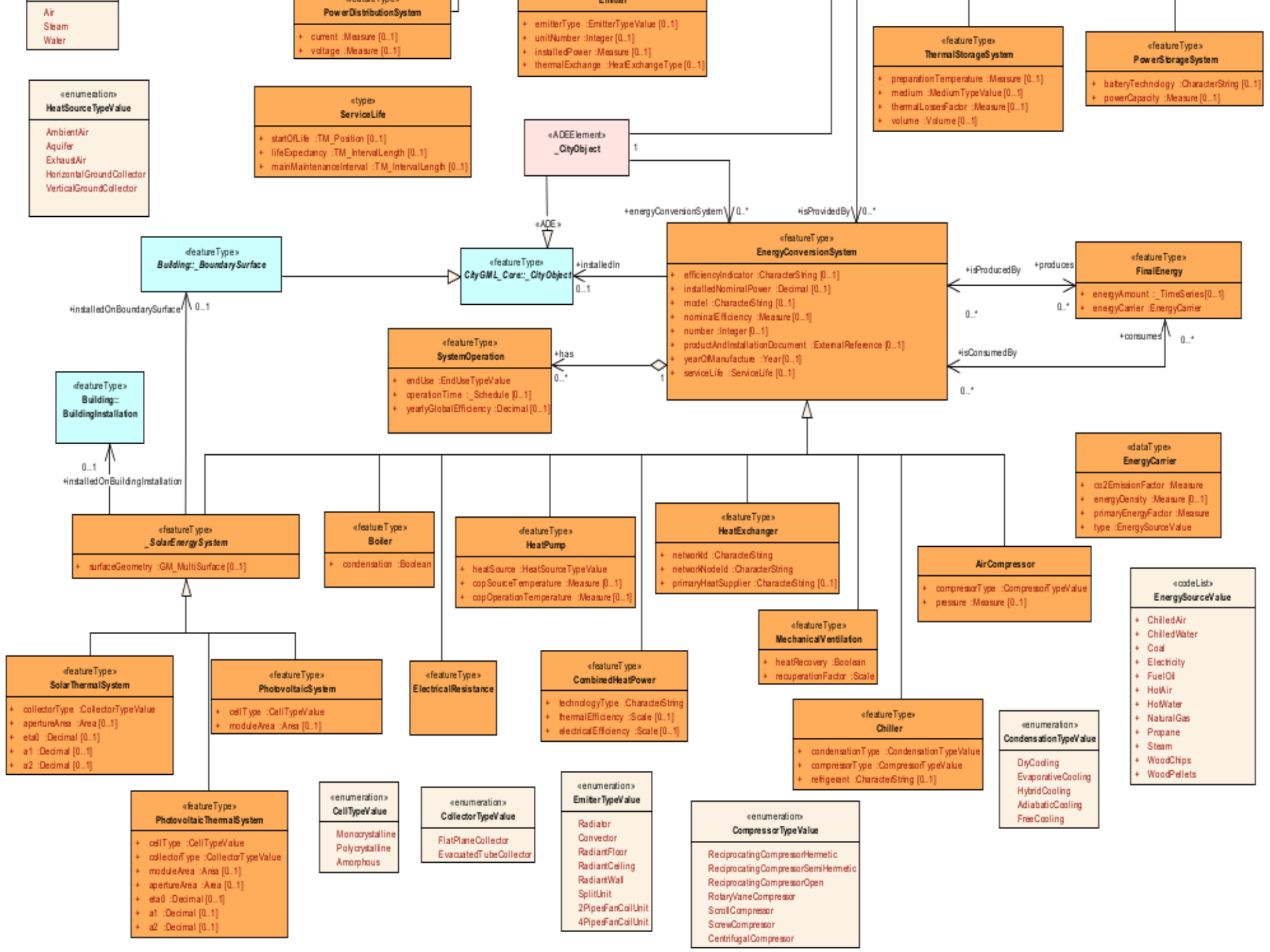
Module 3: Energy use and systems

- Contains the energy forms (energy demand and sources) and energy systems (conversion, distribution and storage systems) to perform energy demand and supply analyses
- Offers a link to the Utility Network ADE (e.g. for district heating, gas and power networks)


«ADEElement»
_AbstractBuilding
+ buildingType :BuildingTypeValue [0..1]
+ constructionWeight :ConstructionWeightValue [0..1]
+ energyPerformanceCertification :EnergyPerformanceCertification [0..*]
+ volume :VolumeType [0..*]
+ isLandmarked :Boolean [0..1]
+ referencePoint :GM_Point [0..1]
+ refurbishmentMeasureOnBuilding :RefurbishmentMeasure [0..*]
+ floorArea :FloorArea [0..*]
+ heightAboveGround :HeightAboveGround [0..*]
+ buildingMainConstruction :AbstractConstruction [0..1]
_Site
«featureType»
Building::_AbstractBuilding
«ADE»
0..*
+address
0..*
«featureType»
CityGML_Core::Address
+ xalAddress :xAl:AddressDetails
+ multiPoint :GM_MultiPoint [0..1]
+address
0..*
1
+thermalZone
0..*
«featureType»
ThermalZone
+ additionalThermalBridgeUValue :Measure [0..1]
+ effectiveThermalCapacity :Measure [0..1]
+ floorArea :FloorArea [0..*]
+ volume :VolumeType [0..*]
+ indirectlyHeatedAreaRatio :Scale [0..1]
+ infiltrationRate :Measure [0..1]
+ isCooled :Boolean = true
+ isHeated :Boolean = true
+ volumeGeometry :GM_Solid [0..1]
«featureType»
CityGML_Core::_CityObject
1
+usageZone
0..*
«featureType»
BuildingUnit
+ numberOfRooms :Integer [0..1]
+ ownerName :CharacterString [0..1]
+ ownershipType :OwnershipTypeValue [0..1]
+ floorArea :FloorArea [0..*]
+ energyPerformanceCertification :EnergyPerformanceCertification [0..*]
+contains
0..*
1
«featureType»
UsageZone
+ coolingSchedule :_Schedule [0..1]
+ heatingSchedule :_Schedule [0..1]
+ usageZoneType :CurrentUseValue
+ usedFloors :integerList [0..1]
+ ventilationSchedule :_Schedule [0..1]
+ floorArea :FloorArea [0..*]
+ volumeGeometry :GM_Solid [0..1]
+ averageInternalGains :HeatExchangeType [0..1]
0..1
+contains
0..*
0..1
0..1
0..1
0..1
«dataType»
FloorArea
+ type :OfficialAreaReferenceValue
+ value :Area
«dataType»
VolumeType
+ type :VolumeTypeValue
+ value :Volume
0..*
+occupiedBy
0..*
+occupiedBy
0..*
+equippedWith
0..*
+equippedWith
«featureType»
Occupants
+ heatDissipation :HeatExchangeType [0..1]
+ numberOfOccupants :Integer [0..1]
+ occupancyRate :_Schedule [0..1]
+ occupantType :OccupantTypeValue [0..1]
«featureType»
Facilities
+ operationSchedule :_Schedule [0..1]
+ heatDissipation :HeatExchangeType [0..1]
«enumeration»
VolumeTypeValue
Attributes
+ NetVolume
+ GrossVolume
+ EnergyReferenceVolume
«dataType»
HeatExchangeType
+ convectiveFraction :Scale [0..1]
+ latentFraction :Scale [0..1]
+ radiantFraction :Scale [0..1]
+ totalValue :Measure
1
+household
0..*
«featureType»
Household
+ residenceType :ResidenceTypeValue [0..1]
+ householdType :HouseholdTypeValue [0..1]
«featureType»
DHWFacilities
+ numberOfBaths :Integer [0..1]
+ numberOfShowers :Integer [0..1]
+ numberOfWashBasins :Integer [0..1]
+ waterStorageVolume :Volume [0..1]
«featureType»
ElectricalAppliances
+ electricalPower :Measure [0..1]
«featureType»
LightingFacilities
+ electricalPower :Measure [0..1]
«type»
WeatherData
+ weatherDataType :WeatherDataTypeValue
+ values :_TimeSeries
+ position :GM_Point [0..1]


«dataType»
FloorArea
+ type :OfficialAreaReferenceValue
+ value :Area
«dataType»
VolumeType
+ type :VolumeTypeValue
+ value :Volume
0..*
+occupiedBy
0..*
+occupiedBy
+equippedWith
0..*
0..*
+equippedWith
«featureType»
Occupants
+ heatDissipation :HeatExchangeType [0..1]
+ numberOfOccupants :Integer [0..1]
+ occupancyRate :_Schedule [0..1]
+ occupantType :OccupantTypeValue [0..1]
«featureType»
Facilities
+ operationSchedule :_Schedule [0..1]
+ heatDissipation :HeatExchangeType [0..1]
«enumeration»
VolumeTypeValue
Attributes
+ NetVolume
+ GrossVolume
+ EnergyReferenceVolume
«dataType»
HeatExchangeType
+ convectiveFraction :Scale [0..1]
+ latentFraction :Scale [0..1]
+ radiantFraction :Scale [0..1]
+ totalValue :Measure
1
+household
0..*
«featureType»
Household
+ residenceType :ResidenceTypeValue [0..1]
+ householdType :HouseholdTypeValue [0..1]
«featureType»
DHWFacilities
+ numberOfBaths :Integer [0..1]
+ numberOfShowers :Integer [0..1]
+ numberOfWashBasins :Integer [0..1]
+ waterStorageVolume :Volume [0..1]
«featureType»
ElectricalAppliances
+ electricalPower :Measure [0..1]
«featureType»
LightingFacilities
+ electricalPower :Measure [0..1]
«type»
WeatherData
+ weatherDataType :WeatherDataTypeValue
+ values :_TimeSeries
+ position :GM_Point [0..1]
«enumeration»
HouseholdTypeValue
Attributes
+ LoneAdult
+ MultiFamily
+ OneFamily
+ PensionerCouple
+ UnrelatedAdults
+ Vacant
+ WorkerCouple
«enumeration»
ResidenceTypeValue
Attributes
+ MainResidence
+ SecondaryResidence
+ Vacant
«codeList»
OccupantTypeValue
+ OthersOrCombination
+ Patients
+ Residents
+ Students
+ Visitors
+ Workers
tags
asDictionary = true
extensibility = any
generateDocumentation = true
generateSchema = true
vocabulary = http://hub.geosmartcity.eu/registry/codelist/OccupantTypeValue/
xsdEncodingRule = iso19136_2007_ShapeChange_1.0_Extensions
«codeList»
CurrentUseValue
tags
asDictionary = true
extensibility = any
generateDocumentation = true
generateSchema = true
vocabulary = http://hub.geosmartcity.eu/registry/codelist/CurrentUseValue/
«codeList»
OwnershipTypeValue
+ Corporation
+ Government
+ Non Occupant Private Owner
+ Non Profit Organisation
+ Occupant Private Owner
+ Other Or Combination
+ Property Management Company
tags
asDictionary = true
extensibility = any
generateDocumentation = true
generateSchema = true
vocabulary = http://hub.geosmartcity.eu/registry/codelist/OwnershipTypeValue/
xsdEncodingRule = iso19136_2007_ShapeChange_1.0_Extensions
«codeList»
OfficialAreaReferenceValue
+ NetFloorArea
+ GrossFloorArea
+ EnergyReferenceArea
tags
asDictionary = true
extensibility = any
generateDocumentation = true
generateSchema = true
vocabulary = http://hub.geosmartcity.eu/registry/codelist/OfficialAreaReferenceValue/


