CityGML – Interoperable Access to 3D City Models

Thomas H. Kolbe

Gerhard Gröger

Lutz Plümer

March 22nd, 2005

INITIATIVE Geodaten Infrastruktur NRW

Institute for Cartography and Geoinformation, Univ. of Bonn, Germany

Prof. Dr. Lutz Plümer, Chair of Geoinformation

Why 3D City Models for Disaster Management?

- 3D visualization, localization and orientation
  - indoor/outdoor
- Visualization of **occluded dangers** (e.g., gas pipes)
  - "augmented reality"
- **Planning** of Disaster Management operations
  - e.g., determination of escape routes
- **Simulations** of disasters
  - e.g., flooding, pollution dispersion
- **Training** of personnel
  - "virtual reality"

Fire Fighting Simulation

Picture: W. Herzberg

Simulation tool COSIMIR (Institute for Robotics, University of Dortmund)

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- **Planning** of DM operations
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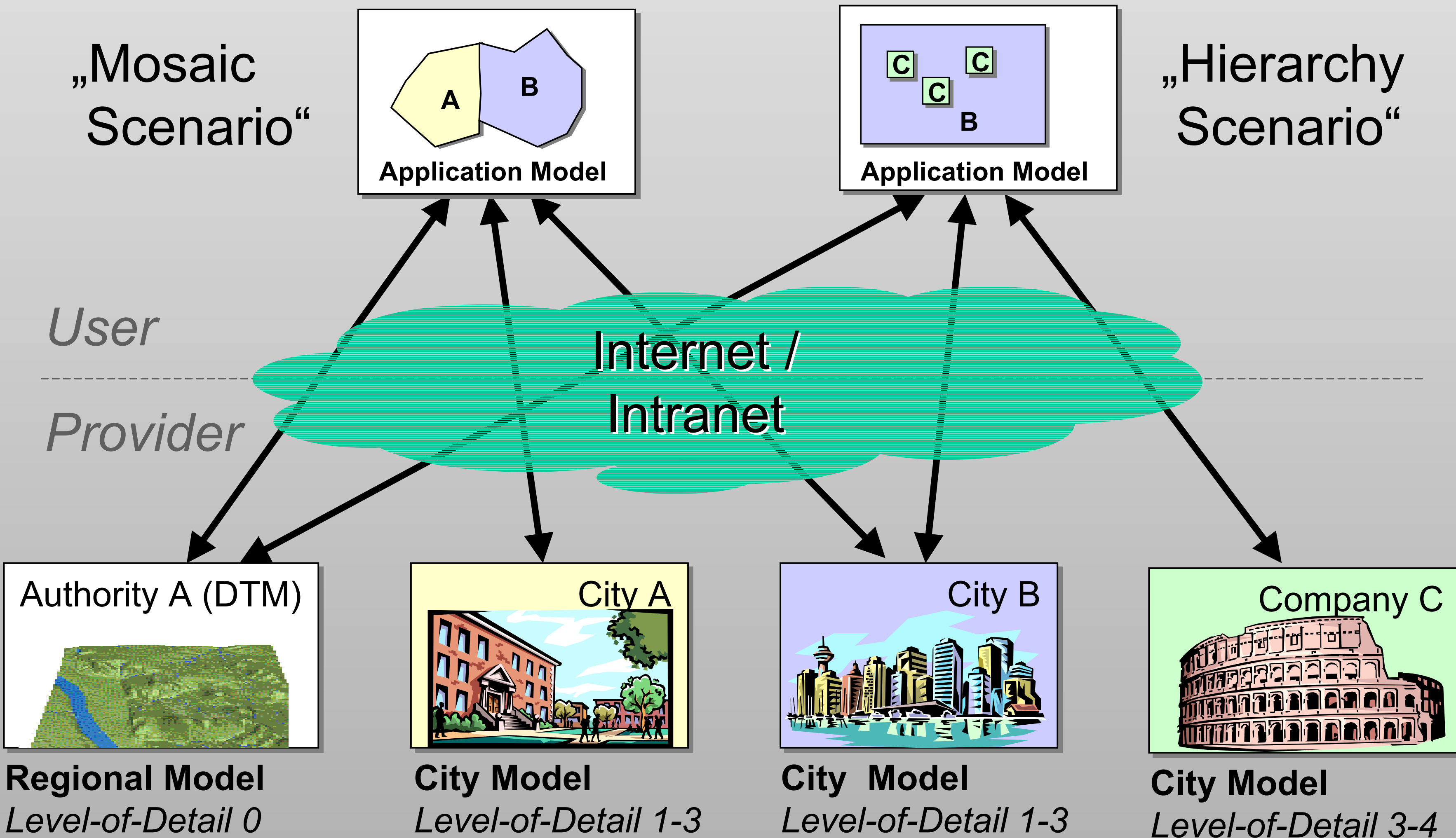
  - e.g., flooding, pollution dispersion
- **Training** of personnel
  - "virtual reality"
- Assess extent of damage
- Rebuild destroyed facilities

Accessing 3D City models for DM

- Disaster Management (DM) requires **remote** and **flexible** access to **up-to-date** 3D City models
- 3D data sets from **different sources** representing **different regions** must be **integrated on demand**

Data Integration: Scenarios



Integrating 3D City Models: Problems

- 3D City models are (often) available, but
  - maintained by **different organizations**
  - in **different systems, data formats** and **schemas**
  - using **different** representations of **geometry**
  - mostly **lack semantic notions**

⇒ **lack** of **interoperability**
  - **difficult** to **integrate** different 3D city models
  - **difficult** to **access** it in a uniform way

Spatial Data Infrastructures

- provide open **standards** and **services** to **integrate** different spatial data set and to **access** it via the WWW
- standards are issued by
  - Open Geospatial Consortium (**OGC**)
  - International Organization for Standardization (**ISO**)
- **common data exchange** service: **Web Feature Service**
- **data integration facilitated:**
  - **Syntactical** Interoperability: **XML** (Extensible Markup Language)
  - Common **geometry model**: **GML 3** (Geography Markup Language), issued by OGC, based on ISO "**Spatial Schema**"
  - common models for metadata, reference systems,...
- but: ISO and OGC provide **no unified semantic urban 3D model**
- 3D models from Computer Graphics or CAD **not sufficient**

CityGML

- unified model for **storing** and **exchanging** 3D city models
- integrated in **Spatial Data Infrastructures**
  - based on ISO/OGC standards (**GML3**, ...)
  - interoperable access by a 3D **Web Feature Server**
- developed by the **Special Interest Group 3D** (**SIG 3D**) of the SDI North Rhine-Westphalia (**GDI NRW**)

SIG 3D members (excerpt)

Municipalities

- Berlin
- Hamburg
- Cologne
- Düsseldorf
- Bremen
- Essen
- Leverkusen
- Wuppertal
- Bochum

Administration

- State survey-ing agencies

Companies

- T-Mobile
- Bayer Industry Services
- Graphisoft
- Rheinmetall
- CPA Geoinformation
- Con Terra
- GraphiX
- Inpho
- Real.IT
- CyberCity (CH)
- Nolimits (AT)
- Snowflake (UK)

Science

- Univ. of Bonn
- Univ. of Hamburg
- Univ. of Potsdam
- Univ. of Hannover
- Univ. of Dortmund
- Univ. of Münster
- Fraunhofer Institute for Computer Graphics, Darmstadt
- Research center Karlsruhe

CityGML

- unified model for **storing** and **exchanging** 3D city models
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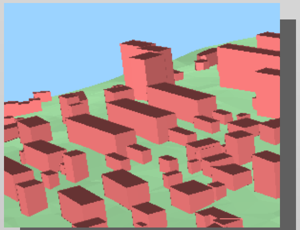
  - based on ISO/OGC standards (**GML3**, ...)
  - data exchange by a 3D **Web Feature Server**
- developed by the **Special Interest Group 3D** (**SIG 3D**) of the SDI North Rhine-Westphalia (**GDI NRW**)
- result of consensus process (different disciplines)
- ongoing research since 2002
- presentation and discussion in OGC

CityGML: Key Features for DM

- **Multi-scale** model
  - flexible, from large scale to small scale utilization
- Coherent **semantic**-geometrical modeling
  - planning of DM operations, simulations
- **References** to objects in **external** data bases
  - accessing additional information
- Representation of **building interiors**
  - enables determination of escape routes
- **Closure Surfaces**
  - compute volume of open subsurface objects

CityGML - Multi-scale modeling: 5 levels of detail (LOD)

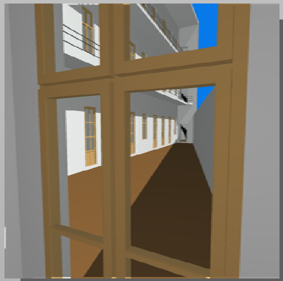
- LOD **0** – **Regional model**
  - 2.5D Digital Terrain Model



- LOD **1** – **City / Site model**
  - “block model“ w/o roof structures

- LOD **2** – **City / Site model**
  - textured, differentiated roof structures

- LOD **3** – **City / Site model**
  - detailed architecture model



- LOD **4** – **Interior model**
  - “walkable“ architecture models

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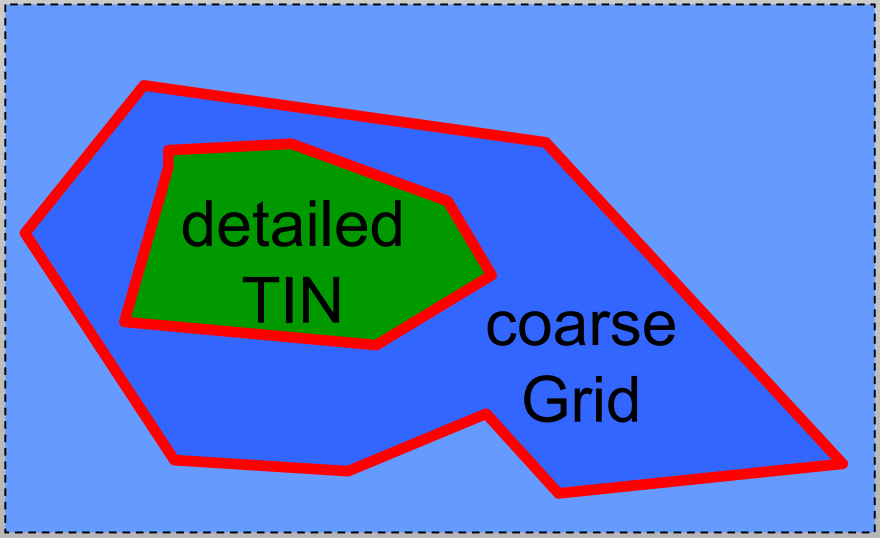
CityGML: Content

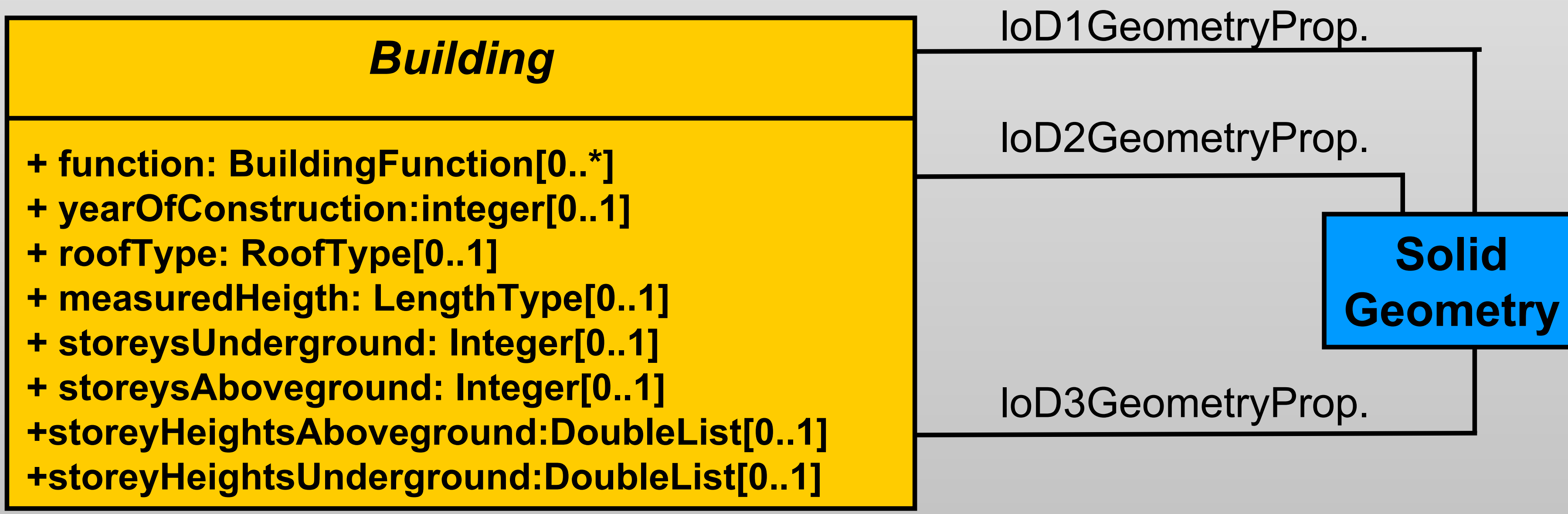
- Digital Terrain Model
  - TIN (Triangulated Irregular Network), Grid, 3D Breaklines, 3D Mass Points
  - flexible, combine different types from different LoDs, explicit validity extent



CityGML: Content

- Digital Terrain Model
  - TIN (Triangulated Irregular Network), Grid, 3D Breaklines, 3D Mass Points
  - flexible, combine different types from different LoDs, explicit validity extent
- Transportation Objects
- Vegetation
- City Furniture (e.g., Hydrants)
- Water Bodies
- Sites
  - Buildings
  - Tunnels, Bridges, ...

