A *gentle* introduction to CityGML

Giorgio Agugiaro

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License

Giorgio in a nutshell

- **2002**, Degree in Environmental Engineering (Uni Padova & BOKU Vienna)
- **2009**, Ph.D. in Geomatics (TU Berlin & Uni Padova)
- **2010-2014**, 3D Optical Metrology Unit, Bruno Kessler Foundation (Trento, Italy)
- **2013**, TU Munich, Institute of Geoinformatics
- **2014-2018**, Austrian Institute of Technology, Smart and Resilient Cities and Regions Unit (Vienna)
- **Since 2018**, TU Delft, 3D Geoinformation Group
  - More info: https://3d.bk.tudelft.nl/gagugiaro/

Research focus: Semantic 3D city modelling for urban applications

3D Geoinformation group

- Founded in 2015
- Faculty of the Built Environment & Architecture
- Head: Prof. Jantien Stoter
- https://3d.bk.tudelft.nl

- (Some) partners:

OGC® Making location count.

isprs

EuroSDR

erc European Research Council Established by the European Commission Supporting top researchers from anywhere in the world

NWO Applied and Engineering Sciences

kadaster

Rijkswaterstaat Ministerie van Infrastructuur en Milieu

cyclomedia

SWECO

GEONOVUM

AMS AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

3D Geoinformation group: team

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Assistant-prof.

Vincent van Altena
PhD candidate (external)

Ken Arroyo Ohori
Postdoc

Lukas Beuster
Research fellow

Martine de Jong-Lansbergen
Secretary

Anna Labetski
PhD candidate

Hugo Ledoux
Associate-prof.

Camilo Alexander Leon Sánchez
PhD candidate

Shenglan Du
PhD candidate

Weixiao Gao
PhD candidate

Clara García-Sánchez
Assistant-prof.

Margo van der Helm
Secretary

Zexin Yang
PhD candidate (external)

Xiaoxin Mi
PhD candidate (external)

Liangliang Nan
Assistant-prof.

Ivan Pađen
PhD candidate

Nadine Hobeika
PhD candidate

Jin Huang
PhD candidate

Nail Ibrahimli
PhD candidate

Patrick Janssen
Associate-prof. (external)

Ravi Peters
Postdoc

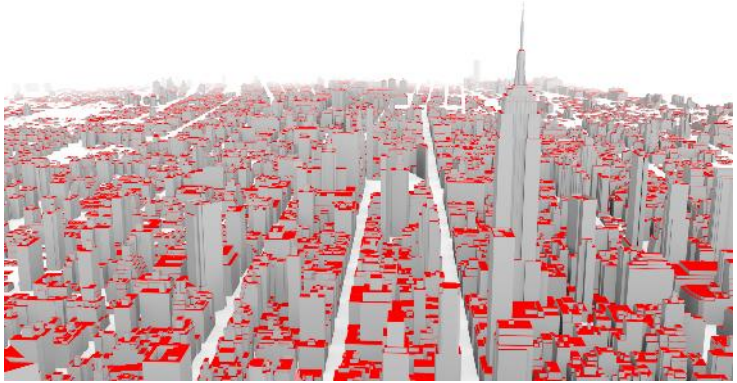
Maarten Pronk
PhD candidate (external)

Jantien Stoter
Professor

Stelios Vitalis
PhD candidate

3D Geoinformation group: mission & vision

- Design, develop, and implement better systems to model Digital Twins of cities, buildings, and landscapes…
- …to support environmental modelling and urban planning & design



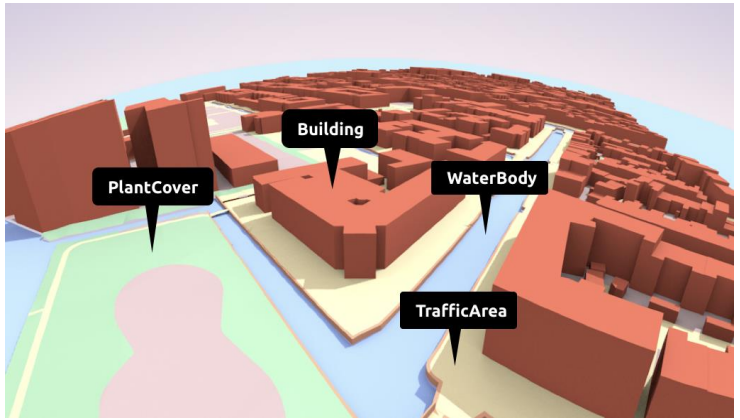


Image source: Flaticon.com

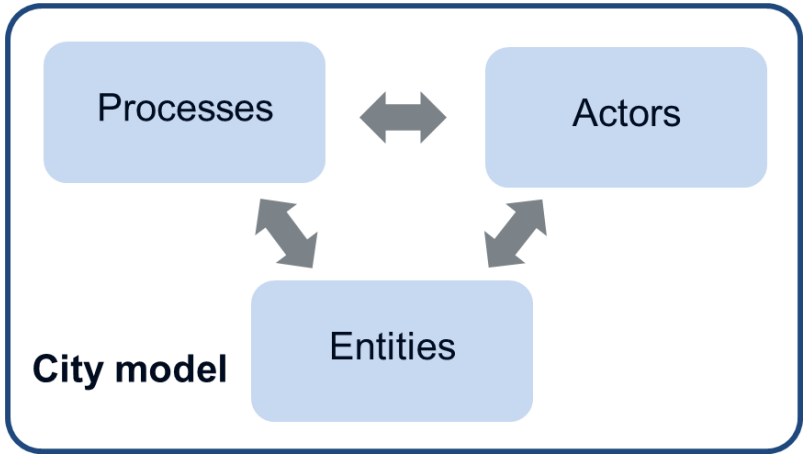
City modelling

Real city

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

represented by

Digital *geo*Twin

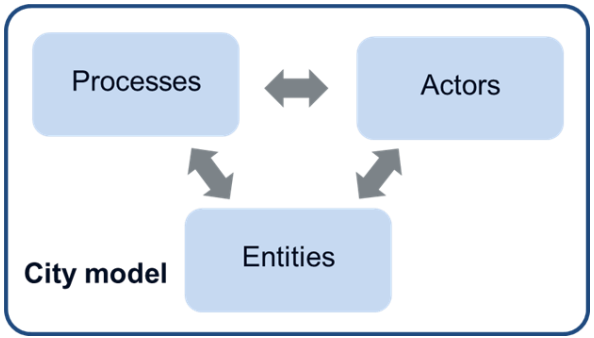


City modelling: today

- Separate modelling, generally by specific sectors, e.g.
  - Energy
  - Mobility
  - Ecology
  - Economy
  - Surveying

  Community
  Models
  Indicators
  Planning

Which digital twin?



Everybody will answer:
"My digital twin, of course!"

