ASAM Ideation Workshop

Modelling Roads and the Streetspace using CityGML 3.0 and its relation to OpenDRIVE

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Semantic 3D City Modeling

- City is decomposed into meaningful objects with clear semantics and defined spatial and thematic properties
  - buildings, roads, railways, terrain, water bodies, vegetation, bridges
  - buildings or roads may be further decomposed into different storeys or sections / intersections (and even more detailed into apartments and single rooms or individual lanes)

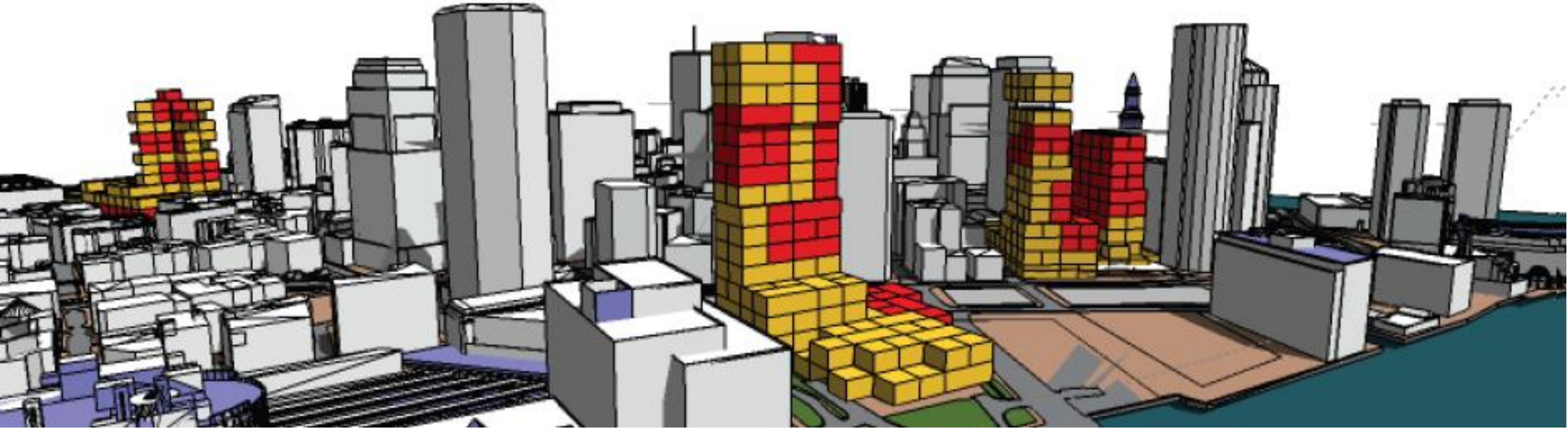
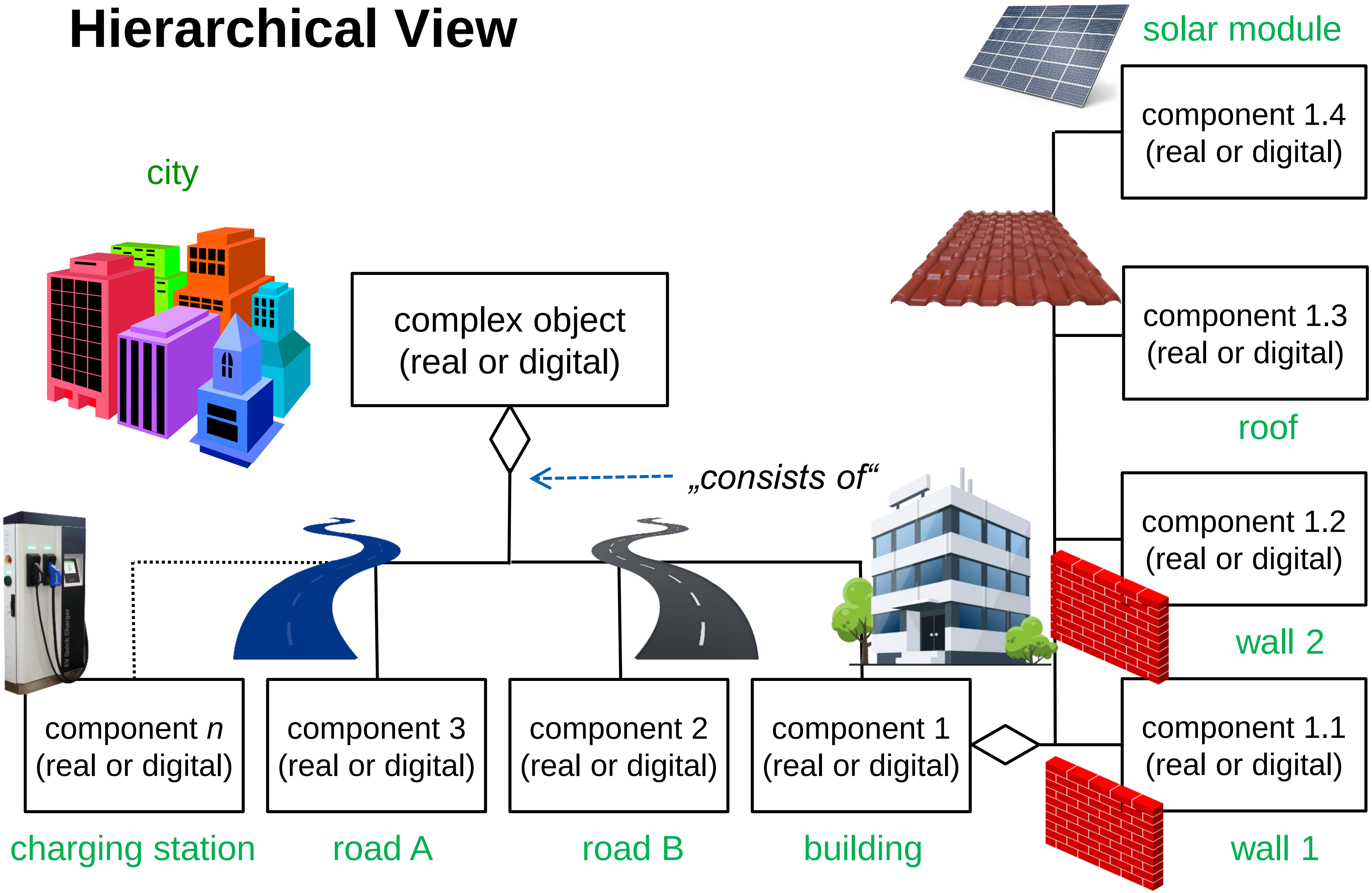
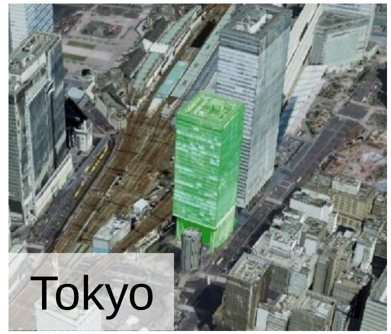