Building Model 1/2



- **object-oriented** modeling (of geometry and semantics)
- attributes; relations between objects
- an object may be represented **in different** LoD **simultaneously**
- further thematic specialization with increasing LoD

Building Model 2/2

- LoD2: bounding surfaces **differentiated semantically**
  - wall, roof, ground surfaces
- LoD3: openings, doors, windows
- LoD4: rooms, interior doors, interior walls/ceilings
- surfaces/rooms/doors etc. are **objects** with **attributes** and **links to geometry**
  - coherent semantic-geometrical modeling
  - extensible: possible to add application-specific attributes or to refine the class taxonomy

Semantic-geometrical Modeling

- Disaster Management Applications:
  - Planning of rescue operations
    - Which window in the 4th floor is accessible by a fire ladder?
    - Where are buildings with flat roofs, large enough for helicopter to land?
  - Assessing extent of damage
    - Which storeys are affected by flooding?

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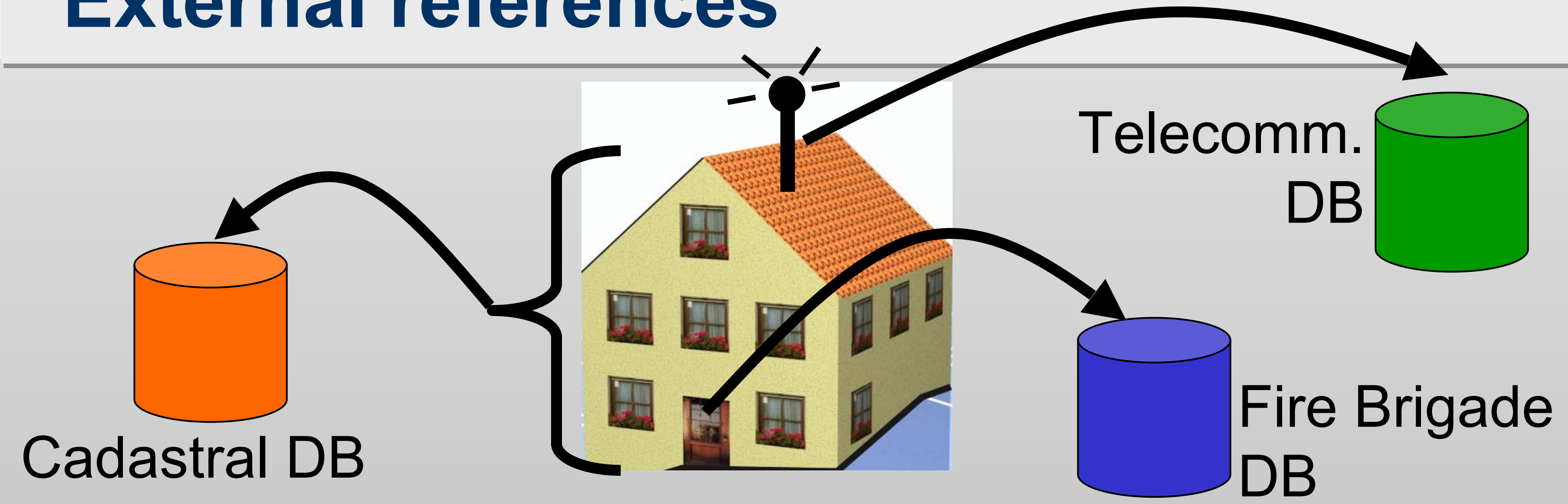
External references



- each object (part) in CityGML may have **references** to **corresponding objects** in **external databases**
- supply with external information relevant for DM, e.g.
  - building: link to cadastre, owner's contact information
  - fire hydrant or door: link to fire brigade data base, technical information

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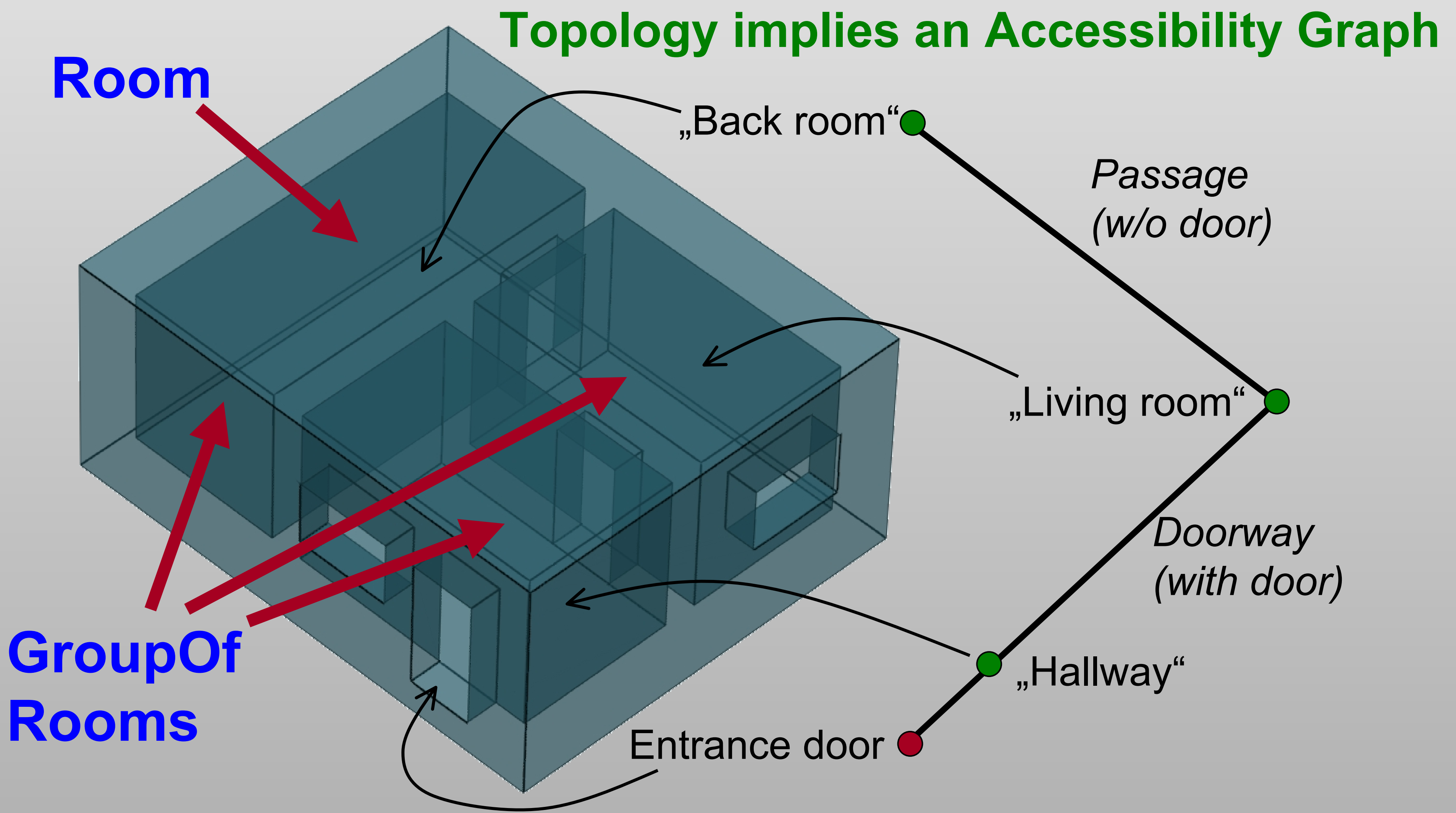
Building Interiors: Room Topology



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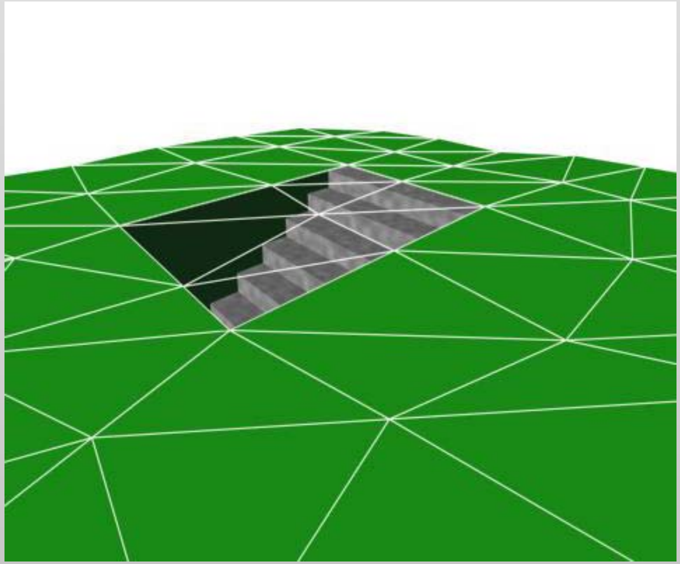
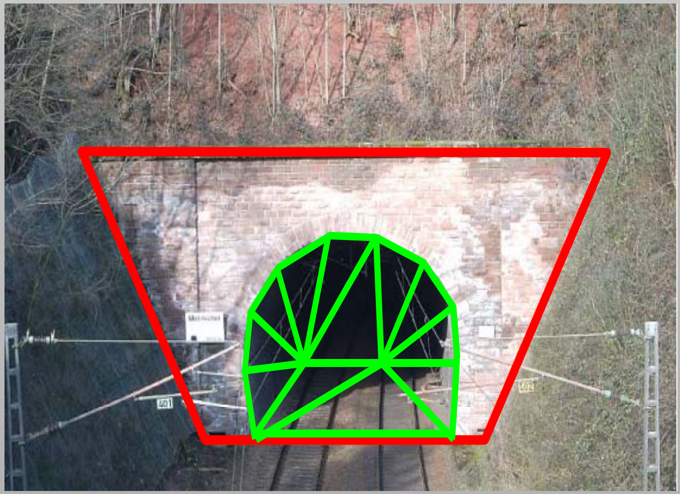
Closure Surfaces





- often subsurface objects are **open** (no closed solid)
  - not possible to calculate volume
- **Closure Surfaces** "seal" open 3D objects
  - to be able to compute their volumes
  - e. g., to compute amount of water/gas/smoke in tunnel/pedestrian underpass
  - flexible; neglected when not needed (e.g., visualizations)

Conclusions

- CityGML: **Unified** 3D City model
- **integrated** in **Spatial Data Infrastructures**
- **interoperable access** to **up-to-date** spatial 3D data
- **multi-functional** model, **semantic** modeling
- well suited for **Disaster Management tasks**
  - escape routes, rescue operations, ...
- first implementations by **Berlin, Hamburg, Düsseldorf, ...**
- discussion in **OGC** and **EuroSDR**
- to do: evaluation for large models, extensions: history, planning versions, more details (transportation, vegetation, ..)
- further details: **www.ikg.uni-bonn.de/sig3d**