Information flow for urban development

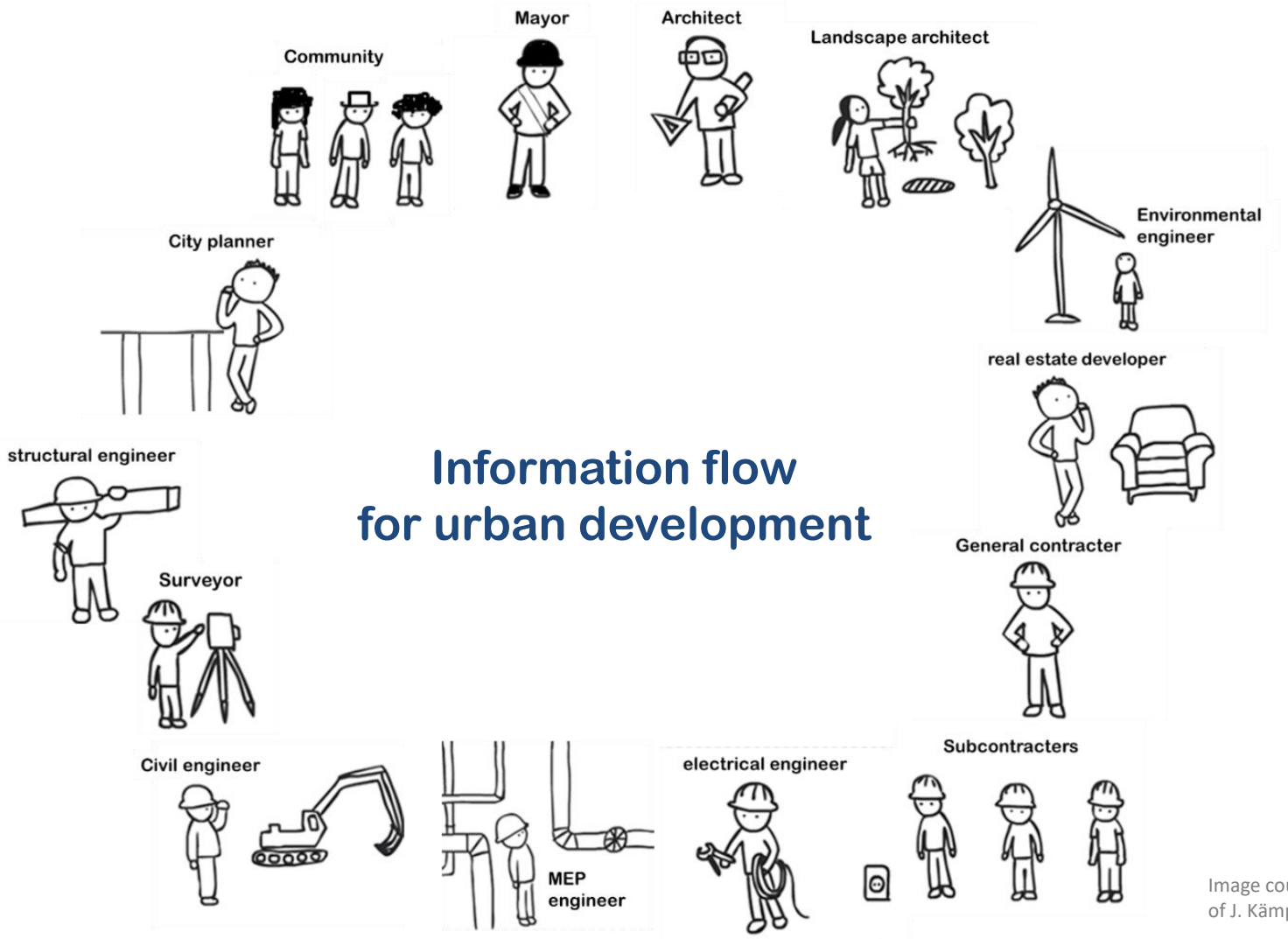


Image courtesy of J. Kämpf

TU Delft 3Dgeoinfo

Semantic 3D city modelling

CityGML 2.0 intro

Applications

CityGML 3.0

Conclusions

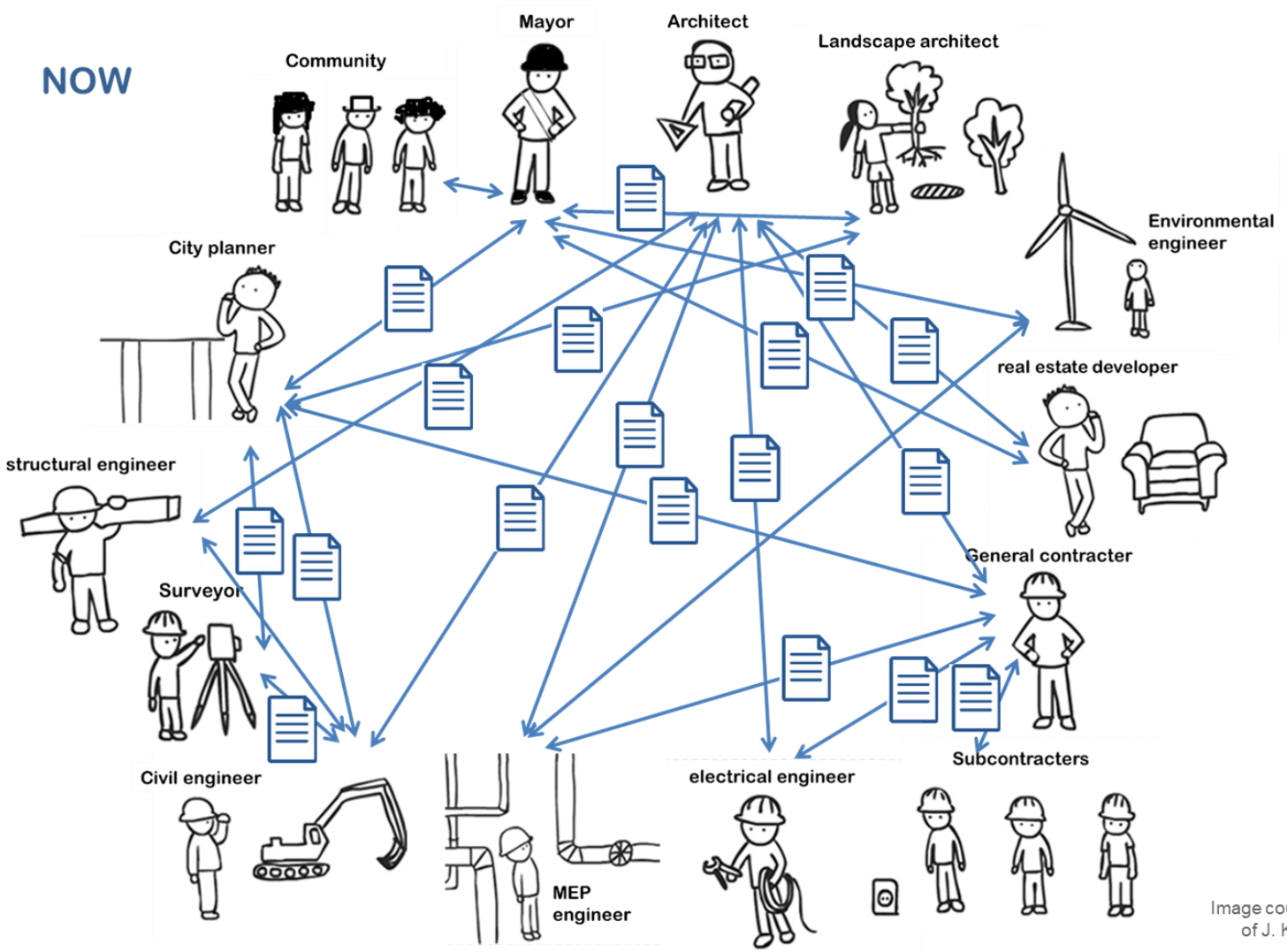


Image courtesy of J. Kämpf

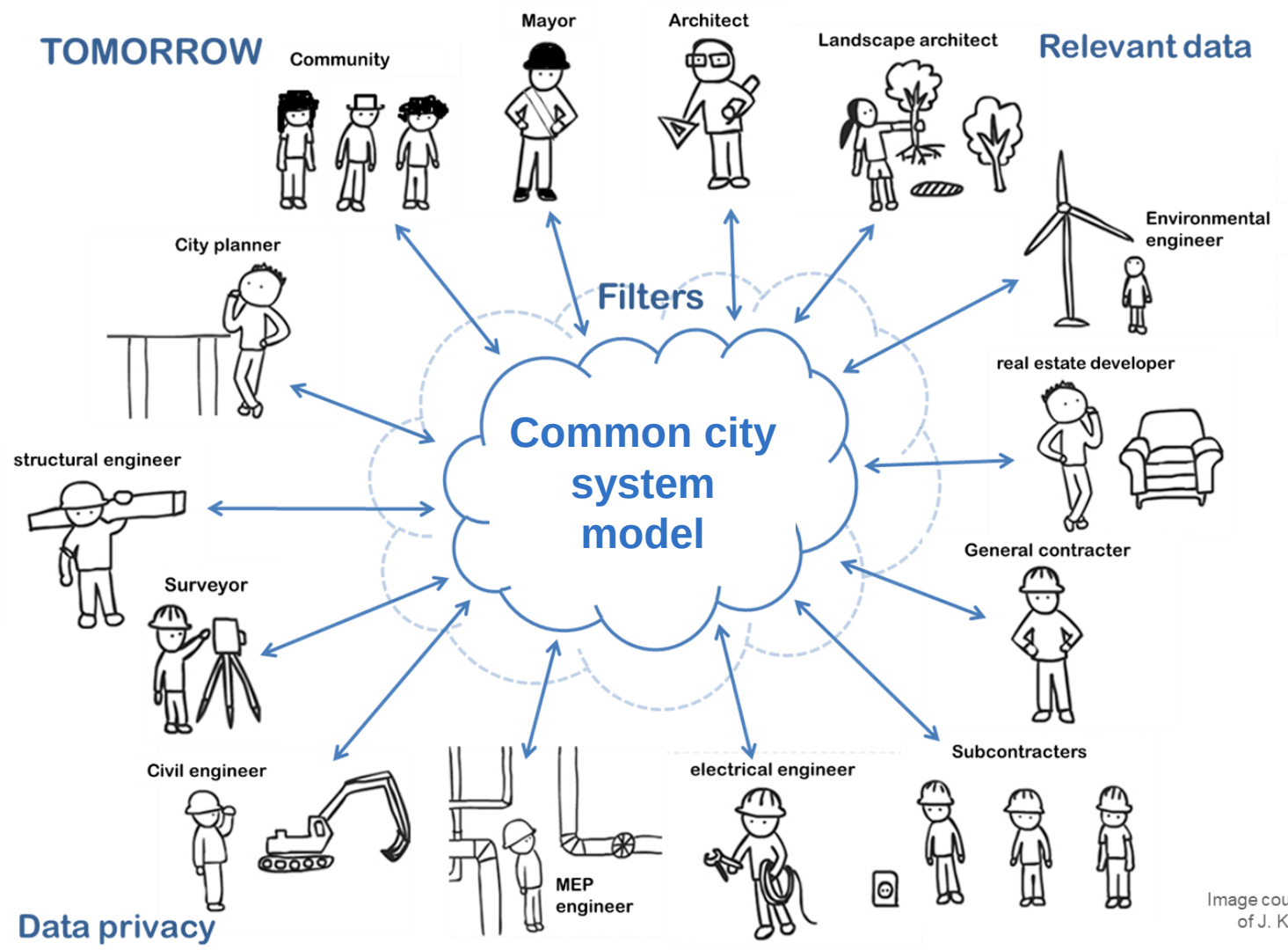


Image courtesy of J. Kämpf

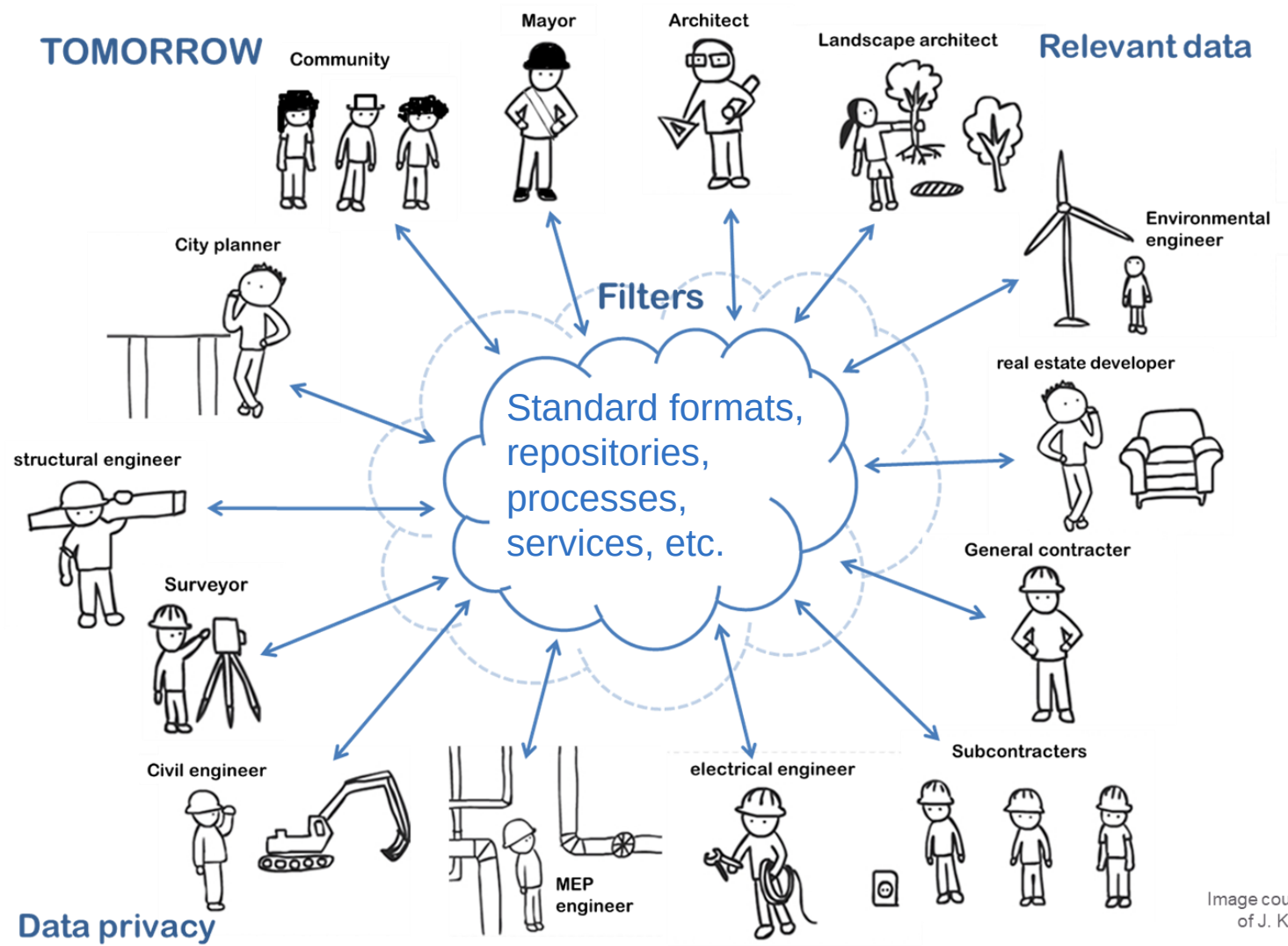
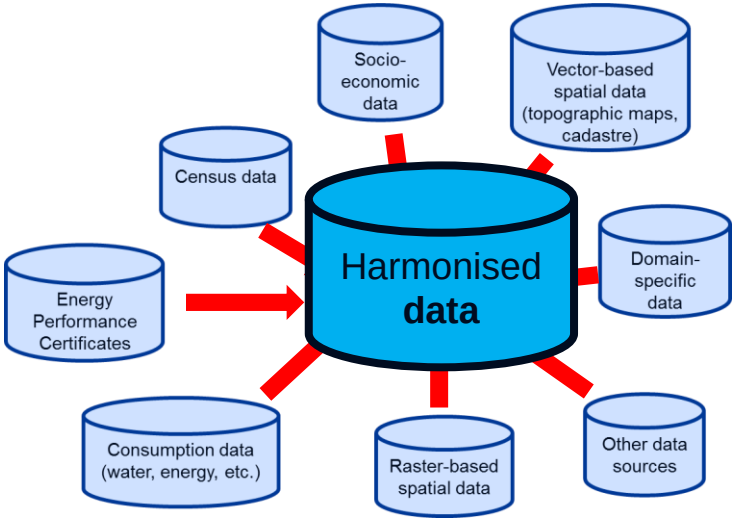
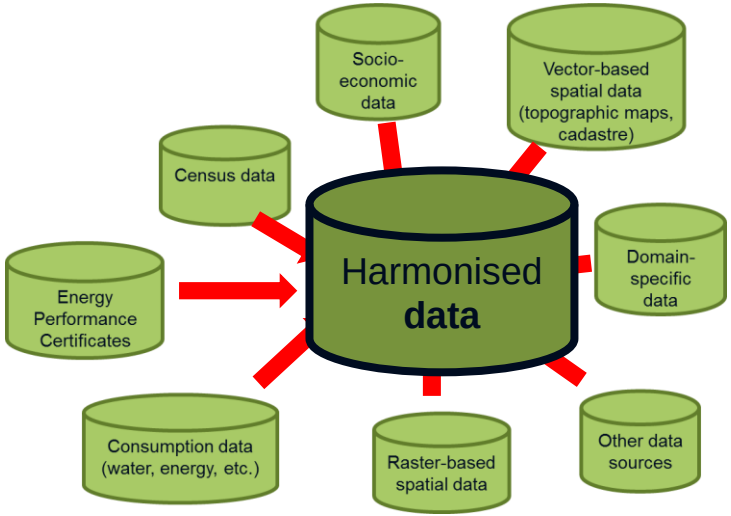


Image courtesy of J. Kämpf

Dealing with urban data...