«enumeration»
EndUseTypeValue
Cooking
DomesticHotWater
ElectricalAppliances
Lighting
OtherOrCombination
SpaceCooling
SpaceHeating
Ventilation
Process
«enumeration»
DistributionTypeValue
Building
Dwelling
GroupOfBuildings
Room
Staircase
Storey
«enumeration»
MediumTypeValue
Air
Steam
Water
«enumeration»
HeatSourceTypeValue
AmbientAir
Aquifer
ExhaustAir
HorizontalGroundCollector
VerticalGroundCollector
«featureType»
ThermalDistributionSystem
+ isCirculation :Boolean [0..1]
+ medium :MediumTypeValue [0..1]
+ nominalFlow :Measure [0..1]
+ returnTemperature :Measure [0..1]
+ supplyTemperature :Measure [0..1]
+ thermalLossesFactor :Measure [0..1]
«featureType»
EnergyDistributionSystem
+ distributionPerimeter :DistributionTypeValue [0..1]
+ serviceLife :ServiceLife [0..1]
+energyDistribution
0..1
1
«featureType»
EnergyDemand
+ endUse :EndUseTypeValue
+ energyAmount :_TimeSeries [0..1]
+ maximumLoad :Measure [0..1]
+storage
1
0..*
«featureType»
_StorageSystem
+ serviceLife :ServiceLife [0..1]
+energyEmission
0..*
«featureType»
PowerDistributionSystem
+ current :Measure [0..1]
+ voltage :Measure [0..1]
«featureType»
Emitter
+ emitterType :EmitterTypeValue [0..1]
+ unitNumber :Integer [0..1]
+ installedPower :Measure [0..1]
+ thermalExchange :HeatExchangeType [0..1]
+energyDemand
0..*
+provides
«featureType»
ThermalStorageSystem
+ preparationTemperature :Measure [0..1]
+ medium :MediumTypeValue [0..1]
+ thermalLossesFactor :Measure [0..1]
+ volume :Volume [0..1]
«featureType»
PowerStorageSystem
+ batteryTechnology :CharacterString [0..1]
+ powerCapacity :Measure [0..1]
«type»
ServiceLife
+ startOfLife :TM_Position [0..1]
+ lifeExpectancy :TM_IntervalLength [0..1]
+ mainMaintenanceInterval :TM_IntervalLength [0..1]
«ADEElement»
_CityObject
1
«ADE»
+energyConversionSystem
0..*
+isProvidedBy
0..*
«featureType»
Building::_BoundarySurface
«featureType»
CityGML_Core::_CityObject
+installedIn
0..1
«featureType»
EnergyConversionSystem
+ efficiencyIndicator :CharacterString [0..1]
+ installedNominalPower :Decimal [0..1]
+ model :CharacterString [0..1]
+ nominalEfficiency :Measure [0..1]
+ number :Integer [0..1]
+ productAndInstallationDocument :ExternalReference [0..1]
+ yearOfManufacture :Year [0..1]
+ serviceLife :ServiceLife [0..1]
+isProducedBy
0..*
+produces
0..*
«featureType»
FinalEnergy
+ energyAmount :_TimeSeries [0..1]
+ energyCarrier :EnergyCarrier
+consumes
0..*
+isConsumedBy
0..*
+installedOnBoundarySurface
0..1
«featureType»
SystemOperation
+ endUse :EndUseTypeValue
+ operationTime :_Schedule [0..1]
+ yearlyGlobalEfficiency :Decimal [0..1]
+has
0..*
1
«featureType»
Building::
BuildingInstallation
0..1
+installedOnBuildingInstallation
«dataType»
EnergyCarrier
+ co2EmissionFactor :Measure
+ energyDensity :Measure [0..1]
+ primaryEnergyFactor :Measure
+ type :EnergySourceValue
«featureType»
_SolarEnergySystem
+ surfaceGeometry :GM_MultiSurface [0..1]
«featureType»
Boiler
+ condensation :Boolean
«featureType»
HeatPump
+ heatSource :HeatSourceTypeValue
+ copSourceTemperature :Measure [0..1]
+ copOperationTemperature :Measure [0..1]
«featureType»
HeatExchanger
+ networkId :CharacterString
+ networkNodeId :CharacterString
+ primaryHeatSupplier :CharacterString [0..1]
AirCompressor
+ compressorType :CompressorTypeValue
+ pressure :Measure [0..1]
«codeList»
EnergySourceValue
+ ChilledAir
+ ChilledWater
+ Coal
+ Electricity
+ FuelOil
+ HotAir
«featureType»
MechanicalVentilation
+ heatRecovery :Boolean
+ recuperationFactor :Scale
«featureType»
SolarThermalSystem
«featureType»
PhotovoltaicSystem
«featureType»
ElectricalResistance
«featureType»
CombinedHeatPower


Air
Steam
Water
«enumeration»
HeatSourceTypeValue
AmbientAir
Aquifer
ExhaustAir
HorizontalGroundCollector
VerticalGroundCollector
«type»
ServiceLife
+ startOfLife :TM_Position [0..1]
+ lifeExpectancy :TM_IntervalLength [0..1]
+ mainMaintenanceInterval :TM_IntervalLength [0..1]
«featureType»
PowerDistributionSystem
+ current :Measure [0..1]
+ voltage :Measure [0..1]
+ emitterType :EmitterTypeValue [0..1]
+ unitNumber :Integer [0..1]
+ installedPower :Measure [0..1]
+ thermalExchange :HeatExchangeType [0..1]
«featureType»
ThermalStorageSystem
+ preparationTemperature :Measure [0..1]
+ medium :MediumTypeValue [0..1]
+ thermalLossesFactor :Measure [0..1]
+ volume :Volume [0..1]
«featureType»
PowerStorageSystem
+ batteryTechnology :CharacterString [0..1]
+ powerCapacity :Measure [0..1]
«ADEElement»
_CityObject
1
+energyConversionSystem
0..*
+isProvidedBy
0..*
«ADE»
«featureType»
Building::_BoundarySurface
«featureType»
CityGML_Core::_CityObject
+installedIn
0..1
+installedOnBoundarySurface
0..1
«featureType»
EnergyConversionSystem
+ efficiencyIndicator :CharacterString [0..1]
+ installedNominalPower :Decimal [0..1]
+ model :CharacterString [0..1]
+ nominalEfficiency :Measure [0..1]
+ number :Integer [0..1]
+ productAndInstallationDocument :ExternalReference [0..1]
+ yearOfManufacture :Year [0..1]
+ serviceLife :ServiceLife [0..1]
+isProducedBy
+produces
0..*
0..*
«featureType»
FinalEnergy
+ energyAmount :_TimeSeries[0..1]
+ energyCarrier :EnergyCarrier
+consumes
0..*
+isConsumedBy
0..*
«featureType»
SystemOperation
+ endUse :EndUseTypeValue
+ operationTime :_Schedule [0..1]
+ yearlyGlobalEfficiency :Decimal [0..1]
+has
0..*
1
«featureType»
Building::
BuildingInstallation
0..1
+installedOnBuildingInstallation
«dataType»
EnergyCarrier
+ co2EmissionFactor :Measure
+ energyDensity :Measure [0..1]
+ primaryEnergyFactor :Measure
+ type :EnergySourceValue
«featureType»
_SolarEnergySystem
+ surfaceGeometry :GM_MultiSurface [0..1]
«featureType»
Boiler
+ condensation :Boolean
«featureType»
HeatPump
+ heatSource :HeatSourceTypeValue
+ copSourceTemperature :Measure [0..1]
+ copOperationTemperature :Measure [0..1]
«featureType»
HeatExchanger
+ networkId :CharacterString
+ networkNodeId :CharacterString
+ primaryHeatSupplier :CharacterString [0..1]
AirCompressor
+ compressorType :CompressorTypeValue
+ pressure :Measure [0..1]
«codeList»
EnergySourceValue
+ ChilledAir
+ ChilledWater
+ Coal
+ Electricity
+ FuelOil
+ HotAir
+ HotWater
+ NaturalGas
+ Propane
+ Steam
+ WoodChips
+ WoodPellets
«featureType»
SolarThermalSystem
+ collectorType :CollectorTypeValue
+ apertureArea :Area [0..1]
+ eta0 :Decimal [0..1]
+ a1 :Decimal [0..1]
+ a2 :Decimal [0..1]
«featureType»
PhotovoltaicSystem
+ cellType :CellTypeValue
+ moduleArea :Area [0..1]
«featureType»
ElectricalResistance
«featureType»
CombinedHeatPower
+ technologyType :CharacterString
+ thermalEfficiency :Scale [0..1]
+ electricalEfficiency :Scale [0..1]
«featureType»
MechanicalVentilation
+ heatRecovery :Boolean
+ recuperationFactor :Scale
«featureType»
Chiller
+ condensationType :CondensationTypeValue
+ compressorType :CompressorTypeValue
+ refrigeant :CharacterString [0..1]
«enumeration»
CondensationTypeValue
DryCooling
EvaporativeCooling
HybridCooling
AdiabaticCooling
FreeCooling
«featureType»
PhotovoltaicThermalSystem
+ cellType :CellTypeValue
+ collectorType :CollectorTypeValue
+ moduleArea :Area [0..1]
+ apertureArea :Area [0..1]
+ eta0 :Decimal [0..1]
+ a1 :Decimal [0..1]
+ a2 :Decimal [0..1]
«enumeration»
CellTypeValue
Monocrystalline
Polycrystalline
Amorphous
«enumeration»
CollectorTypeValue
FlatPlaneCollector
EvacuatedTubeCollector
«enumeration»
EmitterTypeValue
Radiator
Convector
RadiantFloor
RadiantCeiling
RadiantWall
SplitUnit
2PipesFanCoilUnit
4PipesFanCoilUnit
«enumeration»
CompressorTypeValue
ReciprocatingCompressorHermetic
ReciprocatingCompressorSemiHermetic
ReciprocatingCompressorOpen
RotaryVaneCompressor
ScrollCompressor
ScrewCompressor
CentrifugalCompressor