Image: Paul Cote, Harvard Graduate School of Design

Hierarchical View



Standardized Access to Semantic City Models



Mapping the state of a city at time t_i → CityGML ← Virtually carrying out planned actions by changing the city model accordingly

- Energy Demand & Production Estimation
- Noise Immission Simulation & Mapping
- Testing automated driving functions
- Traffic planning and simulation

City Geography Markup Language – CityGML

Application independent Geospatial Information Model
for semantic 3D city and landscape models

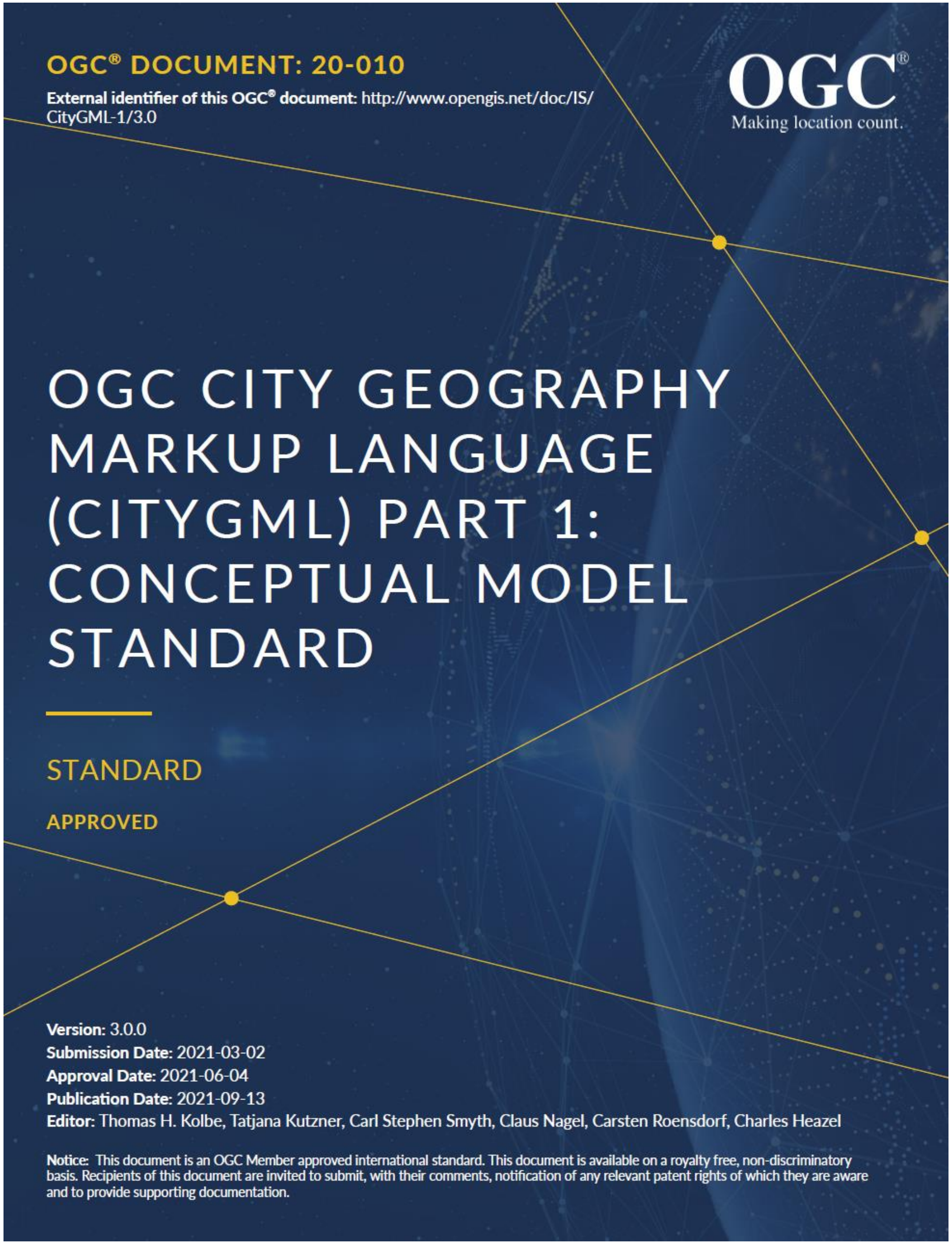
- comprises **different thematic areas** (buildings, roads, vegetation, water, terrain, tunnels, bridges etc.)
- **Data model (UML) + Exchange format**
- Key strengths: **Geo-referenced**, **3D geometries**, **topological** information as well as **semantic capabilities**, **time-dependent properties**, easy **visualization**
- Large scale (entire city) management using **geo-databases** (e.g. 3DCityDB)

International Standard of the **Open Geospatial Consortium**

- Version 2.0.0 was issued in 3/2012
- **Version 3.0 was issued in 2021**

The recent version CityGML 3.0

- On 13 September 2021, after eight years of development, the OGC published version 3.0 of the international standard CityGML
- The new version can be downloaded here: https://docs.ogc.org/is/20-010/20-010.html



OGC® DOCUMENT: 20-010

External identifier of this OGC® document: http://www.opengis.net/doc/IS/CityGML-1/3.0

OGC®
Making location count.