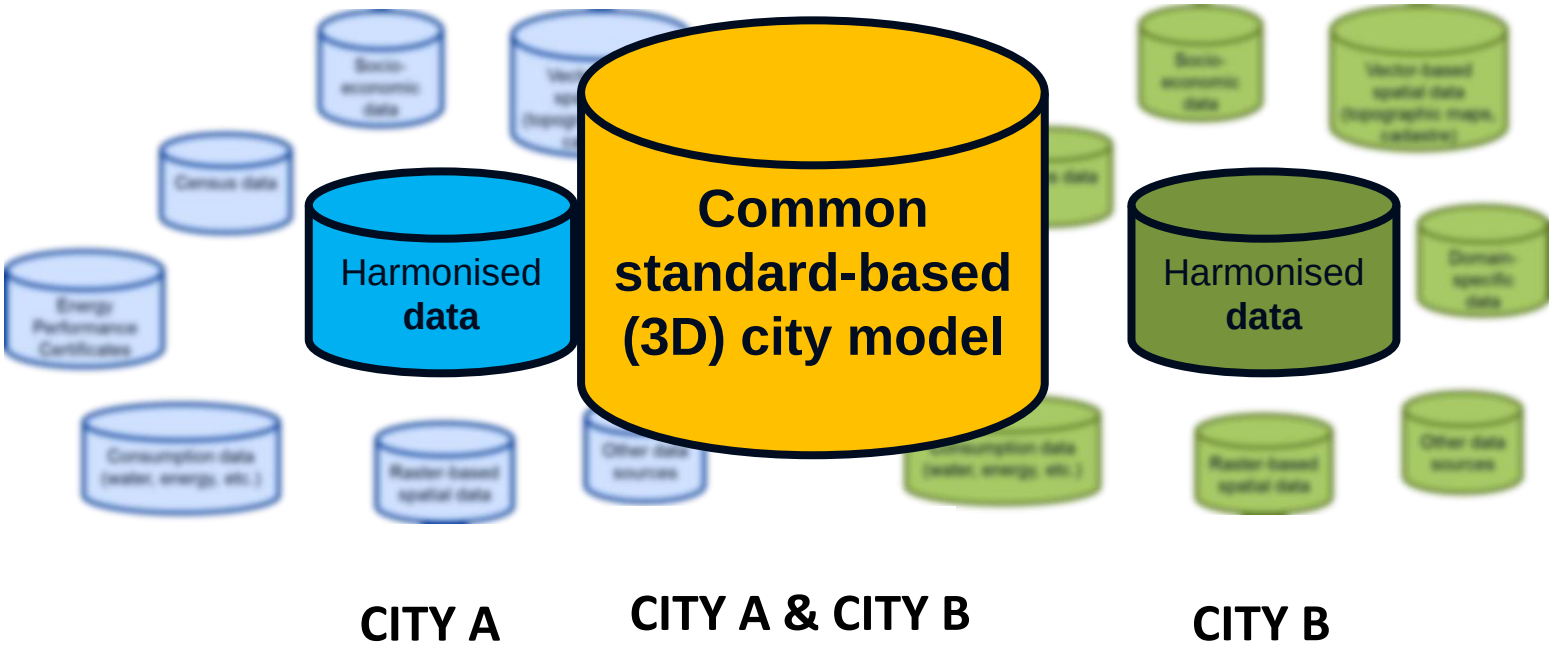


CITY A

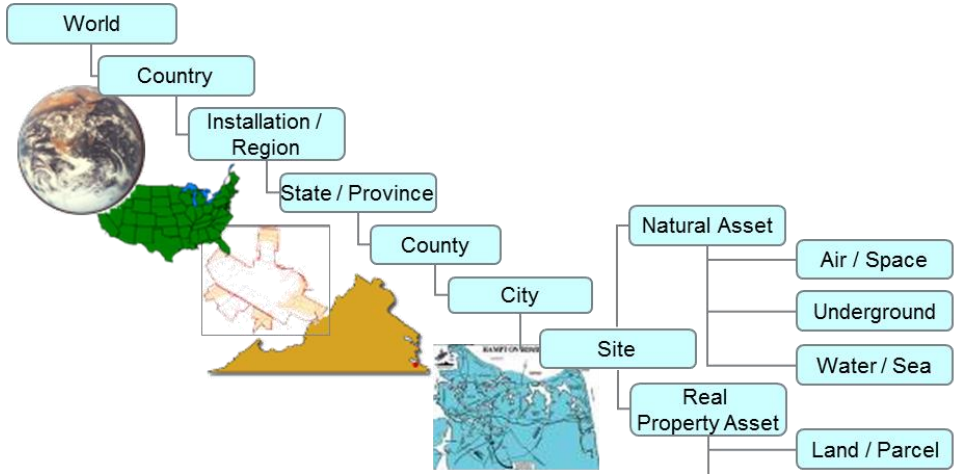


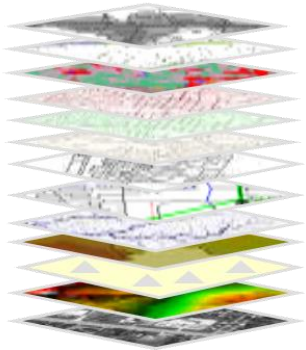
CITY B

Dealing with urban data...

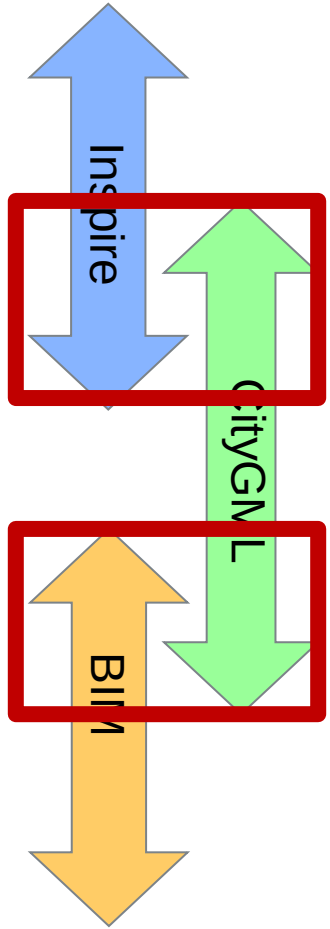


What about existing (open) geospatial standards?

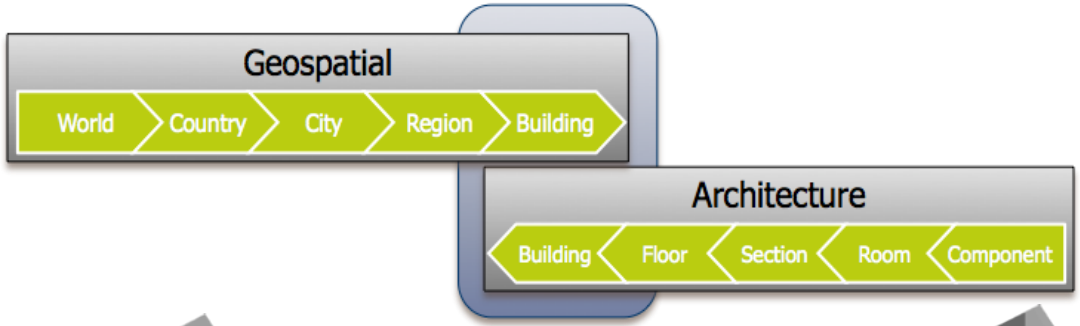


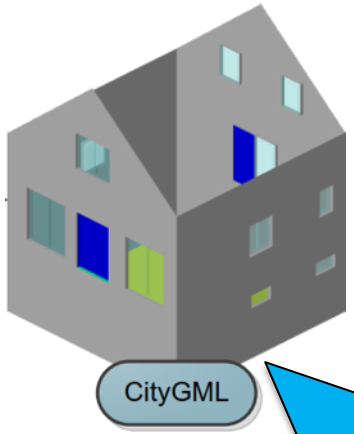


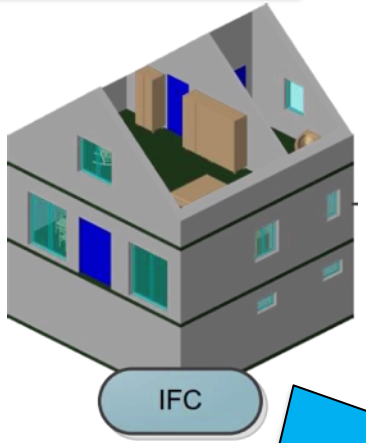
Territorial scales



What about existing geospatial standards?







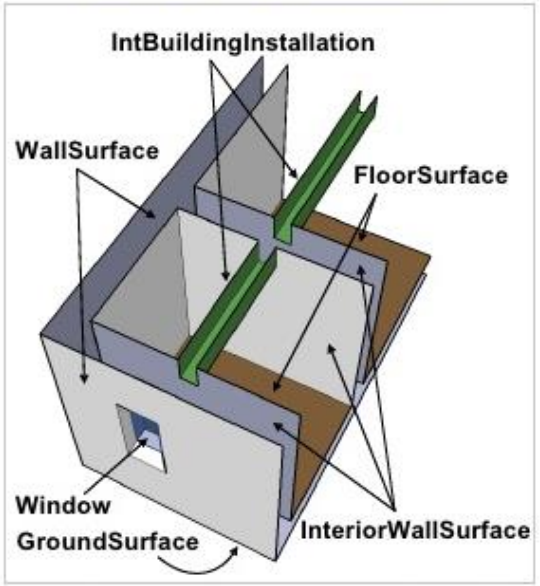
One object modelled as closed volume; no "thick" walls

Many objects (all volumes, mostly modelled as parametrized geometries)

GIS vs BIM world

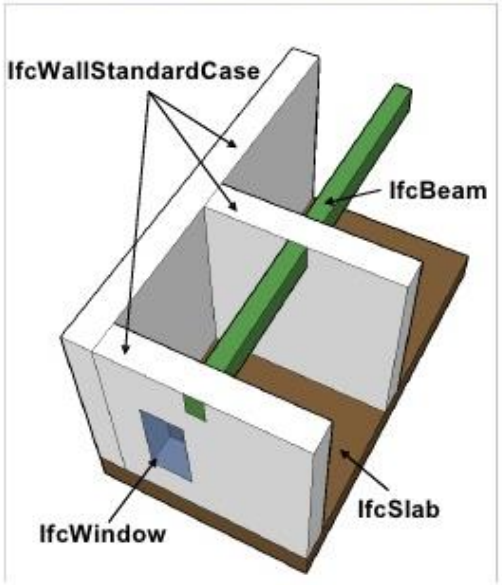
Differing geometric modelling paradigms

Boundary Representation



Accumulation of observable surfaces of topographic features

Constructive Solid Geometry



Volumetric, parametric primitives representing the structural components of buildings

Image source: Kolbe, Nagel, Stadler (2009)

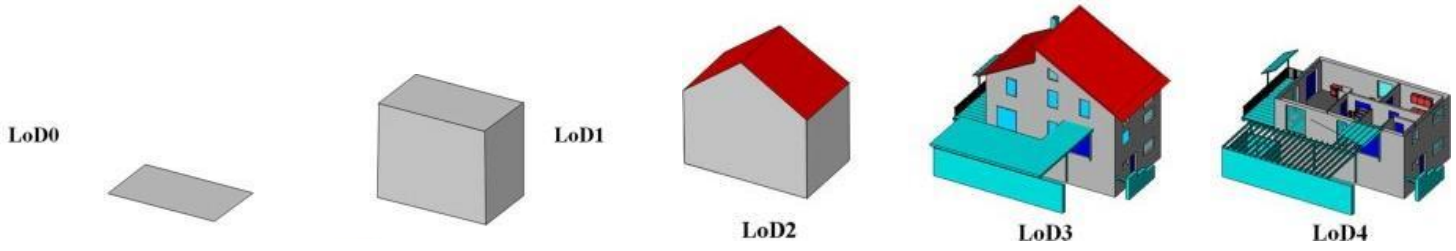
CityGML: City Geography Markup Language

- **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 **3D geometry at multiple levels of detail (LoD)**, topology, semantics and appearance

- **Extendible** to other application domains



CityGML

- CityGML 1.0: released in 2008
  - Released as OGC Standard
- CityGML 2.0: released in 2012
  - Addition of Bridge and Tunnel modules
  - Minor other changes
  - Core of this presentation
- CityGML 3.0: data model released in 2021
  - Major revision of existing modules
  - Addition of Versioning, Dynamizers, support for PointClouds
  - Some slides at the end of this presentation

CityGML 2.0: Modules overview

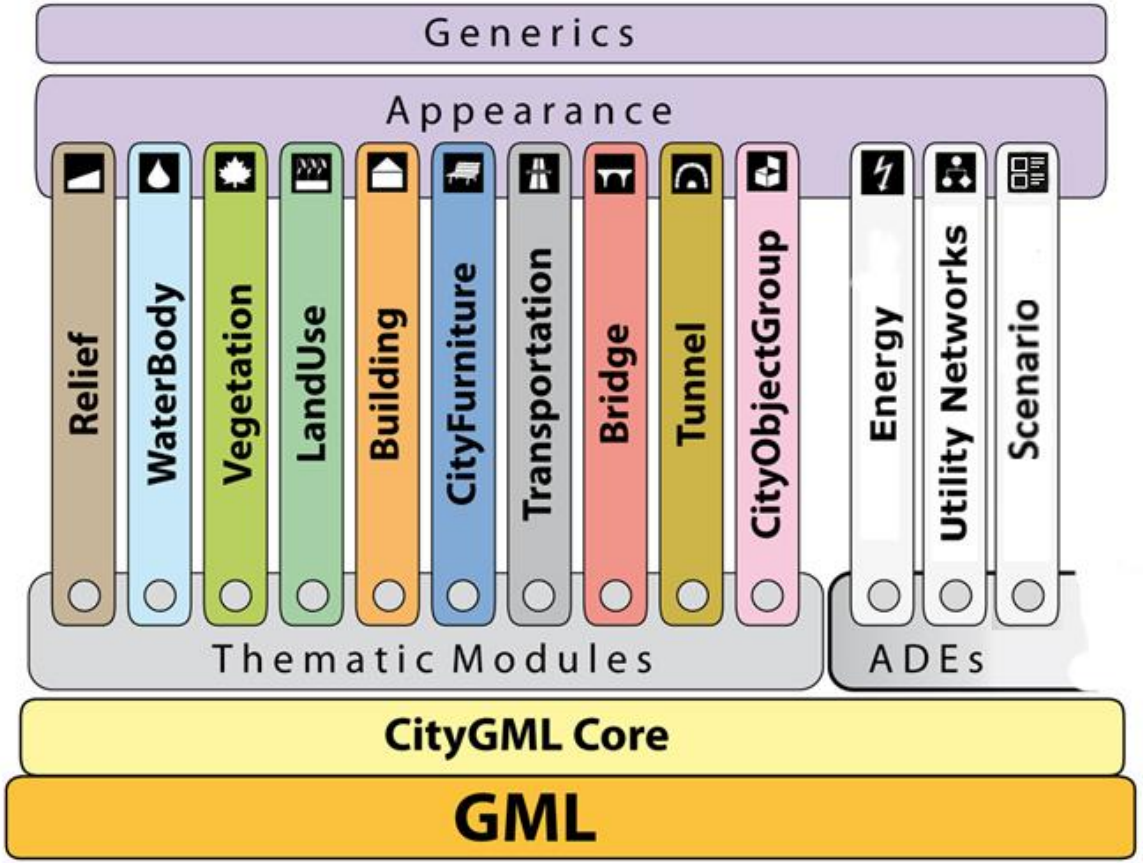
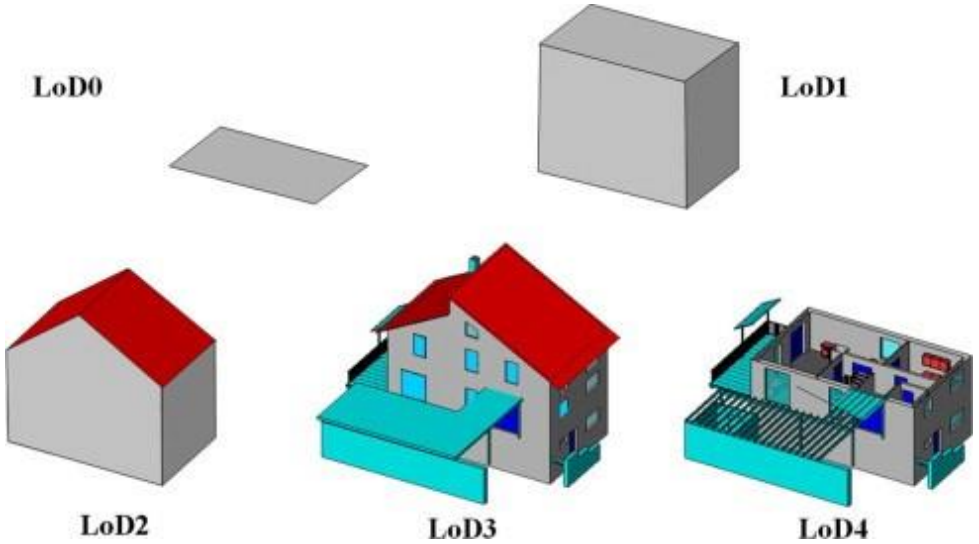