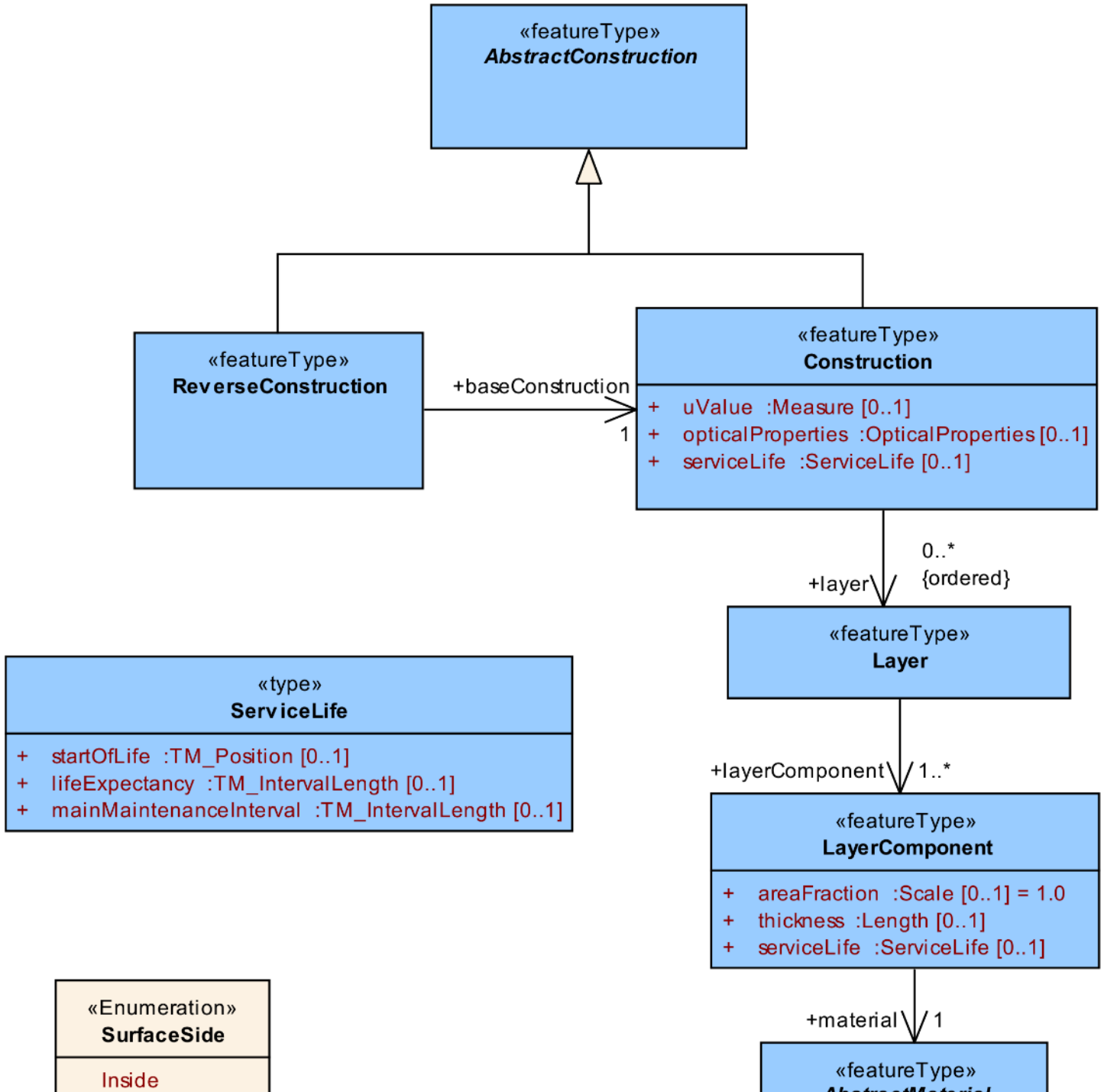
Energy ADE

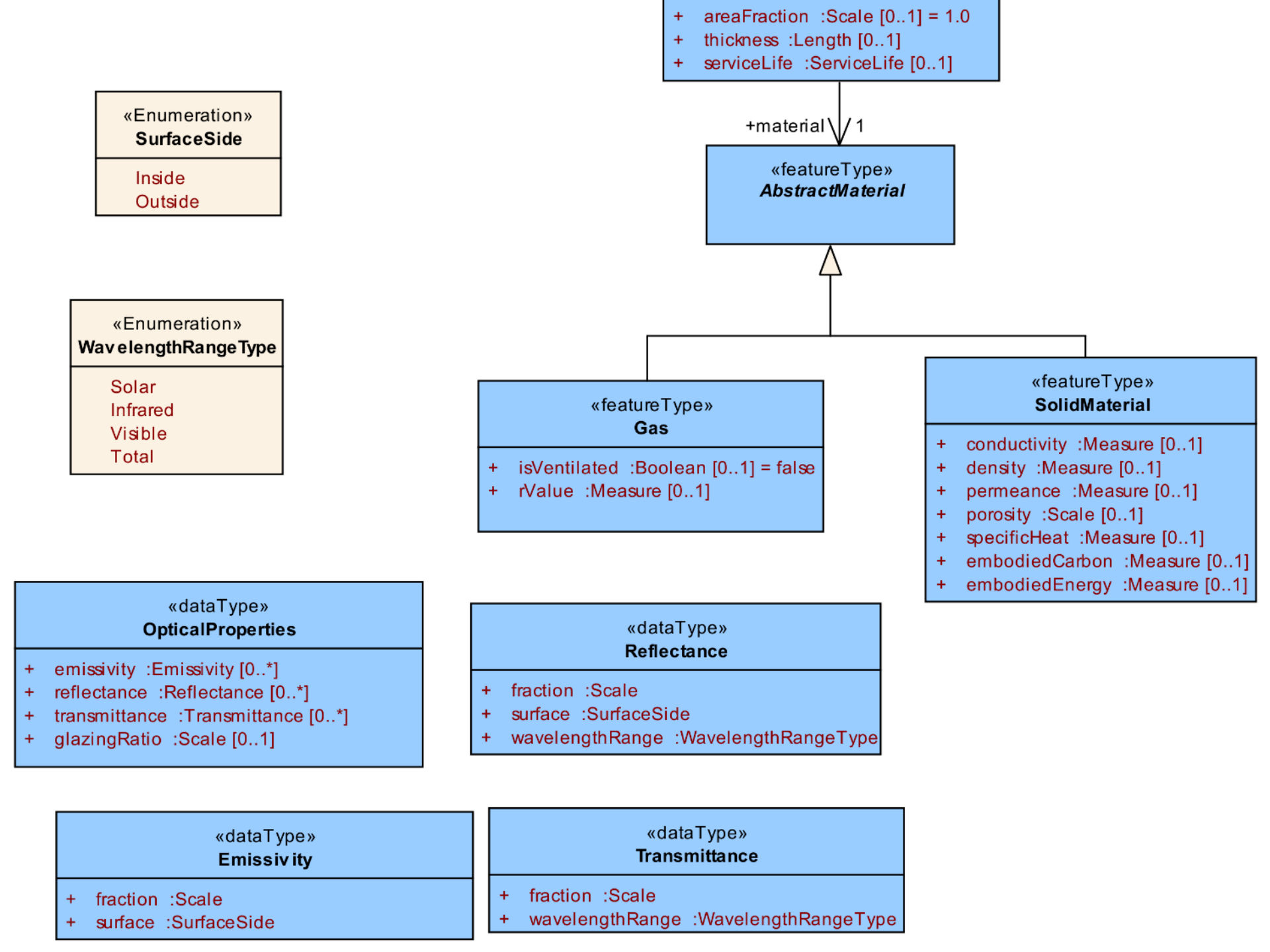
Module 4: Construction & Material

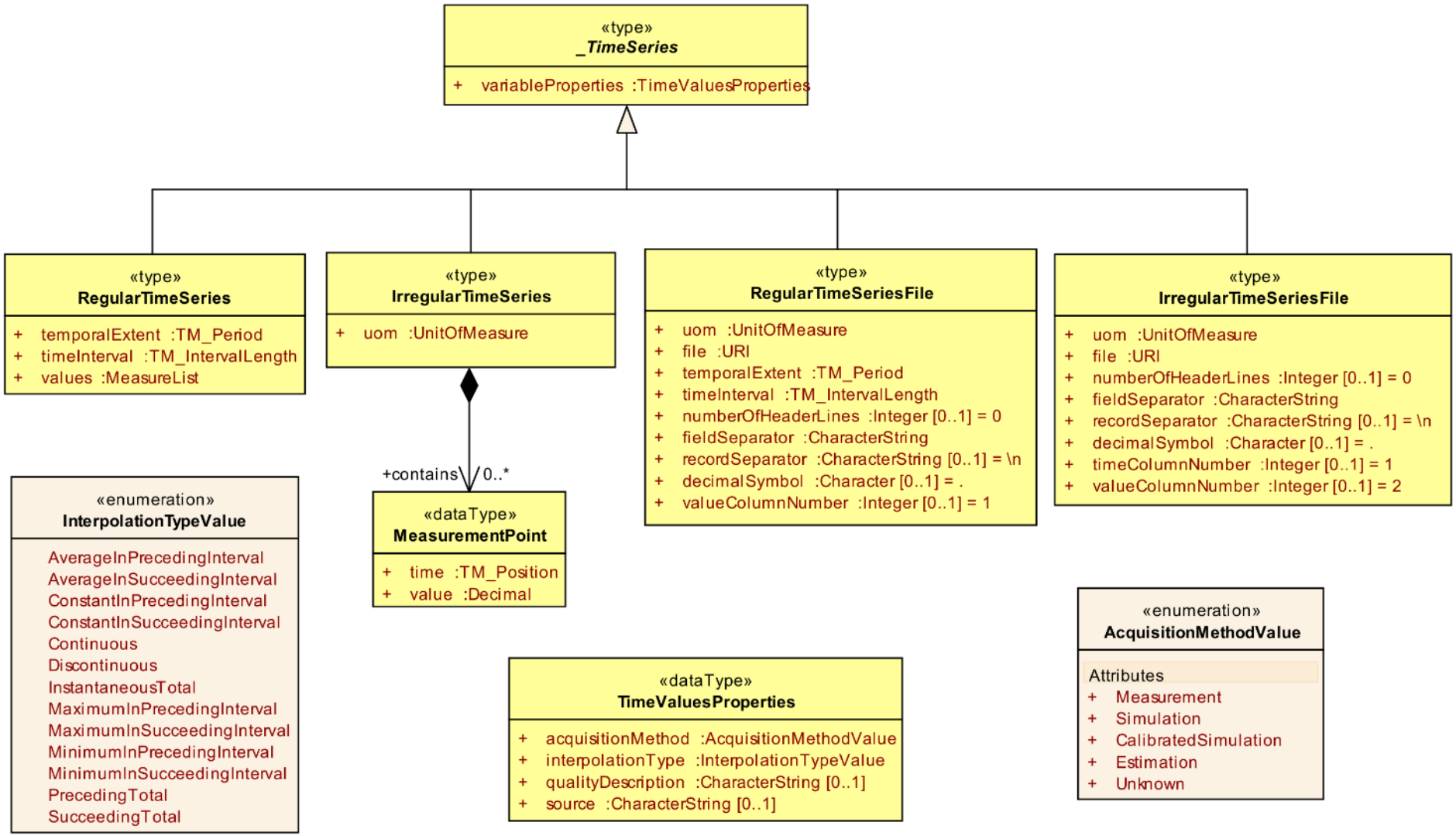
- characterises the building construction parts, detailing their structure and specifying their thermal and optical properties
- Allows for complex, multi-layered constructions

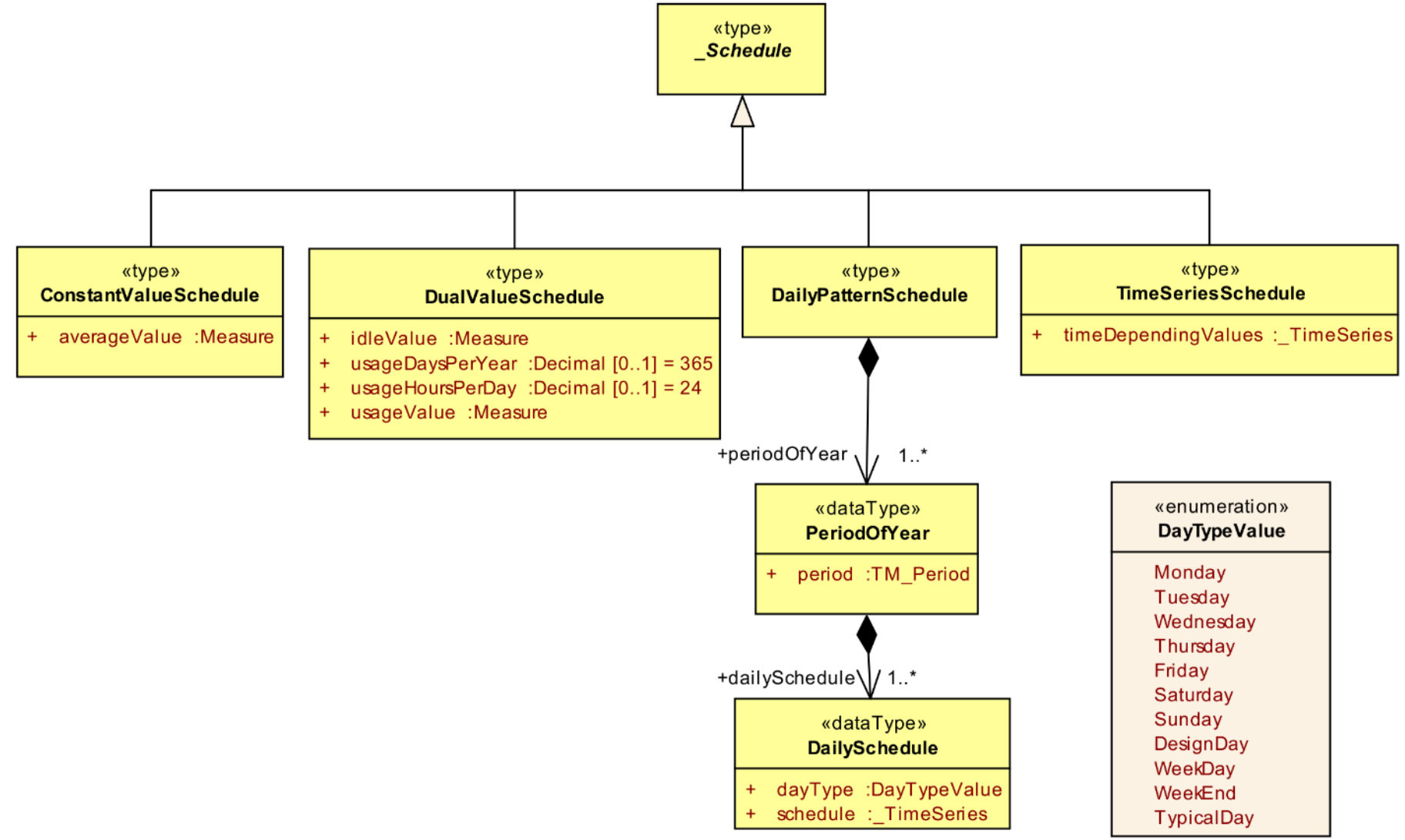
Module 5: Time series and schedules

- Contains "all-purpose" classes to model the time-depending inputs and results, e.g. of urban energy analyses.
- These classes are used in the other modules of the Energy ADE


«featureType»
AbstractConstruction
«featureType»
ReverseConstruction
+baseConstruction
1
«featureType»
Construction
+ uValue :Measure [0..1]
+ opticalProperties :OpticalProperties [0..1]
+ serviceLife :ServiceLife [0..1]
0..*
{ordered}
+layer
«featureType»
Layer
«type»
ServiceLife
+ startOfLife :TM_Position [0..1]
+ lifeExpectancy :TM_IntervalLength [0..1]
+ mainMaintenanceInterval :TM_IntervalLength [0..1]
+layerComponent
1..*
«featureType»
LayerComponent
+ areaFraction :Scale [0..1] = 1.0
+ thickness :Length [0..1]
+ serviceLife :ServiceLife [0..1]
«Enumeration»
SurfaceSide
Inside
+material
1
«featureType»