  Upcoming: **www.citygml.org**

Augmented Reality: Visualization of Gas Pipes

images: http://www.nottingham.ac.uk/aims/ar-seminar/

Real World

Augmented World

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Overview

- Why 3D City models for Disaster Management (DM)?
- Problem of interoperability
- Spatial Data Infrastructures
- CityGML: unified 3D city model
- Key Features of CityGML for DM tasks
- Conclusions

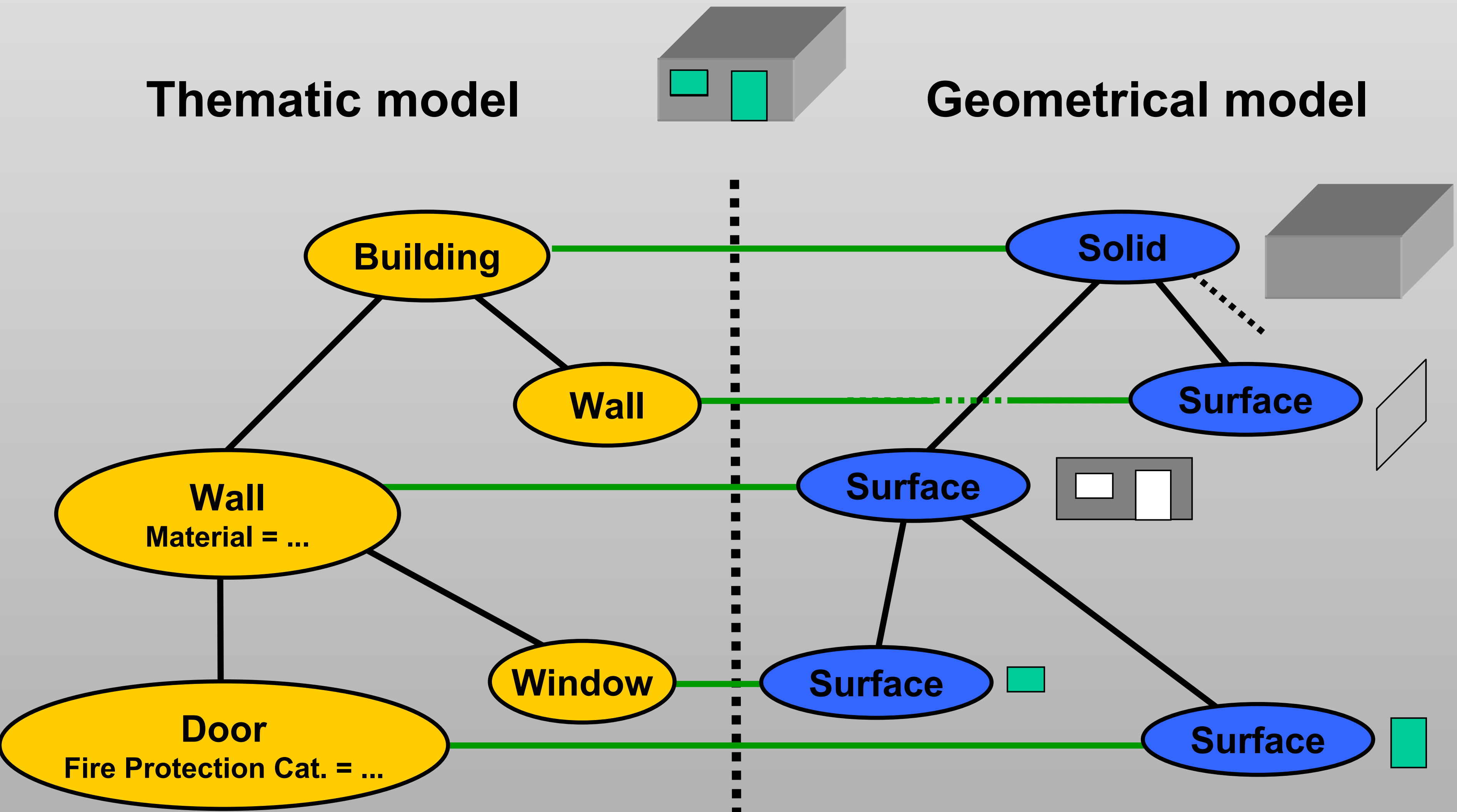
Evaluation of CityGML: Pilot 3D

- Testbed for CityGML 07/2004 – 03/2005
- **Aim:** Interoperable access to / exchange of 3D city models
- Realization of CityGML readers / writers and a visualization tool by different partners
  - Roundtrip evaluation (crosswise data exchange)
- 6 Project groups (each consisting of municipalities, software manufacturers, and academia):
  - Cities: Berlin, Hamburg, Cologne, Düsseldorf, Leverkusen, Recklinghausen, Erkelenz
  - Universities: Bonn, Dortmund, Braunschweig, Freiberg; Fraunhofer Institute for Computer Graphics Darmstadt
  - GIS software companies from Germany

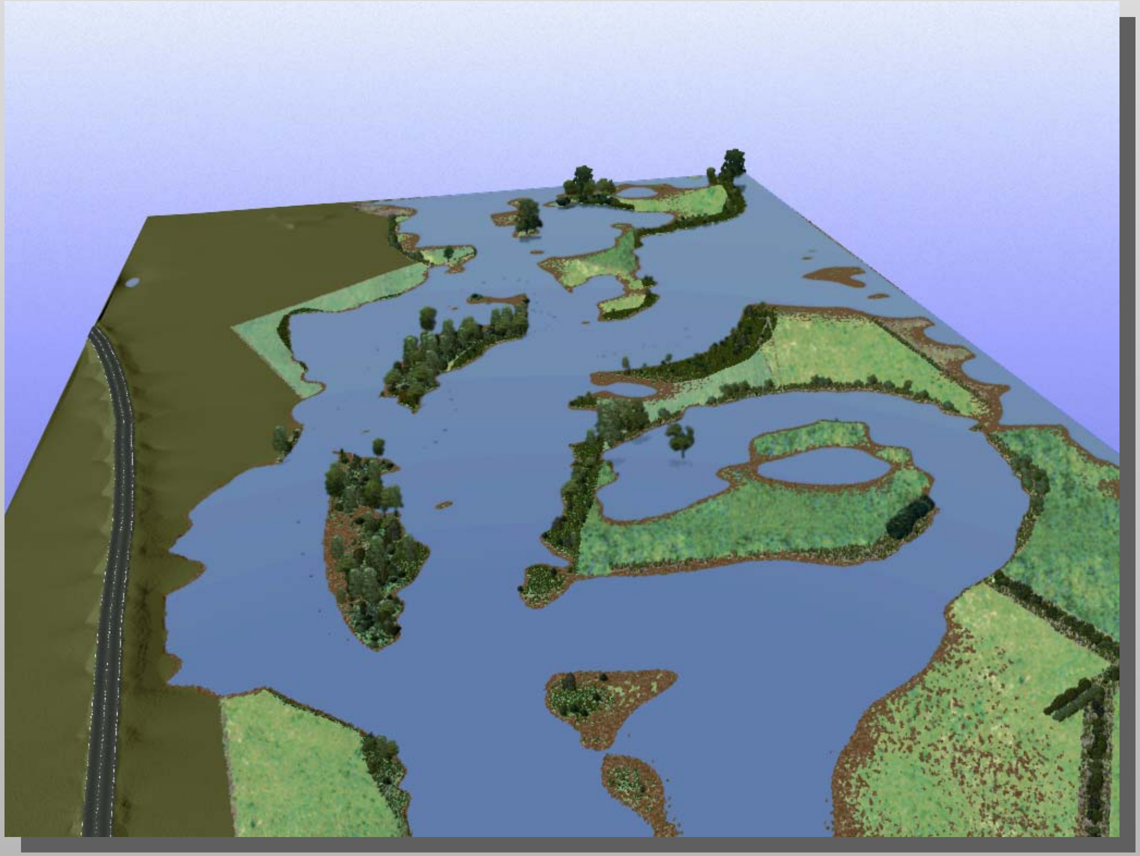
Topology of Building Interiors

- in LoD4, building **interiors** (rooms, group of rooms, ..) are represented as objects
  - incl. interior doors, walls, staircases, furniture, ...
  - **topology** is represented (by sharing of geometry)
- possible to derive the **adjacency** graph (**accessibility** graph) of a building interior
  - augmented by thematic information (room, door,...)
- determination of **escape routes**
  - scenario: fire in floor 33, is there a escape route from room 3 to an exit?

Thematic-geometrical Modeling: Example



3D Simulations: Flooding scenario



Picture: Christoph Uhlenküken, Conterra

Context: SIG 3D of GDI NRW

Spatial Data Infrastructure North Rhine-Westphalia

- founded in 1999 by the state government
- more than 100 institutions organized in 6 Special Interest Groups
- very active in the OGC (WPOS, WCTS, GML3)

INITIATIVE Geodaten Infrastruktur NRW

Special Interest Group 3D (SIG 3D)

- open group with >70 active members; 3 working groups
  - from industry, government, municipalities and academia
  - participants from all over Germany, Austria, Switzerland and UK
- aim: development of solutions for interoperable processing, visualization and exchange of 3D spatial data
  - currently working on a unified 3D city model (CityGML)

Example: CityGML Schema for Buildings

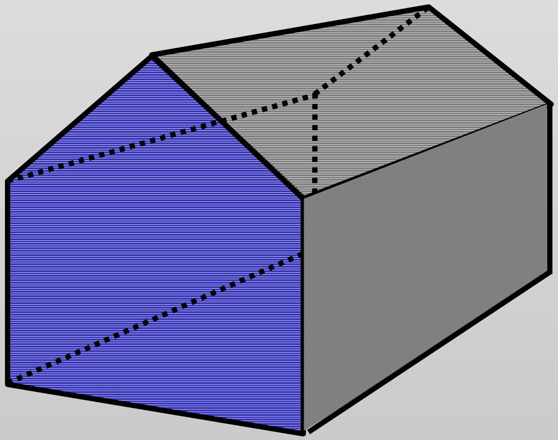
```
<xs:complexType name="_BuildingType" abstract="true">
    <xs:complexContent>
        <xs:extension base="_SiteType">
            <xs:sequence>
                <xs:element name="function" type="BuildingFunctionType" minOccurs="0" />
                <xs:element name="yearOfConstruction" type="xs:gYear" minOccurs="0"/>
                <xs:element name="roofType" type="RoofTypeType" minOccurs="0"/>
                <xs:element name="measuredHeight" type="gml:LengthType".../>
                <xs:element name="lod2SolidProperty" type="gml:SolidPropertyType" ../>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>

<xs:element name="_Building" type="_BuildingType" abstract="true"
                            substitutionGroup="_Site"/>
```

Example: Building in CityGML 1/3

```
<siteMember>
   <Building gml:id="Building0815">
      <externalReference>
         <informationSystem>http://www.adv-online.de</informationSystem>
         <externalObject>
            <uri>urn:adv:oid:DEHE123400007001</uri>
         </externalObject>
      </externalReference>
      <function>31001_1010</function>
      <yearOfConstruction>1985</yearOfConstruction>
      <roofType>3100</roofType>
      <measuredHeight uom="#m">8.0</measuredHeight>
      <lod2SolidProperty>......//see next slide
      </lod2SolidProperty>
   </Building>
</siteMember>
```

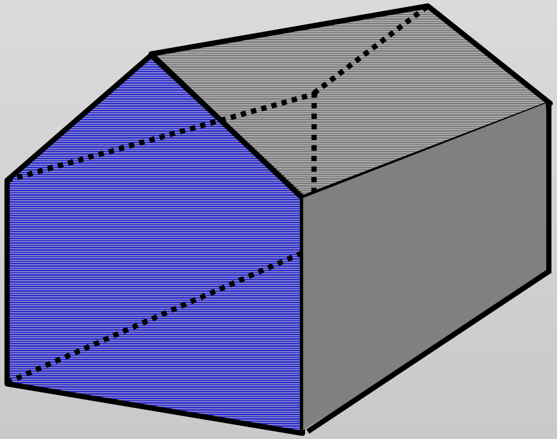
Example: Building in CityGML 2/3



```
<Building gml:id="Building0815"> ..................
  <lod2SolidProperty>
      <gml:Solid srsName="urn:adv:crs:ETRS89_3GK2-h">
          <gml:exterior>
              <gml:CompositeSurface>
                  <gml:surfaceMember>
                      <gml:OrientableSurface orientation="+">
                          <gml:baseSurface>
                              <gml:Polygon>
                                  <gml:exterior>
                                      <gml:LinearRing>
                                          <gml:pos >1.0 1.0 0.0</gml:pos>
                                          <gml:pos >3.0 1.0 0.0</gml:pos>
                                          ..........................
                                      </gml:LinearRing>
                                  .....................
  </lod2SolidProperty>
</Building>
```

