



# Every Object Gets a Brain:

## CityGML as a Foundation for Digital Twins

Dr. Mahmoud Abdelrahman  
Postdoc Researcher - KAIST University



# Today: from a picture to a model

## By the end you can...



Read a CityGML file and say what is in it



Spot why a file is broken



Pick the right tool to check, convert, view and store it

## The path

1

### Look

A picture vs a model

2

### Read

Anatomy of one small file

3

### Check

Why files fail

4

### Use

Tools, databases, libraries

# The difference between a picture/geometry of a city and a model of the city

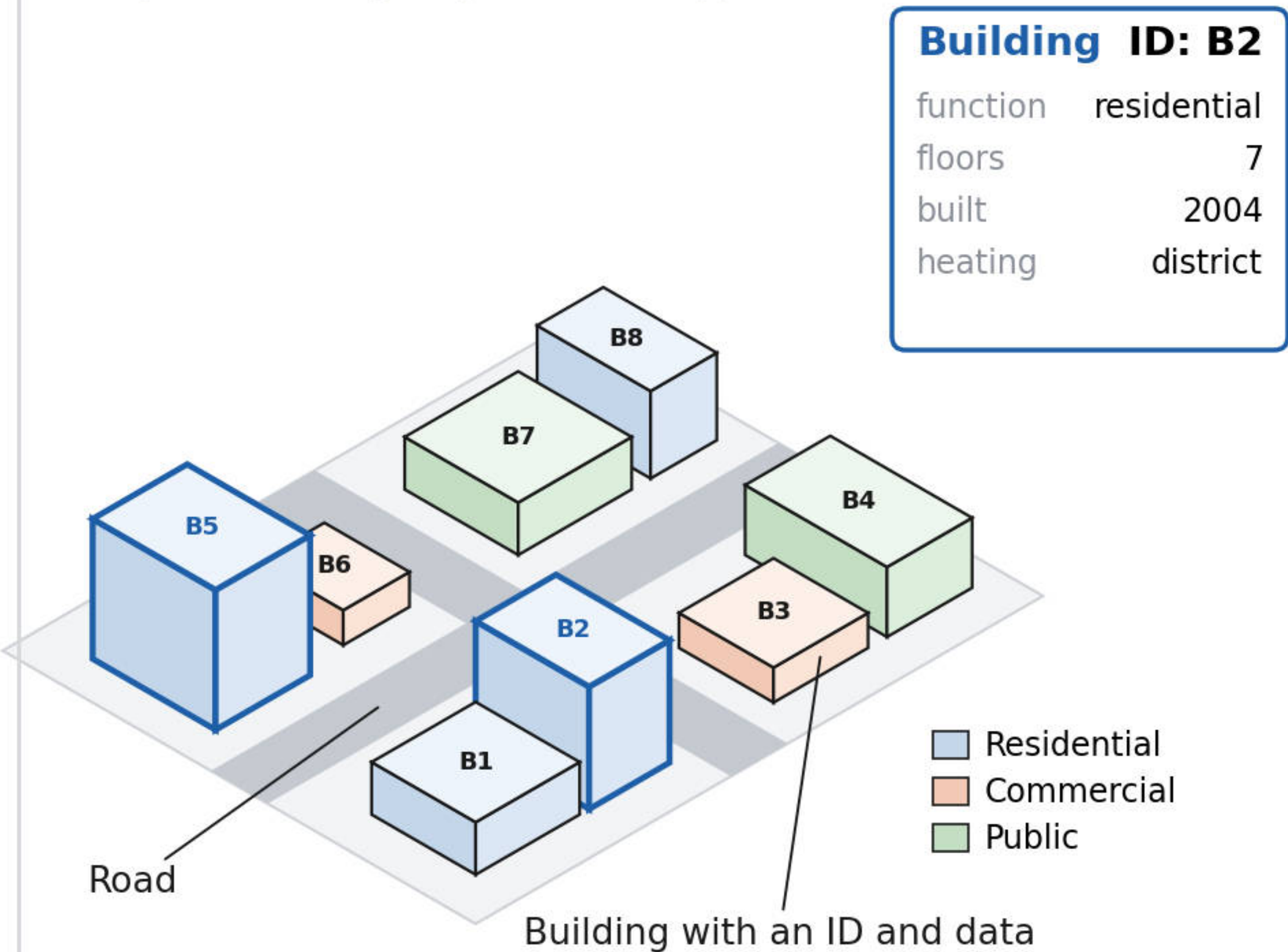
## A picture of the city

a mesh: triangles only



## A model of the city

CityGML: every object has a type and data

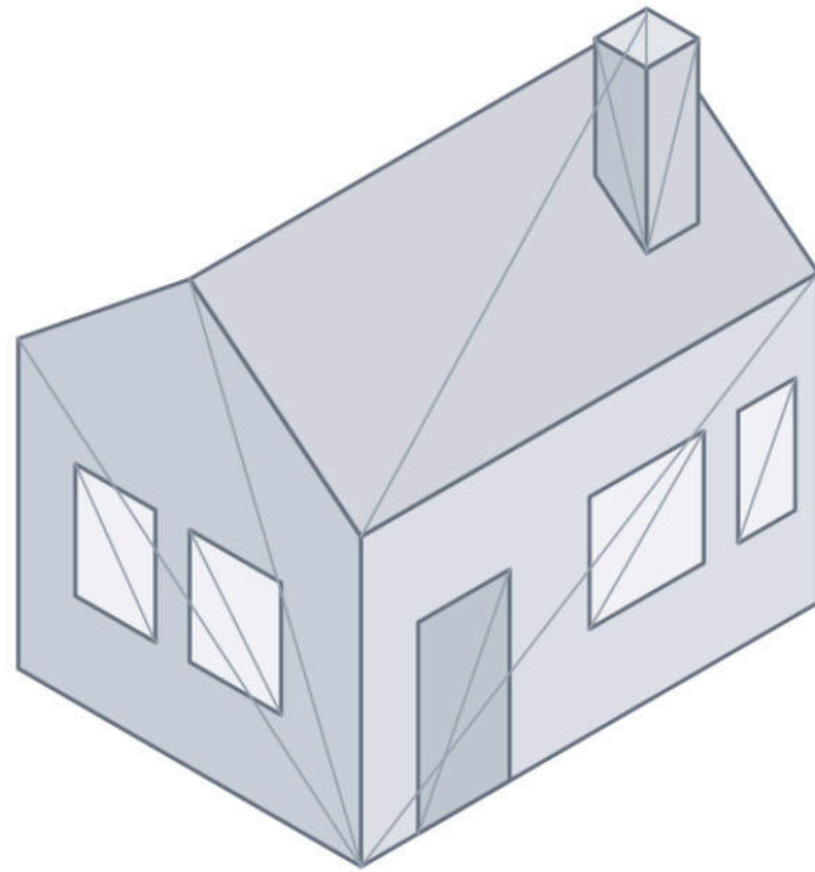


**Question: which residential buildings have more than 6 floors?**

No answer. The computer sees only triangles.

**Answer: B2 and B5.**

### A plain 3D mesh



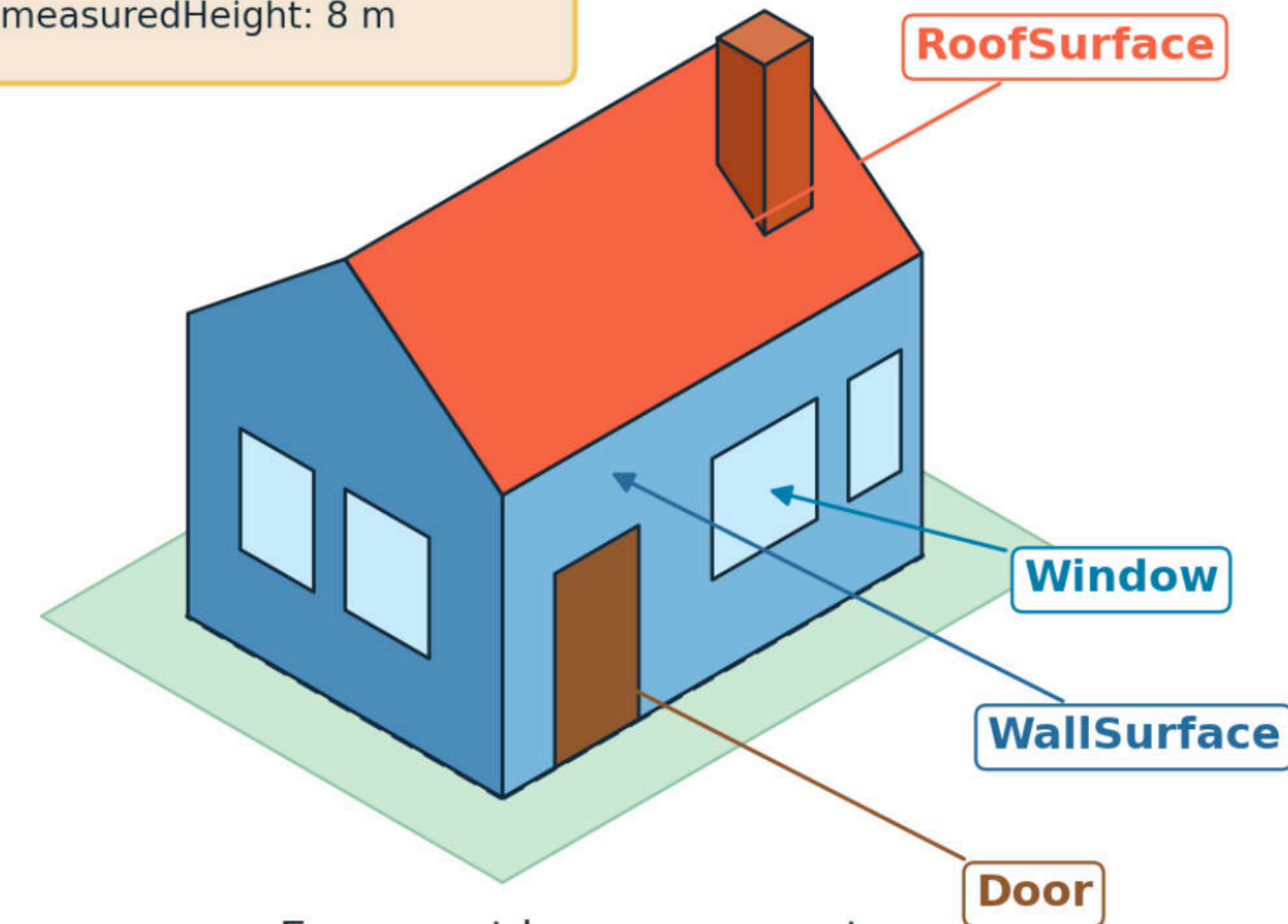
Triangles only. It looks like a house, but the computer sees no 'house'.