+ areaFraction :Scale [0..1] = 1.0
+ thickness :Length [0..1]
+ serviceLife :ServiceLife [0..1]
+material
1
«Enumeration»
SurfaceSide
Inside
Outside
«featureType»
AbstractMaterial
«Enumeration»
WavelengthRangeType
Solar
Infrared
Visible
Total
«featureType»
Gas
+ isVentilated :Boolean [0..1] = false
+ rValue :Measure [0..1]
«featureType»
SolidMaterial
+ conductivity :Measure [0..1]
+ density :Measure [0..1]
+ permeance :Measure [0..1]
+ porosity :Scale [0..1]
+ specificHeat :Measure [0..1]
+ embodiedCarbon :Measure [0..1]
+ embodiedEnergy :Measure [0..1]
«dataType»
OpticalProperties
+ emissivity :Emissivity [0..*]
+ reflectance :Reflectance [0..*]
+ transmittance :Transmittance [0..*]
+ glazingRatio :Scale [0..1]
«dataType»
Reflectance
+ fraction :Scale
+ surface :SurfaceSide
+ wavelengthRange :WavelengthRangeType
«dataType»
Emissivity
+ fraction :Scale
+ surface :SurfaceSide
«dataType»
Transmittance
+ fraction :Scale
+ wavelengthRange :WavelengthRangeType

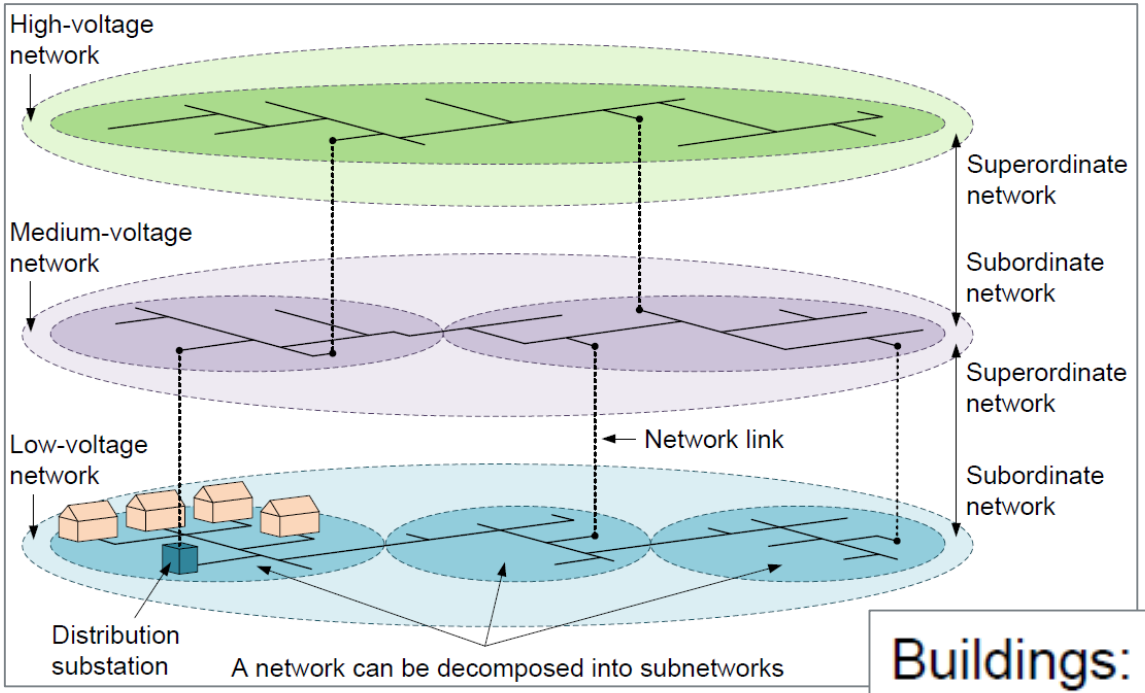

«type»
_TimeSeries
+ variableProperties :TimeValuesProperties
«type»
RegularTimeSeries
+ temporalExtent :TM_Period
+ timeInterval :TM_IntervalLength
+ values :MeasureList
«type»
IrregularTimeSeries
+ uom :UnitOfMeasure
«type»
RegularTimeSeriesFile
+ uom :UnitOfMeasure
+ file :URI
+ temporalExtent :TM_Period
+ timeInterval :TM_IntervalLength
+ numberOfHeaderLines :Integer [0..1] = 0
+ fieldSeparator :CharacterString
+ recordSeparator :CharacterString [0..1] = \n
+ decimalSymbol :Character [0..1] = .
+ valueColumnNumber :Integer [0..1] = 1
«type»
IrregularTimeSeriesFile
+ uom :UnitOfMeasure
+ file :URI
+ numberOfHeaderLines :Integer [0..1] = 0
+ fieldSeparator :CharacterString
+ recordSeparator :CharacterString [0..1] = \n
+ decimalSymbol :Character [0..1] = .
+ timeColumnNumber :Integer [0..1] = 1
+ valueColumnNumber :Integer [0..1] = 2
+contains
0..*
«dataType»
MeasurementPoint
+ time :TM_Position
+ value :Decimal
«enumeration»
InterpolationTypeValue
AverageInPrecedingInterval
AverageInSucceedingInterval
ConstantInPrecedingInterval
ConstantInSucceedingInterval
Continuous
Discontinuous
InstantaneousTotal
MaximumInPrecedingInterval
MaximumInSucceedingInterval
MinimumInPrecedingInterval
MinimumInSucceedingInterval
PrecedingTotal
SucceedingTotal
«dataType»
TimeValuesProperties
+ acquisitionMethod :AcquisitionMethodValue
+ interpolationType :InterpolationTypeValue
+ qualityDescription :CharacterString [0..1]
+ source :CharacterString [0..1]
«enumeration»
AcquisitionMethodValue
Attributes
+ Measurement
+ Simulation
+ CalibratedSimulation
+ Estimation
+ Unknown

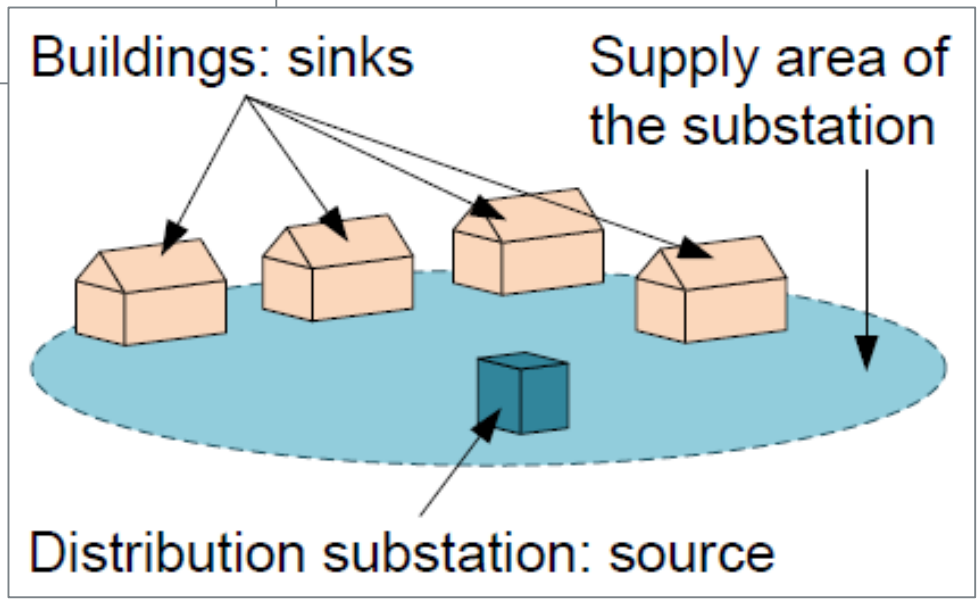

«type»
_Schedule
«type»
ConstantValueSchedule
+ averageValue :Measure
«type»
DualValueSchedule
+ idleValue :Measure
+ usageDaysPerYear :Decimal [0..1] = 365
+ usageHoursPerDay :Decimal [0..1] = 24
+ usageValue :Measure
«type»
DailyPatternSchedule
«type»
TimeSeriesSchedule
+ timeDependingValues :_TimeSeries
+periodOfYear
1..*
«dataType»
PeriodOfYear
+ period :TM_Period
+dailySchedule
1..*
«dataType»
DailySchedule
+ dayType :DayTypeValue
+ schedule :_TimeSeries
«enumeration»
DayTypeValue
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
DesignDay
WeekDay
WeekEnd
TypicalDay

Utility Network ADE

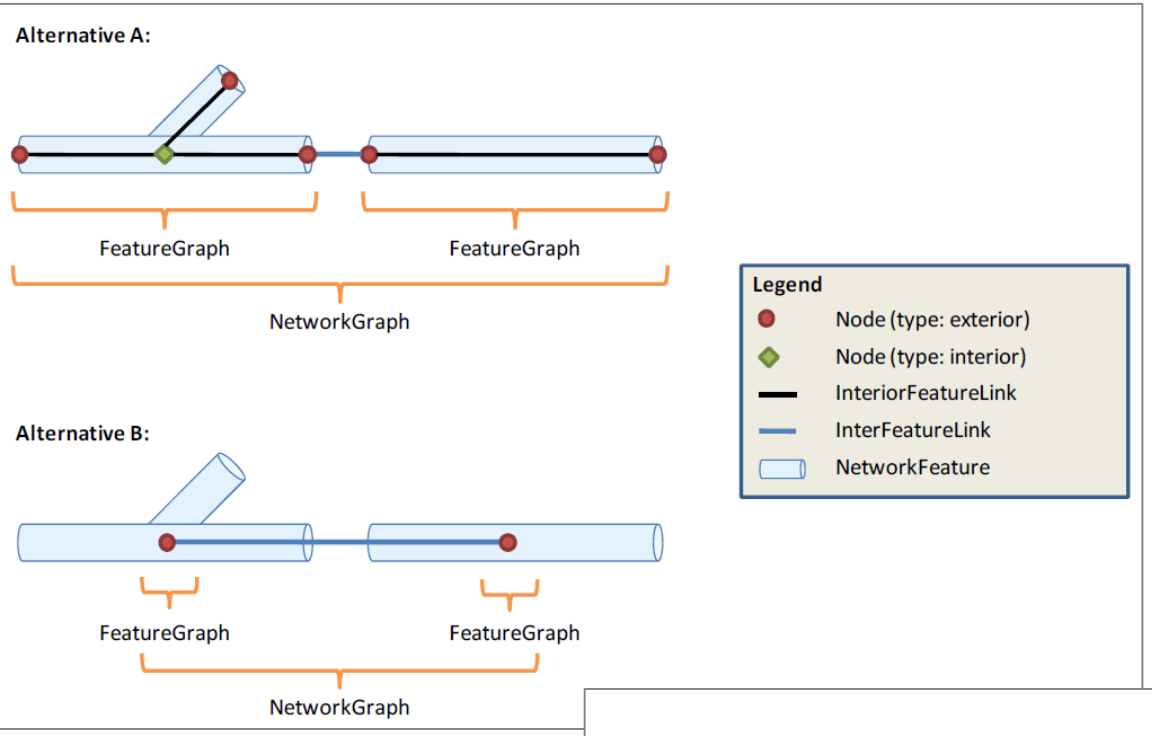
- Extends CityGML and defines standardised entities needed for utility networks (district heating, gas, power grid)
- Goal: tackle interoperability issues among data-model silos
- Allows for heterogeneous applications, e.g.:
  - Road/pipes maintenance
  - Multi-network co-simulation
- Allows for integrated representation of networks:
  - Topological (graph-based) AND geographical representation
  - Hierarchical structure of networks
  - Definition of supply areas (also with missing topology)
- Freely available
  - Apache 2.0 license
  - GitHub: https://github.com/TatjanaKutzner/CityGML-UtilityNetwork-ADE

