

# 3D Data Standards

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## Learning outcomes

At the end of this lecture, the learner is expected to be able to:

- Name several ways how the 3D data can be stored, with focus CityGML encodings
- Summarize the main parts of CityGML Conceptual model and how they can be used
- Understand the aspects of CityGML that are important for conversion to and from BIM

## Semantic 3D City Models

- Provide geographic, topographic and semantic information about objects
- Interactions among objects
- Hierarchical decomposition into smaller parts (e.g. building-wall-window)
- Can be complex and cover large areas



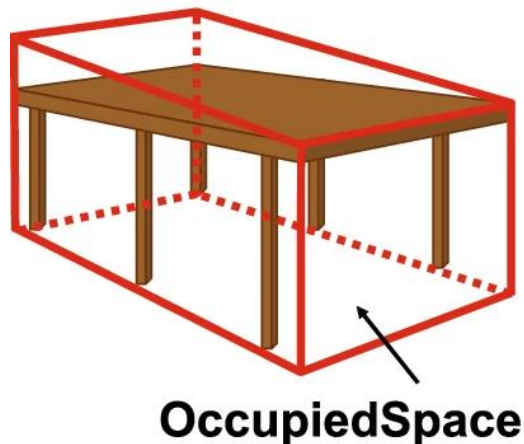
A lot of semantic information can be added into a 3D model  
3D model of Nancy, France, Google Earth



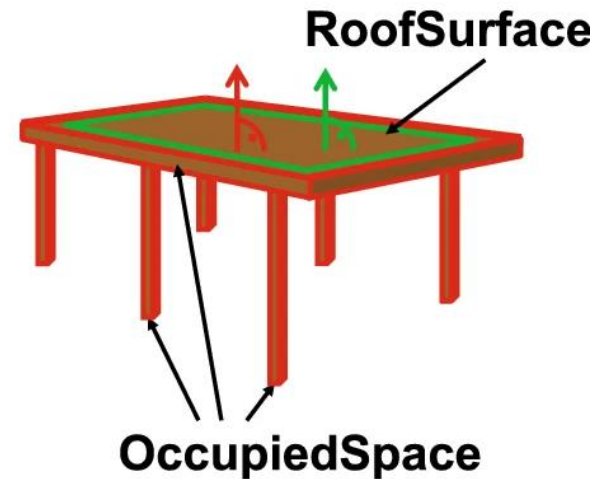
## CityGML Standard

- CityGML is open data model by the Open Geospatial Consortium (OGC)
- Aimed to represent semantic 3D models
- Current version is 3.0, approved in 2021

### Carport in LOD1



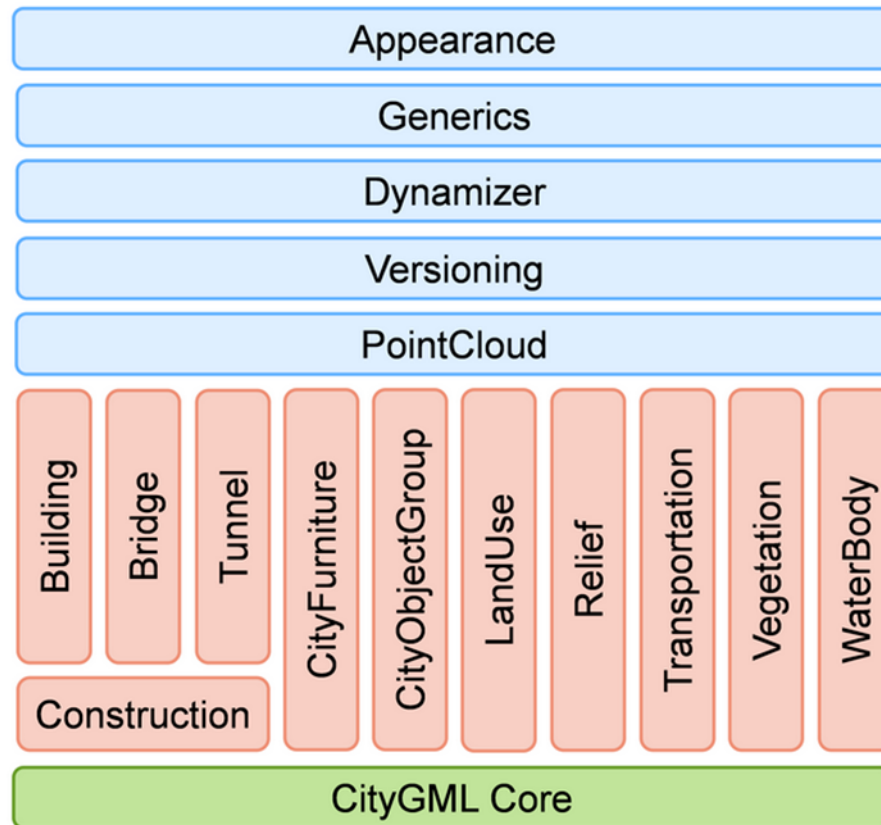
### Carport in LOD2/3



Representation of a carport as OccupiedSpace in different LODs. From: [CityGML 3.0: New Functions Open Up New Applications](#)

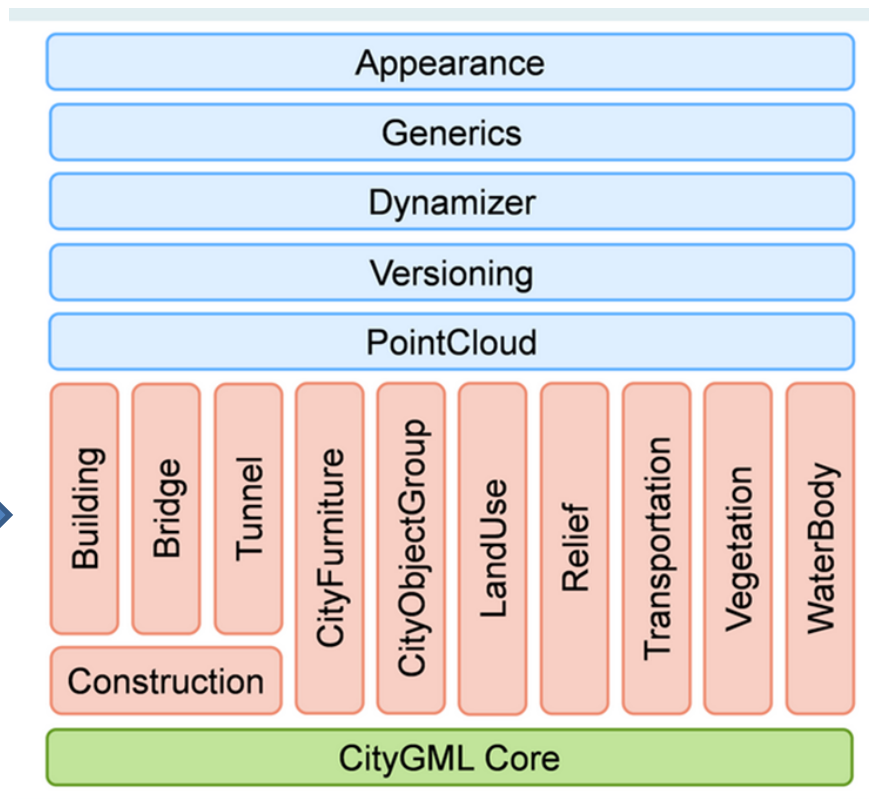
## CityGML Conceptual Model (CM)