Example: Building in CityGML 3/3

```
<Building gml:id=“Building0815"> .................
  <lod2SolidProperty>
      <gml:Solid srsName="urn:adv:crs:ETRS89_3GK2-h">
          <gml:exterior>
              <gml:CompositeSurface>
                  <gml:surfaceMember>
                      //front surface
                  </gml:surfaceMember>
                  <gml:surfaceMember>
                      //side surface
                  </gml:surfaceMember>
                  ......//here come side, back, roof, and ground surfaces
              </gml:CompositeSurface>
          </gml:exterior>
      </gml:Solid>
  </lod2SolidProperty>
</Building>
```



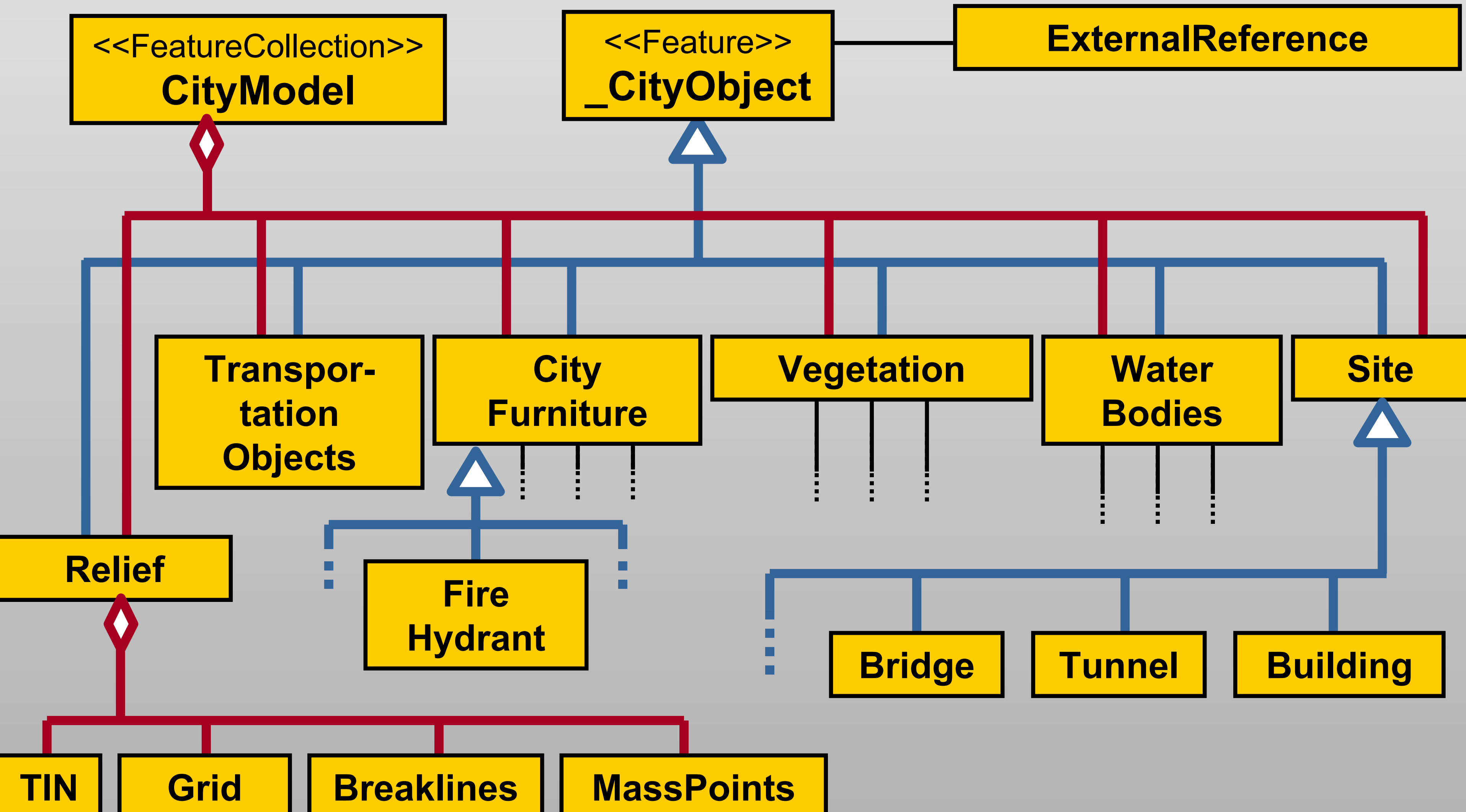
Terrain Intersection Curve

- „Interface between 3D objects and the terrain“
  - ensure matching of object textures with the DTM
  - DTM may be locally warped to fit the TIC

3D City Models

- Many cities recently built up 3D city models
- Application areas:
  - Urban planning
  - Disaster management
  - Tourism
  - Facility management
  - Telecommunication industry
  - 3D cadastre
  - Vehicle and pedestrian navigation
  - Environmental simulations
- Problem: **no appropriate standard** for data exchange
  - DXF (from CAD domain): only geometry; no complex relations
  - IFC standard from the domain of Computer Aided Architectural Design: focus on construction; no terrain, limited georeferencing, no vegetation etc.
  - LandXML: no 3D buildings and other city objects

CityGML: Content (Overview)