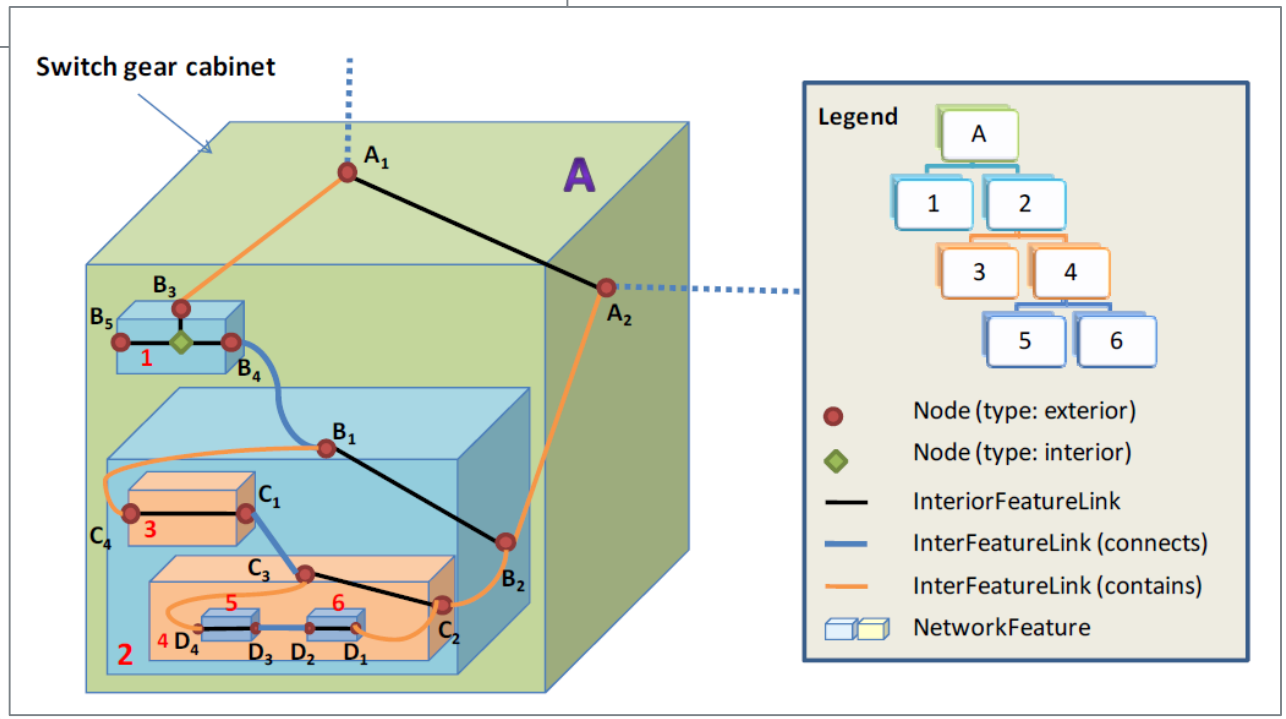
Utility Network ADE



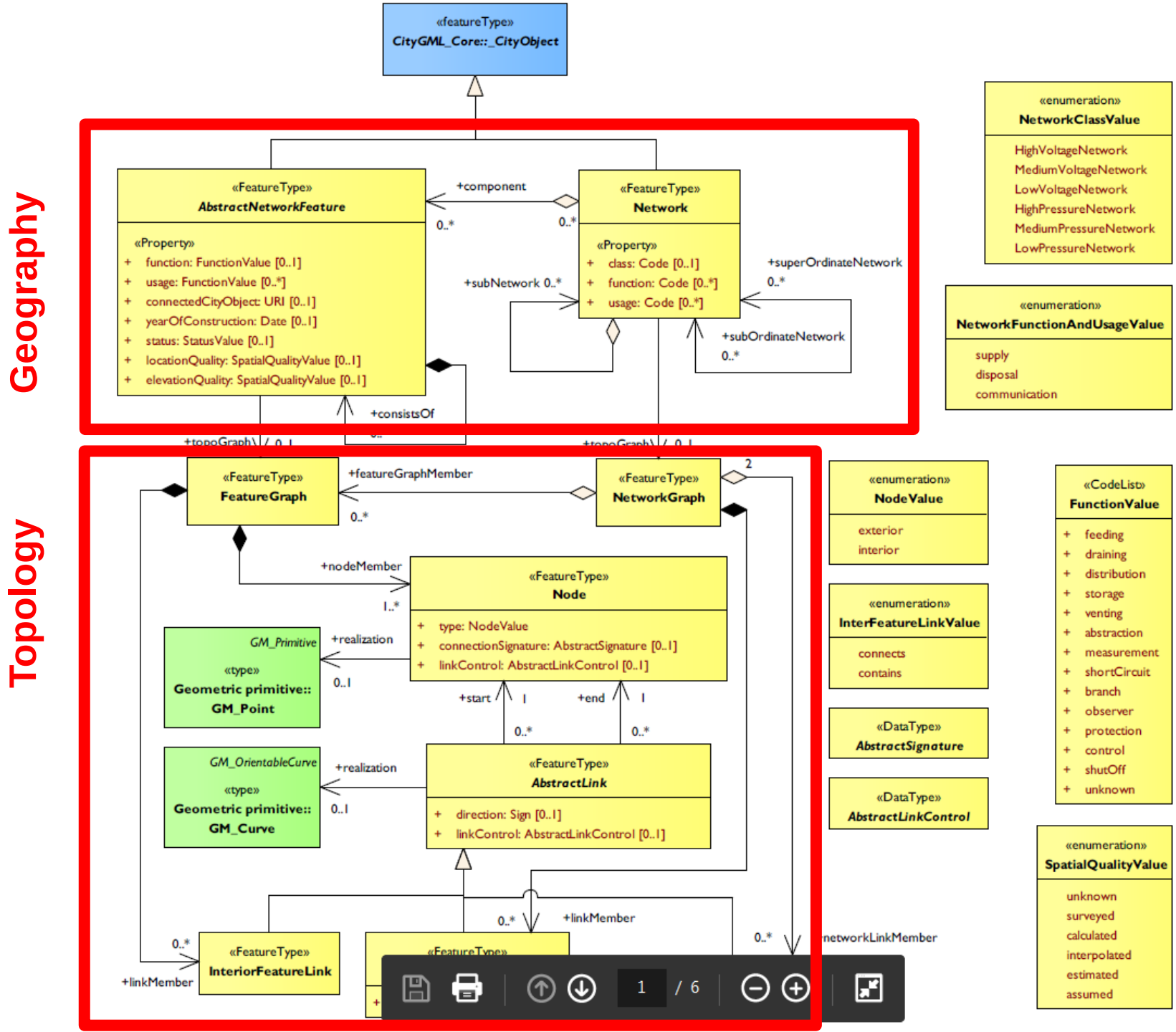


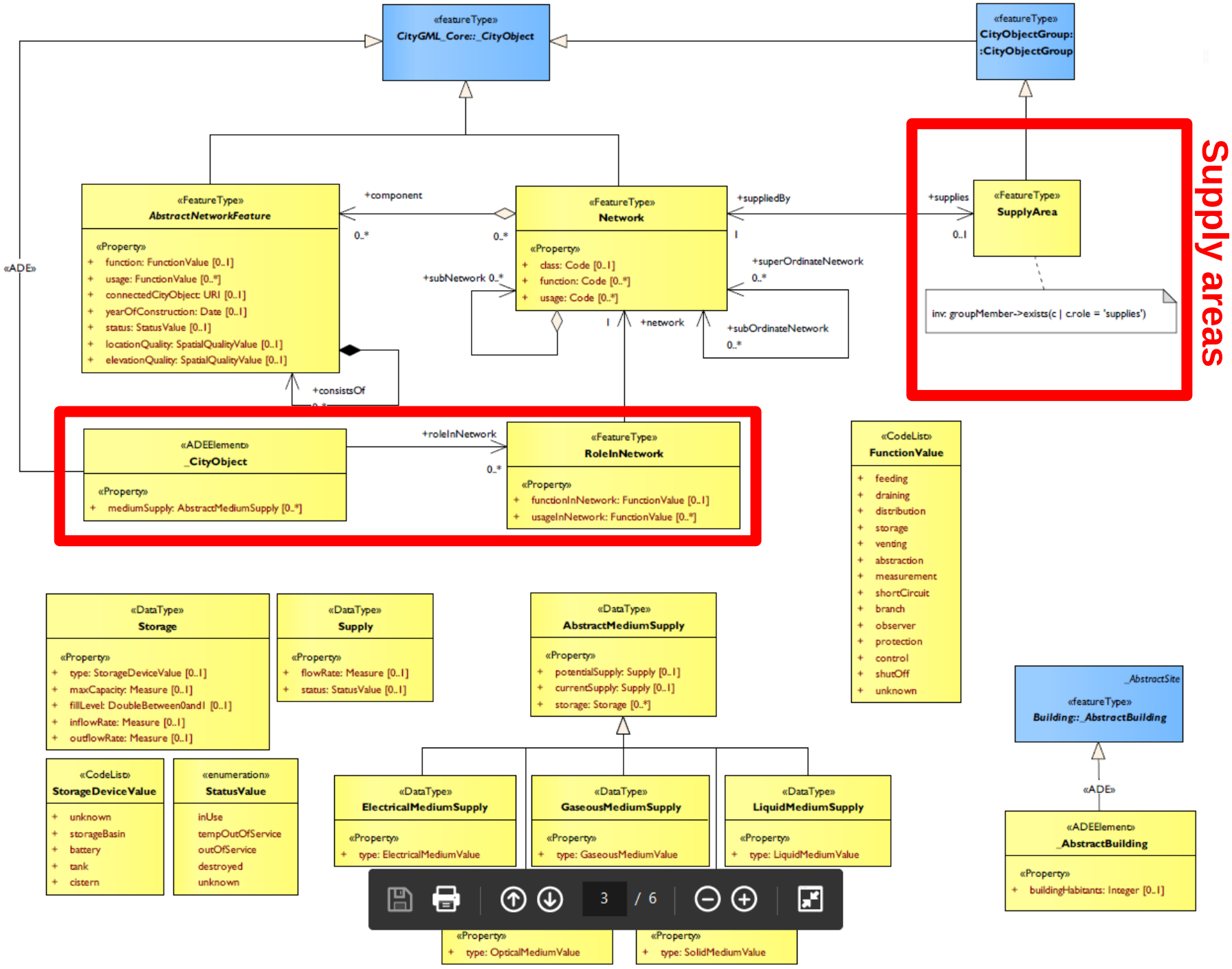
Images source: Kutzner et al., 2016



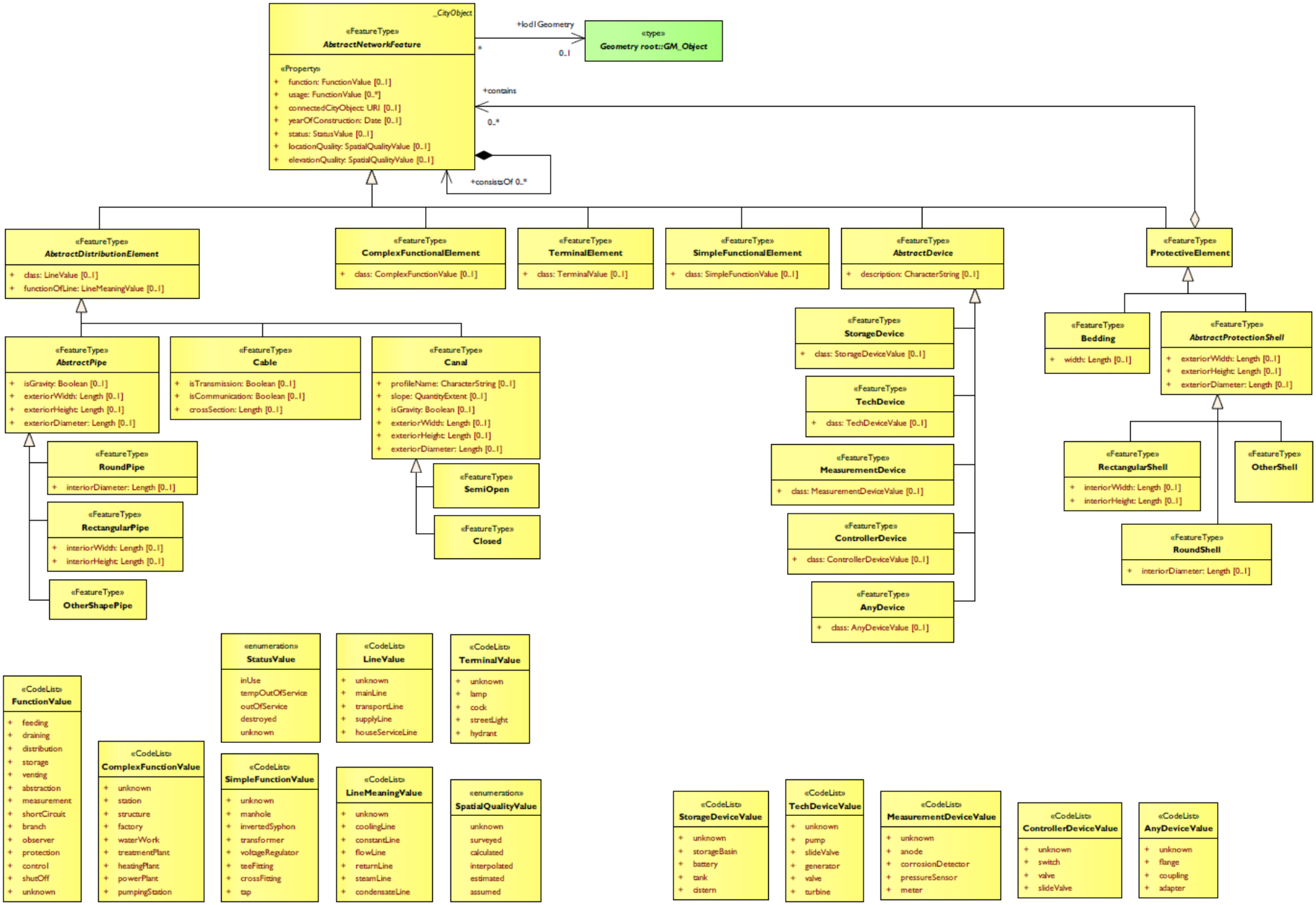


Images source: Becker et al., 2012


Geography
Topology
«featureType»
CityGML_Core::_CityObject
«FeatureType»
AbstractNetworkFeature
«Property»
+ function: FunctionValue [0..1]
+ usage: FunctionValue [0..*]
+ connectedCityObject: URI [0..1]
+ yearOfConstruction: Date [0..1]
+ status: StatusValue [0..1]
+ locationQuality: SpatialQualityValue [0..1]
+ elevationQuality: SpatialQualityValue [0..1]
+component
0..*
0..*
«FeatureType»
Network
«Property»
+ class: Code [0..1]
+ function: Code [0..*]
+ usage: Code [0..*]
+subNetwork 0..*
+superOrdinateNetwork
0..*
+subOrdinateNetwork
0..*
+consistsOf
«enumeration»
NetworkClassValue
HighVoltageNetwork
MediumVoltageNetwork
LowVoltageNetwork
HighPressureNetwork
MediumPressureNetwork
LowPressureNetwork
«enumeration»
NetworkFunctionAndUsageValue
supply
disposal
communication
«FeatureType»
FeatureGraph
+featureGraphMember
0..*
«FeatureType»
NetworkGraph
2
+nodeMember
1..*
«FeatureType»
Node
+ type: NodeValue
+ connectionSignature: AbstractSignature [0..1]
+ linkControl: AbstractLinkControl [0..1]
GM_Primitive
«type»
Geometric primitive::
GM_Point
+realization
0..1
+start
1
+end
1
0..*
0..*
GM_OrientableCurve
«type»
Geometric primitive::
GM_Curve
+realization
0..1
«FeatureType»
AbstractLink
+ direction: Sign [0..1]
+ linkControl: AbstractLinkControl [0..1]
0..*
+linkMember
0..*
networkLinkMember
0..*
+linkMember
«FeatureType»
InteriorFeatureLink
«enumeration»
NodeValue
exterior
interior
«enumeration»
InterFeatureLinkValue
connects
contains
«DataType»
AbstractSignature
«DataType»
AbstractLinkControl
«CodeList»
FunctionValue
+ feeding
+ draining
+ distribution
+ storage
+ venting
+ abstraction
+ measurement
+ shortCircuit
+ branch
+ observer
+ protection
+ control
+ shutOff
+ unknown
«enumeration»
SpatialQualityValue
unknown
surveyed
calculated
interpolated
estimated
assumed
1 / 6


«featureType»
CityGML_Core::_CityObject
«featureType»
CityObjectGroup::CityObjectGroup
«FeatureType»
AbstractNetworkFeature
«Property»
+ function: FunctionValue [0..1]
+ usage: FunctionValue [0..*]
+ connectedCityObject: URI [0..1]
+ yearOfConstruction: Date [0..1]