Image source: VCS

CityGML: Building module

- Nowadays: creation of 3D city models (up to LoD2) is nearly completely automatic
- Geometric modelling as solids, multi-surfaces, or (from LoD2) thematic surfaces
- Possibility to partition buildings in building parts



CityGML: Building module

CityGML: Tunnel module

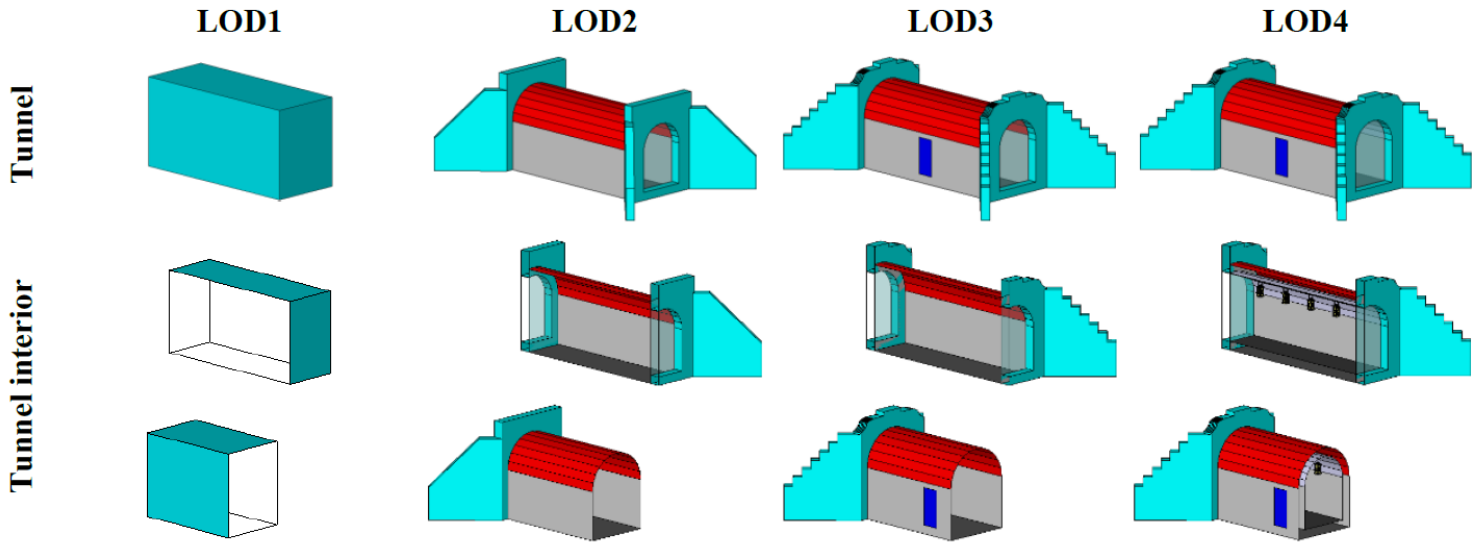


Fig. 40: Tunnel model in LOD1 – LOD4 (source: Karlsruhe Institute of Technology (KIT)).

CityGML: Bridge module

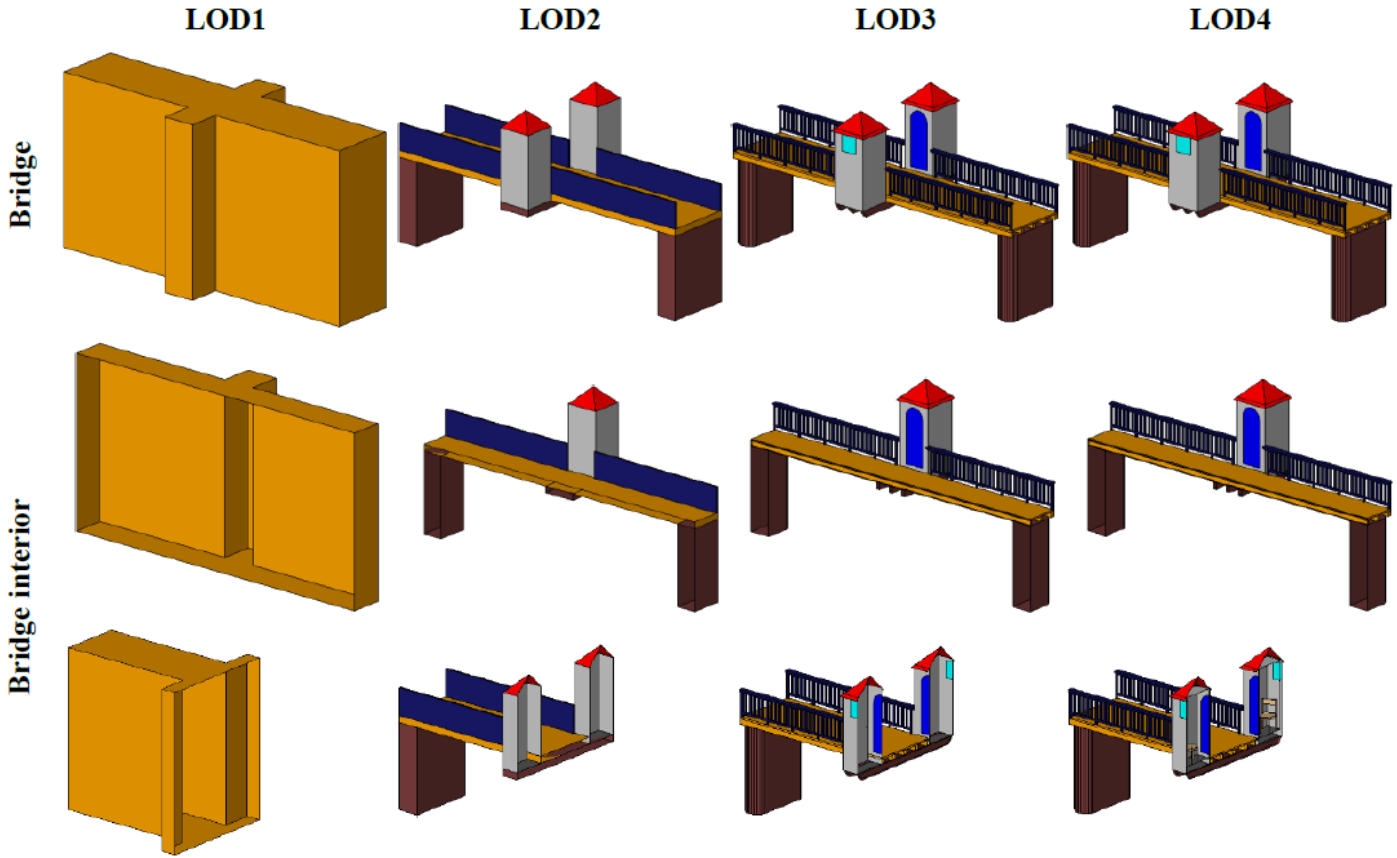


Fig. 46: Bridge model in LOD1 – LOD4. (source: Karlsruhe Institute of Technology (KIT))

CityGML: City furniture module

- Conceived mainly for immovable objects like street lanterns, bus stops, street signs, etc.

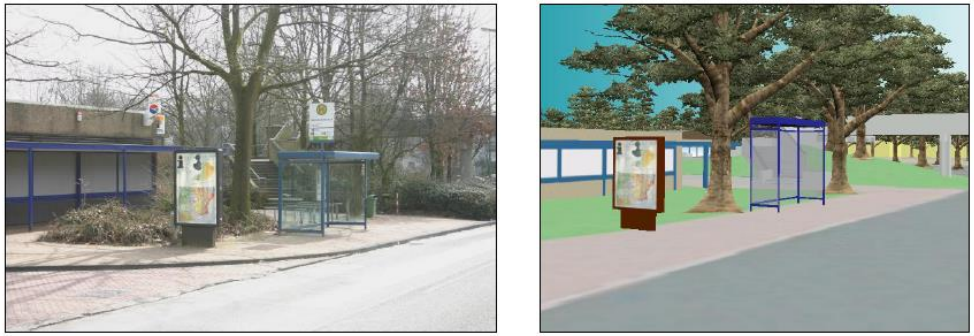


Fig. 67: Real situation showing a bus stop (left). The advertising billboard and the refuge are modelled as *CityFurniture* objects in the right image (source: 3D city model of Barkenberg).

- Can be represented also as <u>implicit geometries</u>
  - You use one geometric prototype that you "clone" several times providing each time the specific position, orientation and scaling

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 module

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

- Plant cover can be represented only as MultiSurface or MultiSolid

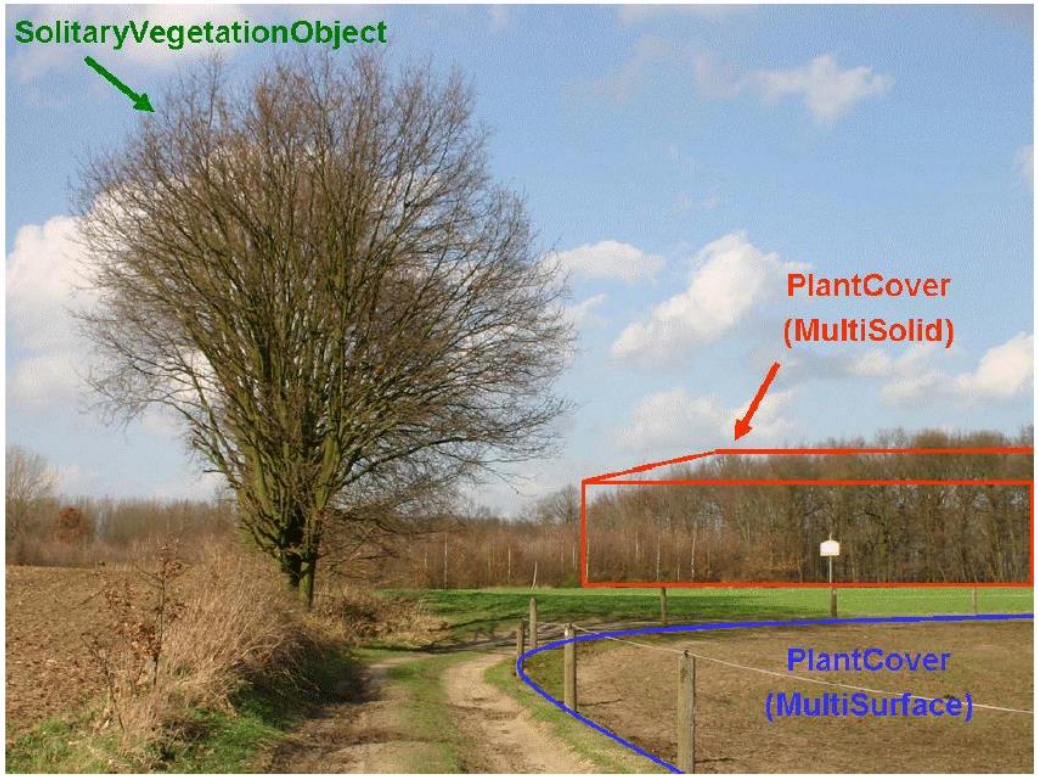
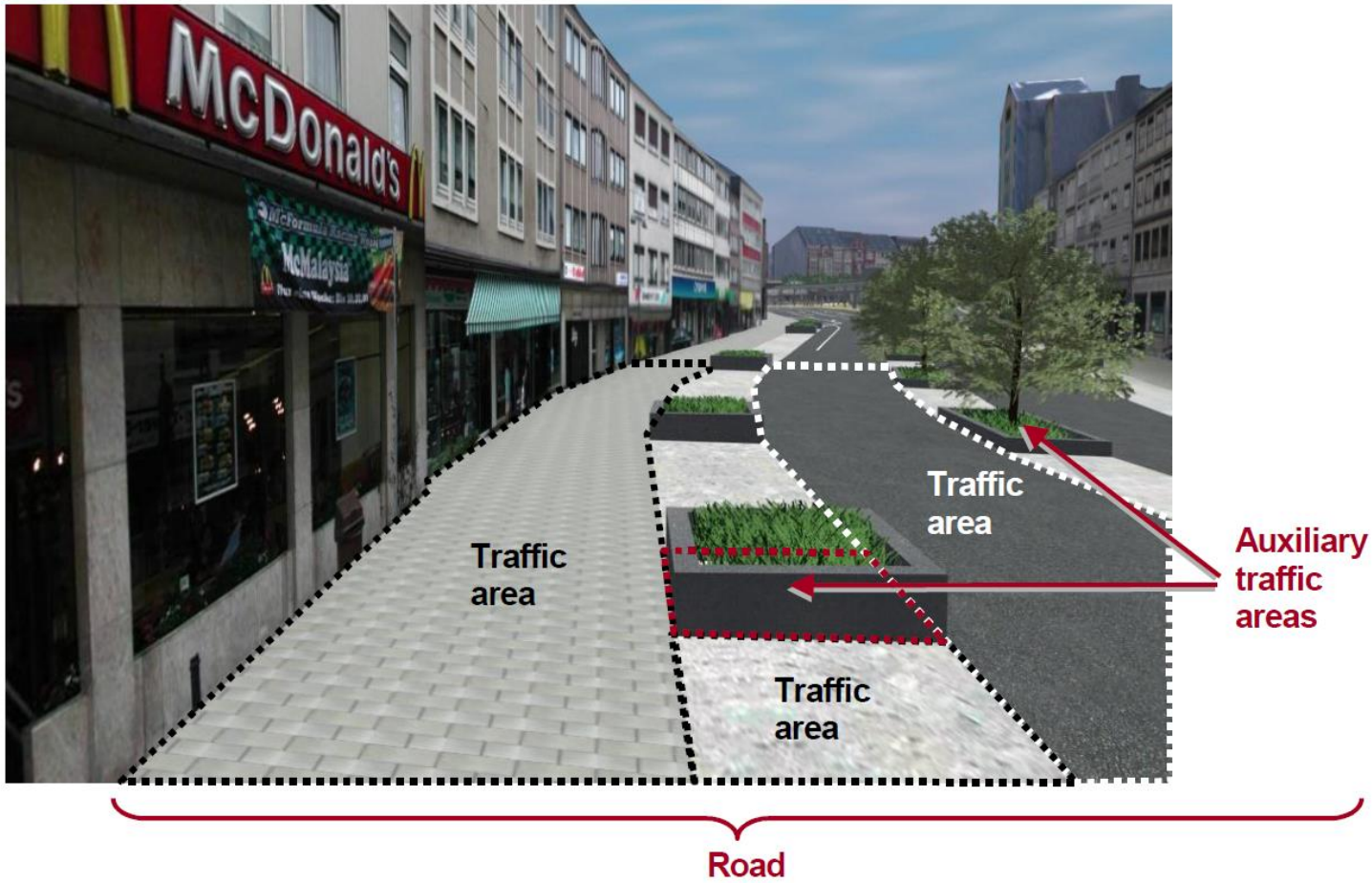
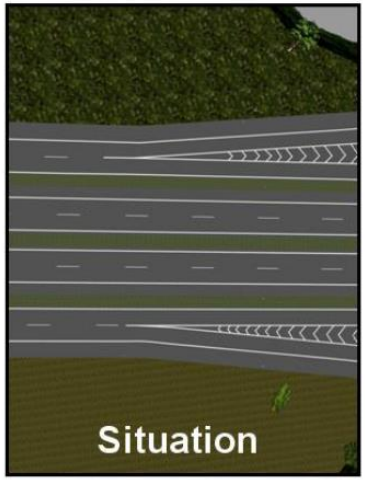