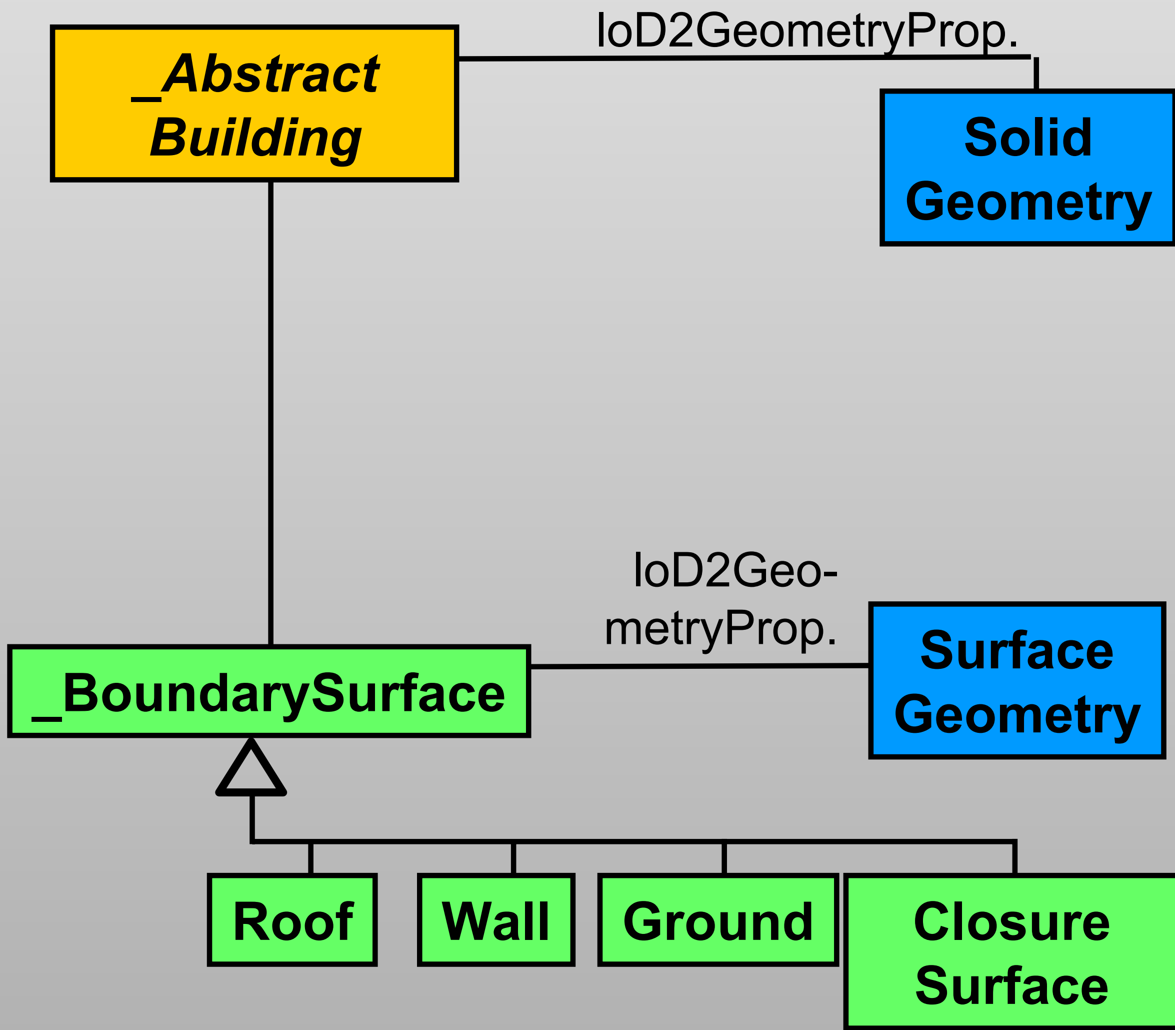


LoD1

Building Model in LoD1 to LoD4

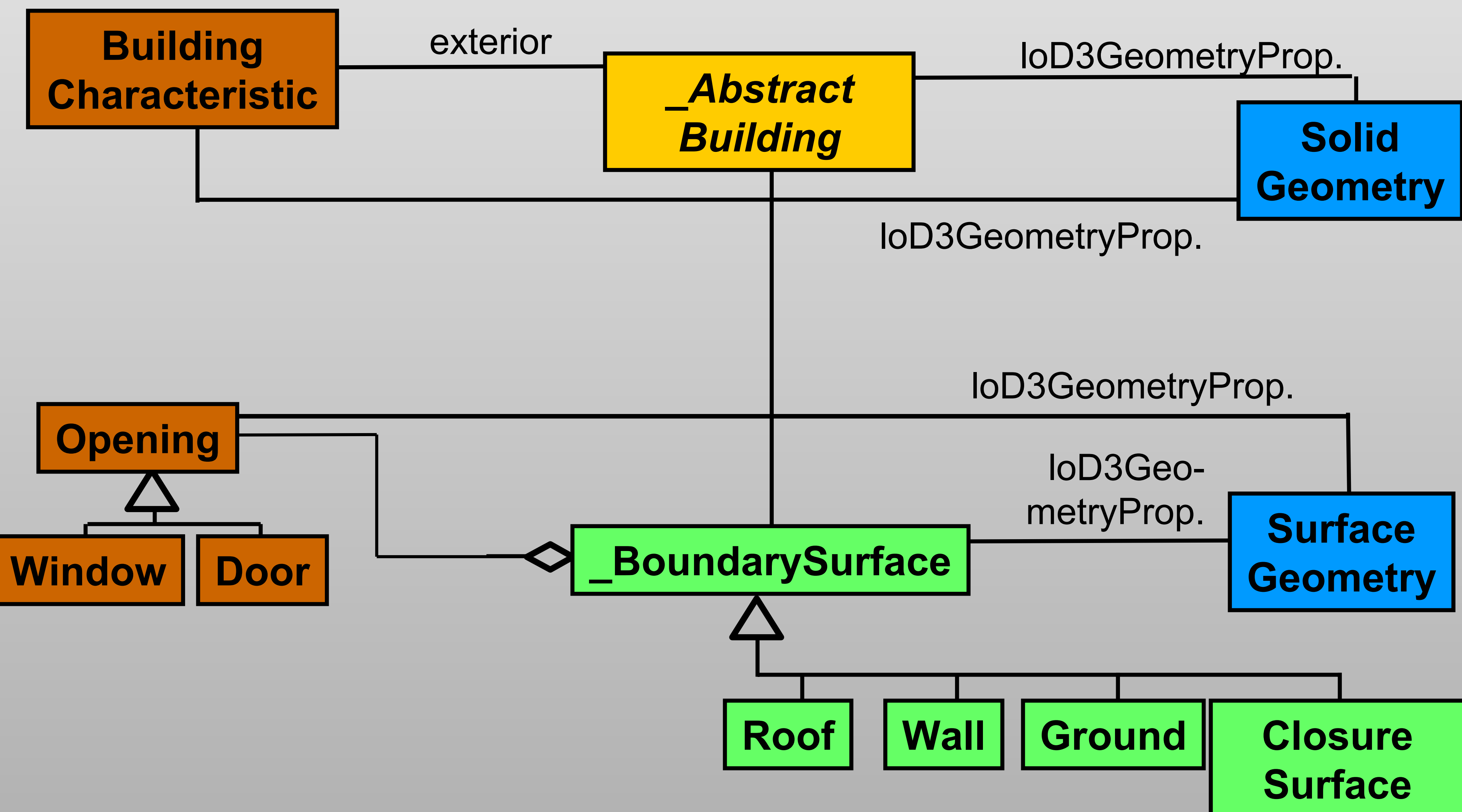
LoD1 LoD2

Building Model in LoD1 to LoD4



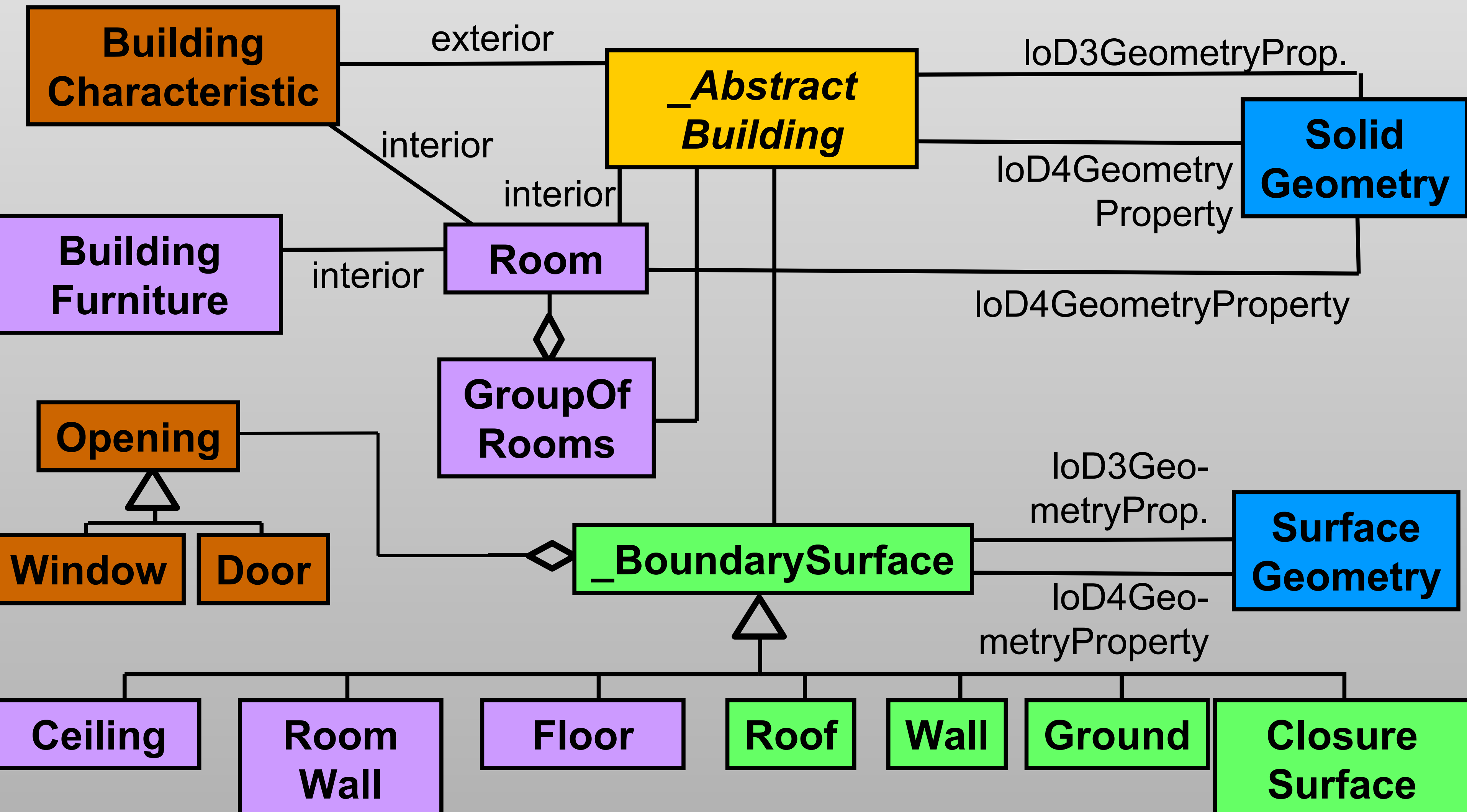
LoD1 LoD2 LoD3

Building Model in LoD1 to LoD4



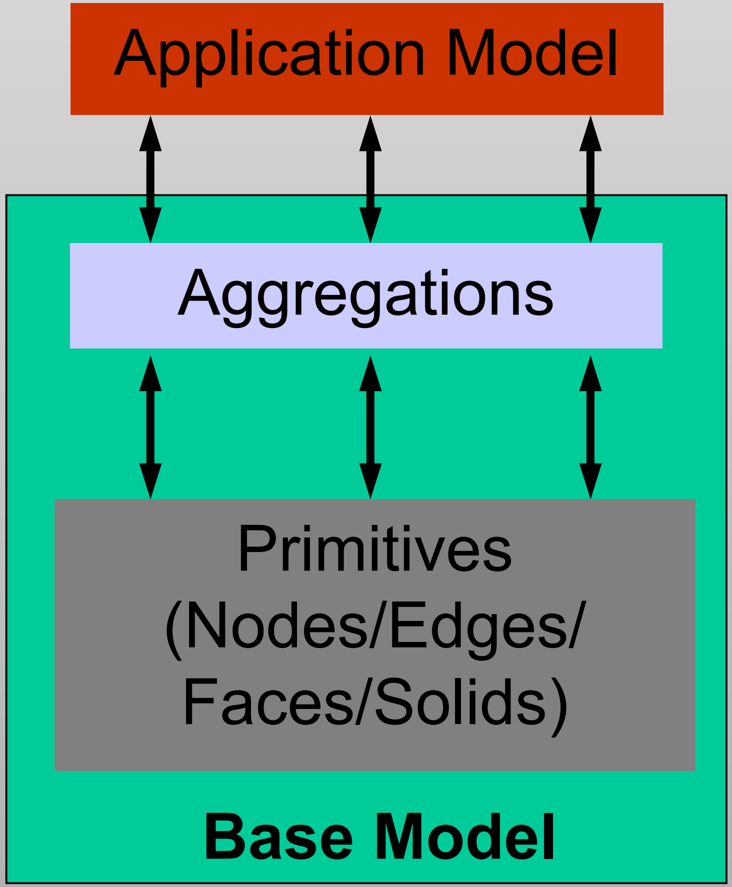
LoD1 LoD2 LoD3 LoD4

Building Model in LoD1 to LoD4

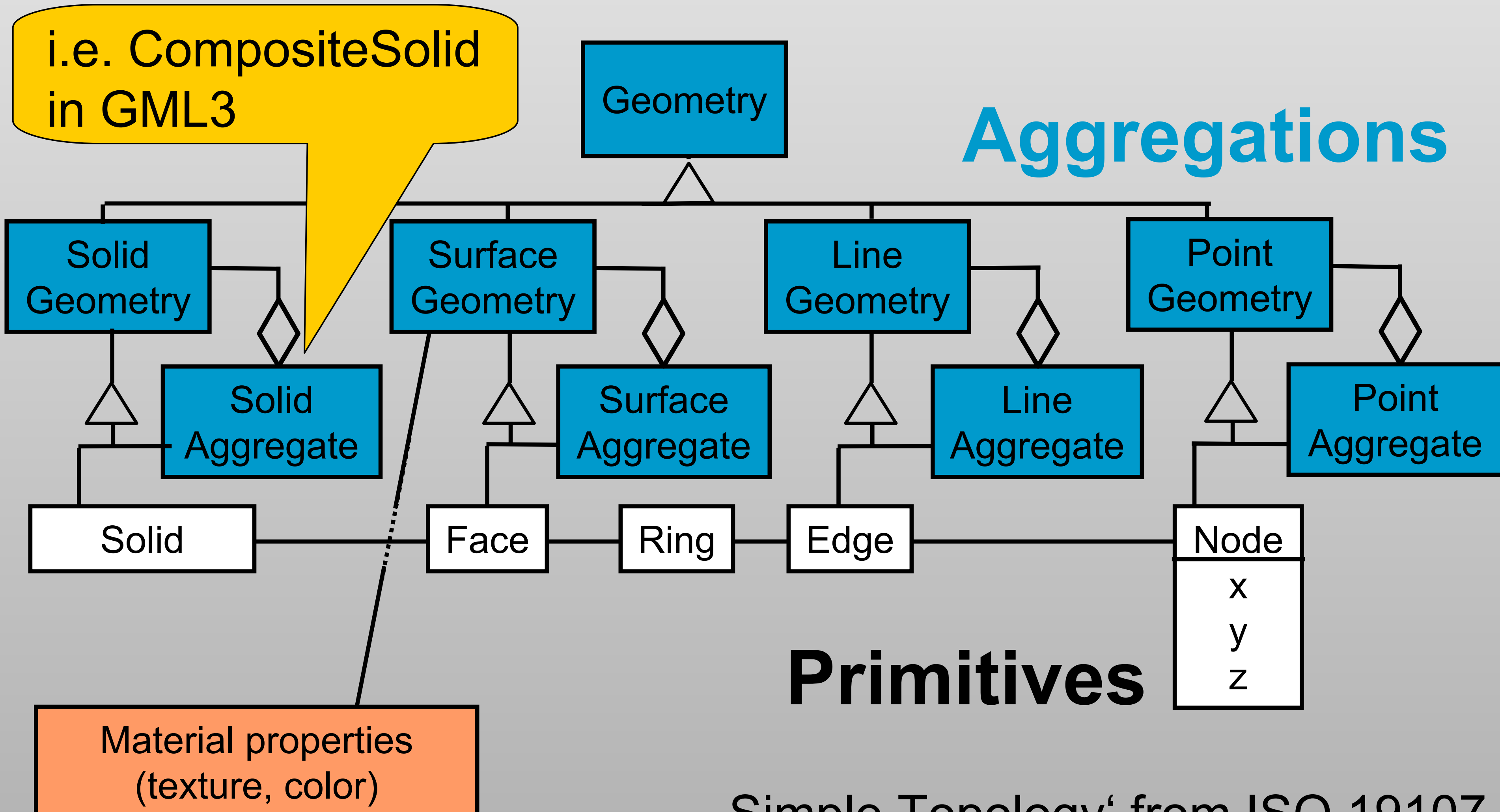


Our Approach: New Unified City Model

- Based on ISO/OGC ‘Spatial Schema’
- Simple, but sufficient
- Defines application models
- Aggregations
- **Supports Level-of-Detail**
- **Defines subsurface objects**
- Data exchange
  by XML / GML3