+ status: StatusValue [0..1]
+ locationQuality: SpatialQualityValue [0..1]
+ elevationQuality: SpatialQualityValue [0..1]
+component
0..*
0..*
«FeatureType»
Network
«Property»
+ class: Code [0..1]
+ function: Code [0..*]
+ usage: Code [0..*]
+suppliedBy
1
+supplies
0..1
«FeatureType»
SupplyArea
inv: groupMember->exists(c | c.role = 'supplies')
Supply areas
«ADE»
+subNetwork 0..*
+superOrdinateNetwork
0..*
+subOrdinateNetwork
0..*
1
+network
+consistsOf
«ADEElement»
_CityObject
«Property»
+ mediumSupply: AbstractMediumSupply [0..*]
+roleInNetwork
0..*
«FeatureType»
RoleInNetwork
«Property»
+ functionInNetwork: FunctionValue [0..1]
+ usageInNetwork: FunctionValue [0..*]
«CodeList»
FunctionValue
+ feeding
+ draining
+ distribution
+ storage
+ venting
+ abstraction
+ measurement
+ shortCircuit
+ branch
+ observer
+ protection
+ control
+ shutOff
+ unknown
«DataType»
Storage
«Property»
+ type: StorageDeviceValue [0..1]
+ maxCapacity: Measure [0..1]
+ fillLevel: DoubleBetween0and1 [0..1]
+ inflowRate: Measure [0..1]
+ outflowRate: Measure [0..1]
«DataType»
Supply
«Property»
+ flowRate: Measure [0..1]
+ status: StatusValue [0..1]
«DataType»
AbstractMediumSupply
«Property»
+ potentialSupply: Supply [0..1]
+ currentSupply: Supply [0..1]
+ storage: Storage [0..*]
«CodeList»
StorageDeviceValue
+ unknown
+ storageBasin
+ battery
+ tank
+ cistern
«enumeration»
StatusValue
inUse
tempOutOfService
outOfService
destroyed
unknown
«DataType»
ElectricalMediumSupply
«Property»
+ type: ElectricalMediumValue
«DataType»
GaseousMediumSupply
«Property»
+ type: GaseousMediumValue
«DataType»
LiquidMediumSupply
«Property»
+ type: LiquidMediumValue
«Property»
+ type: OpticalMediumValue
«Property»
+ type: SolidMediumValue
_AbstractSite
«featureType»
Building::_AbstractBuilding
«ADE»
«ADEElement»
_AbstractBuilding
«Property»
+ buildingHabitants: Integer [0..1]
3 / 6

UtilityNetwork ADE – Network Components



3DCityDB extension for the ADEs

- Additional database schema(s) for the 3DCityDB
  - PostgreSQL version
  - 3DCityDB "Utilities"
  - Energy ADE
  - Utility Network ADE
  - Scenario ADE (not yet publicly available, planned for 2018)

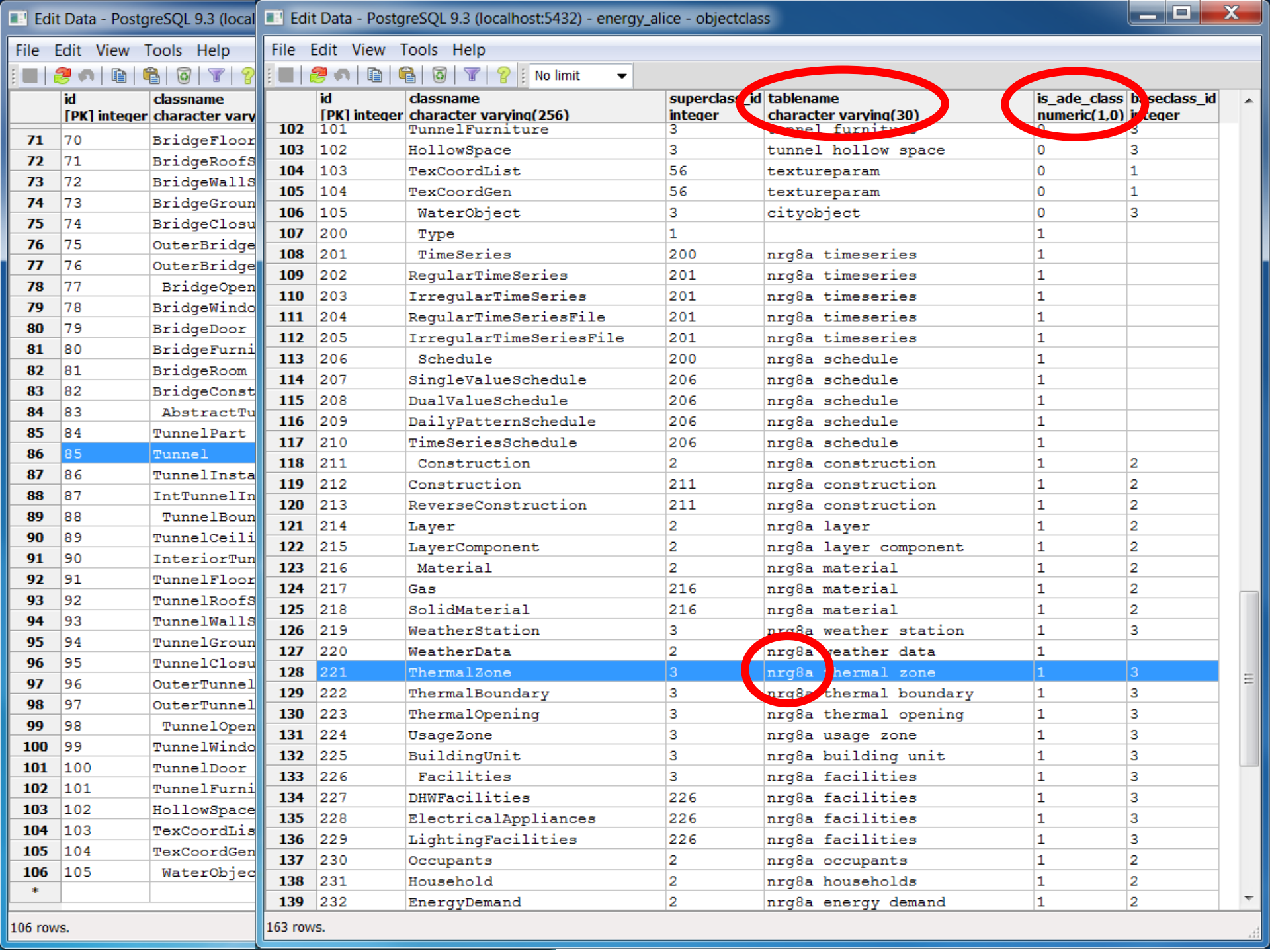
- Developed by AIT
  - GitHub: https://github.com/gioagu/3dcitydb_ade
  - Released in September 2017 (Apache 2.0 license)