typical 3D model is a **mesh**: a bag of triangles.

### A semantic model (CityGML)

#### Building

function: residential  
yearOfConstruction: 1998  
measuredHeight: 8 m

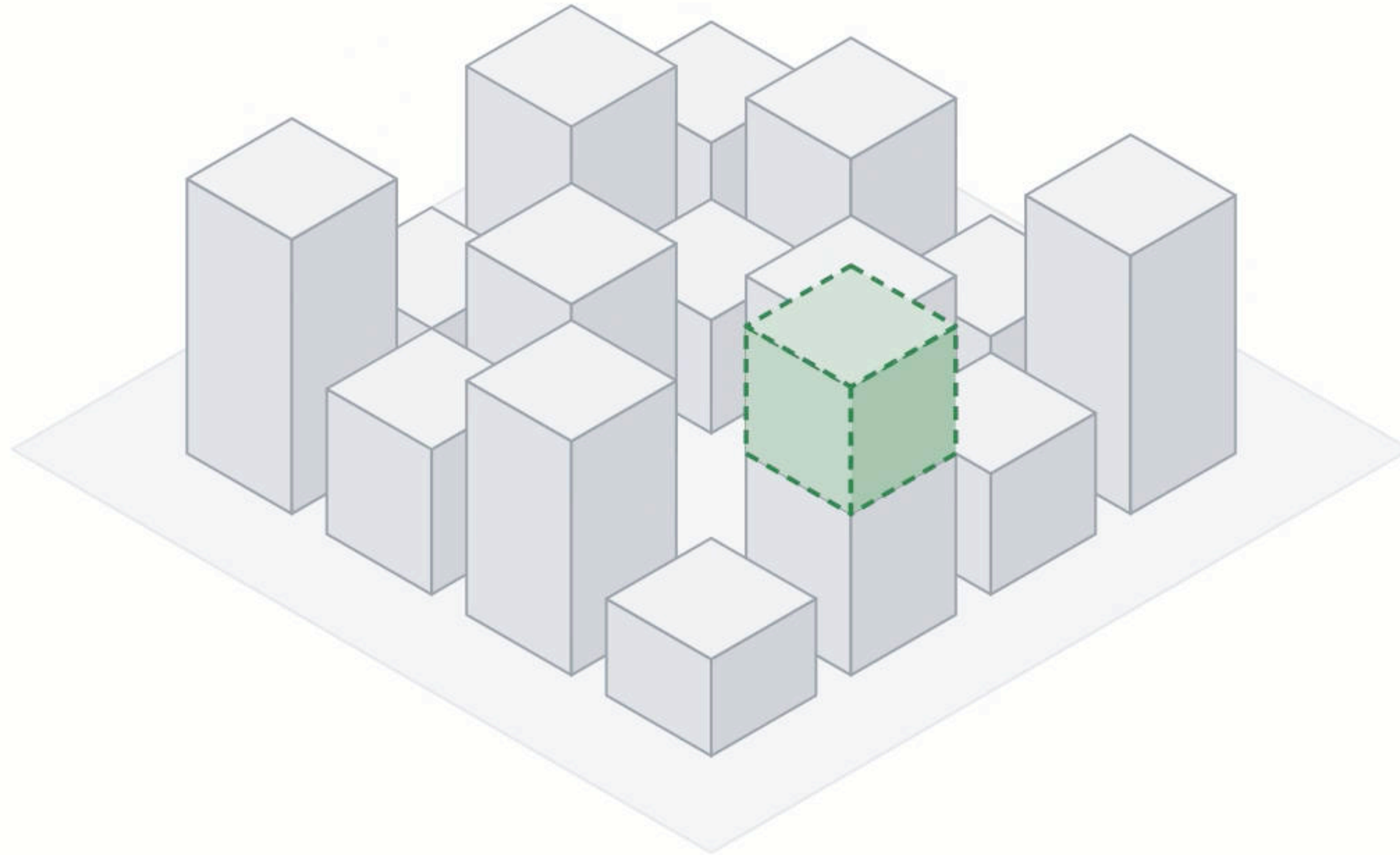


Every part has a name, a type and attributes you can query.

**CityGML** solves this by describing a city as a set of **things** with **types**, **properties** and **relationships**

# What can a city model answer?

What if we build here?



Sun & shadow



Flooding



Noise



Energy



Wind



Planning



# CityGML

## Geography Markup Language

**CityGML** is an **open standard** from the **Open Geospatial Consortium (OGC)** for storing and exchanging 3D city models.

**CityGML** is a **Platform Independent Model (PIM)**

# .xml    .json

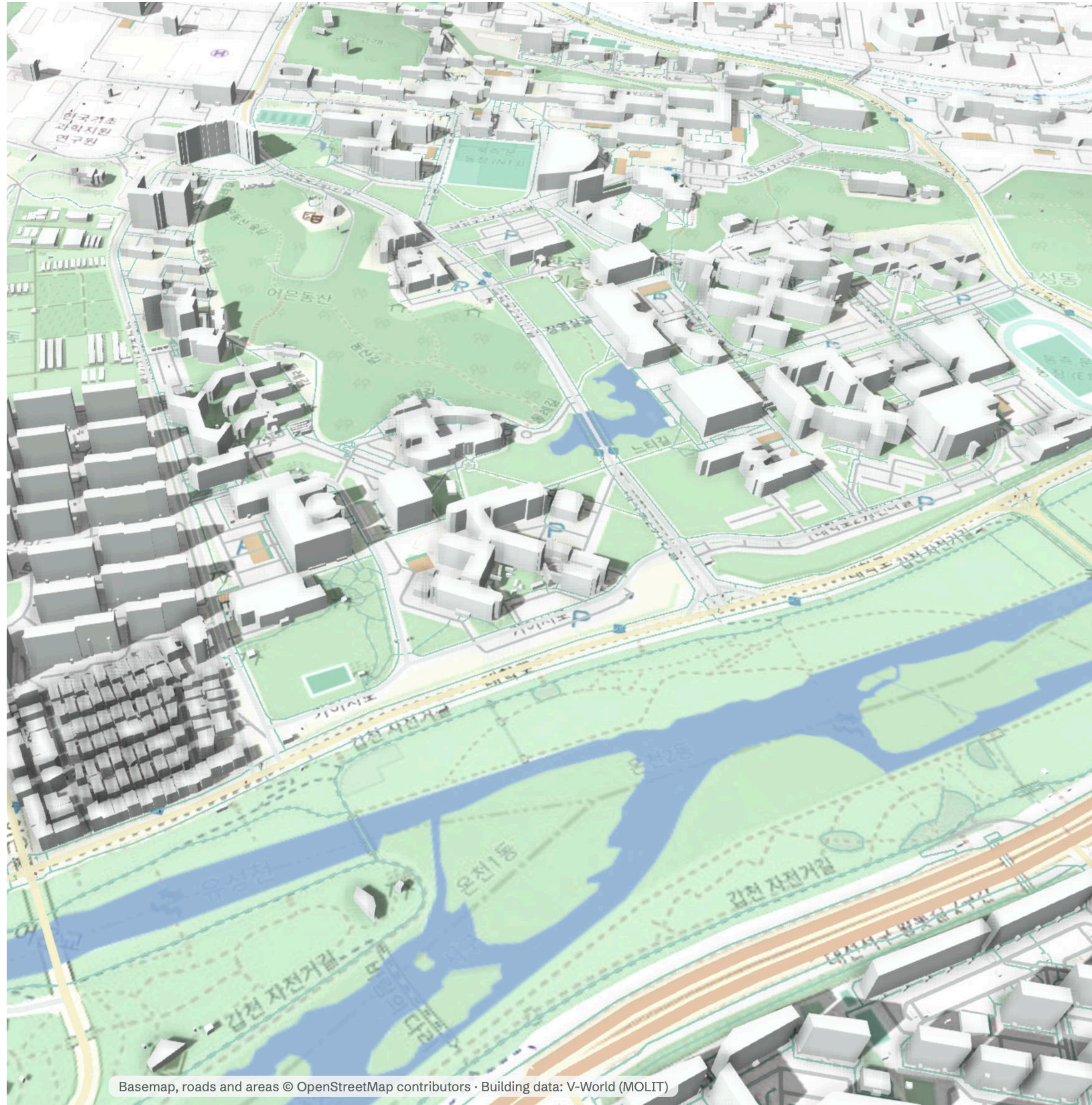
REF:

<https://www.ogc.org/standards/citygml/>

<https://docs.ogc.org/is/21-006r2/21-006r2.html>



# Basic definitions



## Space

an entity of volumetric extent in the real world

## Feature

abstraction of real world phenomena.