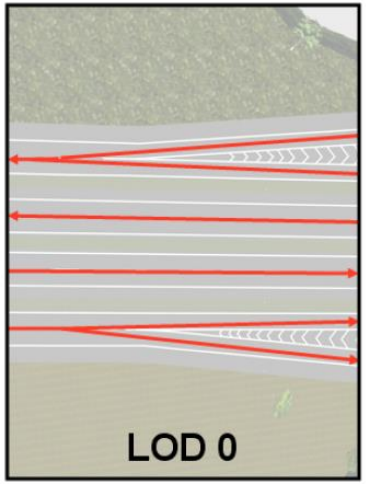
Fig. 63: Example for vegetation objects of the classes *SolitaryVegetationObject* and *PlantCover* (graphic: District of Recklinghausen).

CityGML: Transportation module



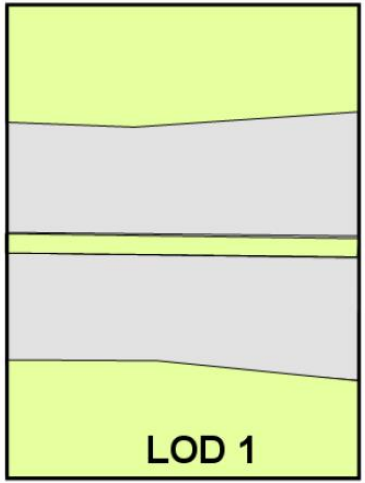
CityGML: Transportation module





TransportationComplex provides linear network with line objects

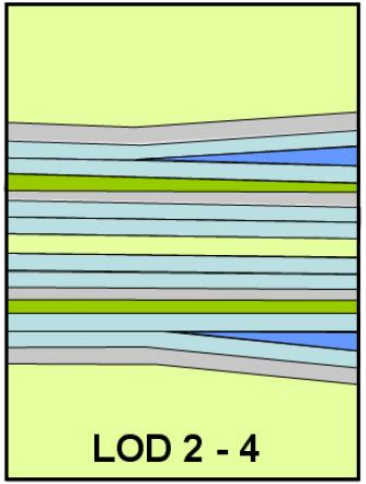
line objects



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 module

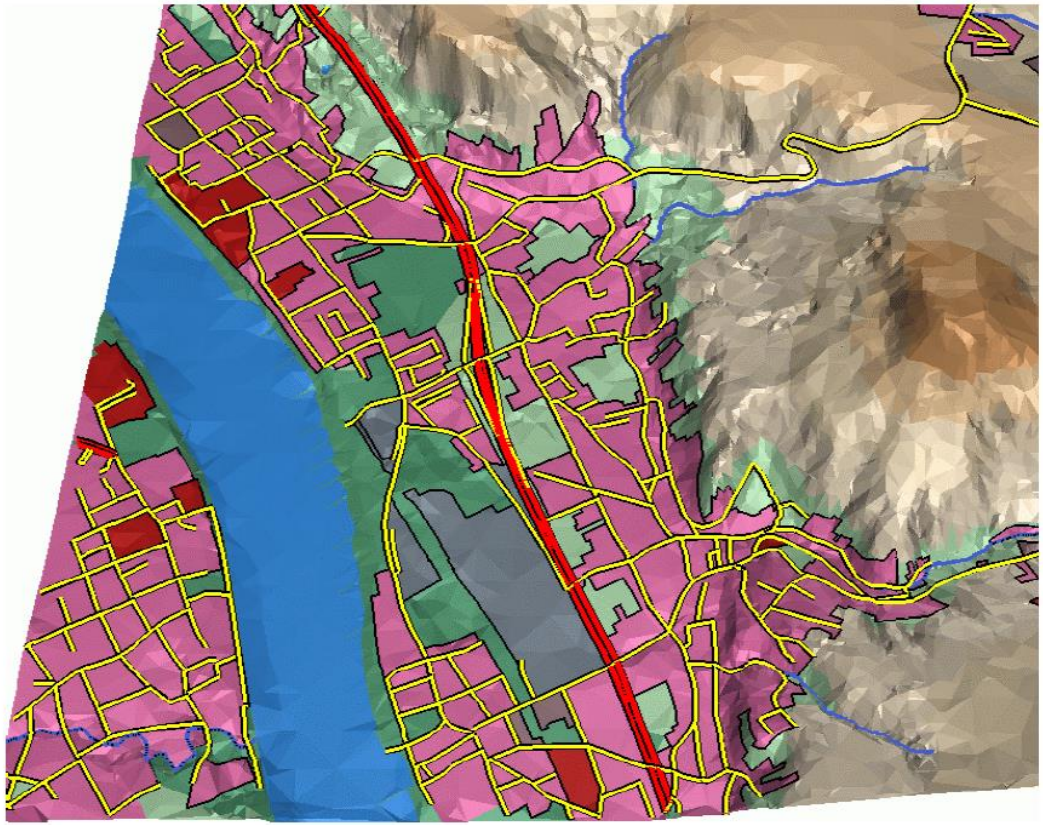


Fig. 72: LOD0 regional model consisting of land use objects in CityGML (source: IGG Uni Bonn).

CityGML: Waterbody module

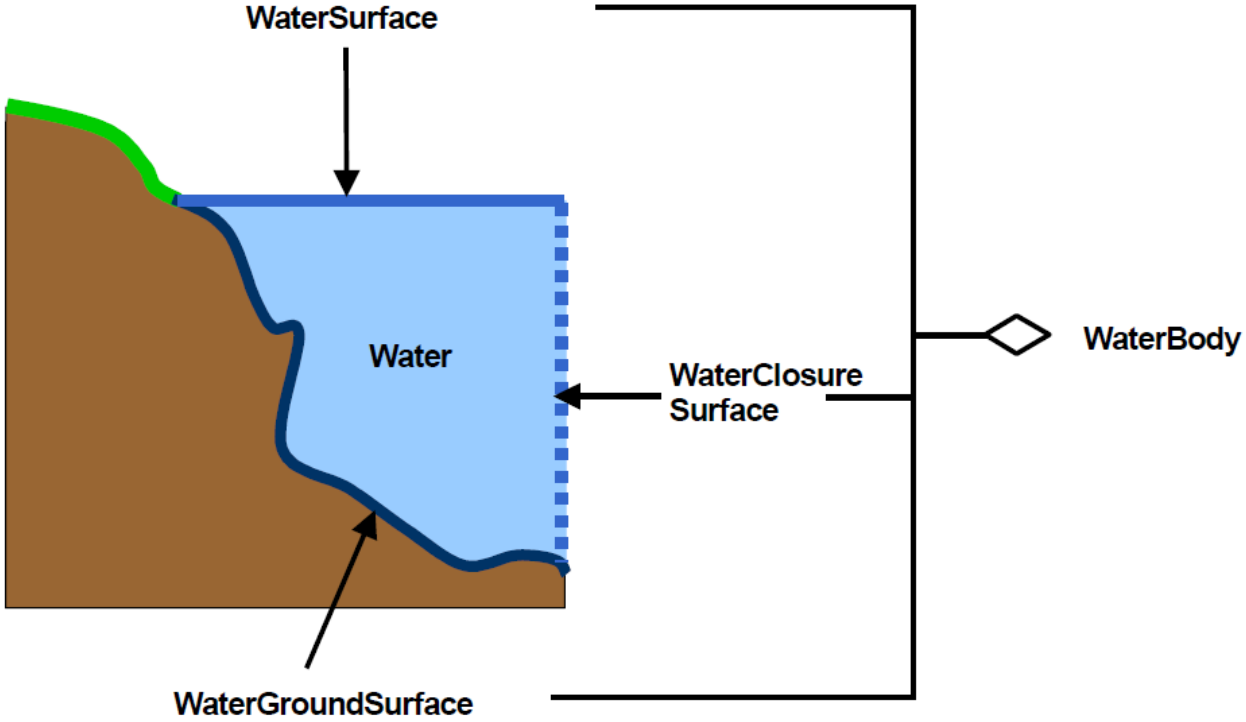
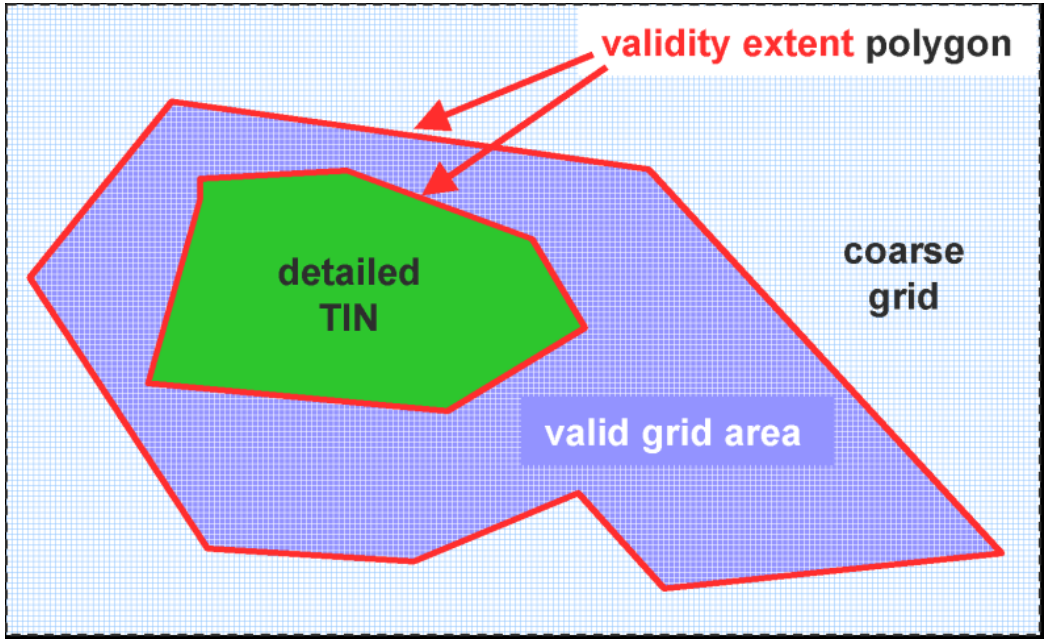


Fig. 55: Illustration of a water body defined in CityGML (graphic: IGG Uni Bonn).

CityGML: Terrain module

- 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

CityGML: beyond 3D geometry!

- 3D visualisation (geometry and graphical appearance) is just the very tip of the iceberg!

- CityGML objects have plenty of attributes, relations
  - They account for the core of semantic modelling
  - But, yes, these are less visible at a first sight…

CityGML: a closer look

- CityGML is actually two things
  a) It refers to the name of the **data model**
  b) It refers to one possible **encoding** of the data model

- The conceptual **data model** consists of UML diagrams (and the accompanying specifications)
- The **encoding** is how this information is actually written (e.g. to a file)
  - The most common encoding is by means of XML
  - The «rules» are encoded in a XSD file (XML Schema Definition)
  - The contents are written in a XML document «obeying» to the rules of the XSD file (the check is called «validation»)

- But there exist other encodings, e.g. **CityJSON** (developed @ TU Delft), or as SQL-based database model (**3D City Database**)

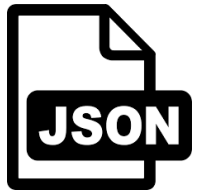
CityGML: a closer look

CONCEPTUAL DATA MODEL
(e.g. specifications, UML diagrams, etc.)