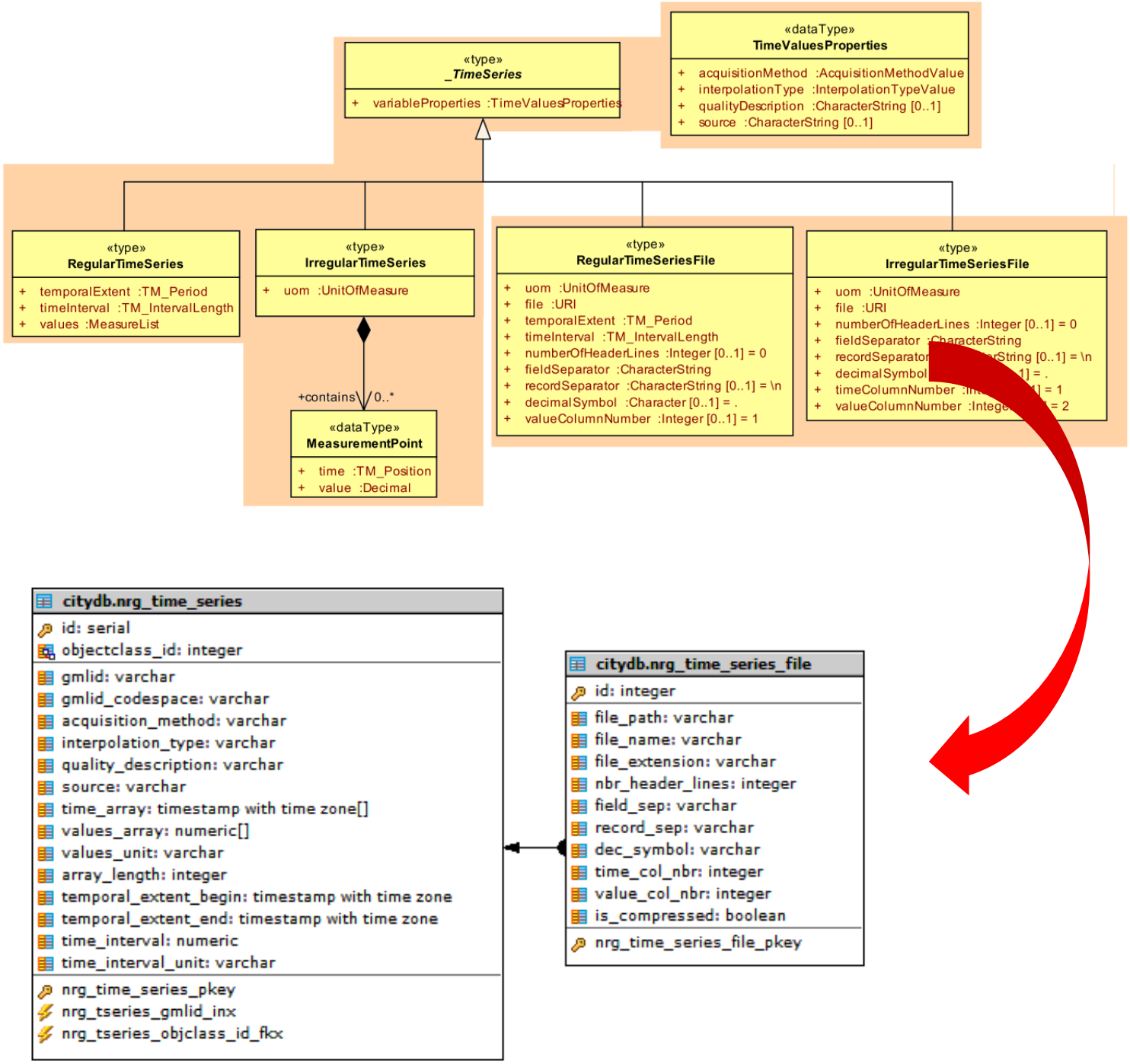
- Design criteria (excerpt)
  - Extend the already available 3D City DB
  - Define a non-concurrent way of extending the 3DCityDB with any ADE
  - Stay close to the original “style” of the 3DCityDB
  - Implementation for PostgreSQL, but open for future conversions to other DBs

Implementation steps

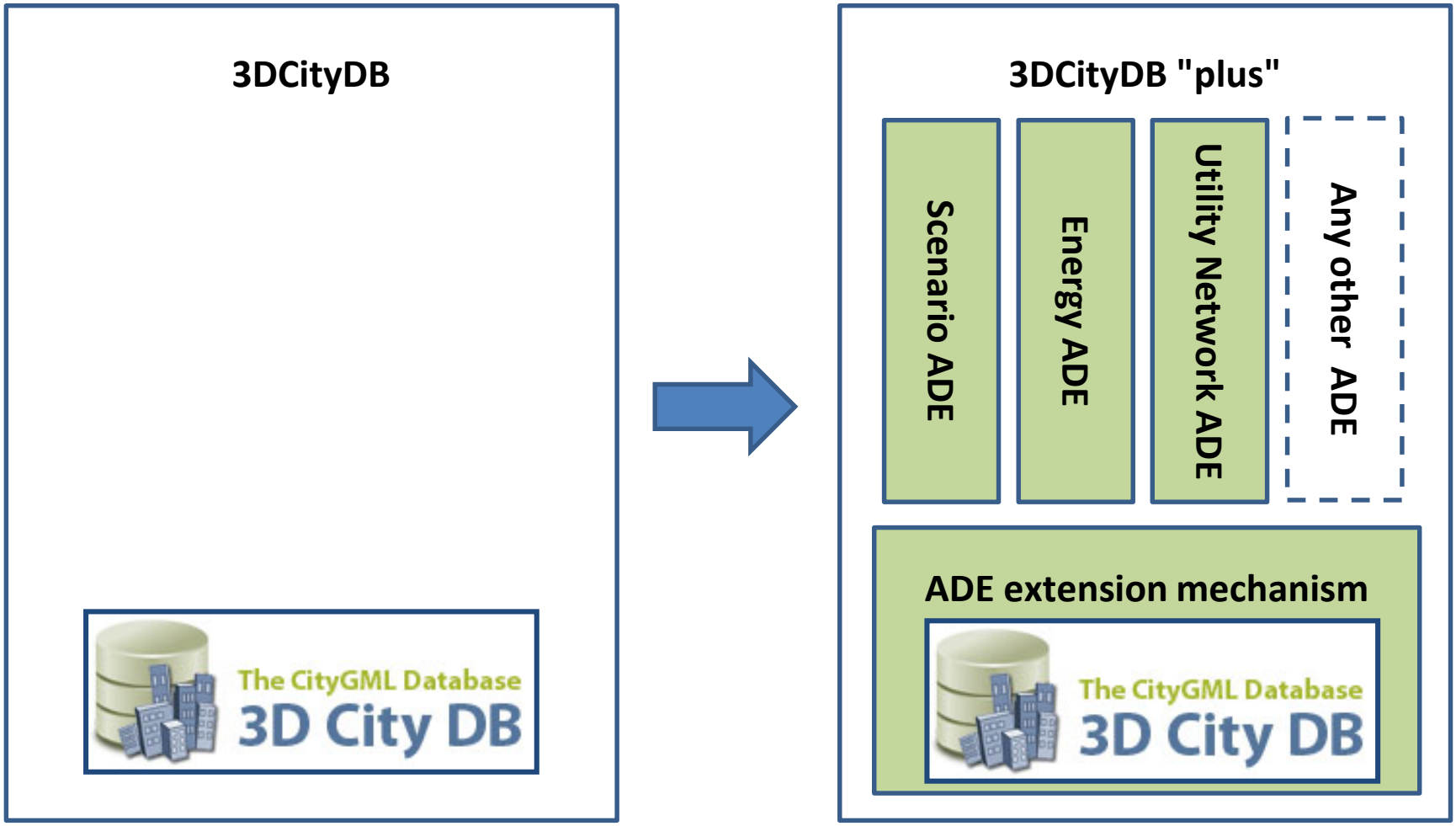
- Define and agree upon rules to make the 3DCityDB "ADE-compatible"
  - Enable to "register" *any* ADE
    - Add a metadata module
    - Add functions to help installing/removing an ADE
  - Define rules how to map ADE-classes to new/existing tables
    - Adopt naming convention for new DB entities
  - Add an ADE-hook mechanism to certain existing functions. E.g.:
    - delete_building() → must work also with ADE-AbstractBuilding
    - delete_cityobject() → must work also with new CityObjects
    - delete_cityobjectgroup() → must work also with new CityObjects
    - get_envelope_cityobject() → same as above
  - (Enable/extend existing tools to be ADE-compatible: citygml4j, Importer/Exporter, etc.)

- All rules are agreed upon within the 3DCityDB development team and are being implemented for the next 3DCityDB release


Edit Data - PostgreSQL 9.3 (local
File Edit View Tools Help
id [PK] integer
classname character vary
71 70 BridgeFloor
72 71 BridgeRoofS
73 72 BridgeWallS
74 73 BridgeGroun
75 74 BridgeClosu
76 75 OuterBridge
77 76 OuterBridge
78 77 BridgeOpen
79 78 BridgeWindo
80 79 BridgeDoor
81 80 BridgeFurni
82 81 BridgeRoom
83 82 BridgeConst
84 83 AbstractTu
85 84 TunnelPart
86 85 Tunnel
87 86 TunnelInsta
88 87 IntTunnelIn
89 88 TunnelBoun
90 89 TunnelCeili
91 90 InteriorTun
92 91 TunnelFloor
93 92 TunnelRoofS
94 93 TunnelWallS
95 94 TunnelGroun
96 95 TunnelClosu
97 96 OuterTunnel
98 97 OuterTunnel
99 98 TunnelOpen
100 99 TunnelWindo
101 100 TunnelDoor
102 101 TunnelFurni
103 102 HollowSpace
104 103 TexCoordLis
105 104 TexCoordGen
106 105 WaterObjec
106 rows.
Edit Data - PostgreSQL 9.3 (localhost:5432) - energy_alice - objectclass
File Edit View Tools Help
No limit
id [PK] integer
classname character varying(256)
superclass_id integer
tablename character varying(30)
is_ade_class numeric(1,0)
baseclass_id integer
102 101 TunnelFurniture 3 3
103 102 HollowSpace 3 tunnel hollow space 0 3
104 103 TexCoordList 56 textureparam 0 1
105 104 TexCoordGen 56 textureparam 0 1
106 105 WaterObject 3 cityobject 0 3
107 200 Type 1 1
108 201 TimeSeries 200 nrg8a timeseries 1
109 202 RegularTimeSeries 201 nrg8a timeseries 1
110 203 IrregularTimeSeries 201 nrg8a timeseries 1
111 204 RegularTimeSeriesFile 201 nrg8a timeseries 1
112 205 IrregularTimeSeriesFile 201 nrg8a timeseries 1
113 206 Schedule 200 nrg8a schedule 1
114 207 SingleValueSchedule 206 nrg8a schedule 1
115 208 DualValueSchedule 206 nrg8a schedule 1
116 209 DailyPatternSchedule 206 nrg8a schedule 1
117 210 TimeSeriesSchedule 206 nrg8a schedule 1
118 211 Construction 2 nrg8a construction 1 2
119 212 Construction 211 nrg8a construction 1 2
120 213 ReverseConstruction 211 nrg8a construction 1 2
121 214 Layer 2 nrg8a layer 1 2
122 215 LayerComponent 2 nrg8a layer component 1 2
123 216 Material 2 nrg8a material 1 2
124 217 Gas 216 nrg8a material 1 2
125 218 SolidMaterial 216 nrg8a material 1 2
126 219 WeatherStation 3 nrg8a weather station 1 3
127 220 WeatherData 2 nrg8a weather data 1
128 221 ThermalZone 3 nrg8a thermal zone 1 3
129 222 ThermalBoundary 3 nrg8a thermal boundary 1 3
130 223 ThermalOpening 3 nrg8a thermal opening 1 3
131 224 UsageZone 3 nrg8a usage zone 1 3
132 225 BuildingUnit 3 nrg8a building unit 1 3
133 226 Facilities 3 nrg8a facilities 1 3
134 227 DHWFacilities 226 nrg8a facilities 1 3
135 228 ElectricalAppliances 226 nrg8a facilities 1 3
136 229 LightingFacilities 226 nrg8a facilities 1 3
137 230 Occupants 2 nrg8a occupants 1 2
138 231 Household 2 nrg8a households 1 2
139 232 EnergyDemand 2 nrg8a energy demand 1 2
163 rows.


«type»
_TimeSeries
+ variableProperties :TimeValuesProperties
«dataType»
TimeValuesProperties
+ acquisitionMethod :AcquisitionMethodValue
+ interpolationType :InterpolationTypeValue
+ qualityDescription :CharacterString [0..1]
+ source :CharacterString [0..1]
«type»
RegularTimeSeries
+ temporalExtent :TM_Period
+ timeInterval :TM_IntervalLength
+ values :MeasureList
«type»
IrregularTimeSeries
+ uom :UnitOfMeasure
+contains
0..*
«dataType»
MeasurementPoint
+ time :TM_Position
+ value :Decimal
«type»
RegularTimeSeriesFile
+ uom :UnitOfMeasure
+ file :URI
+ temporalExtent :TM_Period
+ timeInterval :TM_IntervalLength
+ numberOfHeaderLines :Integer [0..1] = 0
+ fieldSeparator :CharacterString
+ recordSeparator :CharacterString [0..1] = \n
+ decimalSymbol :Character [0..1] = .
+ valueColumnNumber :Integer [0..1] = 1
«type»
IrregularTimeSeriesFile
+ uom :UnitOfMeasure
+ file :URI
+ numberOfHeaderLines :Integer [0..1] = 0
+ fieldSeparator :CharacterString
+ recordSeparator
String [0..1] = \n
+ decimalSymbol
1] = .
+ timeColumnNumber
1] = 1
+ valueColumnNumber :Integ
= 2
citydb.nrg_time_series
id: serial
objectclass_id: integer
gmlid: varchar
gmlid_codespace: varchar
acquisition_method: varchar
interpolation_type: varchar
quality_description: varchar
source: varchar
time_array: timestamp with time zone[]
values_array: numeric[]
values_unit: varchar
array_length: integer
temporal_extent_begin: timestamp with time zone
temporal_extent_end: timestamp with time zone
time_interval: numeric
time_interval_unit: varchar
nrg_time_series_pkey
nrg_tseries_gmlid_inx
nrg_tseries_objclass_id_fkx
citydb.nrg_time_series_file
id: integer
file_path: varchar
file_name: varchar
file_extension: varchar
nbr_header_lines: integer
field_sep: varchar
record_sep: varchar
dec_symbol: varchar
time_col_nbr: integer
value_col_nbr: integer
is_compressed: boolean
nrg_time_series_file_pkey

3DCityDB extension for the ADEs



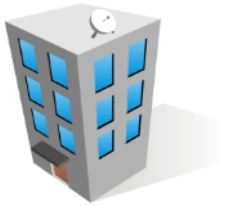
Conclusions

- CityGML offers several ways to be extended
- The ADE mechanism is the more elegant one, however it is lacking (for now) support by the Importer/Exporter
- Research work is being carried out by the 3DCityDB development team to
  - Automatically derive the database schema from ANY ADE
  - Automatically generate a plugin for the Importer/Exporter able to handle the corresponding ADE contents

Overview

- Part 1: Semantic 3D city modelling & a first look at CityGML
- Part 2: A second look at CityGML and the 3D City Database
- Part 3: Experiences from Trento and Vienna
- Part 4: Extending CityGML
- **Part 5: Energy & cities**

Part 5: Energy and cities



- Where are inefficient buildings?
- How to increase their efficiency?
- How to evaluate the impact of these measures?
- How to simulate different scenarios according to different energy policies?