- Common city objects should be described in the same way in all the models
- CityGML defines classes of the most important objects, how to decompose them and useful attributes
- These classes are defined in CityGML Conceptual Model



## Class Modules in CM

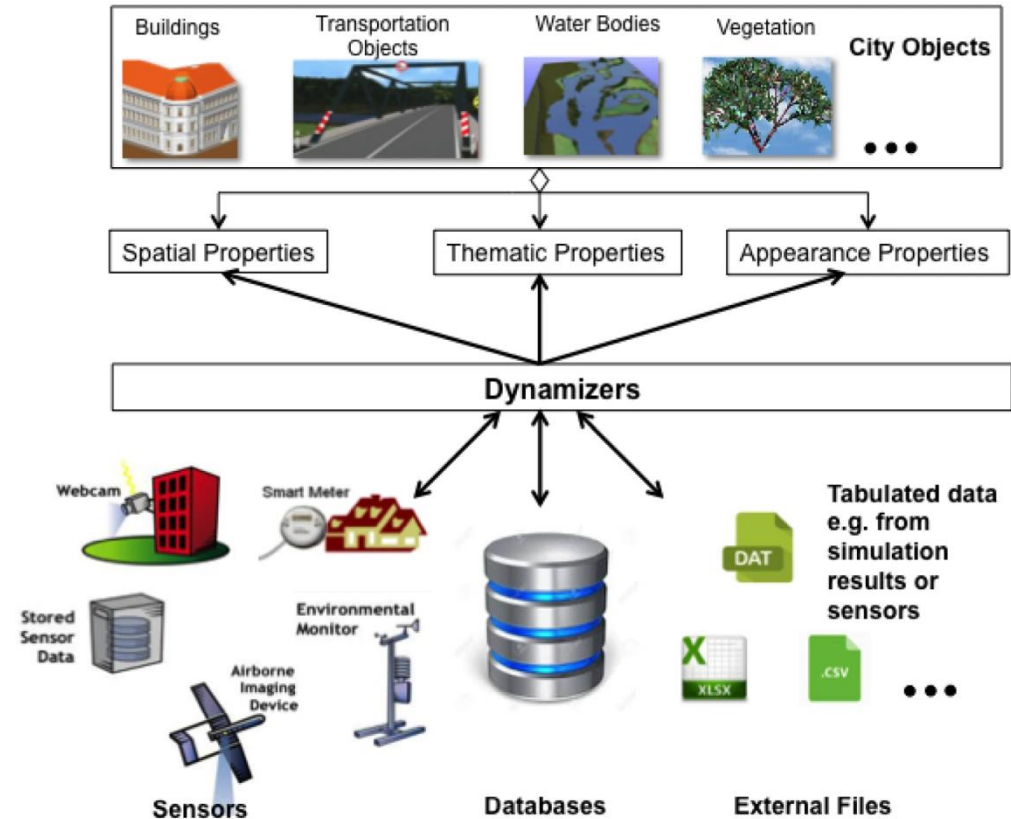
- Extension Class Modules, shown vertically in rose
- The modules are specific thematic classes of the most important objects
- Not all extension modules have to be included in a 3D model



CityGML Conceptual Model, [CityGML - Open Geospatial Consortium \(ogc.org\)](http://ogc.org)

## Specific Aspect Modules in CM

- The five blue-coloured vertical modules in the CM
- Add specific modelling aspects, e.g. textures, colours, time, model versions...
- Can be used together with all extension modules



Conceptual representation of Dynamizers allowing enhancing the properties of city objects,  
From: [CityGML 3.0: New Functions Open Up New Applications](#)



## Semantic Information in the 3D models

- All objects belong to a class or can be defined as “generic” objects
- The object can be represented by semantics (= non-spatial properties), 3D geometry, 3D topology, appearances and changes over time
- Unique and mandatory *featureID* for each object

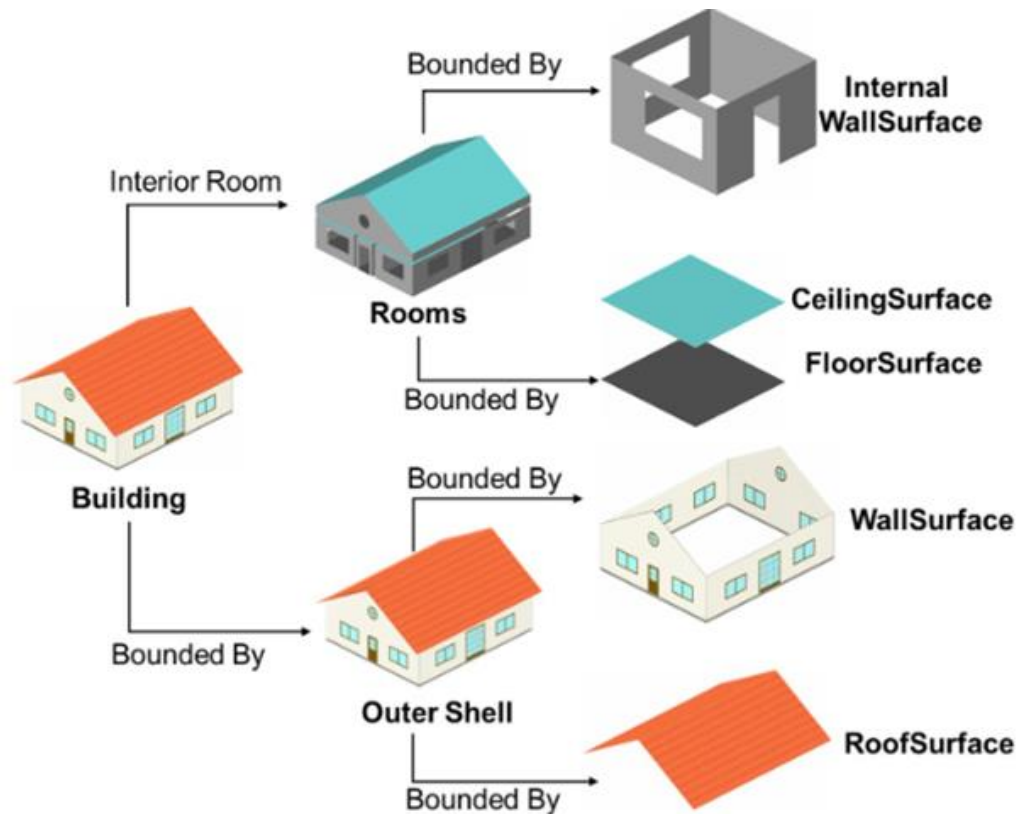


*TU Delft example of five types of roofs: flat, gabled, hipped, pyramidal, and shed.*