## Geometry

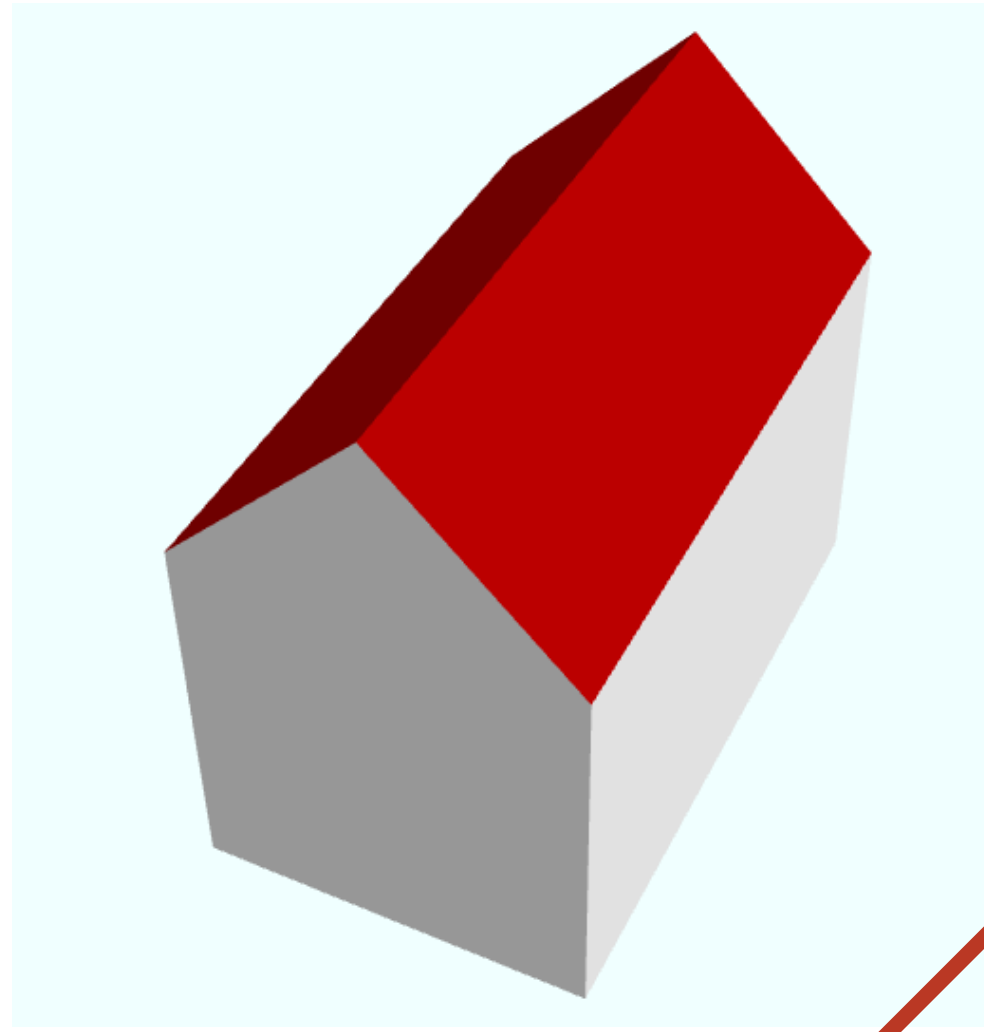
an ordered set of n-dimensional points in a given coordinate reference system; can be used to model the spatial extent or shape of a feature

## Levels of detail

Quantity of information that portrays the real world

*More definitions can be found in the supplementary materials*

# Example



## Space

an entity of volumetric extent in the real world

## Feature

abstraction of real world phenomena.

## Geometry

an ordered set of n-dimensional points in a given coordinate reference system; can be used to model the spatial extent or shape of a feature

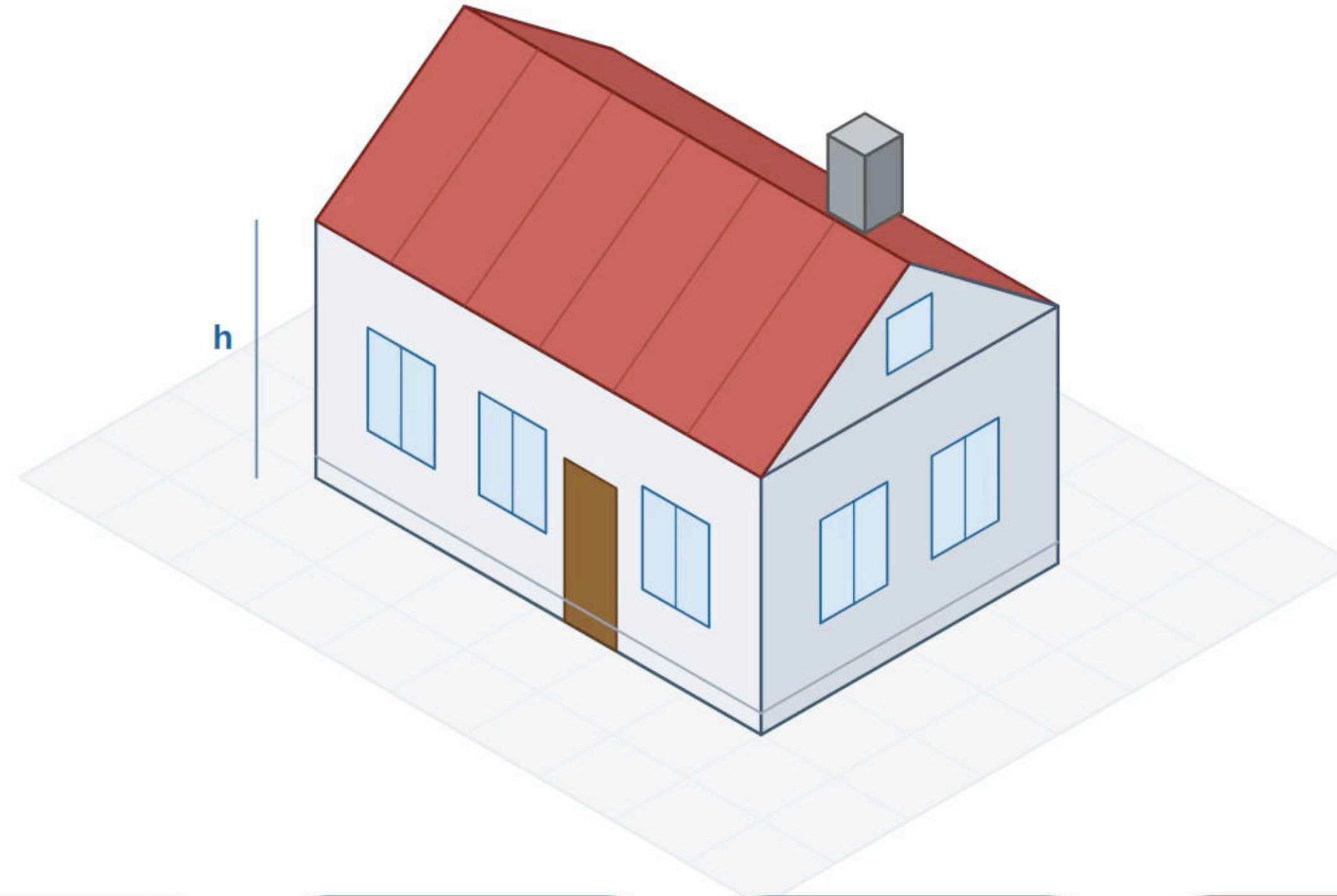
## Levels of detail

Quantity of information that portrays the real world

The building (=space) above is modeled in **LOD2** as Solid geometry and is bounded by four **WallSurfaces**, one **RoofSurface**, and one **GroundSurface** (=space boundaries). All space boundaries are modeled as Polygon geometries.