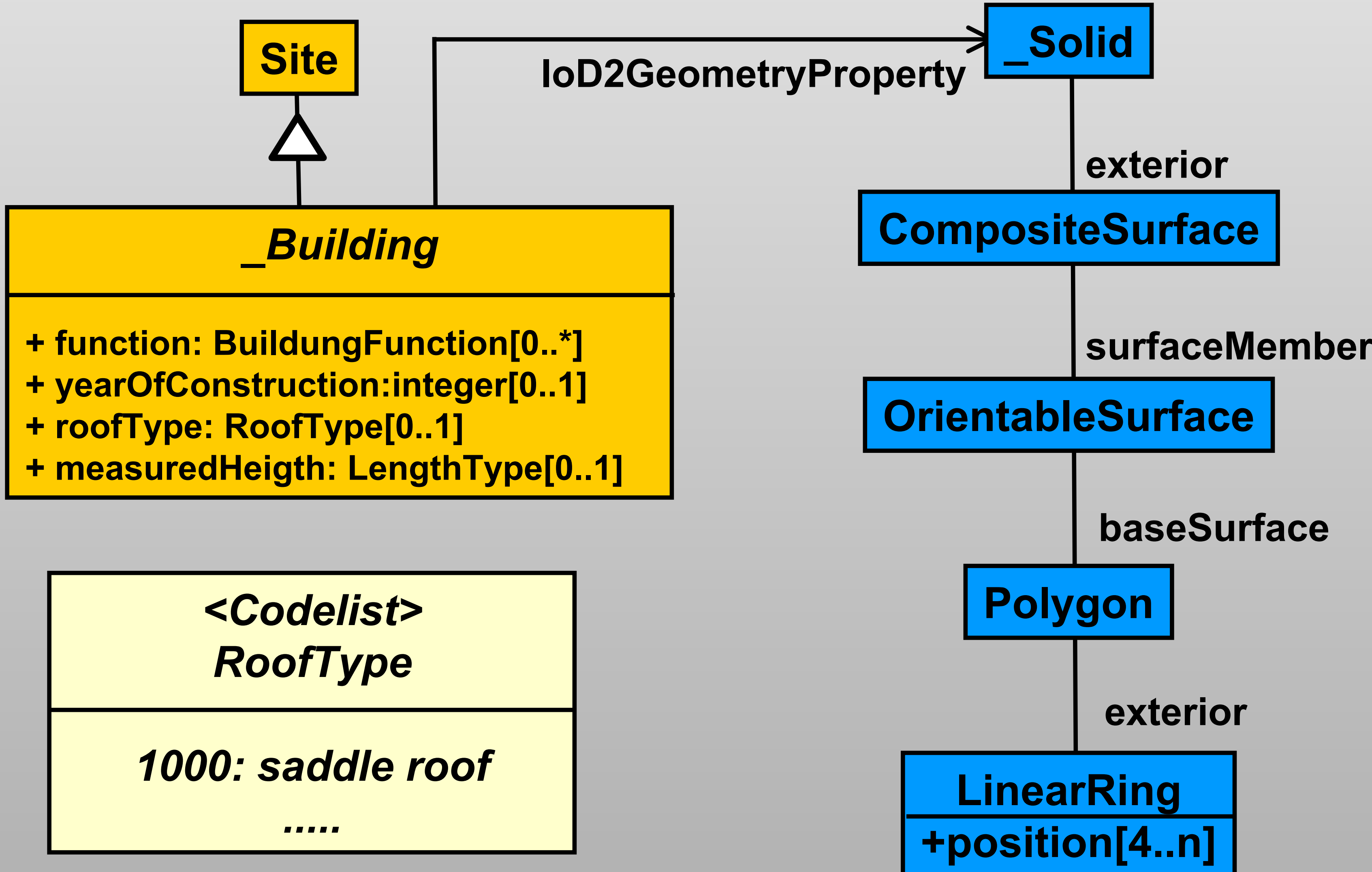


Geometric-topological Modeling



‚Simple Topology' from ISO 19107

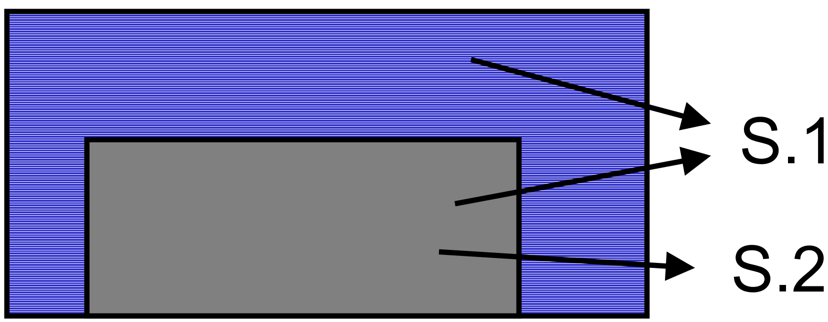
Building representation using GML3



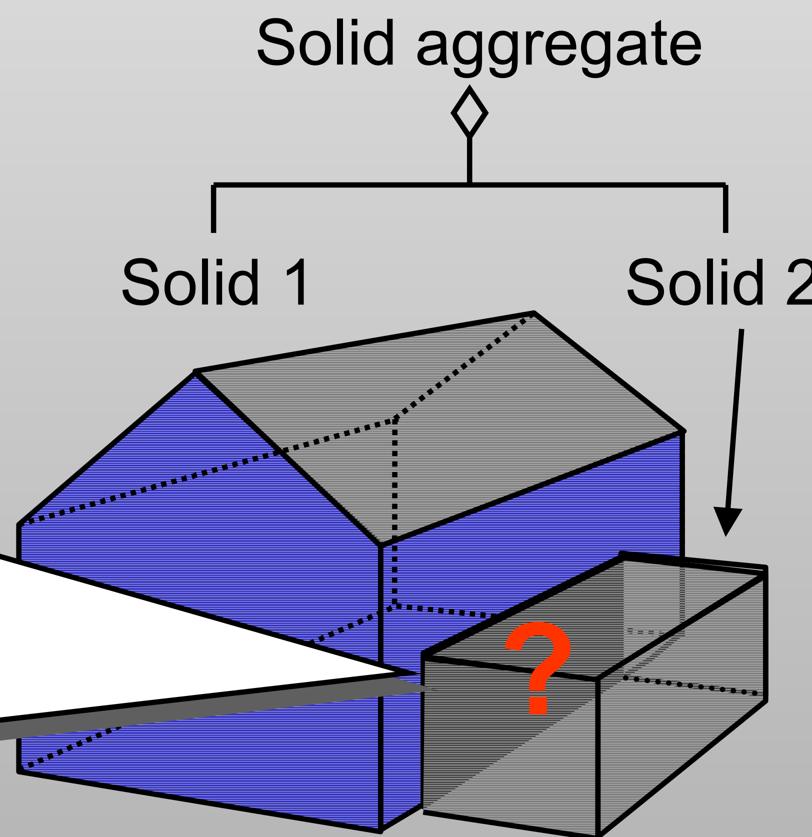
Geometric-topological Composition

- recursive aggregation
  - ➔ arbitrary depth

- Wall face will be partitioned into 2 faces



➔ explicit topol. connection
- but: goes beyond B-Rep



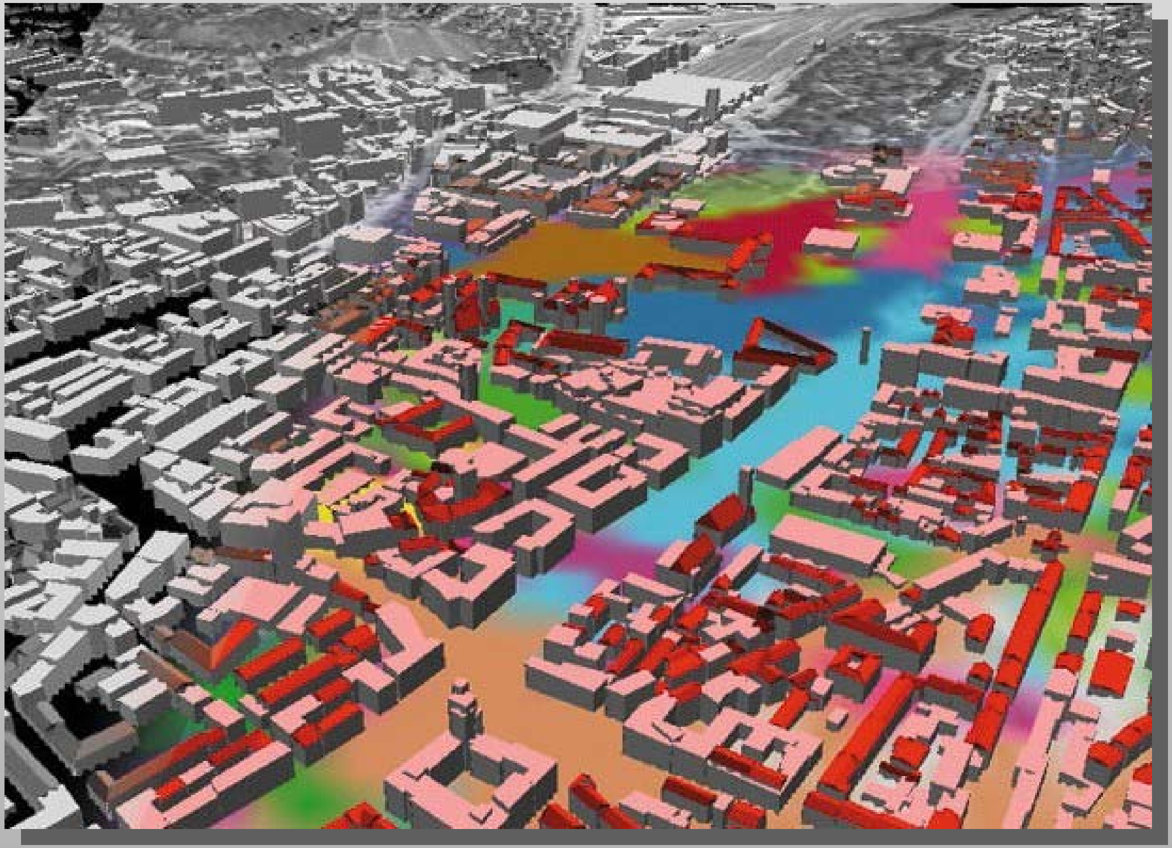
3D City Models – Multifunctional Use (II)

- Training simulators (e.g. police, armed forces)

Pictures: Frank Bildstein, Rheinmetall Defence Electronic

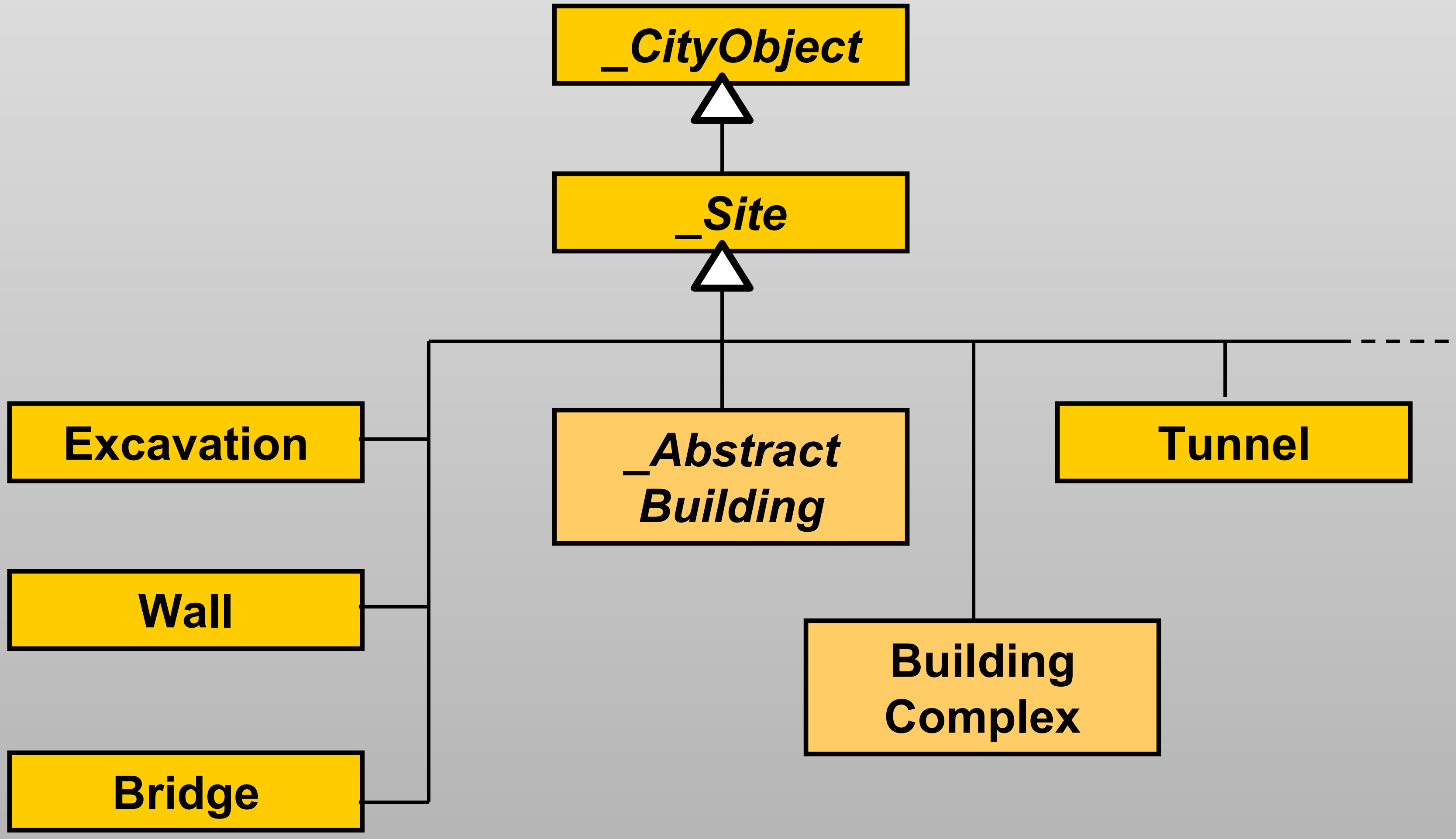
3D City Models – Multifunctional Use (IV)