[GitHub - tudelft3d/3dbook](https://github.com/tudelft3d/3dbook): Book for the course GEO1004: 3D modelling of the built environment

## Aggregation Schema

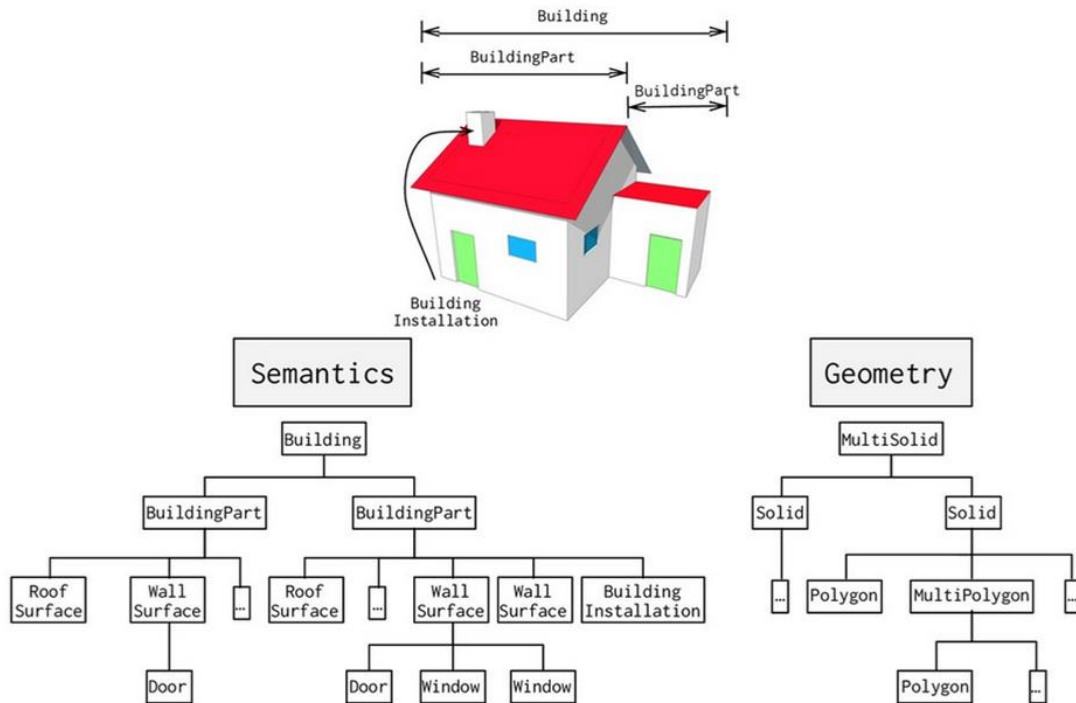
- There can be hierarchical interrelations among city objects
- Aggregation hierarchy – whole building and its decomposition to parts (see figure)
- Useful for queries, simulations and analyses



## Coherent Semantic -Geometric Modelling

- Building and its parts = semantic aggregation hierarchy
- There is also geometric hierarchy – location, shape, extent...
- Crucial that semantic and geometry of the corresponding objects are linked together

## Spatio-semantic coherence



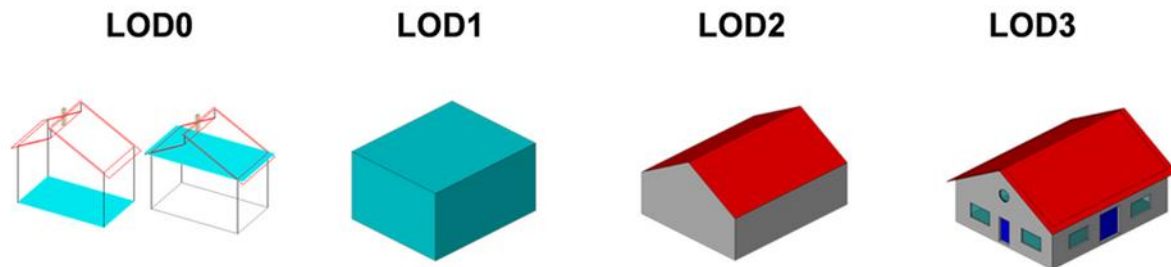
## Level of Detail, LoD I

LOD0 – Highly generalized model

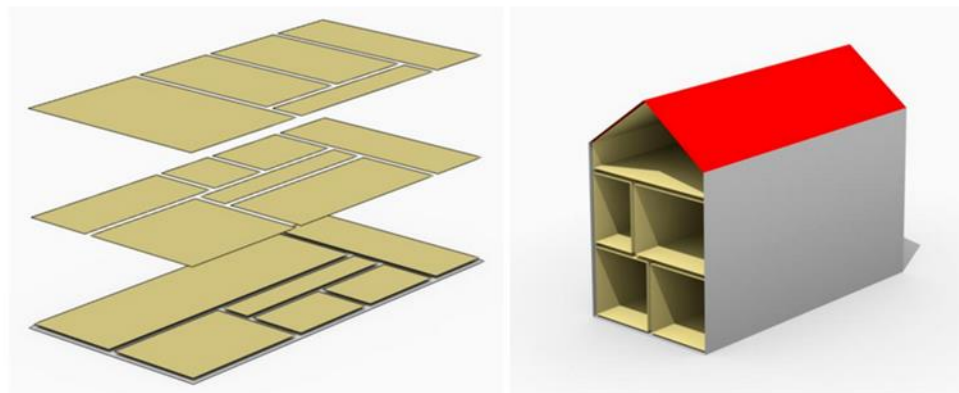
LOD1 – Block model / extrusion objects

LOD2 – Realistic, but still generalized model

LOD3 – Highly detailed model



Representation of the same real-world building in the Levels of Detail 0-3



Floor-plan representation in LoD0 (left) and in LoD2 (right). From: <https://www.gim-international.com/content/news/citygml-3-0-conceptual-model-approved-as-official-ogc-standard>

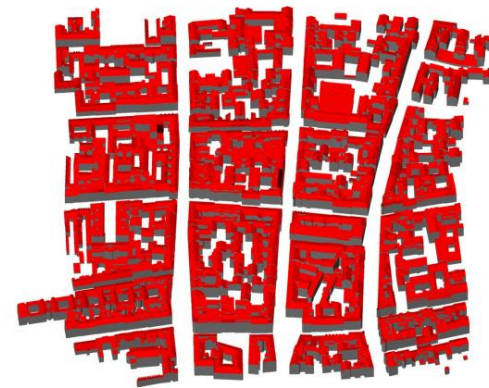
## Level of Detail, LoD II

- LoDs are applicable to both interior and exterior
- Individual building or whole neighbourhoods
- possible to combine different LODs in same model