# Levels of Detail in CityGML

The same building, four levels of geometric abstraction

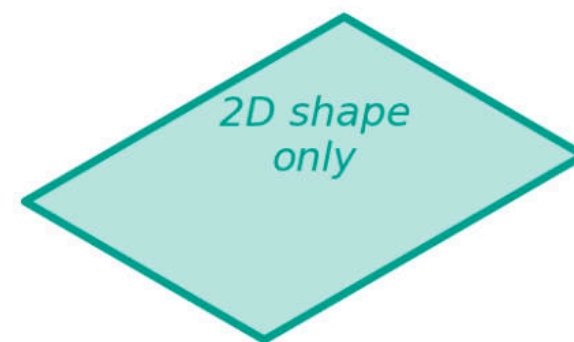


**LoD0**  
Footprint

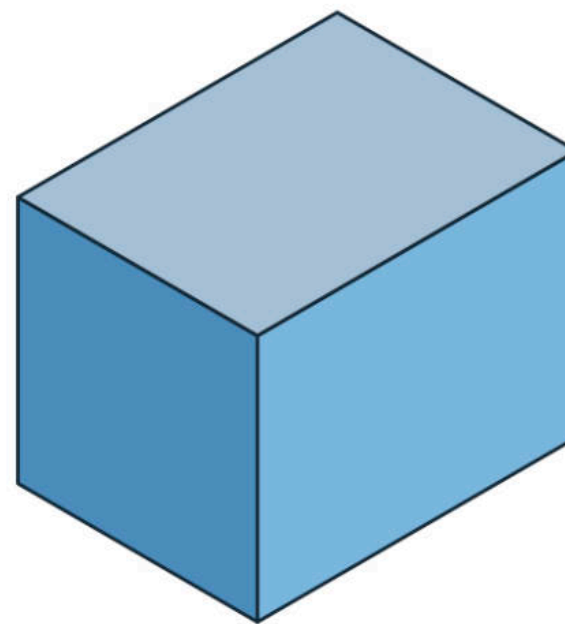
**LoD1**  
Block model

**LoD2**  
Roof shapes

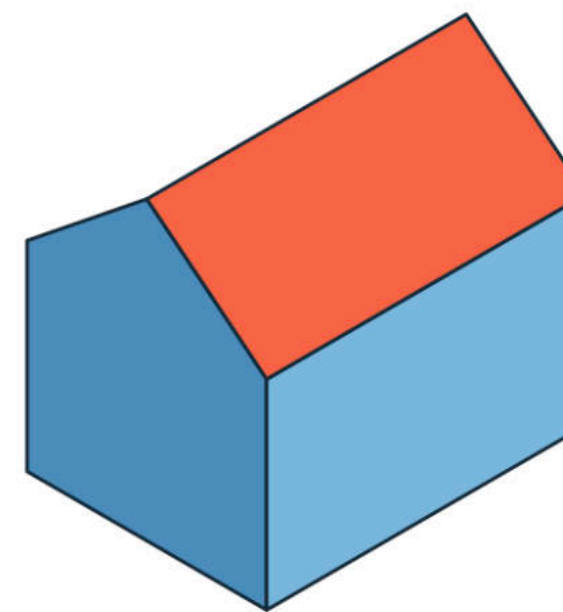
**LoD3**  
Architectural detail



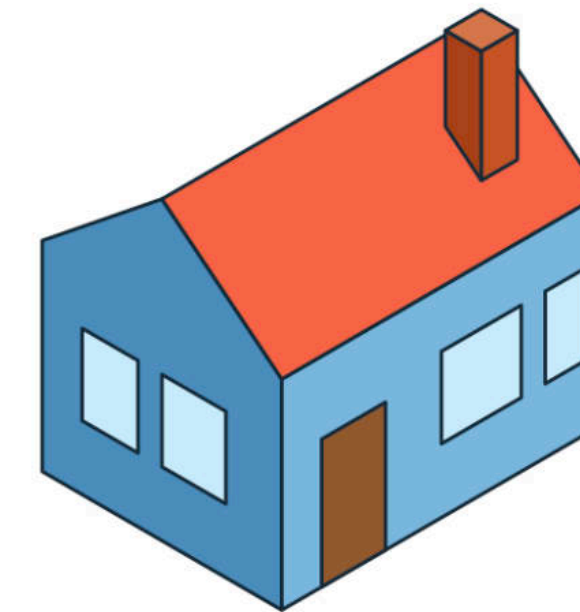
Footprint



Block model



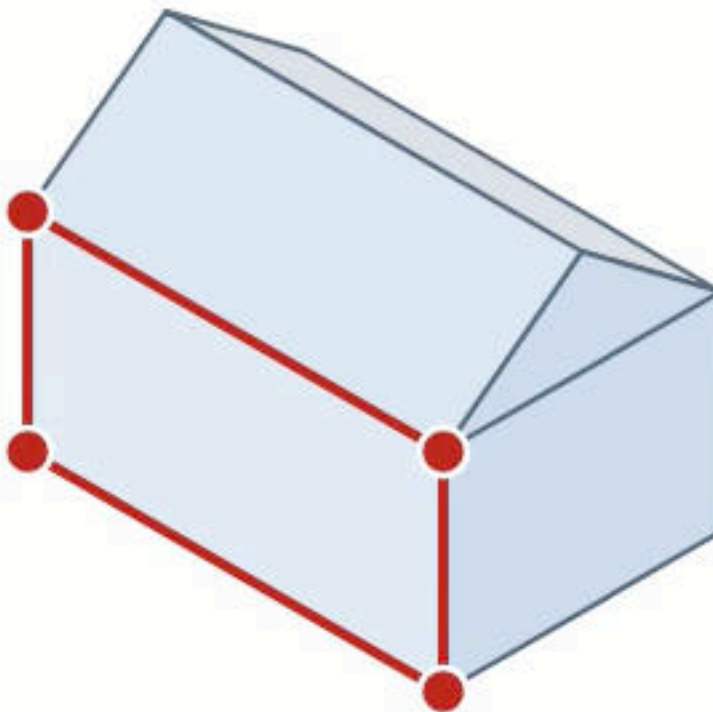
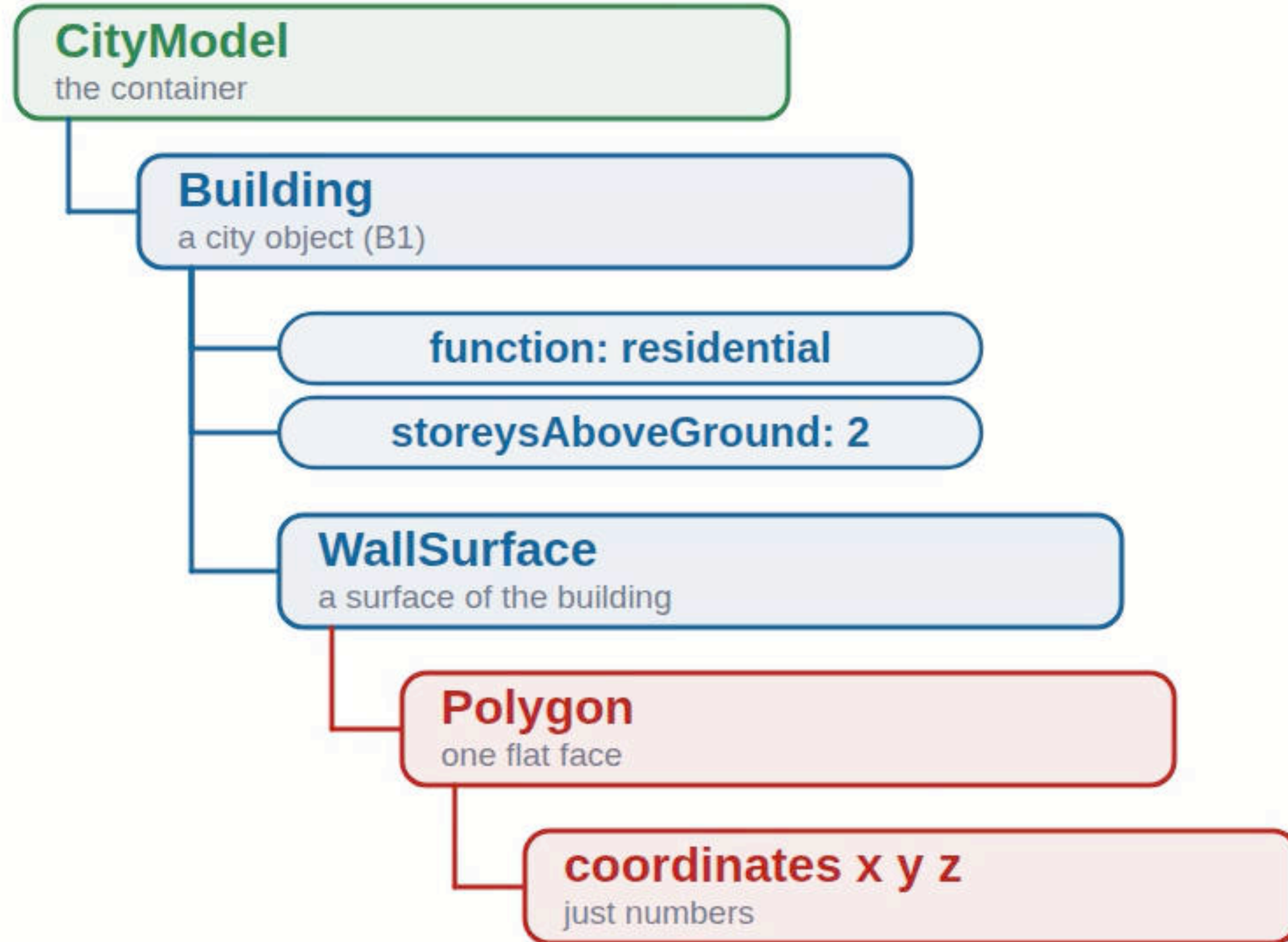
Roof shape +  
labelled surfaces