OGC CITY GEOGRAPHY MARKUP LANGUAGE (CITYGML) PART 1: CONCEPTUAL MODEL STANDARD

STANDARD

APPROVED

Version: 3.0.0
Submission Date: 2021-03-02
Approval Date: 2021-06-04
Publication Date: 2021-09-13
Editor: Thomas H. Kolbe, Tatjana Kutzner, Carl Stephen Smyth, Claus Nagel, Carsten Roensdorf, Charles Heazel

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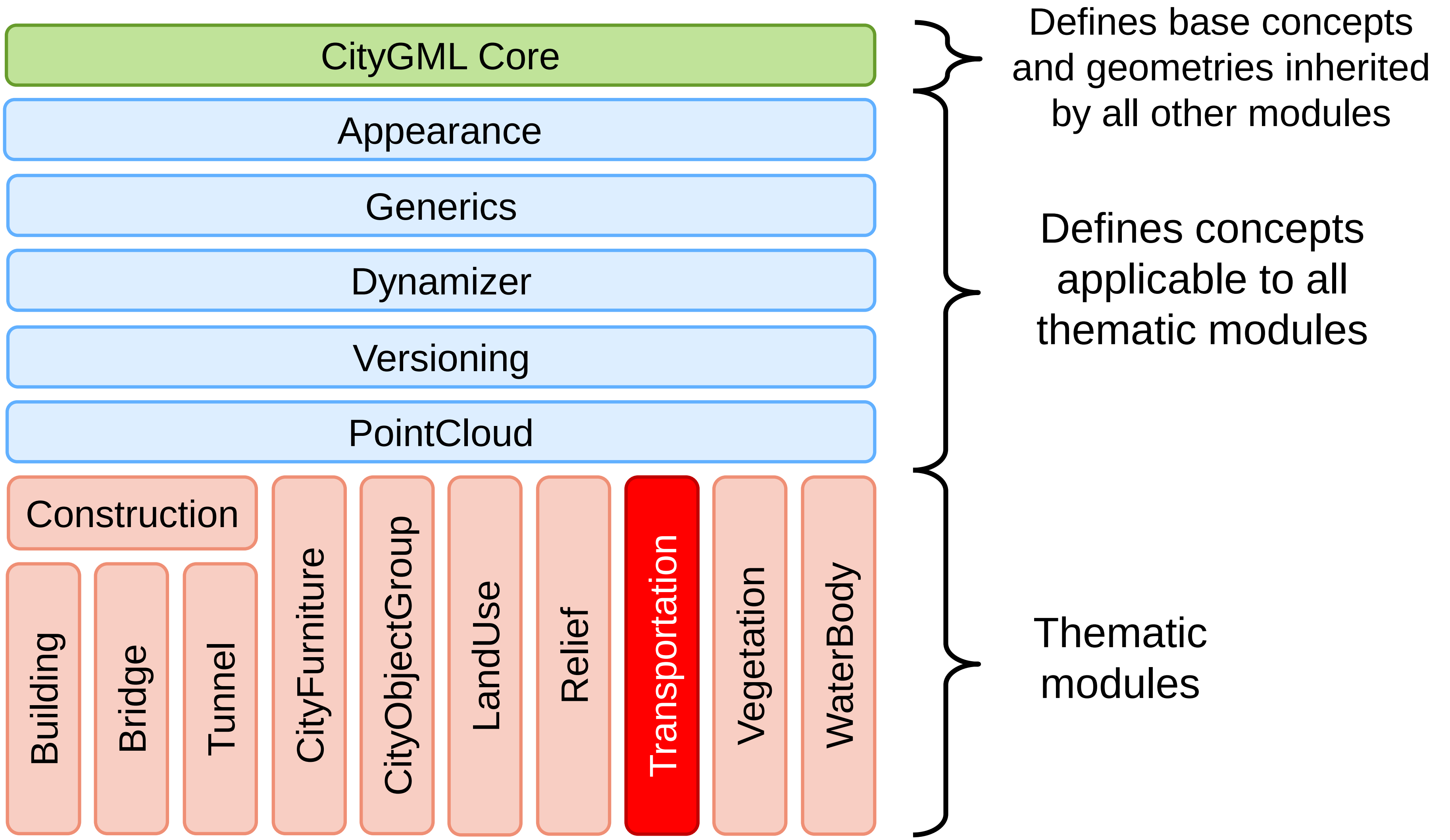
CityGML Usage