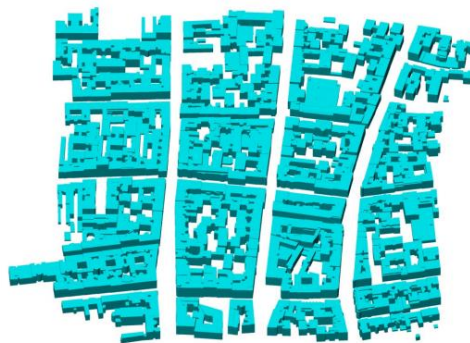
Visual representation of several housing-blocks in Vienna (a) underlying image from Google Maps, (b) representation of open LoD2 CityGML model, (c) LoD1 model transformed from LoD2, (d) LoD0 CityGML models. From Malhotra et al (2021)



(a)



(b)



(c)

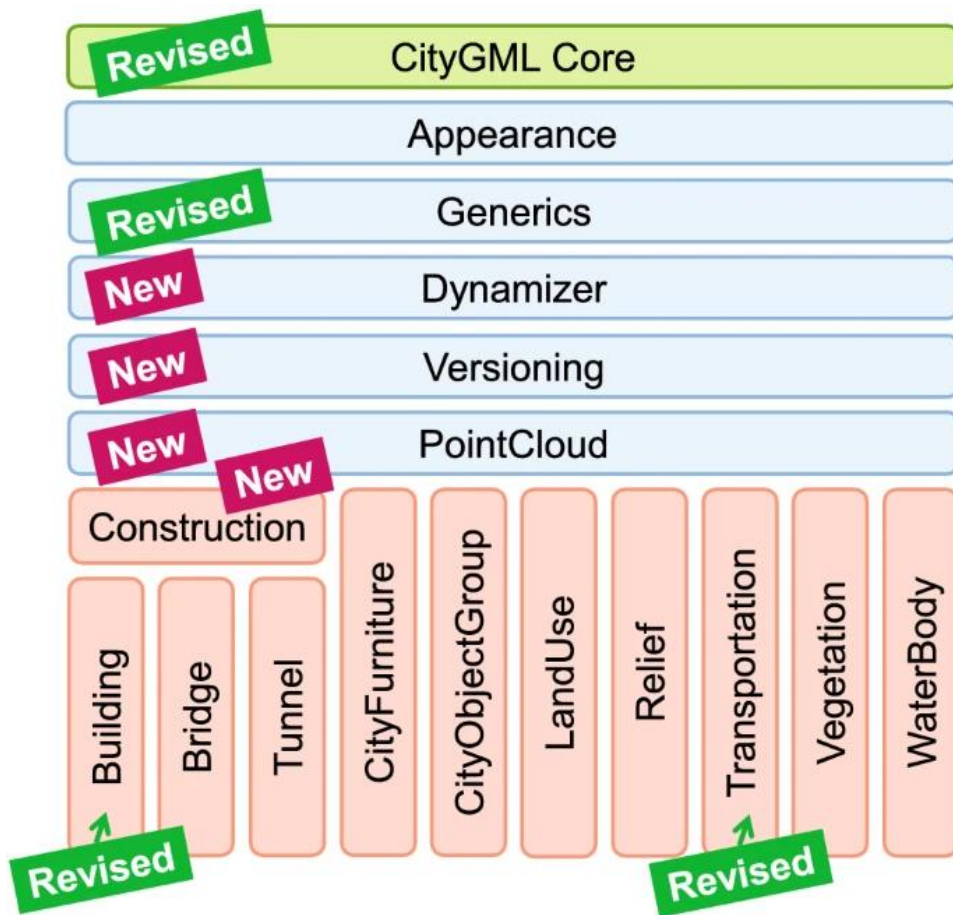


(d)

## Previous versions of CityGLM, 1.0 and 2.0

- CityGML 3.0 is an evolution of versions 1.0 and 2.0.
- 1.0 and 2.0 still used in many models, but can be updated to 3.0
- 3.0 has many new capabilities

New and revisited parts of 3.0 version, compared to 2.0.  
From: Kutzner et al (2020) [CityGML 3.0: New Functions Open Up New Applications | PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science \(springer.com\)](#)





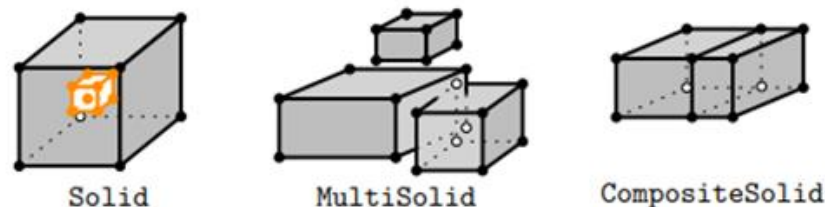
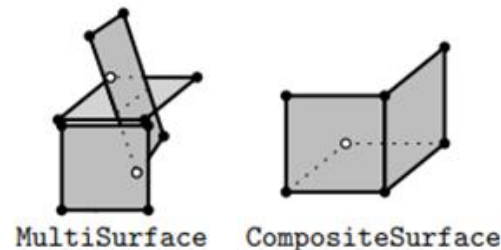
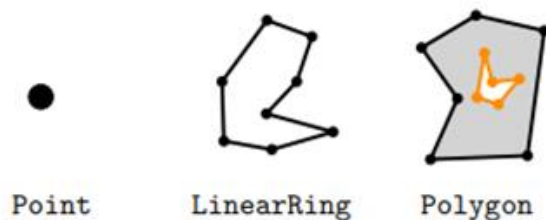
## Geometry Representation

Spatial properties of all CityGML objects are represented by geometry classes defined in ISO 19107

These include:

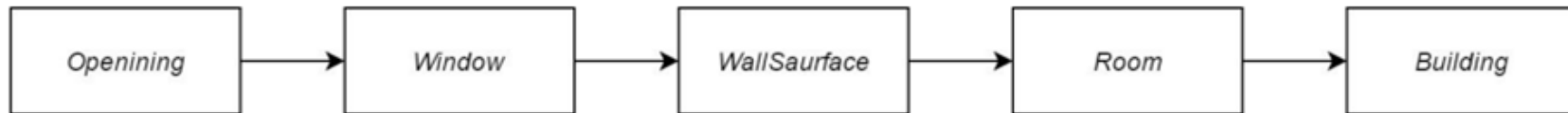
- primitive geometries - points, curves, surfaces and solids
- different kinds of aggregated geometries

All geometries saved in Core module



Some of the CityGML primitives, including aggregates and composites.  
From Ohori et al (2020-2022) [Releases · tudelft3d/3dbook \(github.com\)](https://github.com/tudelft3d/3dbook/releases)