Openings and  
fine details

# How a CityGML file is organized

Geometry is only a list of points



CityGML (GML/XML), simplified

```
<core:CityModel>

  <bldg:Building gml:id="B1">

    <bldg:function>residential</bldg:function>

    <bldg:storeysAboveGround>2</bldg:storeysAboveGround>

    <bldg:boundedBy>

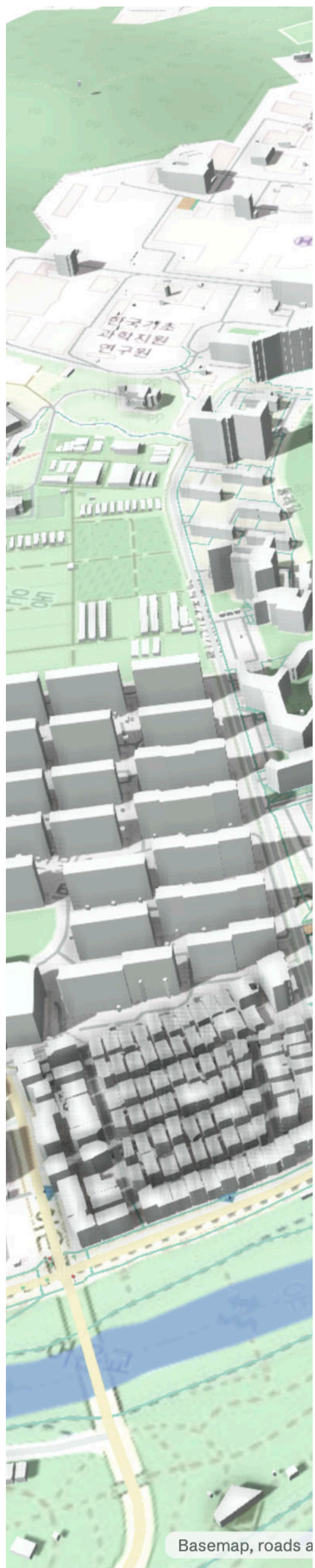
      <bldg:WallSurface>

        <gml:Polygon>

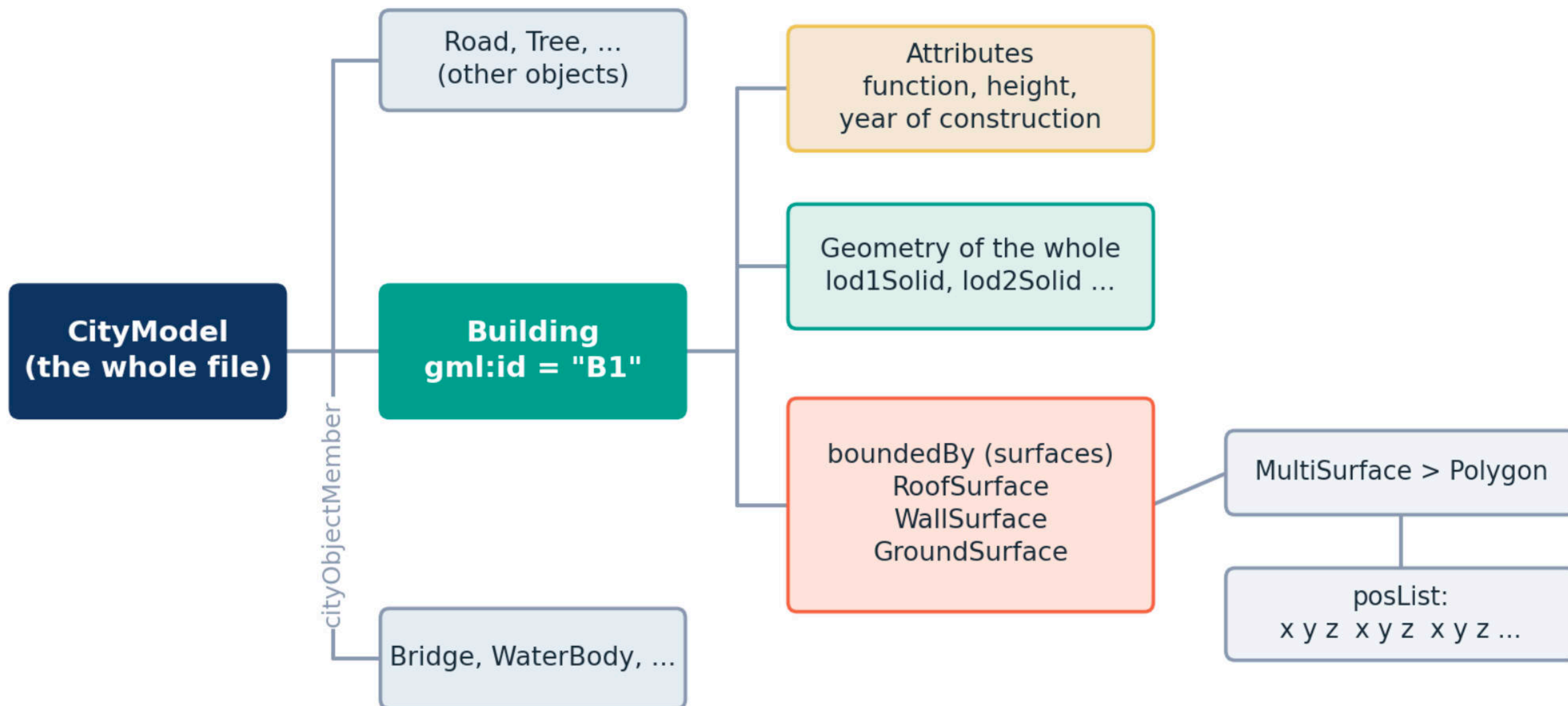
          <gml:posList>

            0 0 0 6 0 0 6 0 3 0 0 3
```

Simplified for the slide



## Container > Object > Parts > Geometry > Numbers



# Same model, two encodings

Same building. Same meaning. Less text.

## CityGML (GML/XML)

```
<core:CityModel>
  <core:cityObjectMember>
    <bldg:Building gml:id="B1">
      <bldg:function>residential</bldg:function>
      <bldg:storeysAboveGround>2</bldg:storeysAboveGround>
      <bldg:boundedBy>
        <bldg:WallSurface>
          <bldg:lod2MultiSurface>
            <gml:MultiSurface>
              <gml:surfaceMember>
                <gml:Polygon>
                  <gml:posList>0 0 0 6 0 0 6 0 3 0 0 3</gml:posList>
                ... and the closing tags
```

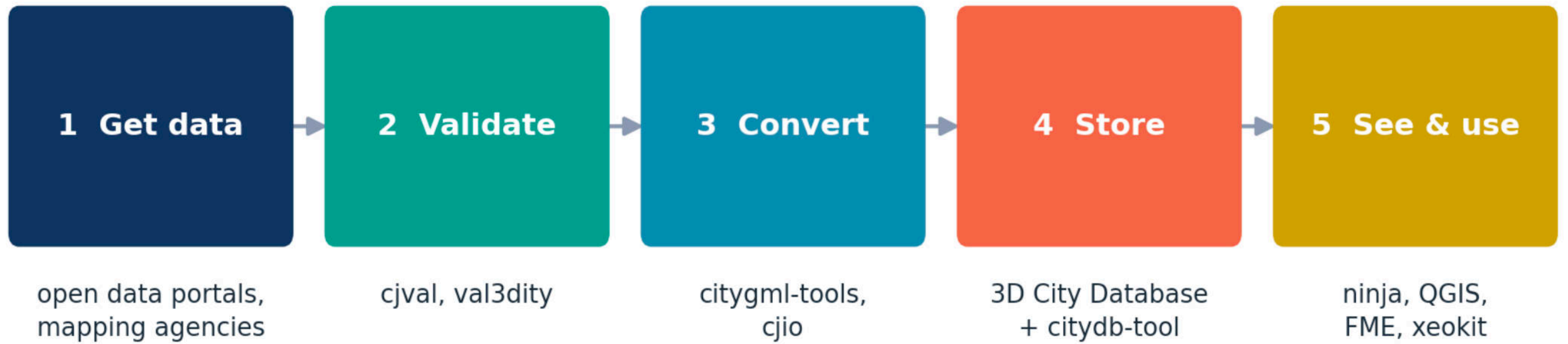
## CityJSON (JSON)

```
{
  "type": "CityJSON", "version": "2.0",
  "CityObjects": {
    "B1": { "type": "Building",
      "attributes": { "function": "residential",
        "storeysAboveGround": 2 },
      "geometry": [{ "type": "MultiSurface", "lod": "2",
        "boundaries": [[[0, 1, 2, 3]]] }] },
    "vertices": [[0,0,0],[6,0,0],[6,0,3],[0,0,3]]
  }
}
```