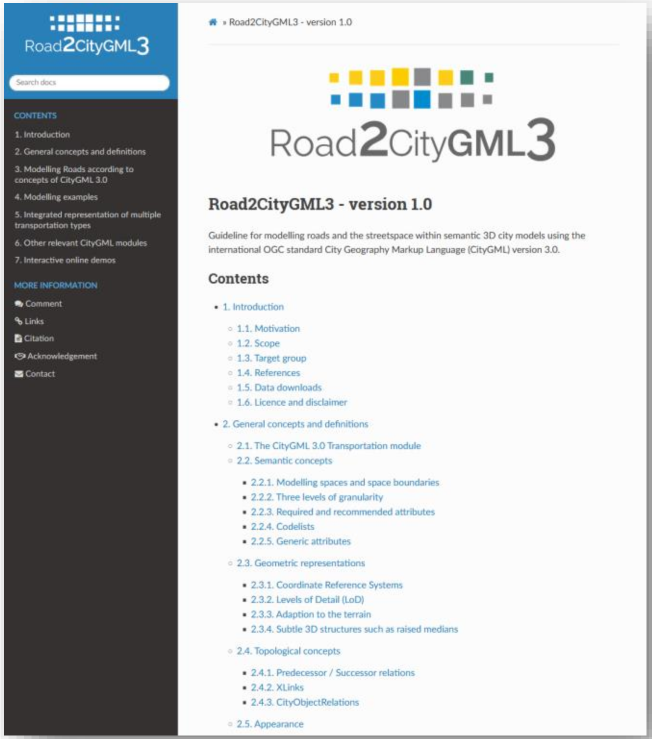
- CityGML is already successfully used at national scale
  - The official national and municipal 3D geoinformation standards of Germany and the Netherlands based on CityGML 1.0/2.0
  - Japan published 3D city models for >100 cities based on CityGML and the i-Urban Revitalization Application Domain Extension
- Many cities worldwide use CityGML for their 3D city models
- List of Open CityGML Datasets: https://github.com/OloOcki/awesome-citygml
  - from 18 countries, in different Levels of Detail, most data are officially maintained 3D city models

Modular structure of the CityGML standard



Guideline Road2CityGML3

- https://tum-gis.github.io/road2citygml3
- Concepts of the CityGML 3.0 for modelling the streetspace
  - Semantics
  - Geometries
  - Topology
  - Appearance
- Examples
  - E.g. NYC, Melbourne, Ingolstadt, Munich
- Data downloads



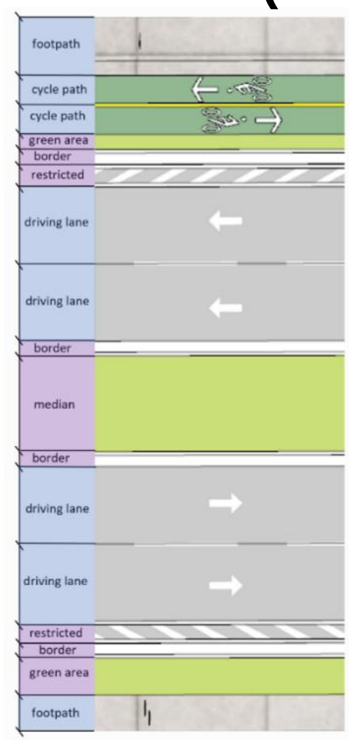
Representation of Road Infrastructure

- Real world objects are represented by geographic features as defined in **ISO 19109**
- Each object has a **unique identifier** (gml:id attribute)
- **Hierarchical structure** / decomposition into individual objects

Road

Section

Traffic Areas (Lanes)