## Topology Representation



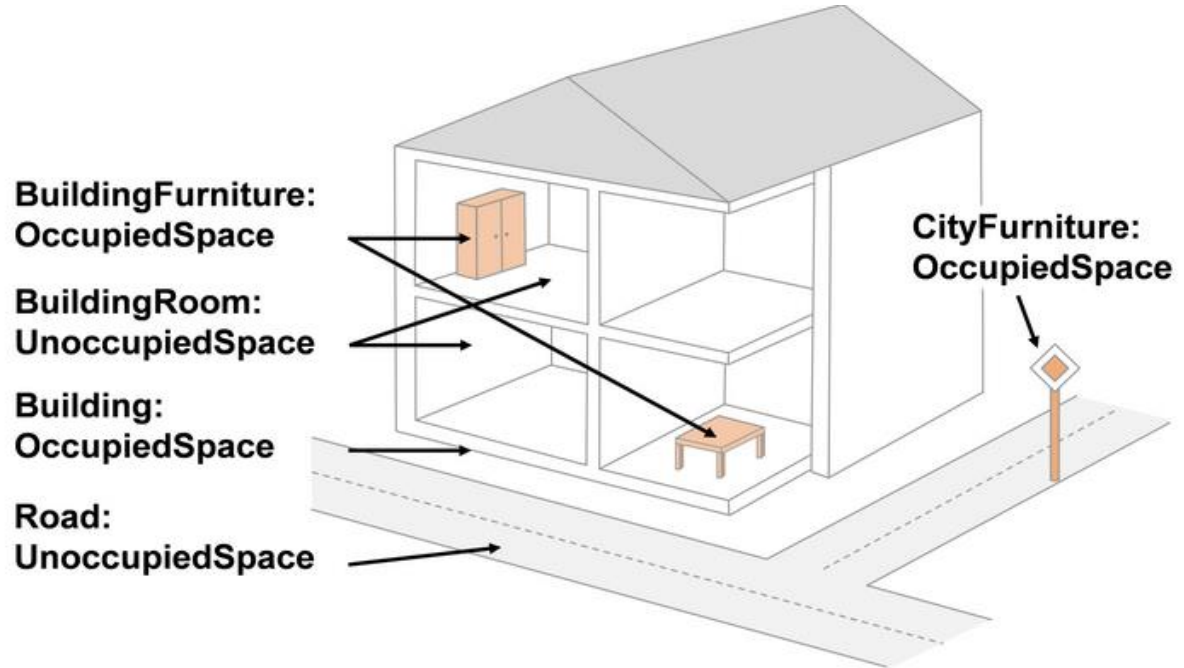
CityGML schema showing relationship from Window towards the Room to the Building.

From: Salheb (2019) Automatic Conversion of CityGML to IFC

- Topology follows full decomposition, similar to the geometry
- Relationships between element well defined in CityGLM 3.0
- Spaces – real world objects
- Space boundaries – delimit and connect the Spaces (e.g. wall surface, road surface...)

## Physical and Logical Spaces

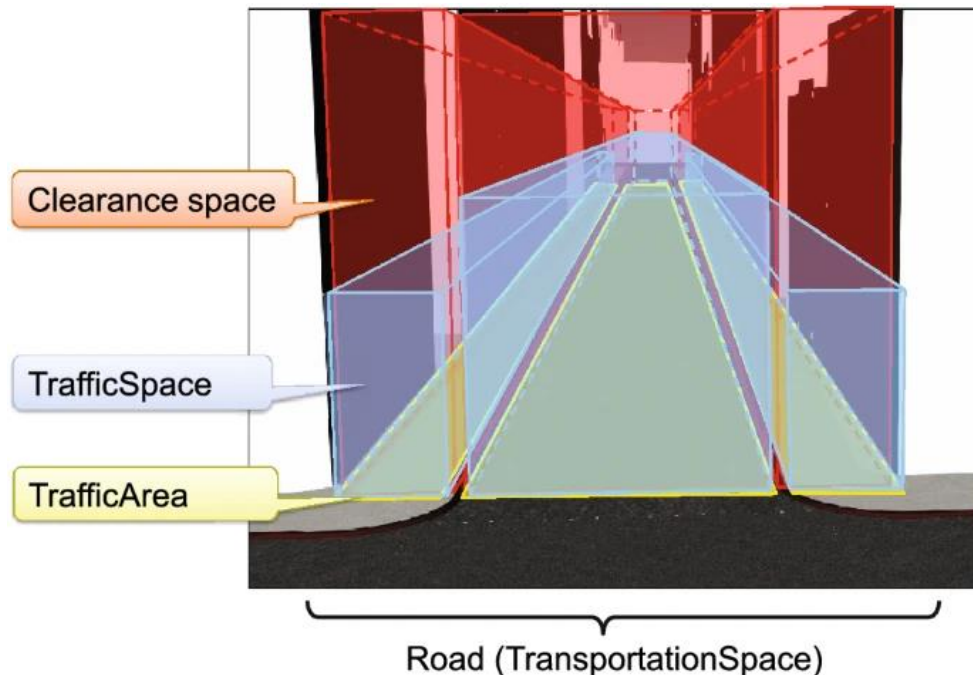
- Physical spaces are bounded by physical objects, e.g. buildings, trees...
- Occupied or unoccupied (see figure)
- Logical spaces – thematic, e.g. city district, building unit



Occupied and unoccupied spaces. From: Kutzner et al (2020) CityGML 3.0: New Functions Open Up New Applications

## Exteriors, Interiors and Hierarchies

- Each building can have exterior, interior, underground
- Automatic classification and decomposition possible only for outer (visible) parts, not the inner ones
- Applications require more detailed information
- Semi-automatic classification for smaller unites possible



Decomposition of transportation space; it is hard to get it in fully automatised way. From: Kutzner et al (2020) CityGML 3.0: New Functions Open Up New Applications

## Coordinates and Elevation

All geometries in CityGML must:

- use 3D coordinate values
- be absolutely georeferenced

They can include terrain models

2.5D – only one Z coordinate for all buildings

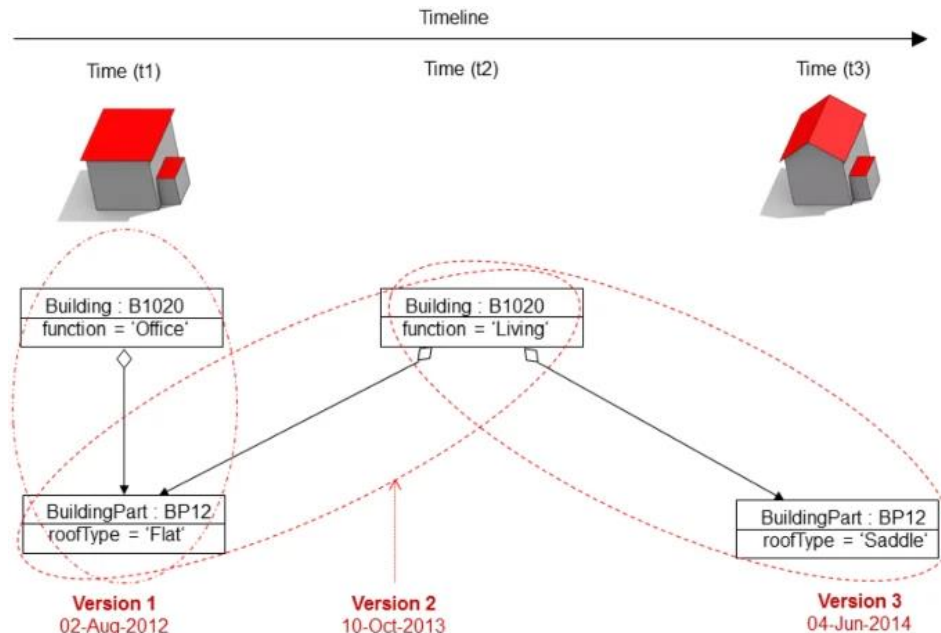


Screenshot from ArcGIS Pro using Esri's training data

## 4D – Time Dimension

- Important in Smart Cities, Digital Twins
- Versioning module – slow changes
- Dynamizer module – fast changes, e.g. sensor data

```
<cityObjectMember>
  <Building gml:id="B1020_t1">
    <identifier>B1020</identifier>
    <consistsOfBuildingPart>
      <BuildingPart xlink:href="//identifier[text()='BP12']"/>
    </consistsOfBuildingPart>
    <creationDate>2012-08-02</creationDate>
    <terminationDate>2013-10-10</terminationDate>
    <function>Office</function>
  </Building>
</cityObjectMember>
<cityObjectMember>
  <Building gml:id="B1020_t2">
    <identifier>B1020</identifier>
    <consistsOfBuildingPart>
      <BuildingPart xlink:href="//identifier[text()='BP12']"/>
    </consistsOfBuildingPart>
    <creationDate>2013-10-10</creationDate>
    <function>Living</function>
  </Building>
</cityObjectMember>
```



Example of versions representing modifications of a building (up)  
Representation of different versions of city objects within one CityGML dataset encoded in GML (left)

From: Kutzner et al (2020) CityGML 3.0: New Functions Open Up New Applications

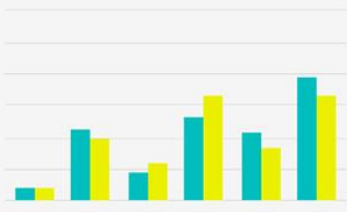


## Application Domain Extensions, ADEs

Data added using the CityGML ADE feature

LOD (-2)

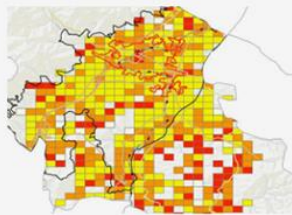
Graphs and charts



- National level, city level
- Indexing and projecting
- National government income and expenditures/economic activity

LOD (-1)

Heat maps



- Subregions/grids/administrative divisions
- Aggregate values for indices/areas
- Population/aging rates/road-to-area ratios, etc.
- Comparisons between cities/city analysis
- GIS/i-Urban Revitalization/e-Stat

LOD 0

Basic city planning maps



- Buildings/land (flat)
- Topographic models (height data)
- Building use/structure/area
- City plan studies/analysis
- GIS data

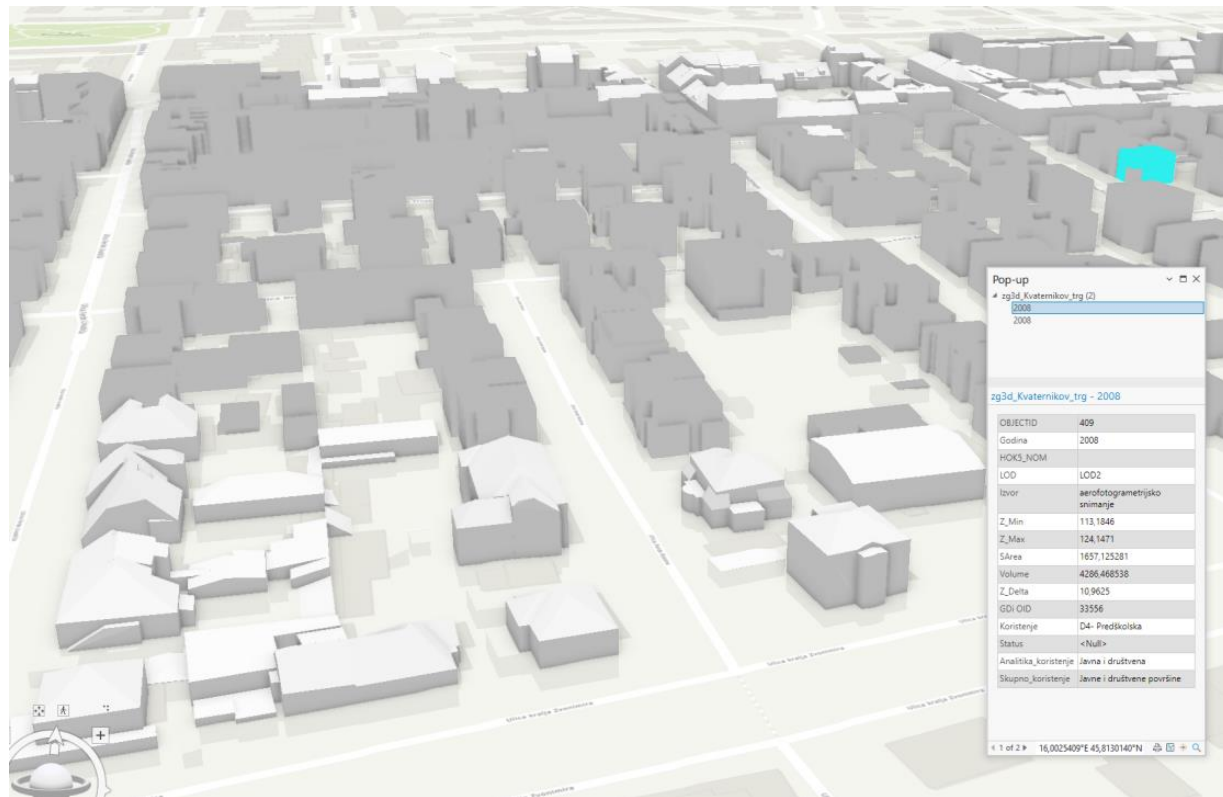
- ADEs facilitate to add new classes, attributes or relationships
- e.g. Energy ADE
- Utility Network ADE

## Data Quality

City models are complex  
large datasets

Data quality is crucial issue

- Accuracy
- Completeness
- Usability
- Consistency
- Uniqueness



Semantic 3D model of Zagreb, Croatia. Screenshot from ArcGIS Pro.