CityGML

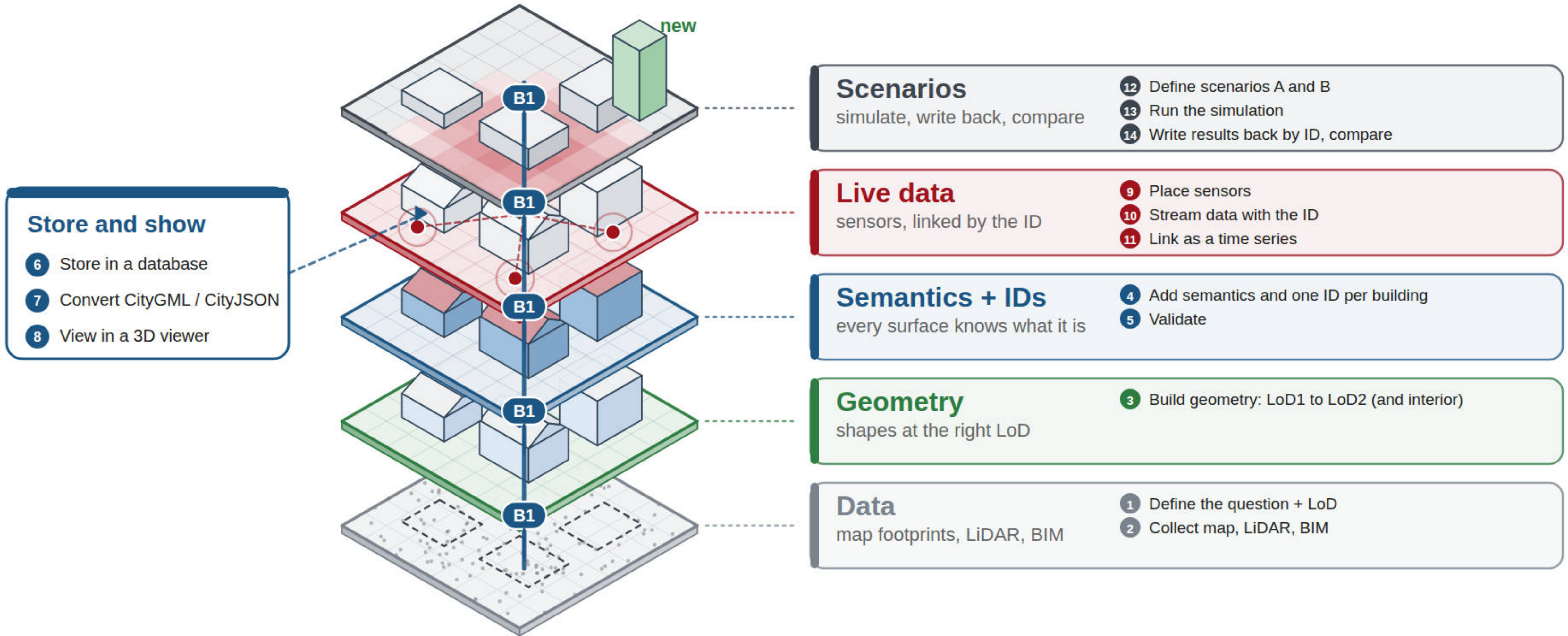
CityJSON





# One ID runs through every layer

From a campus to a digital twin



Tools depend on the case. Steps are numbered in pipeline order.

# Hands-on demo

<https://kaist-twin-vercel.vercel.app/>

Daejeon · KAIST twin

14,074 objects · V-World LoD1 + LoD4 → CityGML

GO TO

KAIST

LoD4 district

Overview

Orbit

Find by MODEL\_ID or parcel (PNU)

MAP STYLE

Streets

Light

Dark

Detail

Satellite

Topo

Plain

Basemaps are pre-rendered images of this area (zoom 16), not live map tiles.

TIME AND SUNLIGHT

05/10/2026

Live

Play

14:30 KST · sun 39° · az 224° ↑06:35 ↓18:10

☒ Shadows

☒ Ambient occlusion

AO strength

COLOUR BY

Use code

Height

Occupancy

Energy use

Dataset

Edited

BDU003

3,432

BDU999

2,379

BDU010

2,167

BDU002

1,622

BDU001

859

BDU006

144

BDU020

116

BLD010000005RKP8N

LoD1 extrusion

17.0 m · base 42.2 m · Academic / lab

live data synthetic

Live

Attributes

CityJSON

CityGML

787

people now

71%

space utilization

173.4

load, kW

Capacity

1,064 people · 14,893 m<sup>2</sup> over 5 floors

Archetype

Academic / lab

Occupancy, 24 h (2026-10-05)

Electrical load, kW

Load split

plug 108.9 · light 64.5 · HVAC 0.0 kW

Energy today

2.76 MWh so far

CO<sub>2</sub> / indoor

849 ppm · 22.4 °C · 42% RH

Water

2,556 L/h

Roof PV potential

182.6 kW now (0.55 of roof, 19% panels)

All values on this tab are generated from schedule and weather models. They are placeholders for sensor feeds (BMS, meters, Wi-Fi counts), not measurements.

Basemap, roads and areas © OpenStreetMap contributors · Building data: V-World (MOLIT)

# Take-aways

- 1 A mesh is a picture. CityGML is a model.**  
Types, properties and relations, not just triangles
- 2 Model once, ask many questions.**  
Pick the LoD for the question; one ID per building
- 3 Live data and scenarios attach by the same ID.**  
CityGML is the base, not the physics or the AI

## Mahmoud Ouf

Ma mood · 마무드 | Postdoc, KAIST  
Urban AI

EMAIL

[mahmoud@kaist.ac.kr](mailto:mahmoud@kaist.ac.kr)

[mahmoud@u.nus.edu](mailto:mahmoud@u.nus.edu)

[arch.mahmoud.ouf111@gmail.com](mailto:arch.mahmoud.ouf111@gmail.com)

[mahmoud.work](http://mahmoud.work)

# **Supplementary Materials**

# CityGML Definitions

## 2D data

geometry of features is represented in a two-dimensional space

NOTE In other words, the geometry of 2D data is given using (X,Y) coordinates.

## 2.5D data

geometry of features is represented in a three-dimensional space with the constraint that, for each (X,Y) position, there is only one Z

## 3D data

Geometry of features is represented in a three-dimensional space.

NOTE In other words, the geometry of 2D data is given using (X,Y,Z) coordinates without any constraints.

## application schema

A set of [conceptual schema](#) for data required by one or more applications. An application schema contains selected parts of the base schemas presented in the ORM Information Viewpoint. Designers of application schemas may extend or restrict the types defined in the base schemas to define appropriate types for an application domain. Application schemas are information models for a specific information community.

## city-object relation

a specific relation from the city object in which the relation is included to another city object

## codelist

A value domain including a code for each permissible value.

## Implementation Specification

Specified on the OGC Document Types Register at <http://www.opengis.net/def/doc-type/is>

## life-cycle information

set of properties of a spatial object that describe the temporal characteristics of a version of a spatial object or the changes between versions

## Platform (Model Driven Architecture)

the set of resources on which a system is realized.

## space

an entity of volumetric extent in the real world

NOTE Spaces can be spatially represented in different LODs and by different types of geometric objects.

## space boundary

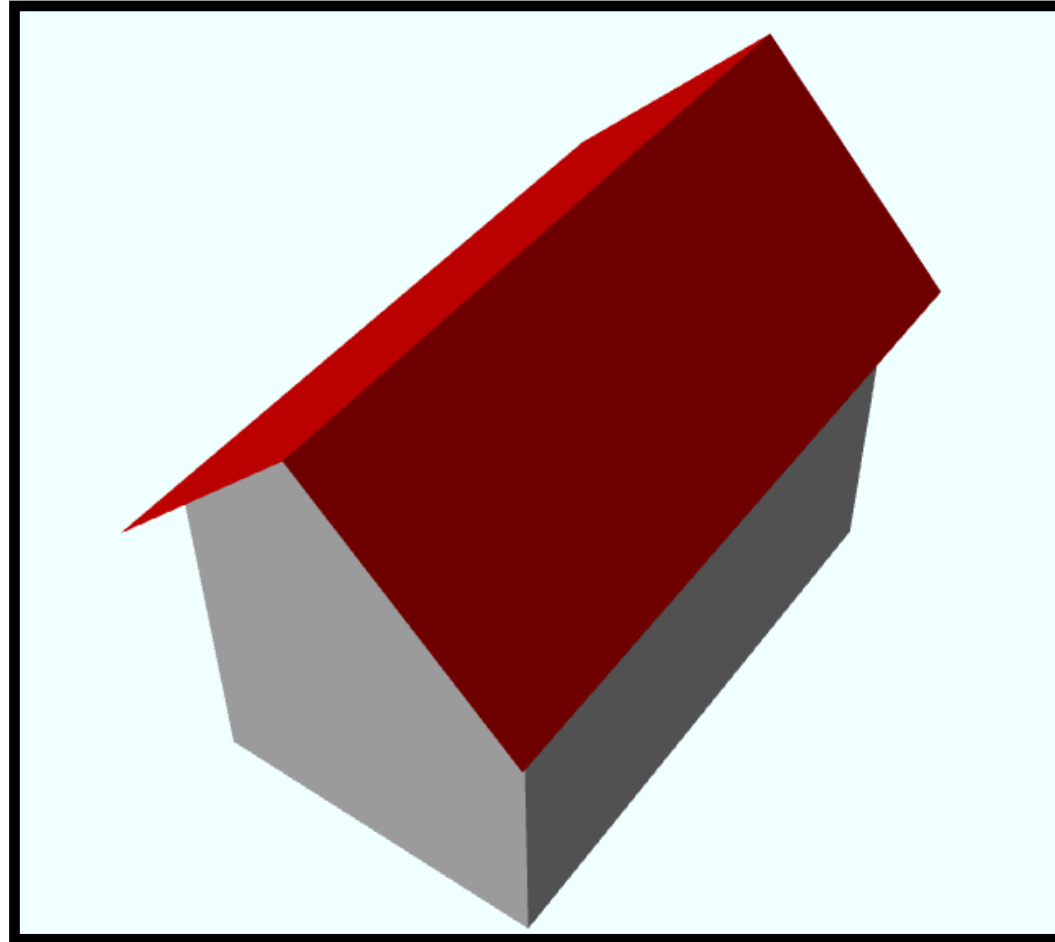
an entity with areal extent in the real world. Space boundaries are objects that bound a Space. They also realize the contact between adjacent spaces.