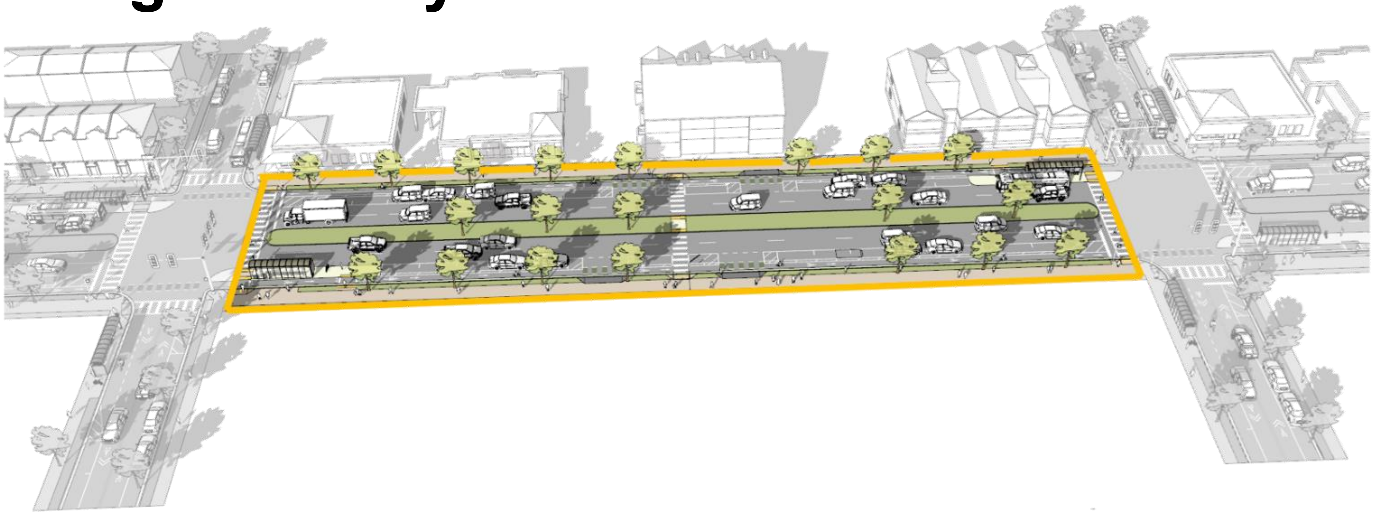


Representation of Roads

- A **Road** is a transportation space used by vehicles, bicycles and/or pedestrians.
- Usually **Roads** should be distinguished by individual names

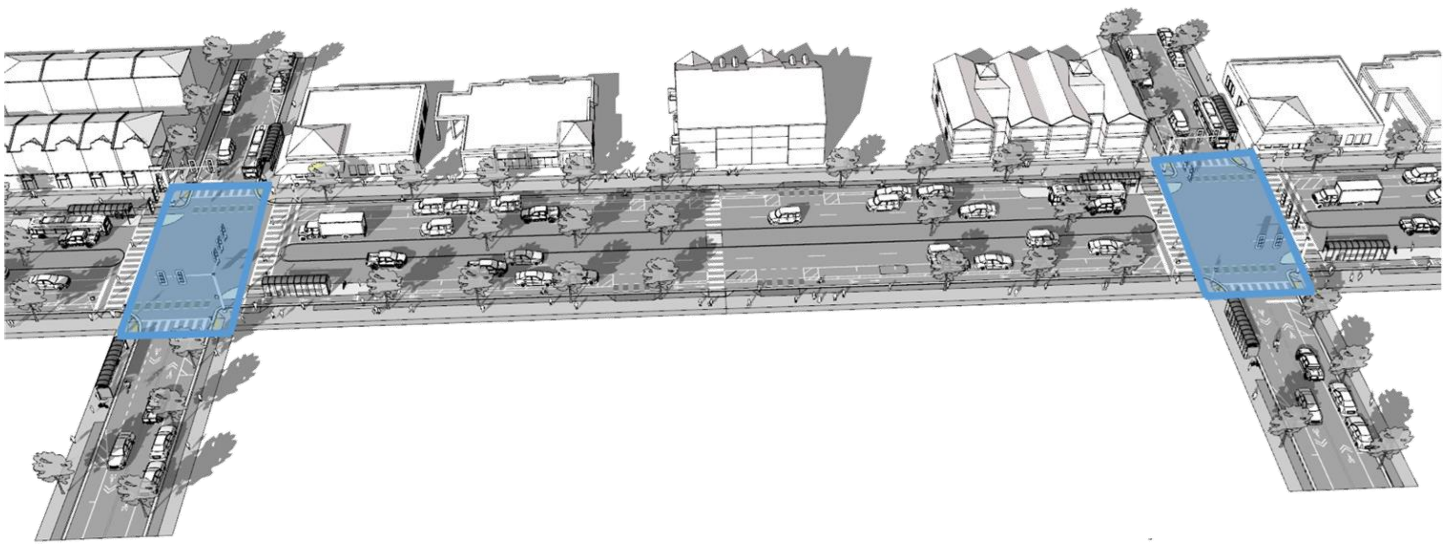
Segmenting road networks into Sections and Intersections

- **Roads** can consist of several **Sections**
- A **Section** is a transportation segment that can clearly be assigned to one **Road** (or **Railway, Track, Waterway**) object.
- **Sections** should cover the entire width of a **Road** and thus directly correspond to the representation of transportation objects in **granularity 'area'.**