- Telecommunications: Transmitter Positioning



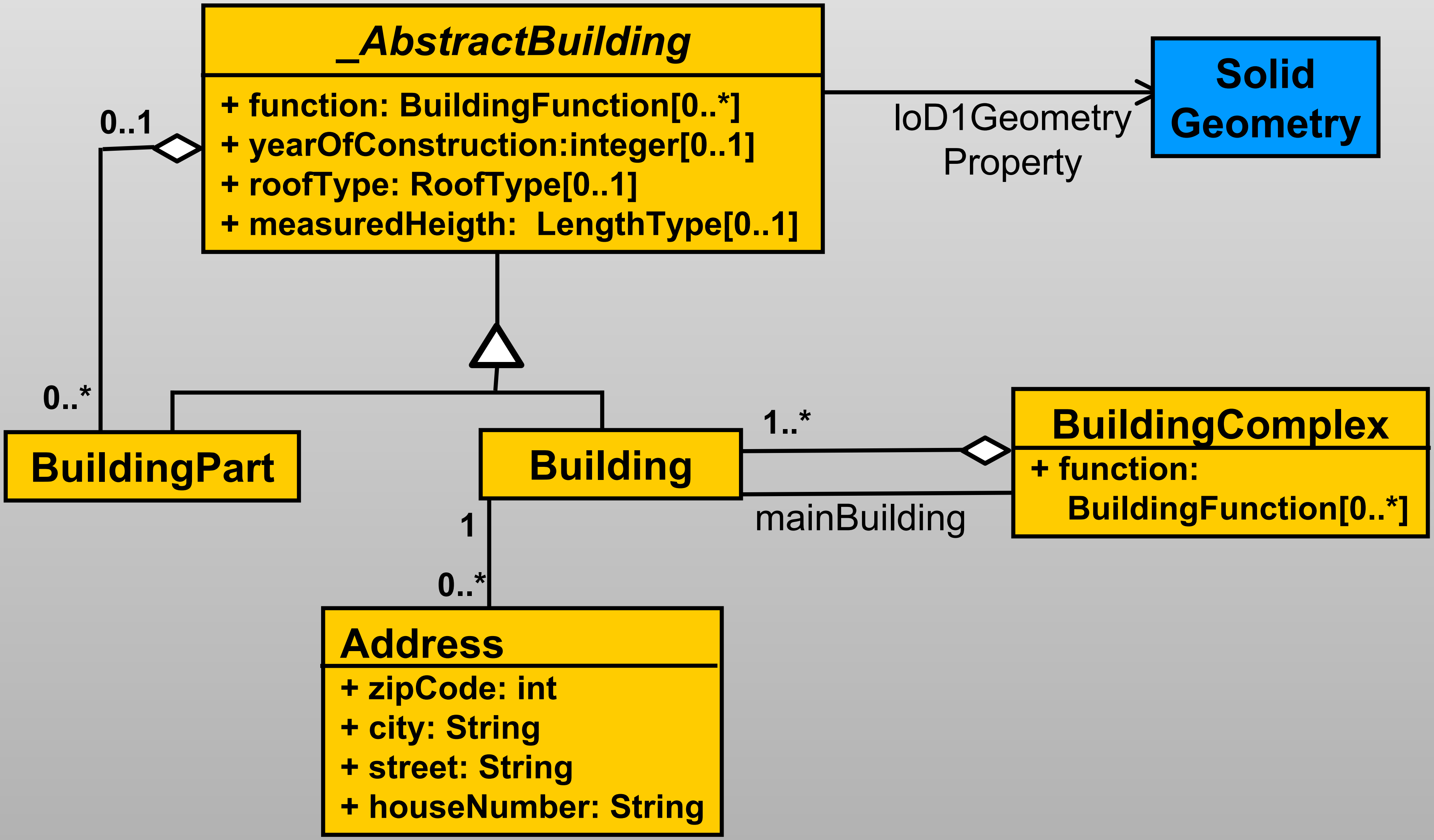
Picture: Bernhard Ruff, T-Mobile Germany

Site Model

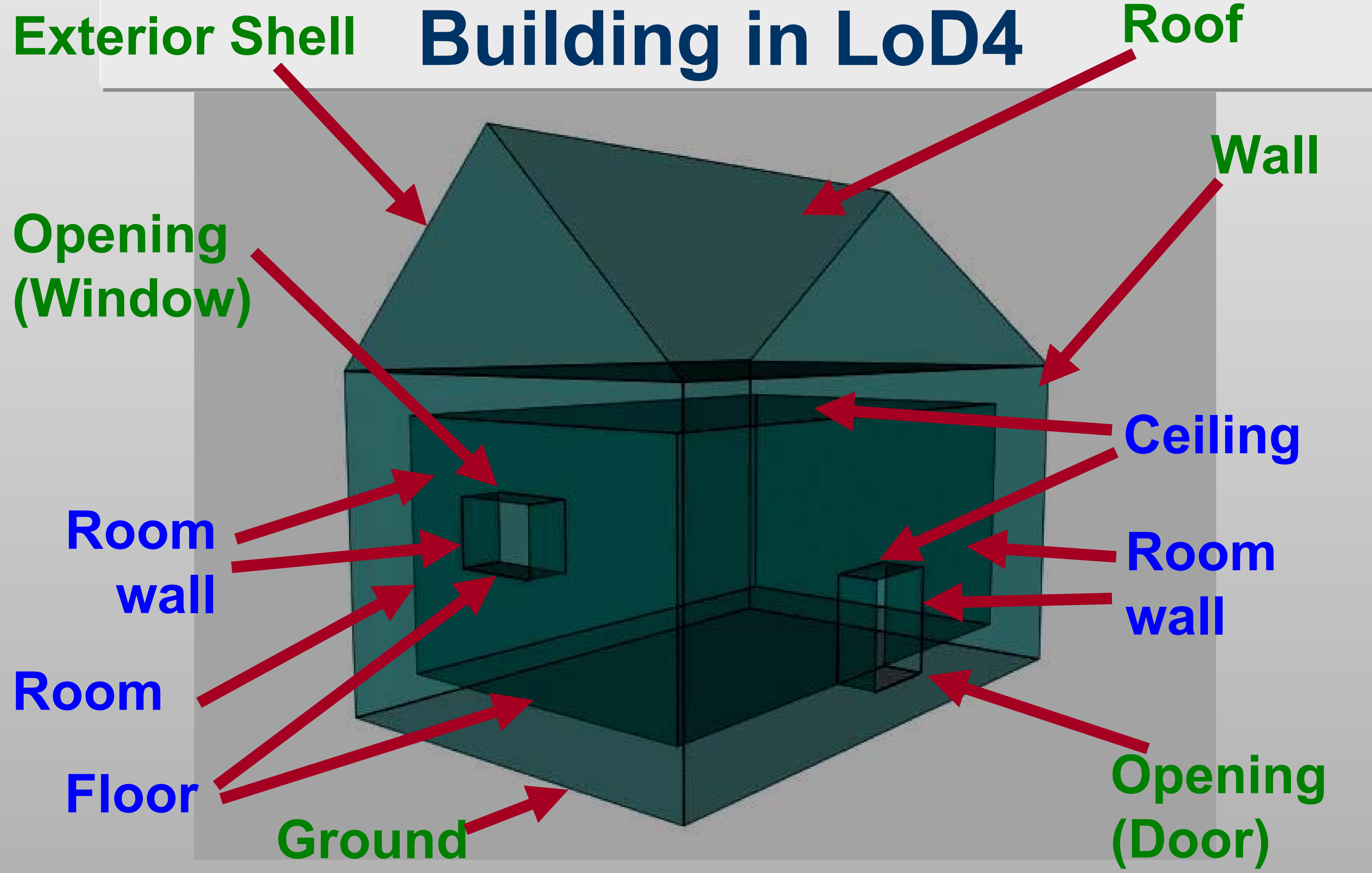


_CityObject
_Site
Excavation
_Abstract Building
Tunnel
Wall
Building Complex
Bridge