## Encodings of CityGML

GML – Geography Markup Language

CityGML is name both for:

- XML-based GML encoding
- conceptual data-model

Issued by Open Geospatial  
Consortium (OGC)

CityGML 3 allows data to be encoded  
in XML, in JSON or database schemas

Three encodings:

- XML-based →



- JSON-based →



- SQL-based →



## XML Encoding

### Original encoding of CityGLM

- verbose
- hierarchical
- complex
- not adapted for the web

Not much used any more

```
1 <?xml version="1.0" encoding="UTF-8"?>
2 <CityModel xmlns:xlink="http://www.w3.org/1999/xlink"
3   xmlns:gml="http://www.opengis.net/gml"
4   xmlns="http://www.opengis.net/citygml/2.0"
5   xmlns:bldg="http://www.opengis.net/citygml/building/2.0"
6   xsi:schemaLocation="http://www.opengis.net/citygml/2.0">
7   <cityObjectMember>
8     <bldg:Building gml:id="9a06451677c7">
9       <bldg:function>1070</bldg:function>
10      <bldg:lod1Solid>
11        <gml:Solid>
12          <gml:exterior>
13            <gml:CompositeSurface>
14              <gml:surfaceMember>
15                <gml:Polygon>
16                  <gml:exterior>
17                    <gml:LinearRing>
18                      <gml:pos>0.0 0.0 0.0</gml:pos>
19                      <gml:pos>0.0 1.0 0.0</gml:pos>
20                      <gml:pos>1.0 1.0 0.0</gml:pos>
21                      <gml:pos>1.0 0.0 0.0</gml:pos>
22                      <gml:pos>0.0 0.0 0.0</gml:pos>
23                    </gml:LinearRing>
24                  </gml:exterior>
25                </gml:Polygon>
26              </gml:surfaceMember>
27            ...
28          </bldg:Building>
29          <bldg:Building gml:id="jdhd76sa">
30            ...
31          </bldg:Building>
32        </cityObjectMember>
33      </CityModel>
```

## CityJSON Encoding I

- the most used alternative to XML encoding  
JSON - JavaScript Object Notation
- even CityJSON is an OGC standard
- coordinates are stored on one place only, in a  
separate array, i.e. the "vertices"

CityJSON allows full compression and  
simplifies file structure, compared to  
XML encoding (right figure)  
Example of coordinates in CityJSON (left  
figure)

```
1  "vertices": [  
2    [23234, 111009, 1392],  
3    [29456, 115134, 1007],  
4    [54508, 229995, 1961],  
5    ...  
6    [23134, 625134, 203]  
7  ]
```

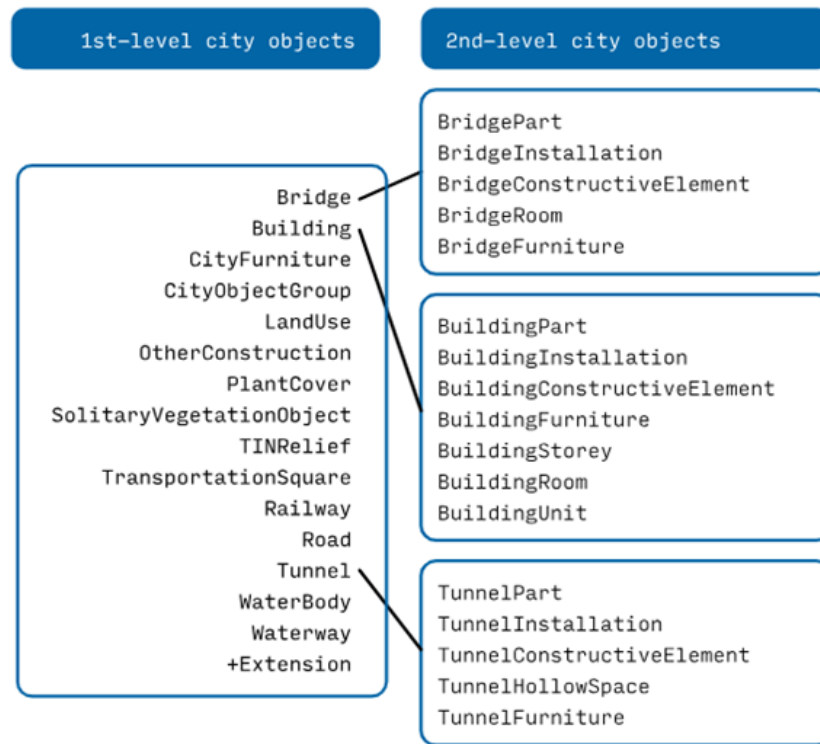
```
1  "CityObjects": {  
2    "id-1": {  
3      "type": "Building",  
4      "attributes": {...},  
5      "children": ["id-2", "id-3"],  
6      "geometry": [{...}]  
7    },  
8    "id-2": {  
9      "type": "BuildingPart",  
10     "parents": ["id-1"],  
11     "geometry": [{...}]  
12     ...  
13   },  
14   "id-3": {  
15     "type": "BuildingPart",  
16     "parents": ["id-1"],  
17     "geometry": [{...}]  
18     ...  
19   }  
20 }
```

## CityJSON Encoding II

CityJSON:

- is well suitable for web application
- reduces data-size; JSON file takes about 6x less space than XML
- can be stored both in relational as well as in no-SQL database

Two kinds of city objects – 1<sup>st</sup> and 2<sup>nd</sup> level (parents and children)

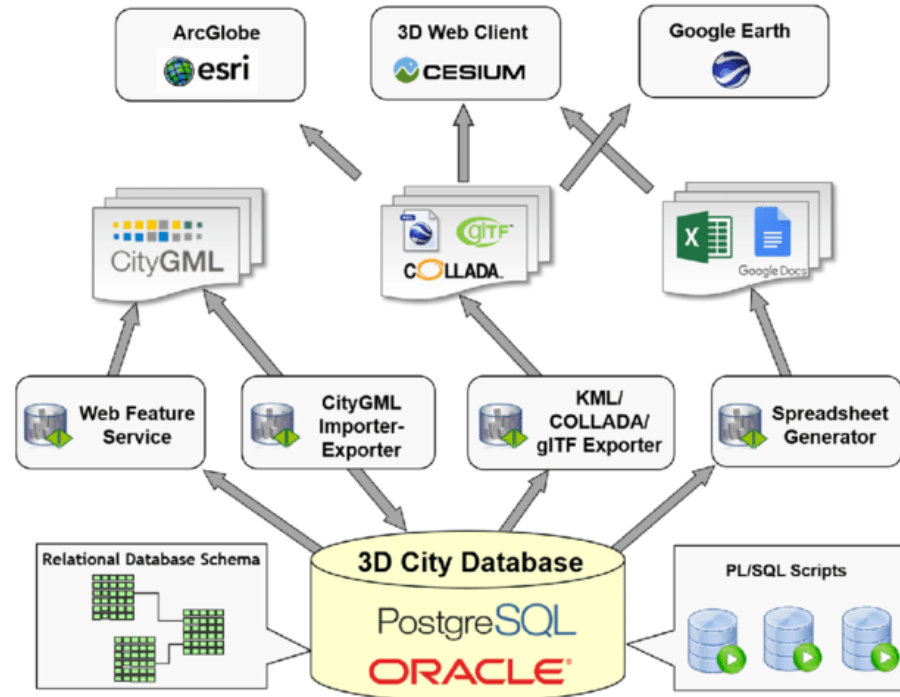




## 3D City Database Encoding

- database schema called 3DCityDB
- not official standard
- even open source software

[3DCityDB Database – Homepage](#)