Application
+ **D**omain
Extensions

ENCODINGS

CityGML

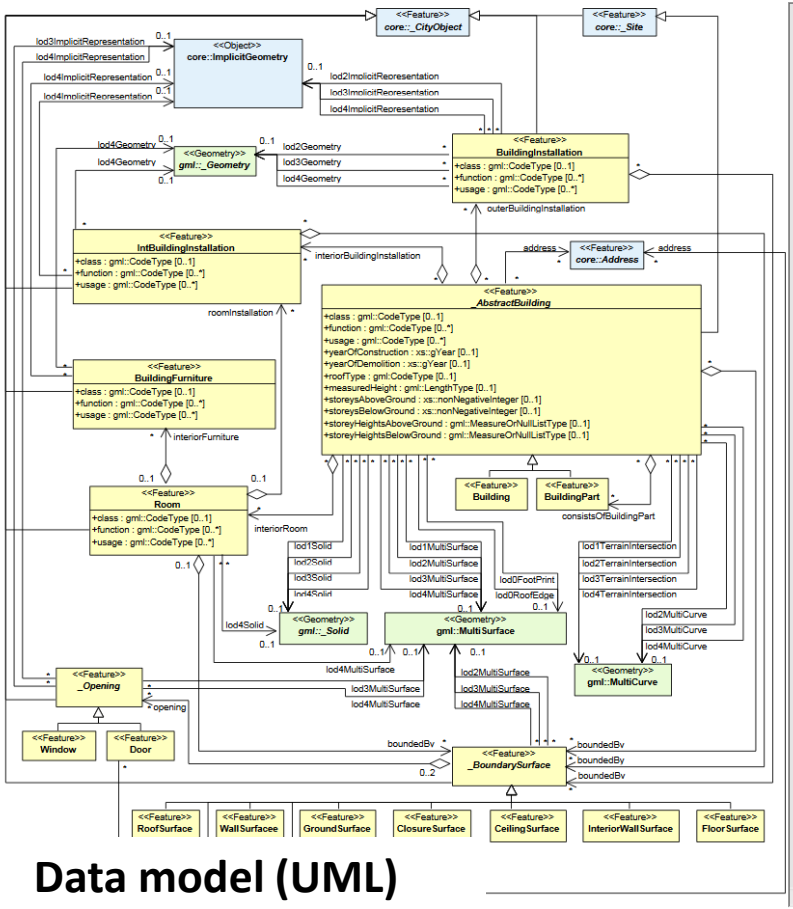


CityJSON

3D City Database

CityGML: a closer look

Semantic 3D city modelling
CityGML 2.0 intro
Applications
CityGML 3.0
Conclusions



Data model (UML)