Building Model in LoD1: UML Diagram



Building in LoD4



Mixing Levels-of-Detail in one Scene

LoD1

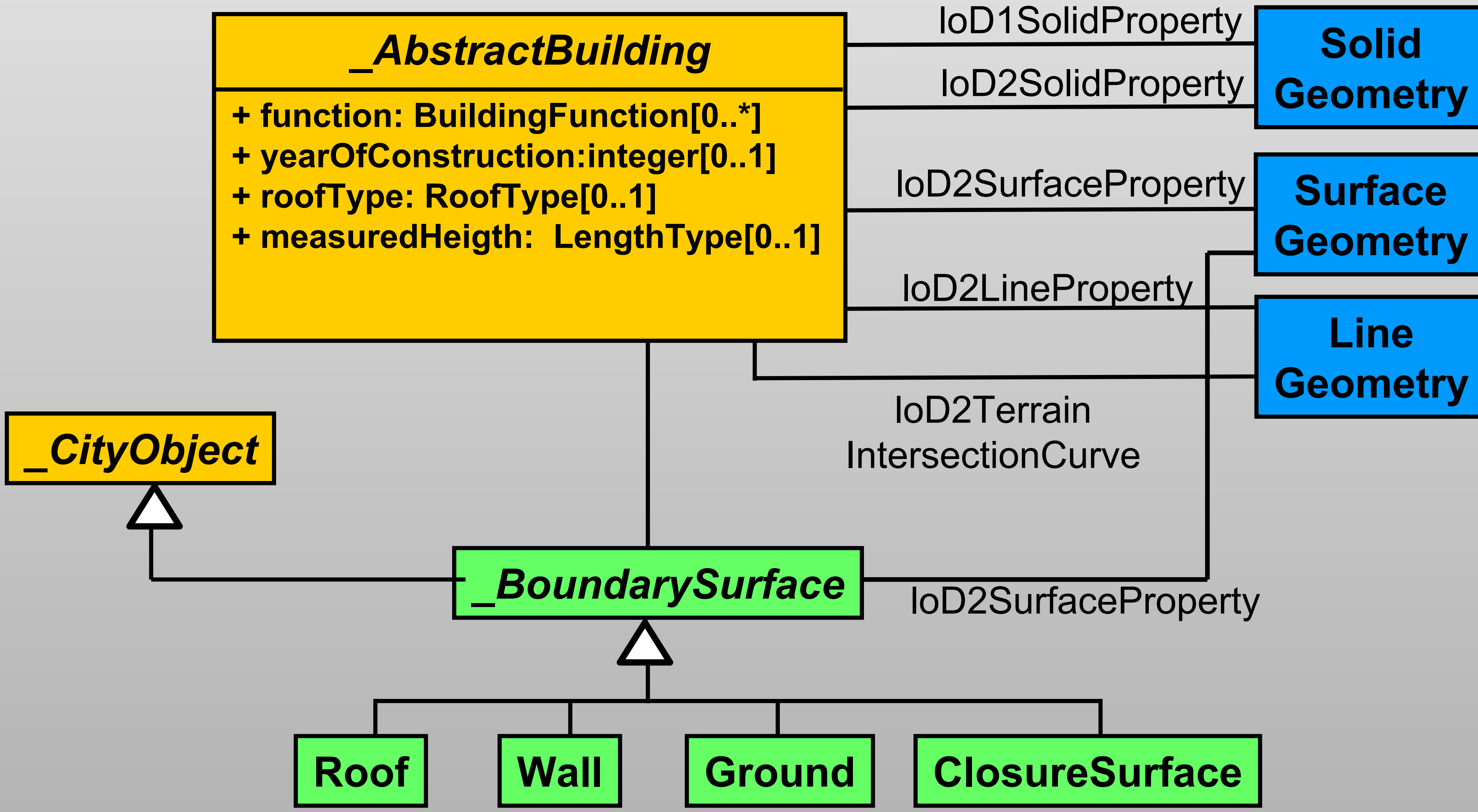
LoD2

LoD3

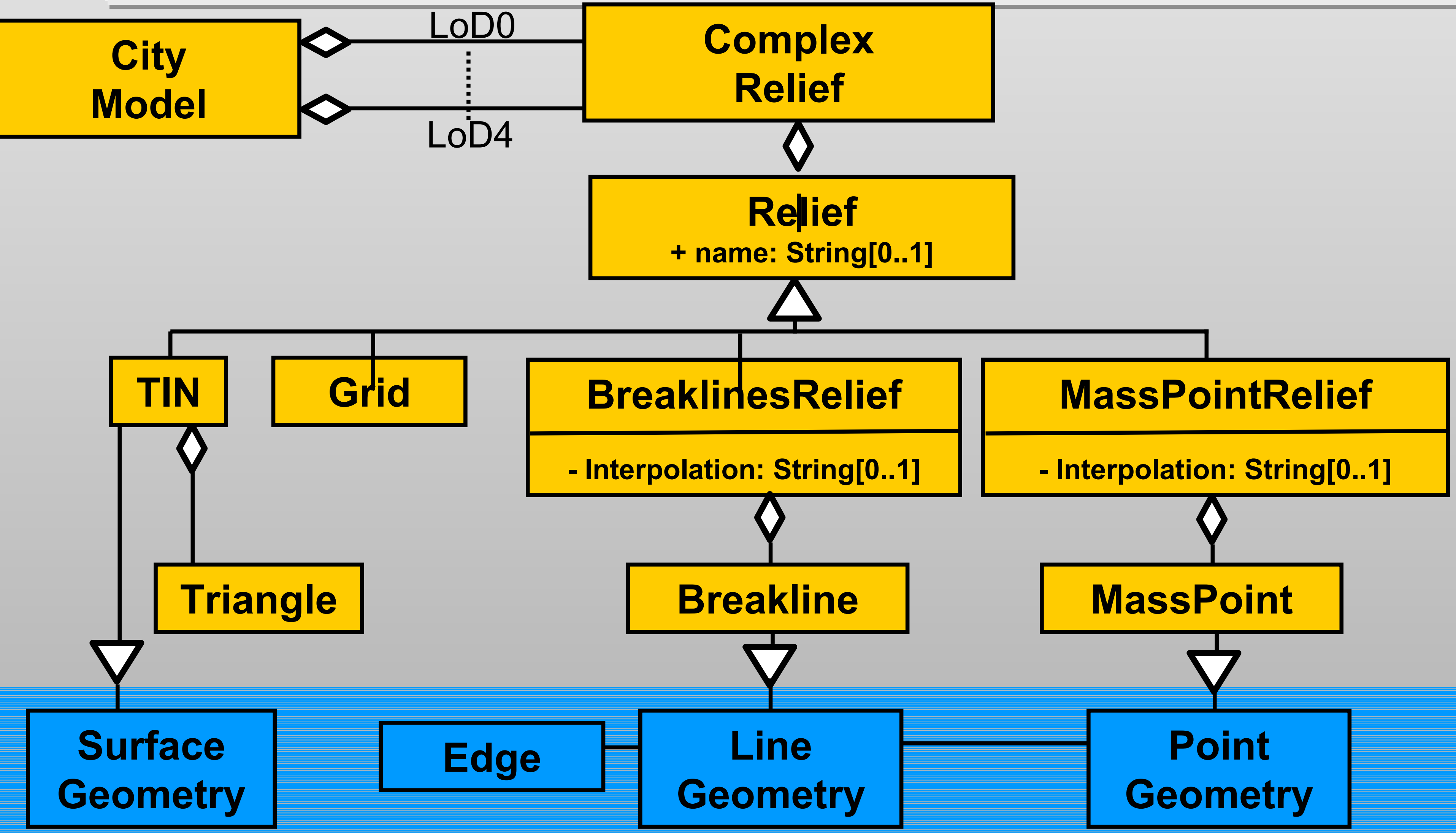
Picture: Dr. Steidler, CyberCity Modeler

LoD1 LoD2

Building Model in LoD2



Digital Terrain Model: UML Diagram



Unified City Models

Need	Existing GIS standards - Sufficient for City Models?
Syntactical Interoperability	
Semantical / Schema Interoperability	

Unified City Models

Need	**Existing GIS standards - Sufficient for City Models?**
Syntactical Interoperability	XML / GML 3 (nearly) sufficient
Semantical / **Schema** Interoperability	ISO/OGC 19107 'Spatial Schema' not sufficient: • no application model • too complex – geometry too extensive – topology separated from geometry • Level-of-Detail not supported

“3D City” Data Model

- Specified as UML class diagrams
- **Geometry / topology** according to **ISO 19107**
  - ‘Simple Topology Profile’ (extended to 3D)
- Topmost base class: _*CityObject*
  - **references to** corresponding objects in arbitrary **external data bases** (e.g., cadastral information system)
  - timestamps for **history management**
- Code lists for enumerative attributes
  - e.g., building function, roof type
  - reference to existing models (ALKIS) or customized
- Status quo: **building model and DTM complete**

Unified 3D city model: “City 3D“

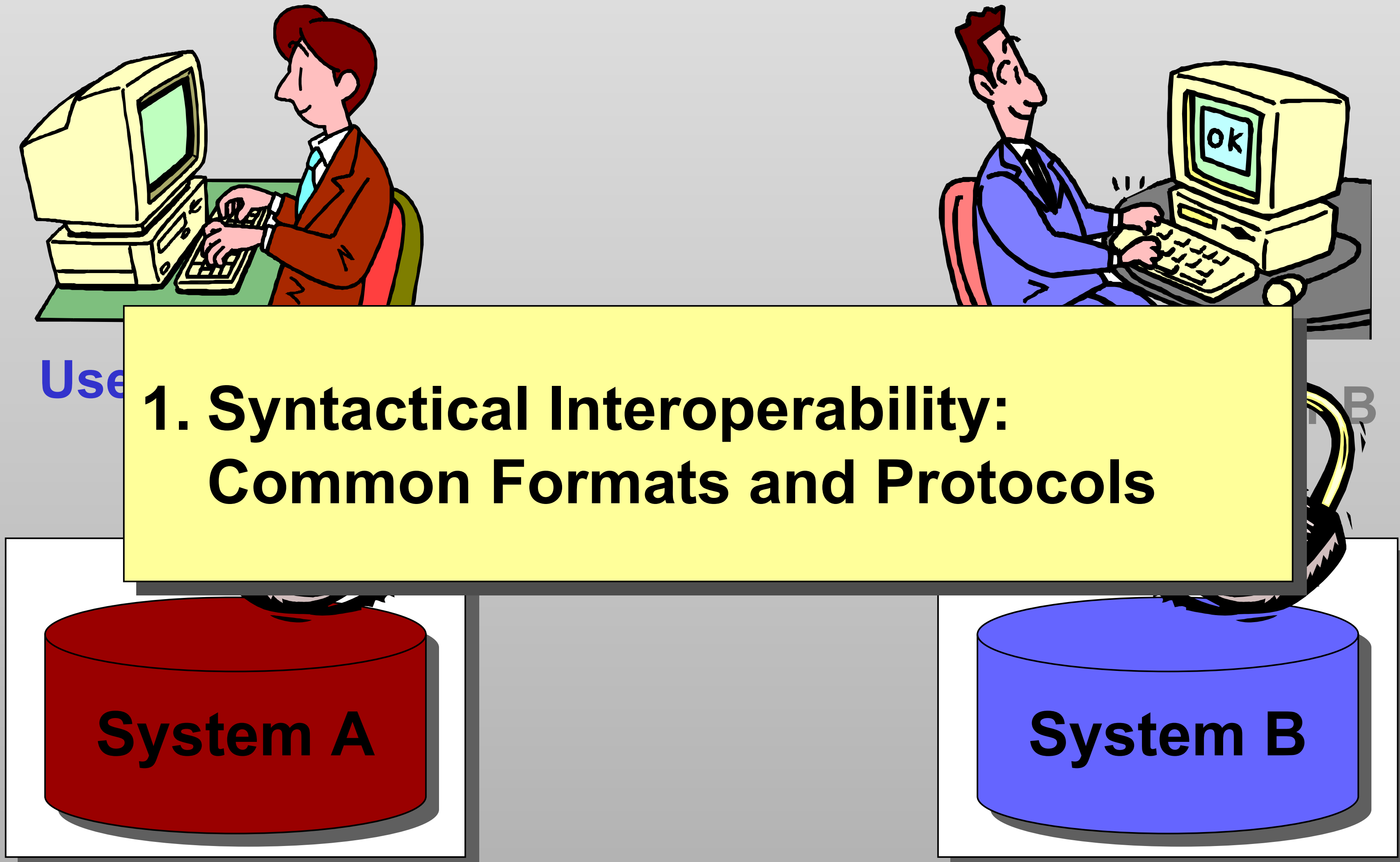
- **Aim:** Standard for 3D city models
- ongoing development in SIG 3D since May 2002

- **Content / Entities:**
  - **Digital Terrain Model / Relief**
  - **Sites**
    - Buildings
    - Bridges
    - Tunnels
    - Walls
    - Landfills
    - Excavations
  - **Transportation objects**
    - Streets
    - Railways
  - **Water bodies**
  - **Vegetation objects**
  - **City furniture**
    - e.g. street lights, traffic lights, benches

Interoperability

- syntaczical: XML (Extensible Markup Language)
- Schema
- Semantical

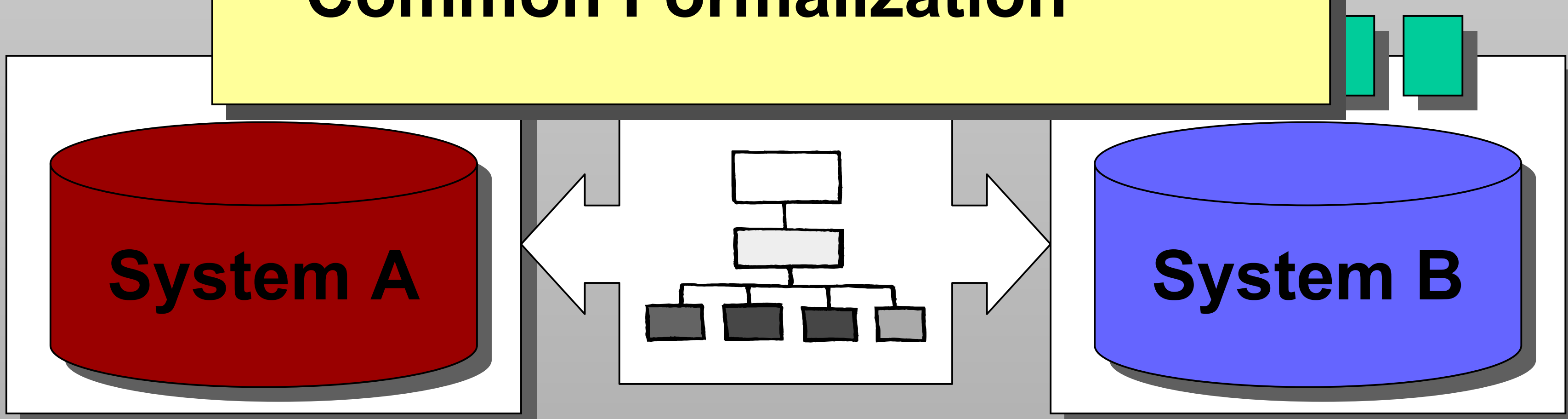
Levels of Interoperability



1. Syntactical Interoperability: Common Formats and Protocols

Levels of Interoperability

2. Schema Interoperability: Common Formalization



Levels of Interoperability

User A

B

3. Semantic Interoperability: Common Notions and Definitions

System A

System B