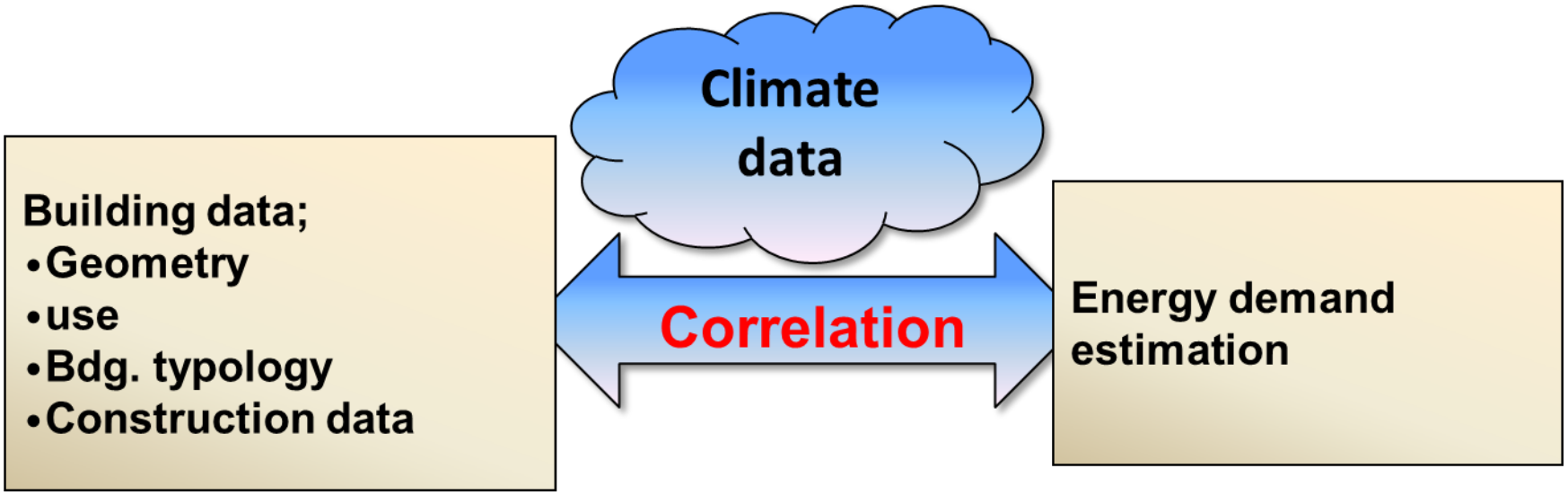
- How to evaluate spatially and temporally the energy performance of a city and quarter respectively?
- How to choose between different types of energy production and distribution technologies?
- How to deal with extension of existing infrastructures?

SEMANTIC 3D CITY MODELS AS INFORMATION HUB FOR ENERGY-RELATED APPLICATIONS?

Estimation of energy demand

- Characterisation of each (residential) building by means of "typical" values extracted from the 3D city model and existing libraries

- Energy balance based on algorithms defined by national norms, e.g.
  - UNI/TS 11300 in Italy
  - Institut Wohnen und Umwelt, Germany
  - OIB-6, Austria
  - …



Characterisation of (each) residential building

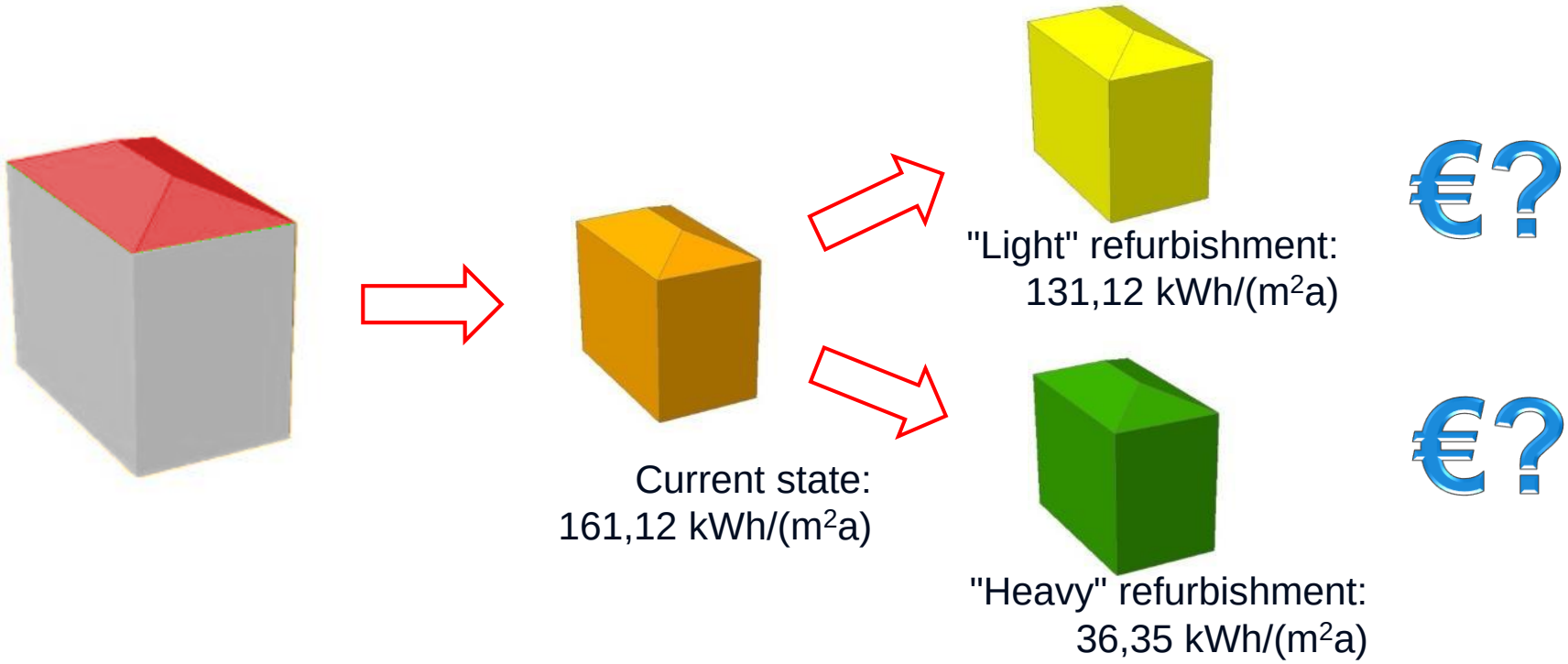
- From semantic 3D city model:
  - Volume, surf. of roof, walls, shared walls, etc.
  - Year of construction
  - Number of flats, families, residents
  - Number of floors

- From parameter libraries
  - Building typology class, building age class
  - "Typical" U and g values for windows, walls, floors & roofs

- Climate data
  - Climate zone, degree days, heating period, etc.

Evaluation of refurbishment scenarios

- Identification of (reasonable) refurbishment measures
- Definition of a limited number of scenarios
- Comparison with regards to national and European legislation
- Cost-benefit analysis



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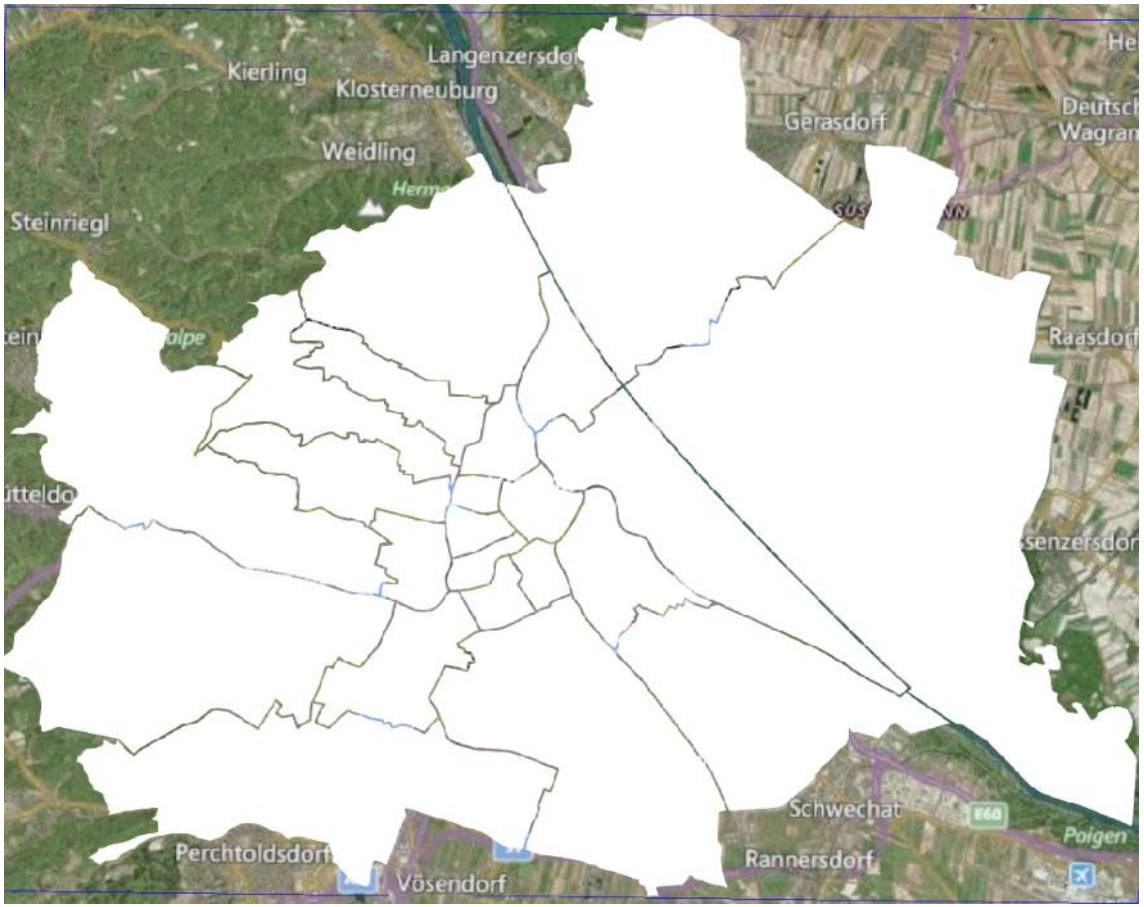
Heating energy demand of residential buildings

Heating energy demand of residential buildings (retrofit)

Web-based (plugin-free) visualisation



http://sbc1.ait.ac.at:10180/projects/meidling/cesium/webmap_nrg/index.html

Conclusions

- Semantic 3D city models & energy
  - Description of the building stock by means of integrated approach
  - Characterisation of the building stock by means of meaningful KPIs
  - Identification and geo-localisation of particular building blocks (or single buildings) depending on selected criteria, e.g.
    - All building (blocks) requiring upcoming / urgent refurbishment
    - All building (blocks) with low energy efficiency
    - All building with the greatest investment return potentials

- Accuracy of the results is still object of research and further investigation
  - Different strategies to validate the energy models, depending on simulation/estimation strategies and on available data
    - In general: deviation between estimated and real values ≈ 20÷40% from other similar case studies
  - In general: acceptable trade-out between accuracy and completeness

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your ingenious partner

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Smart and Resilient Cities Research Field
https://www.ait.ac.at/city
Center for Energy
AIT - Austrian Institute of Technology GmbH