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  <gml:description>CityGML-based 3D model of the city of Vienna generated by Giorgio
  <gml:name>Wien</gml:name>
  <gml:boundedBy>
    <gml:Envelope srsName="urn:ogc:def:crs,crs:EPSG::31256,crs:EPSG::5176" srsDimensi
      <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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    <grp:CityObjectGroup gml:id="UUID_e8f506df-8878-4ab8-b55a-ddac90da26b3">
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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">
          <gml:description>This is a single-part building</gml:description>
          <core:creationDate>2016-04-07</core:creationDate>
          <bldg:function>Building</bldg:function>
          <bldg:roofType>Satteldach</bldg:roofType>
          <bldg:measuredHeight uom="m">15.67</bldg:measuredHeight>
          <bldg:lod0FootPrint>
            <gml:MultiSurface gml:id="multi_surf_uuid_e07d7e62-8983-439d-b6e3-e42462f
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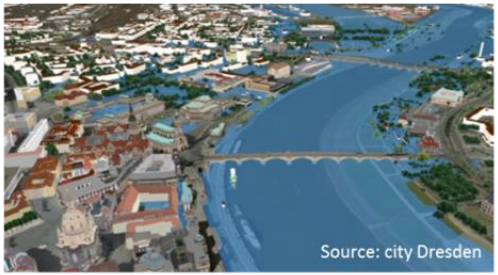
```

(XML) encoding

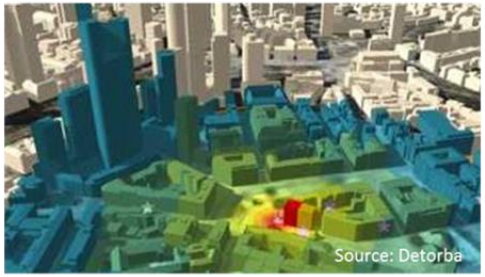
CityGML in action

(Some) applications

3D city models for…

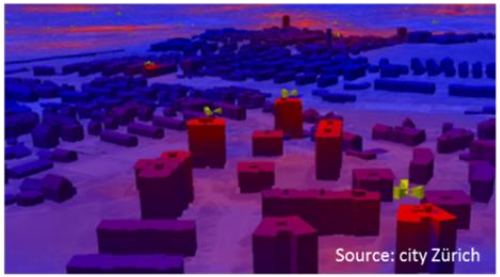


Flood risk analysis

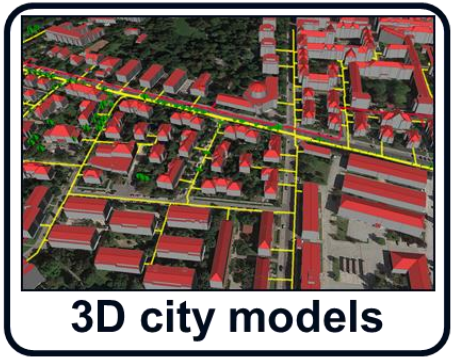


Explosion simulation

Urban planning



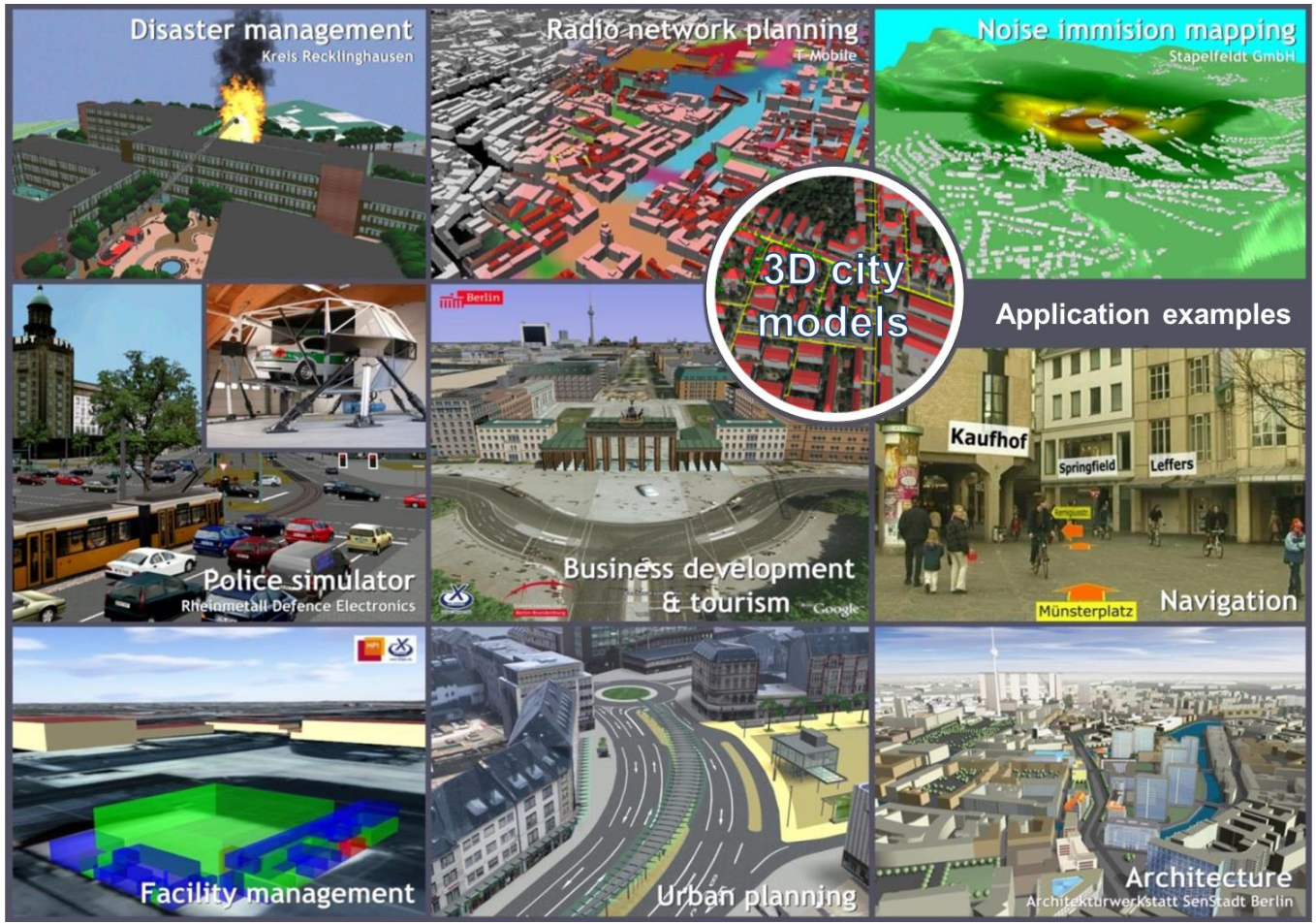
Cellular radio planning/pollution



3D city models

Lighting simulation

3D city models for…



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3D city models for…

Solar irradiation and photovoltaic suitability

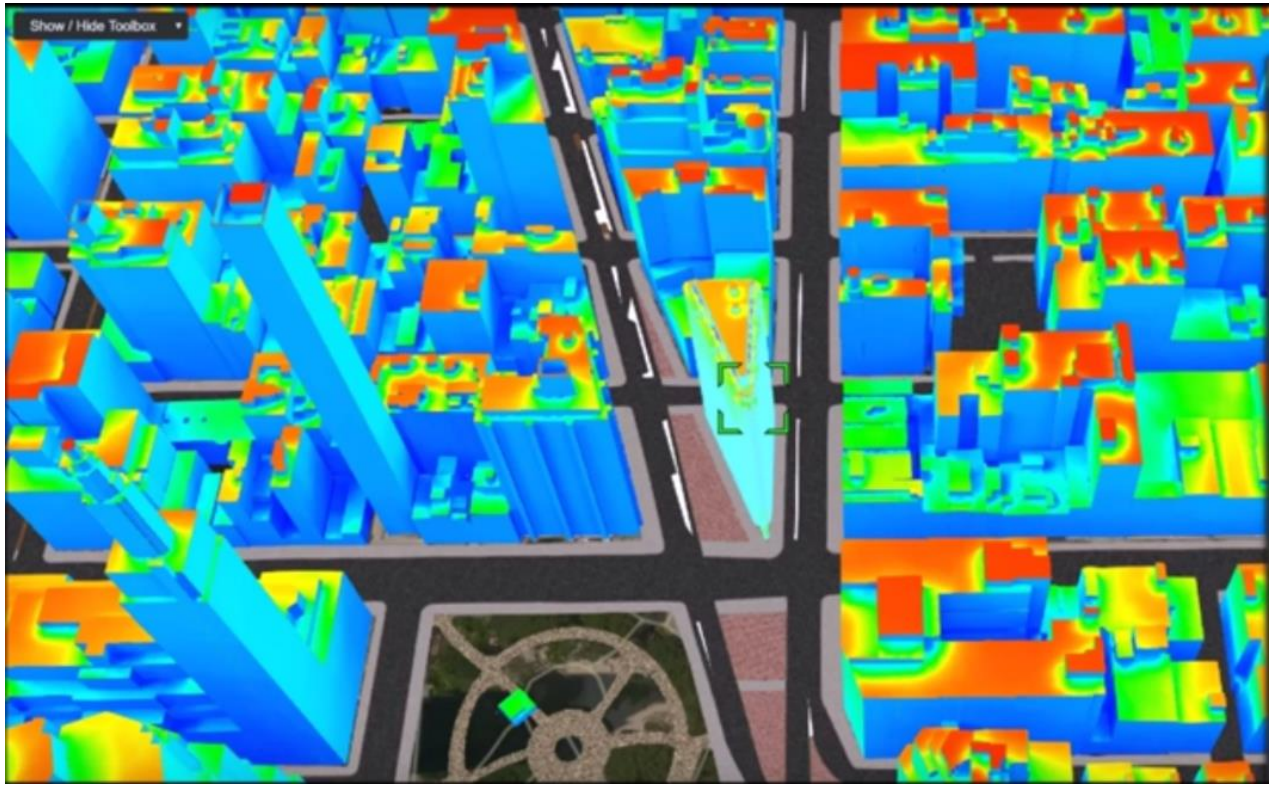


Image source: https://youtu.be/pba-ernLoNo?t=23

3D city models for…

Traffic simulation

Image source: https://youtu.be/nLRUyfwVESg?t=25

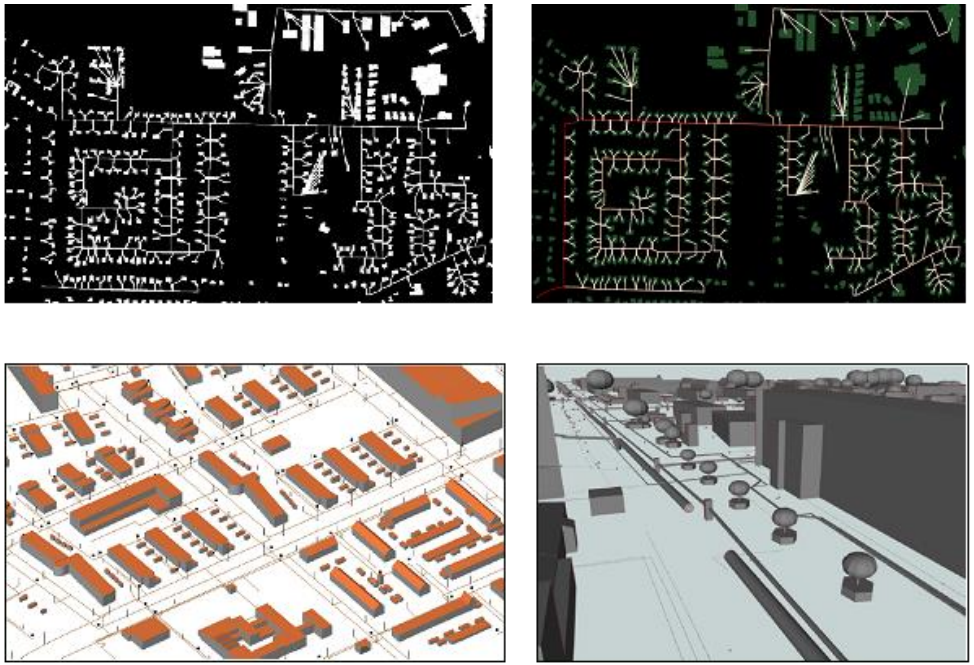
3D city models for…

Planning of street lighting

Image source: https://www.virtualcitysystems.de/images/newsletter/Streetlight_Energy_Simulator_Berlin_Moabit.PNG

3D city models for…

Management of supply networks



More details:
Den Duijn, X., Agugiaro, G., Zlatanova, S., 2018, **Modelling below- and above-ground utility network features with the CityGML Utility Network ADE: experiences from Rotterdam**. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, IV-4/W7, pp. 43-50. https://www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/IV-4-W7/43/2018/

3D city models for…

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Urban noise studies

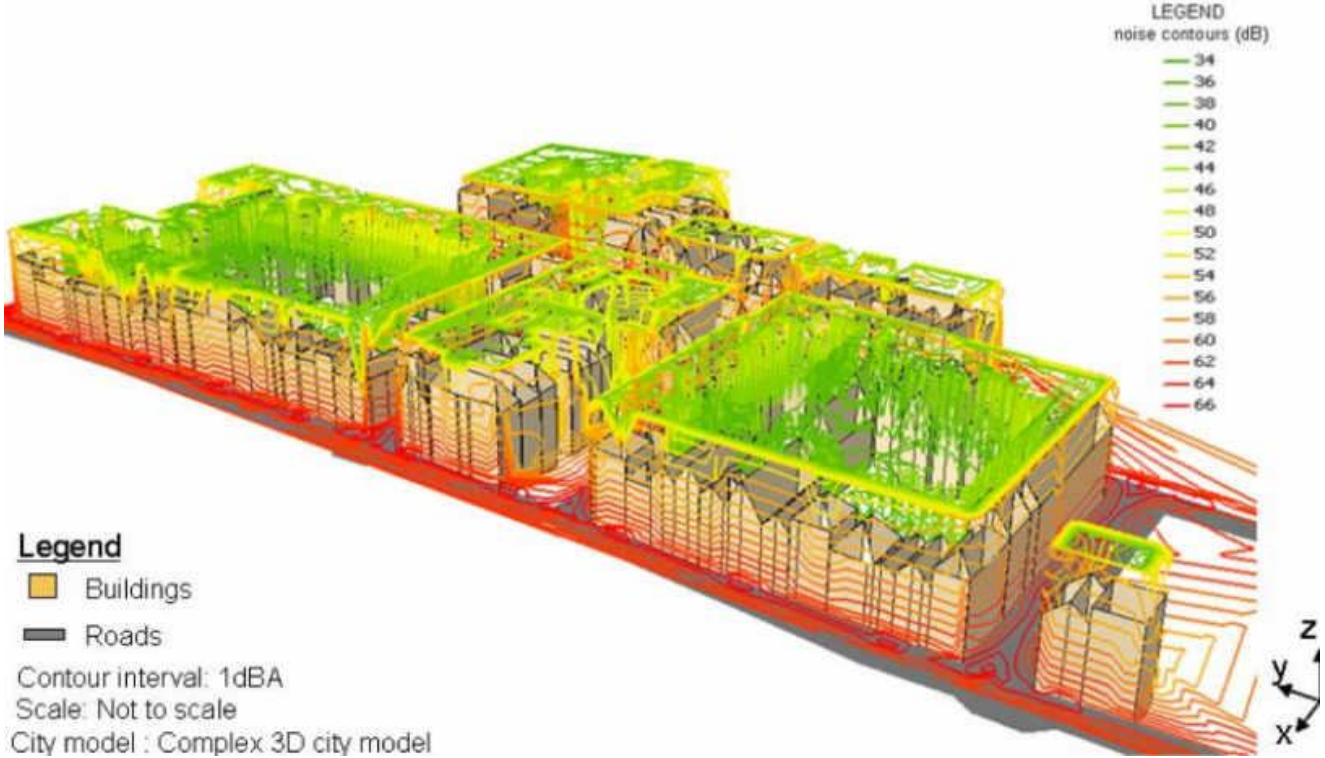

Image source: https://3d.bk.tudelft.nl/projects/noise3d/

3D city models for…

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Energy assessment of the built environment

Image source: Agugiaro (2016)

3D city models for…

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Energy assessment of the built environment

Further details:
Skarbal, B., Peters-Anders, J., Faizan Malik, A., Agugiaro, G., 2017,
How to pinpoint energy-inefficient buildings? An approach based on the 3D city model of Vienna.
ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-4-W3, pp. 71-78
https://www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/IV-4-W3/71/2017/

3D city models for…

Energy assessment of the built environment

3D city models for…

Micro-climate simulations

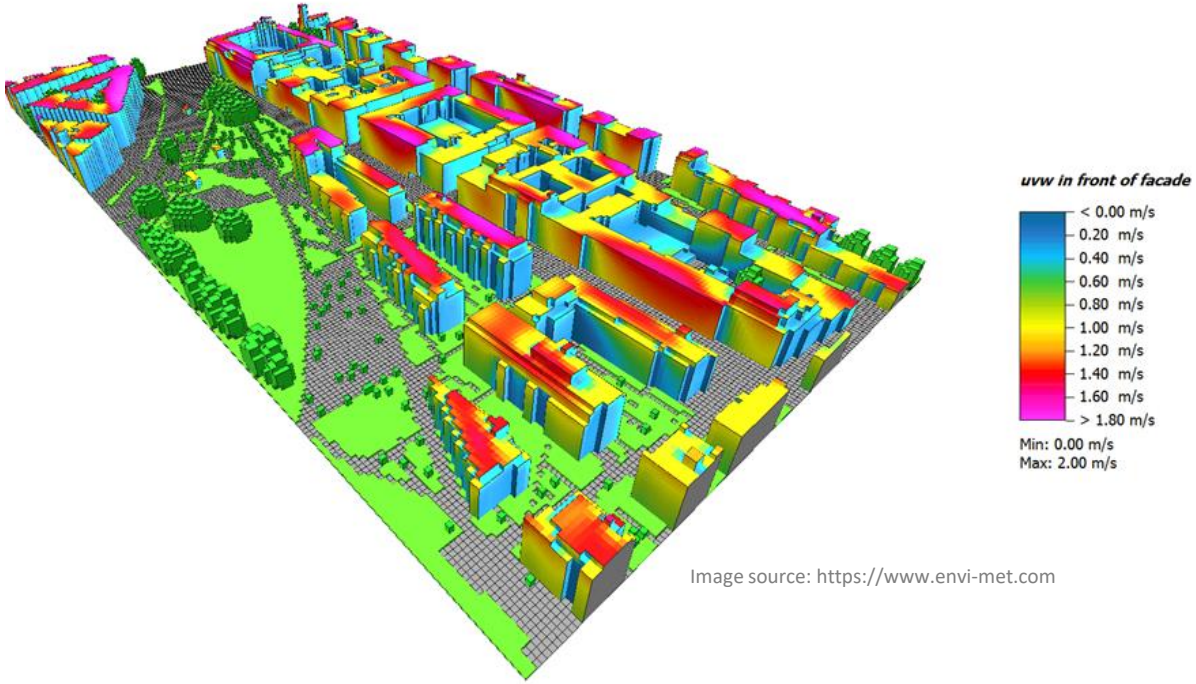

Image source: https://www.envi-met.com

More details:
T. Arapakis, 2019 **The use of digital models in microclimatic studies : First steps in coupling CityGML with ENVI-met** (MSc thesis)
https://repository.tudelft.nl/islandora/object/uuid%3A03ab695a-dc68-403a-b934-c810f087df42?collection=education

3D city models for…

Simulation of urban flows

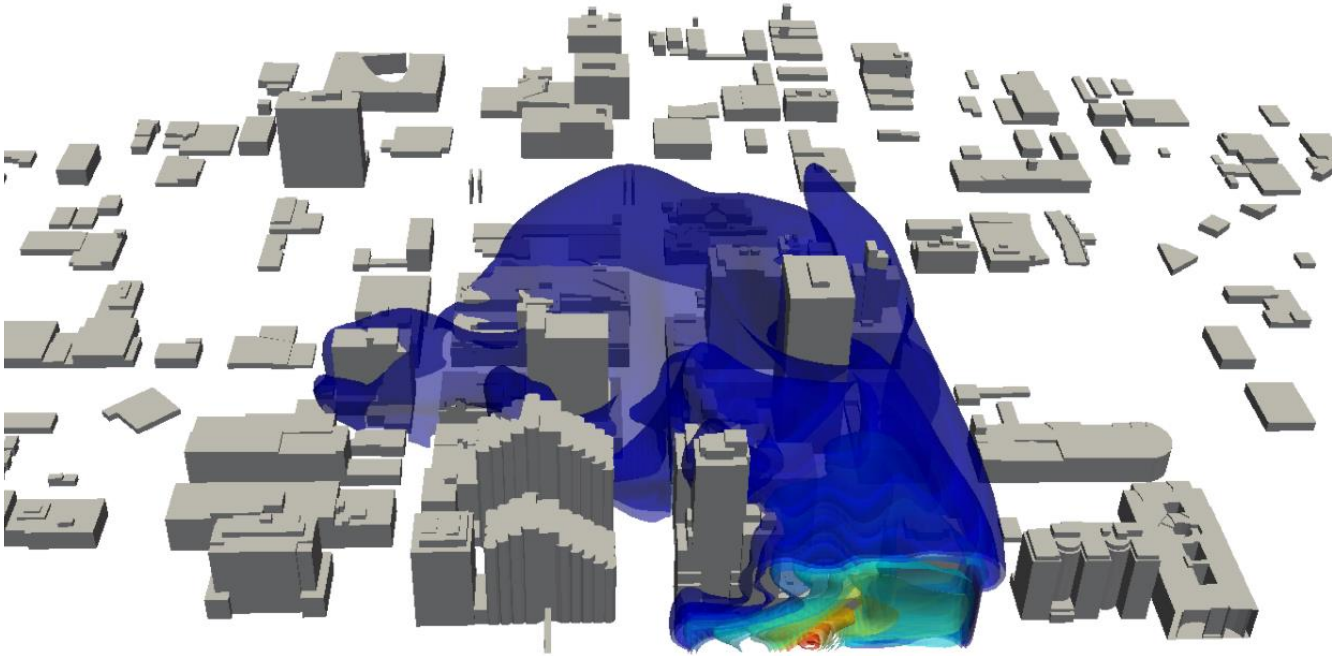

Image courtesy of Clara García-Sánchez (TU Delft)

3D city models for…

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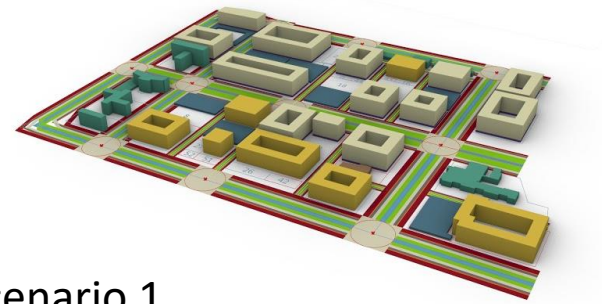
Urban planning (Computer-assisted design of new districts)

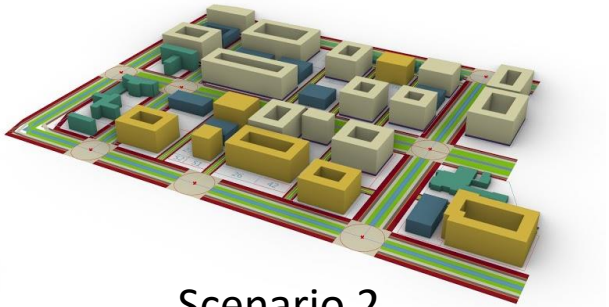
Further details:
Agugiaro, G., García González, F.G., Cavallo, R., 2020,
The city of tomorrow from… the data of today.
ISPRS Int. Journal of Geo-Information, 2020, 9(9), 554.
https://www.mdpi.com/2220-9964/9/9/554

3D city models for…

Urban planning (Computer-assisted design of new districts)



Scenario 1

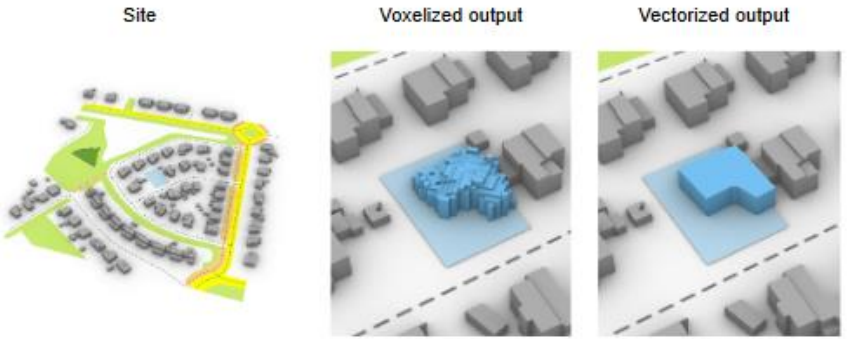


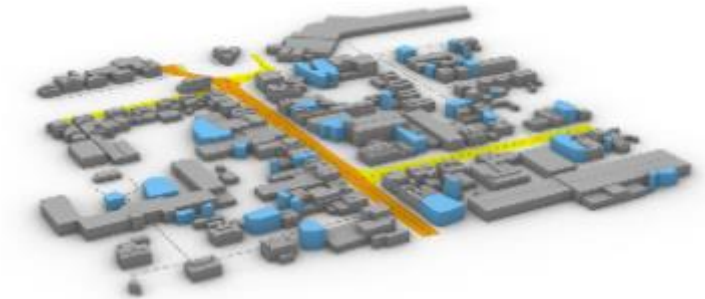
Scenario 2

Scenario 3

3D city models for…

- **Urban planning** (Computer-assisted densification of new districts)





More details:
O. Veselý, 2022, **Building massing generation using GAN trained on Dutch 3D city mode**ls (MSc thesis)