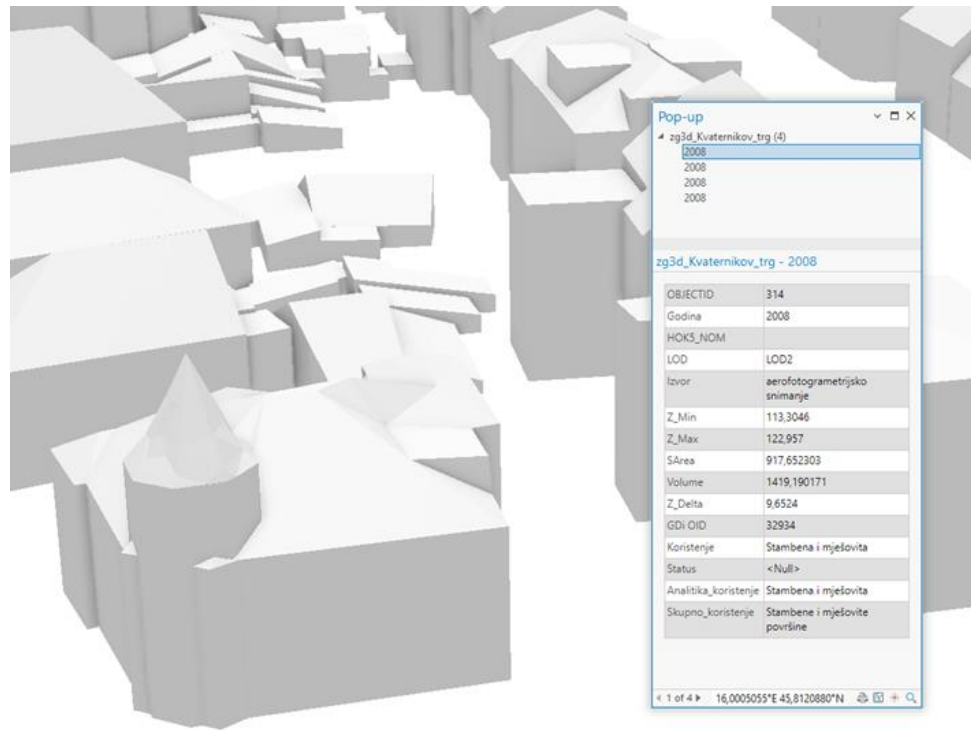


3DCityDB - a 3D geodatabase solution for the management, analysis, and visualization of semantic 3D city models based on CityGML, Yao et al. (2018)

## Other 3D formats

GML can be combined with many other formats

- Web Feature Service (WFS)
- Web Processing Service (WPS)
- KML/COLLADA or X3D files
- Web 3D Service (W3DS)
- Web Terrain Service (WTS)
- Indoor GLM



Example of a 3D model

## LandInfra

- Another 3D data standard
- Land and civil engineering
- Some overlap with CityGML
- Includes features not available in CityGML



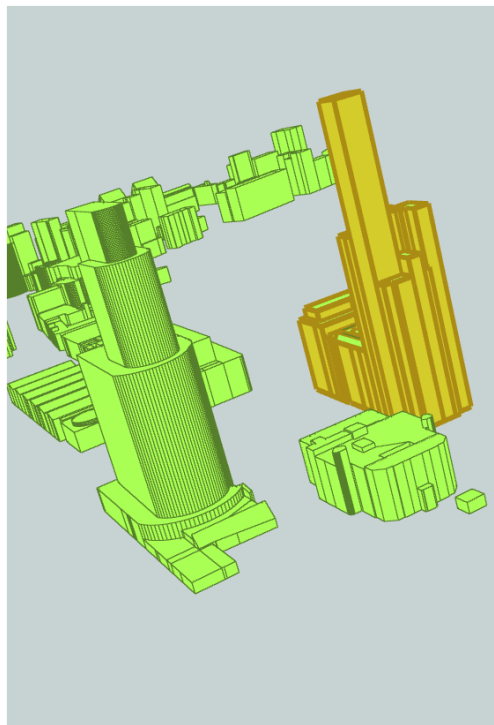
[Comparison between IFC, CityGML and LandInfra. Source: LandInfra BIM GIS.pdf](#)

## Inspire 3D Buildings

Influenced by CityGLM,  
but simplified

Aim to guarantee  
interoperability of spatial  
data and services from  
different EU countries

Requirements of EU  
Directives (e.g. Noise,  
Energy Performance)



Property	Value
Feature Type	BuildingPart
Coordinate System	EPSG:28992
Dimension	3D
Number of Vertices	606
Min Extents	92930.945999999996, 435425.1972, 0.0
Max Extents	93029.243000000002, 435500.67200000002, 135.50008840000001
Attributes (12)	
beginLifespanVersion (encoded: utf-16)	2013-01-15T00:00:00
conditionOfConstruction.owns (encoded: utf-16)	false
conditionOfConstruction.xsi_nil (encoded: utf-16)	true
fme_geometry (string)	fme_aggregate
fme_type (string)	fme_area
geometry3DLoD2.BuildingGeometry3DLoD2.horizontalGeometry...	1.0
geometry3DLoD2.BuildingGeometry3DLoD2.horizontalGeometry...	m
gml_id (encoded: utf-16)	fme-gen-778f112c-1978-4-ca9-a52d-f1c525f42f52
gml_original_coordinate_system (encoded: utf-16)	EPSG:28992
inspireId.Identifier.localId (encoded: utf-16)	fme-gen-778f112c-1978-4-ca9-a52d-f1c525f42f52
inspireId.Identifier.namespace (encoded: utf-16)	EUJRC.BU
xml_type (string)	xml_area
IFEMultiArea (123 Parts)	
Name (encoded: utf-16)	geometry3DLoD2.BuildingGeometry3DLoD2.geometryMultiSurface
Geometry Traits (1)	
Part 0: IFMEPolygon	
Name (encoded: utf-16)	surfaceMember
Geometry Traits (1)	
gml_id (encoded: utf-16)	fme-gen-778f112c-1978-4-ca9-a52d-f1c525f42f52-1
Linear Boundary	True
Convex	True
Orientation	Right Hand Rule
Boundary: IFMELINE (4 Coordinates)	(92971.863129999998, 435461.867299999998, 32.1908558399999998, ...)
Closed	Yes
Coordinates (4)	
0	92971.863129999998, 435461.867299999998, 32.1908558399999998
1	92983.949670000002, 435471.024700000001, 32.1909623299999998
2	92983.949670000002, 435471.024700000001, 32.19067957
3	92971.863129999998, 435461.867299999998, 32.1908558399999998
Part 1: IFMEPolygon	
Name (encoded: utf-16)	surfaceMember
Geometry Traits (1)	
gml_id (encoded: utf-16)	fme-gen-778f112c-1978-4-ca9-a52d-f1c525f42f52-2
Linear Boundary	True
Convex	True
Orientation	Right Hand Rule
Boundary: IFMELINE (5 Coordinates)	(92983.949670000002, 435471.024700000001, 32.1909623299999998, ...)
Closed	Yes

INSPIRE Buildings GML viewed with Data Inspector. From: [Converting CityGLM to INSPIRE 3D Buildings \(Annex III\) \(safe.com\)](#)

**Thank you for your attention**



<https://birgitproject.eu/>