NOTE Space boundaries can be spatially represented in different LODs and by different types of geometric objects.

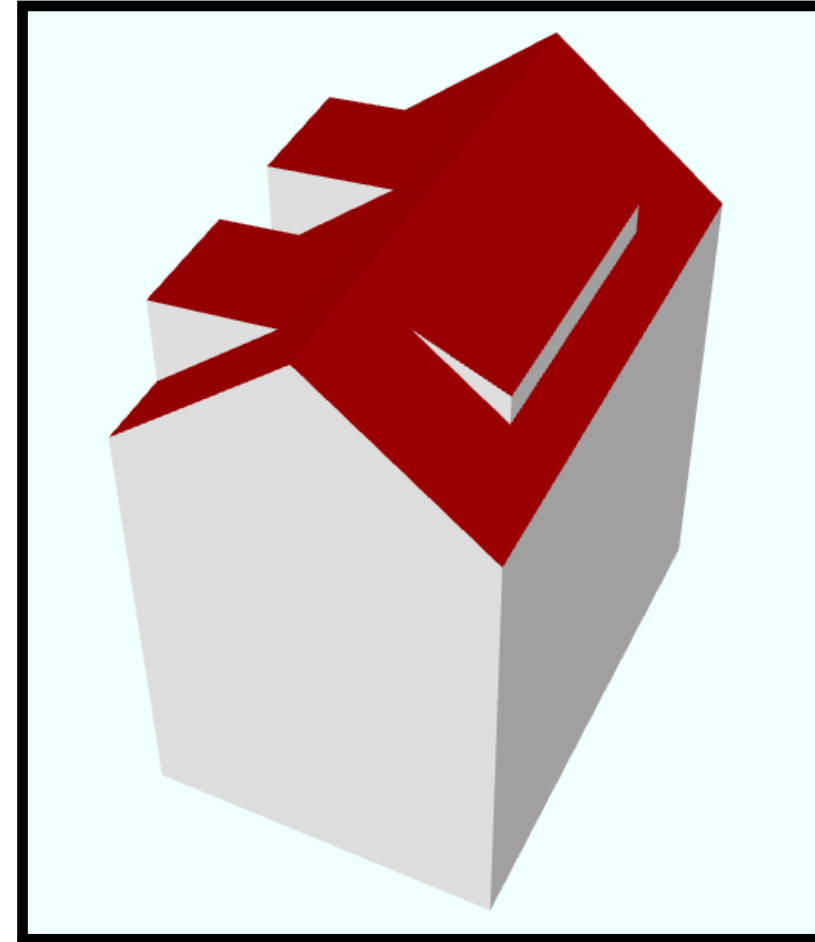
## top-level feature

a feature that represents one of the main components of 3D city models; can be further semantically and spatially decomposed and substructured into parts

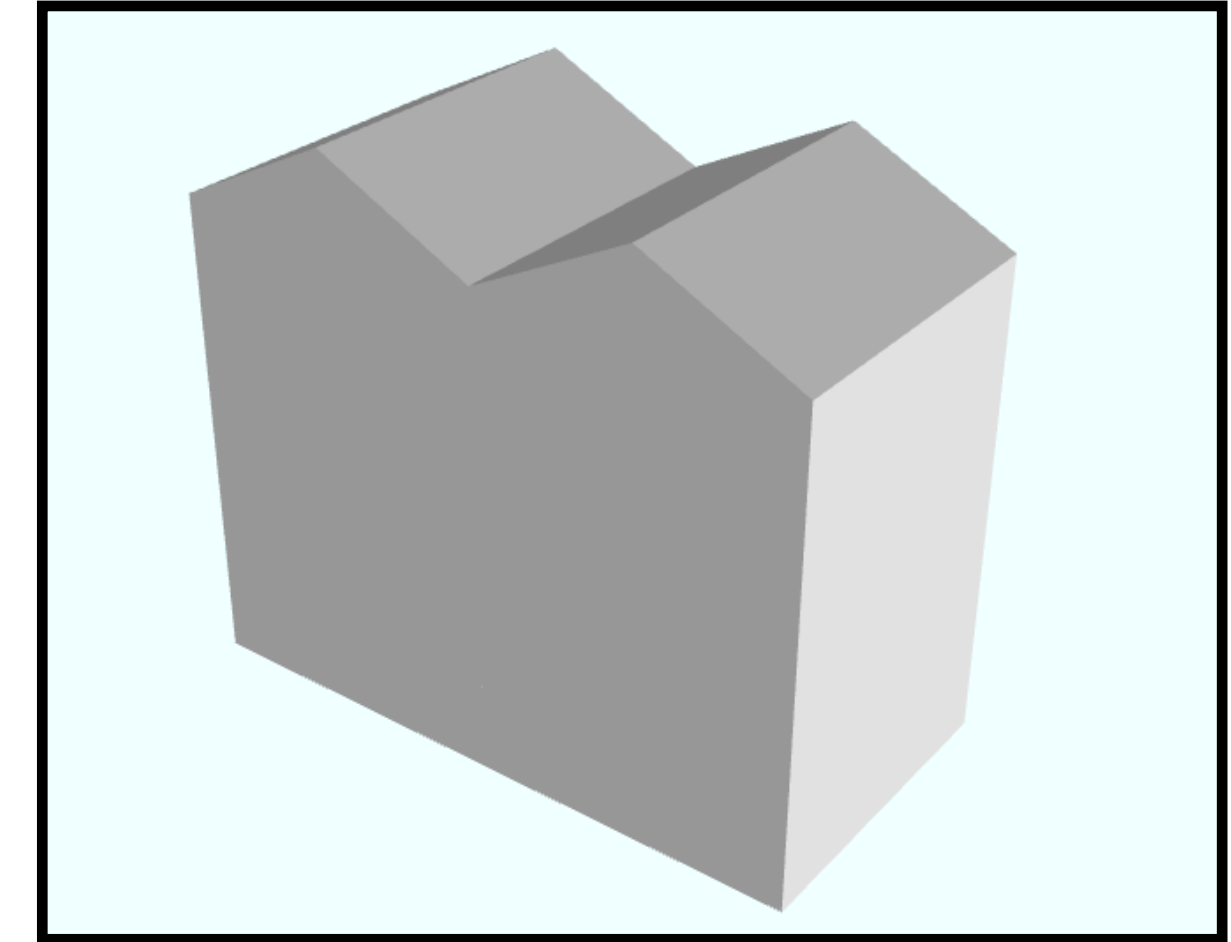
# More basic examples



Example 1 : Building  
with roof overhangs  
[\(link\)](#)