https://repository.tudelft.nl/islandora/object/uuid%3A27085fd4-654a-4748-92d0-61563fe6040c

3D city models for…

Sustainable urban planning and transformation

Micro-climate (e.g. heat islands)

Air quality

Solar analyses (e.g. for PV)

Noise

3D city models

Urban nature-based solutions

Participatory planning

Energy

Mobility

Relation to BIM

Relation to supply networks

A glimpe of

CityGML 3.0

General changes: Overview

Goal: Increase usability for more user groups and use cases

Defined as Conceptual Model Standard via UML class diagrams

Refined Application Domain Extension mechanism

Major revision of some modules and addition of new ones

New Space and LOD concepts defined in Core

General changes: Modules

- Horizontal modules build the basis and are used by the other modules
- Vertical modules build up on them
- The CityGML core module introduces common base classes which are further specialized in the other modules
- Construction module contains common classes which are relevant for man-made structures (in Building, Bridge and Tunnel modules)
- Building module includes specific building-related classes

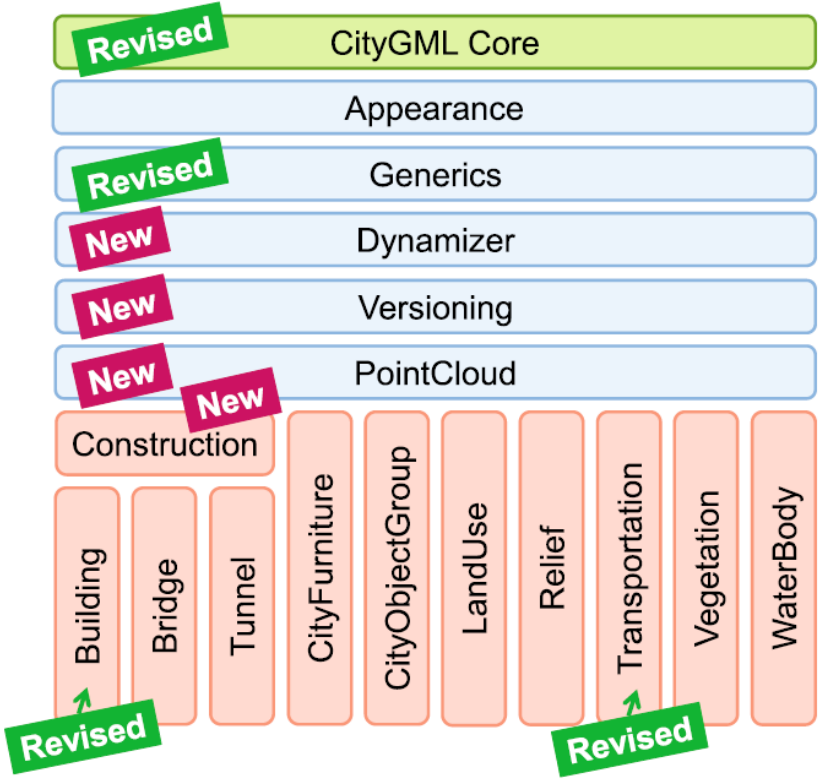


Image Source: OGC City Geography Markup Language Part 1: Conceptual Model Standard

Core module

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Versioning

Dynamizer

Point Clouds

Geometries

Space Concept

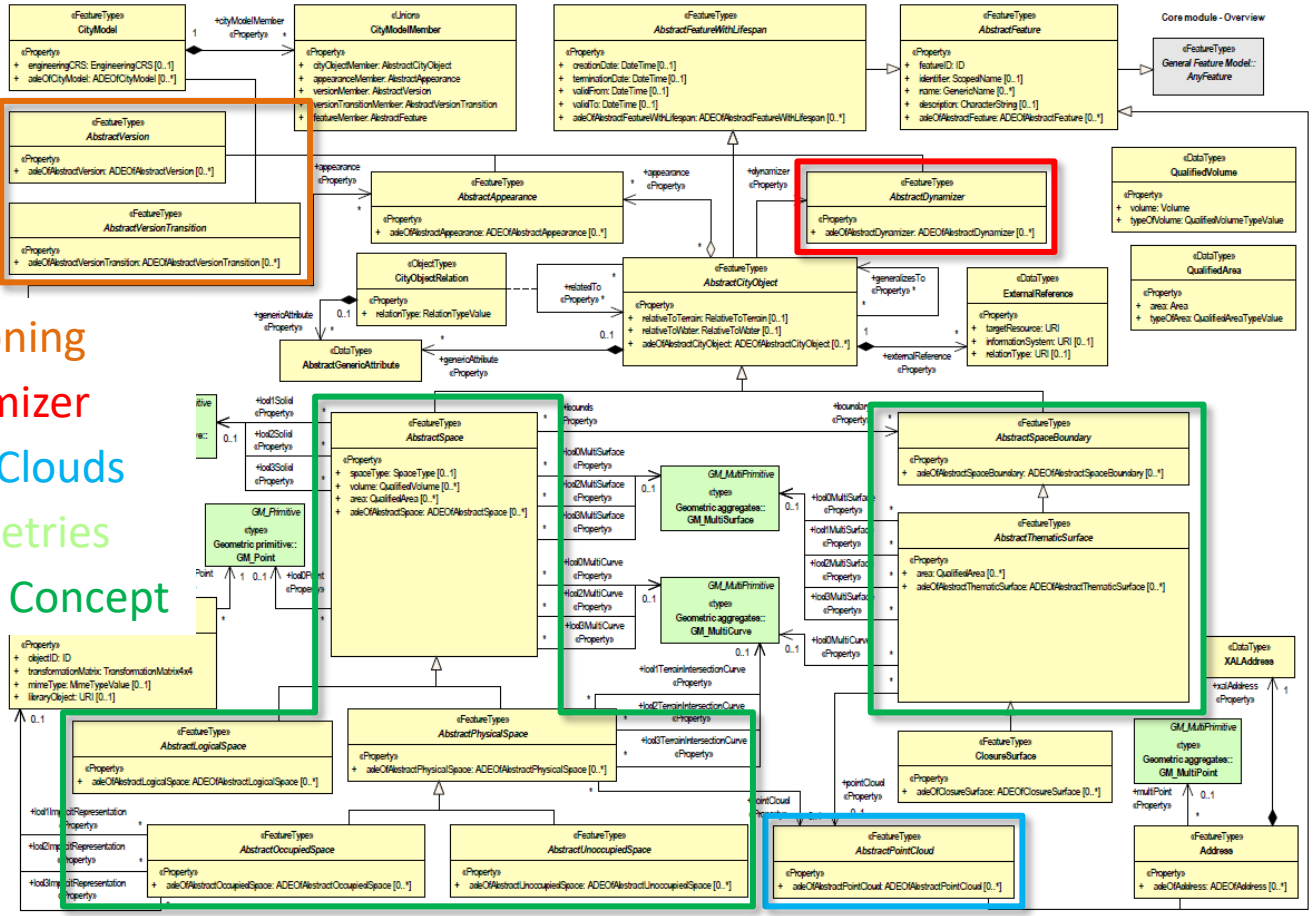


Image source: Excerpts from the CityGML 2.0 and 3.0 UML Models

Core module: Space concept

- **1st level: Division in AbstractSpace and AbstractSpaceBoundary**
  - *AbstractSpace*: **Volumetric** extent (e.g. buildings, trees, traffic spaces)
  - *AbstractSpaceBoundary*: **Areal** extent – delimits and connects spaces (e.g. roof surfaces)

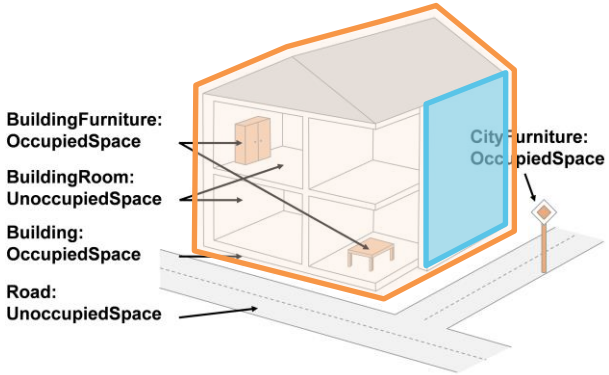


Image source: OGC City GML Part 1: Conceptual Model Standard

Core module: Space concept

- **2nd level: Division in *AbstractLogicalSpace* and *AbstractPhysicalSpace***
  - *AbstractPhysicalSpace:* Fully or partially bounded by physical objects
  - *AbstractLogicalSpace:* Defined according to thematic considerations, can be bound by virtual or physical boundaries

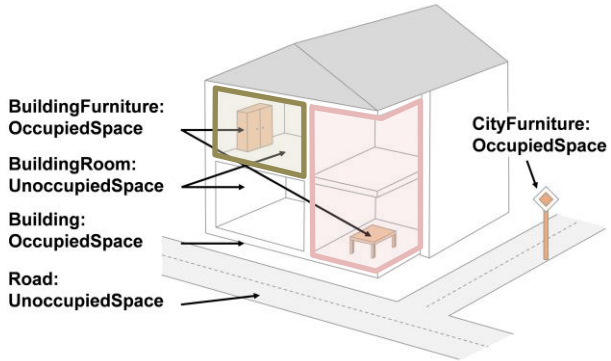


Image source: OGC City GML Part 1: Conceptual Model Standard

Core module: Space concept

- **3rd level: Division in *AbstractOccupiedSpace* and *AbstractUnoccupiedSpace***
  - *AbstractOccupiedSpace:* Volumetric physical objects that occupy space in its surroundings
  - *AbstractUnoccupiedSpace:* Volumetric physical objects that do not block space for other things

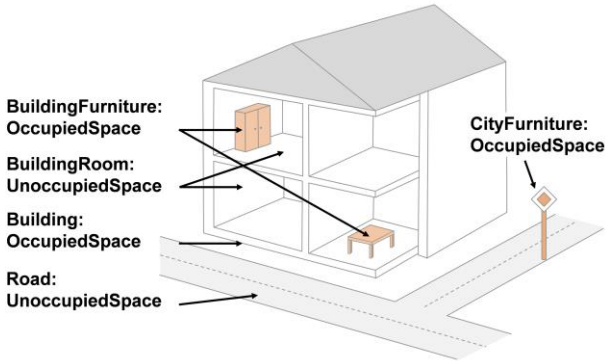
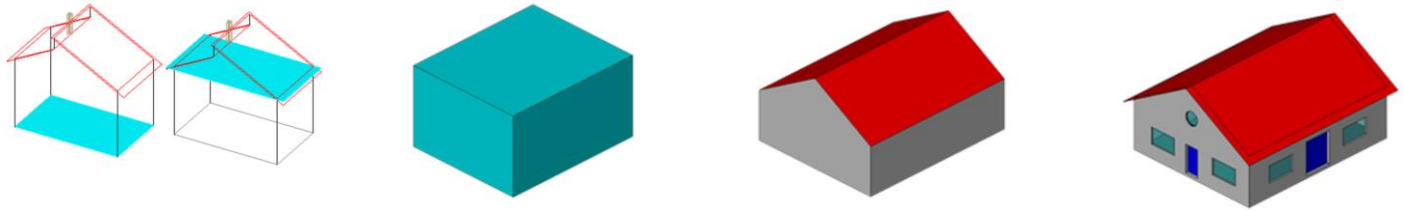


Image source: OGC City GML Part 1: Conceptual Model Standard

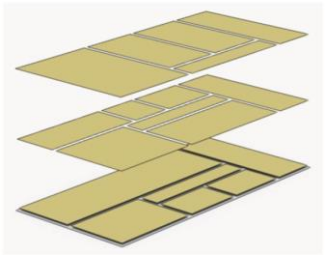
Core module: Geometry and LOD concepts

No LOD4 anymore

LOD0 **LOD1** **LOD2** **LOD3**

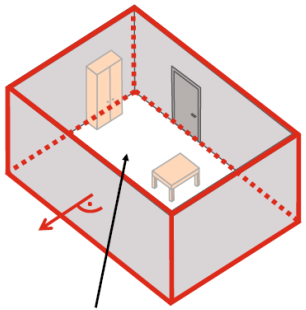


Independent LODs



Building in LOD0

+



Room in LOD1 + Interior in LOD3

Image source: OGC City Geography Markup Language Part 1: Conceptual Model Standard

Dynamizer module

- Enables to represent time-varying attribute values
  - Example: Temperature throughout a day/month/year
- Provides classes to integrate sensor data with 3D models
- A Dynamizer itself is an object that injects timeseries data for an individual attribute of an CityObject

Conclusions

3D city models can be a very powerful and useful tool

BUT

there still exist today some challenges (technical, conceptual, etc.) that make working with them not always straightforward.

NEVERTHELESS

before starting a new project, it might be worth to consider

- what you want to do, which data/tools you need
- whether a 3D city model already exists in your study area
- how far a 3D city model might help you (or not)
- and… in case of doubts: ASK the experts for help!

Semantic 3D city models will not solve ALL your problems, but chances are high that you might profit from them!

Conclusions

- Feeling lost or overwhelmed? Do NOT worry, it is normal! ☺
- CityGML is an extremely vast and fascinating world, but…
- …it is also a dish that takes long to be appreciated (and digested!), *surely* longer than today's few slides
- You do not necessarily need to focus on ALL "ingredients" (modules) at a time!

Thank you for your attention!

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3D Geoinformation Group
TU Delft
The Netherlands
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Acknowledgements:

Some slides on CityGML 3.0 adapted from work of Carolin Bachert (con terra GmbH)