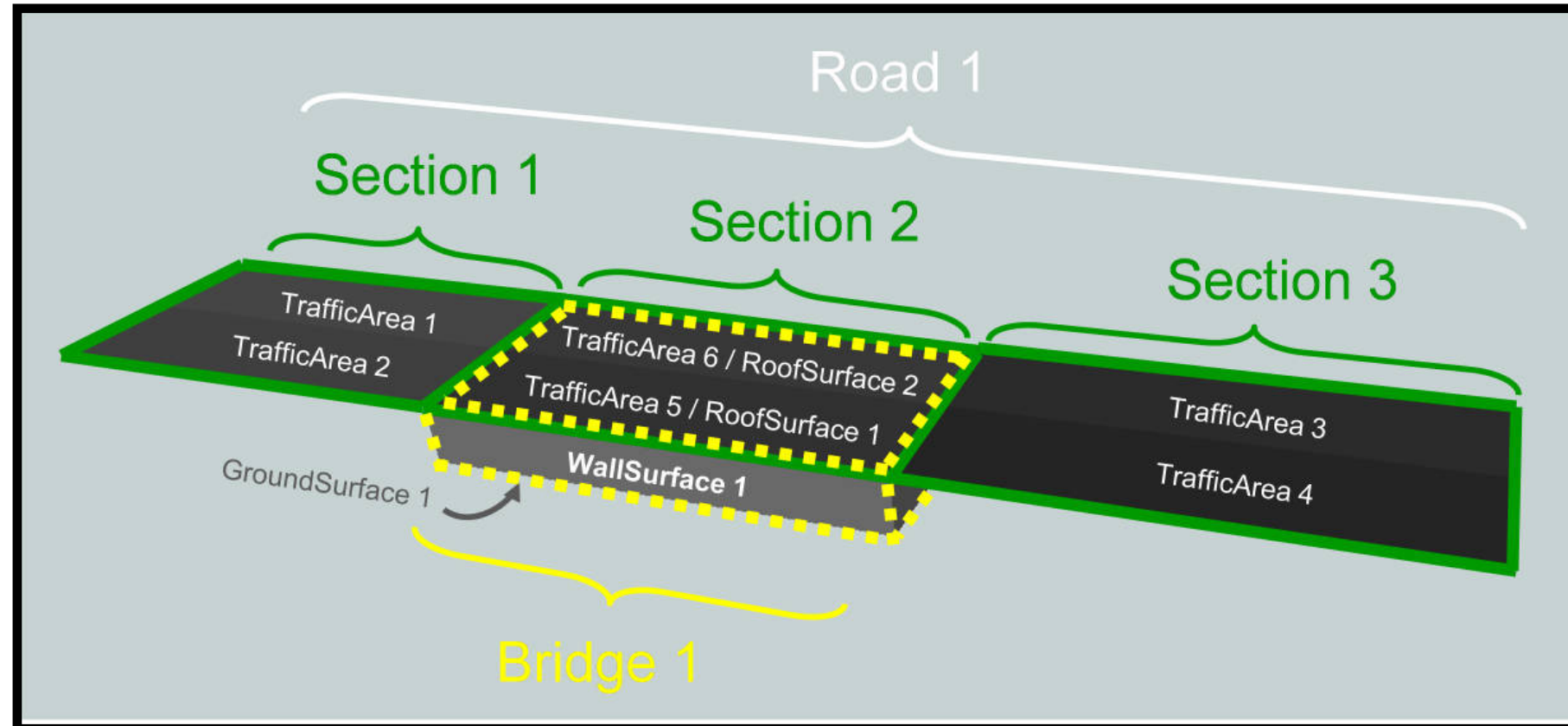


Example 2 : Building  
with building installation  
[\(link\)](#)

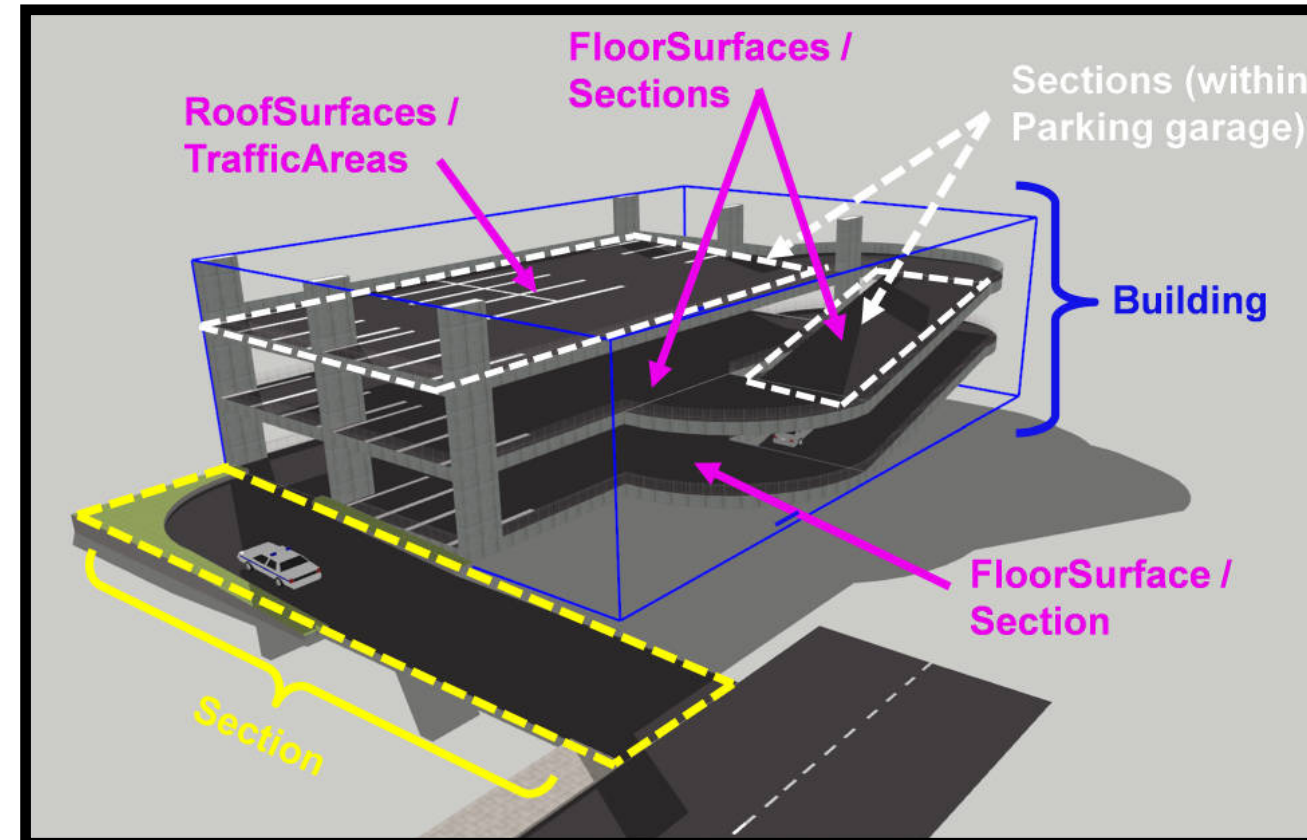


Example 3: Two  
buildings with shared  
boundary surface [\(link\)](#)

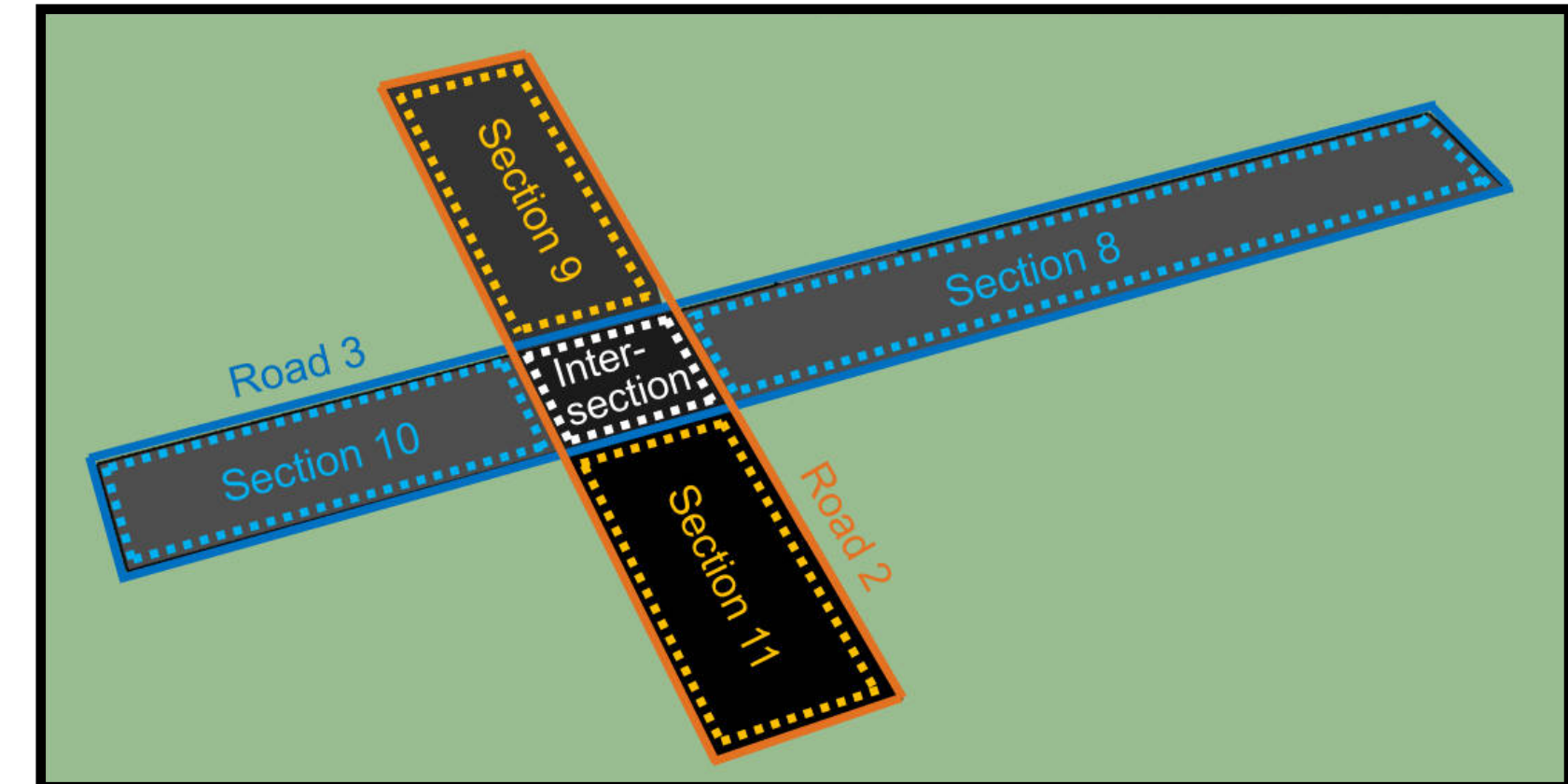
# More basic examples



Example 4: Shared surfaces between a road and a bridge (link)



Example 5: Shared surfaces in a parking garage (link)



Example 6: Intersection shared by two roads (link)