Segmenting road networks into Sections and Intersections

- An **Intersection** is a transportation space that is a shared segment of multiple **Roads** or other transportation objects such as **Railways** (e.g. a crossing of two **Roads** or a level crossing of a **Road** and a **Railway**).
- The link of an **Intersection** to multiple **Roads** can be explicitly modelled (using **XLinks**)



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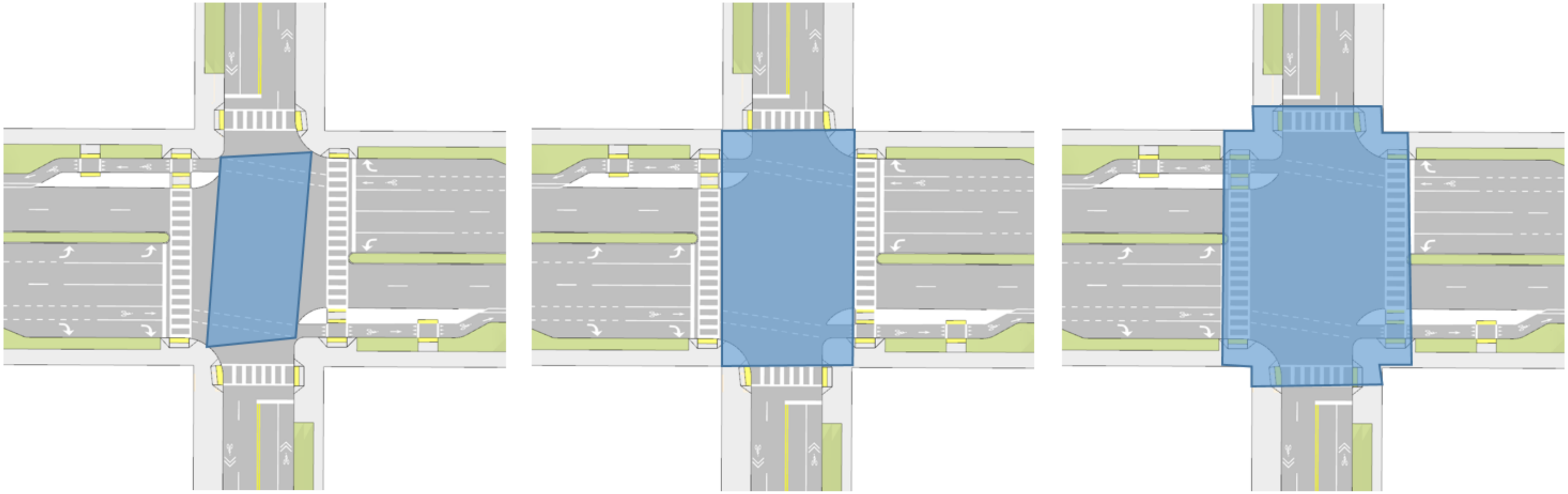
- Different possibilities to define Intersections areas

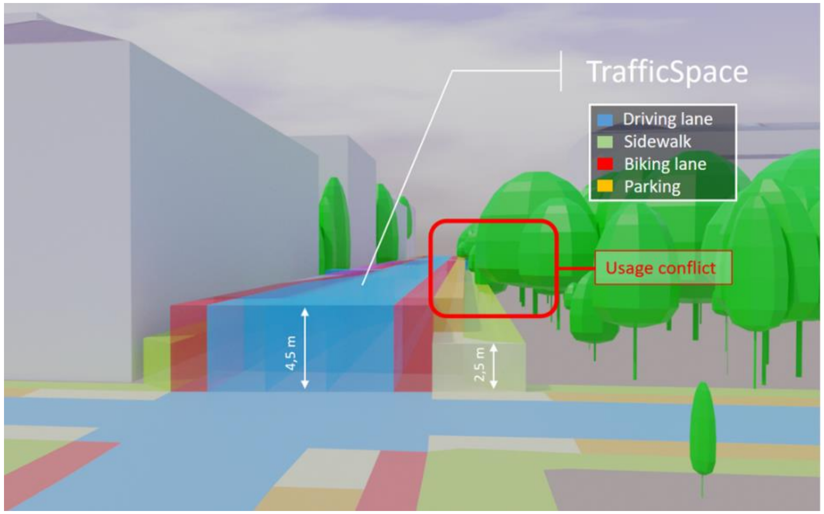


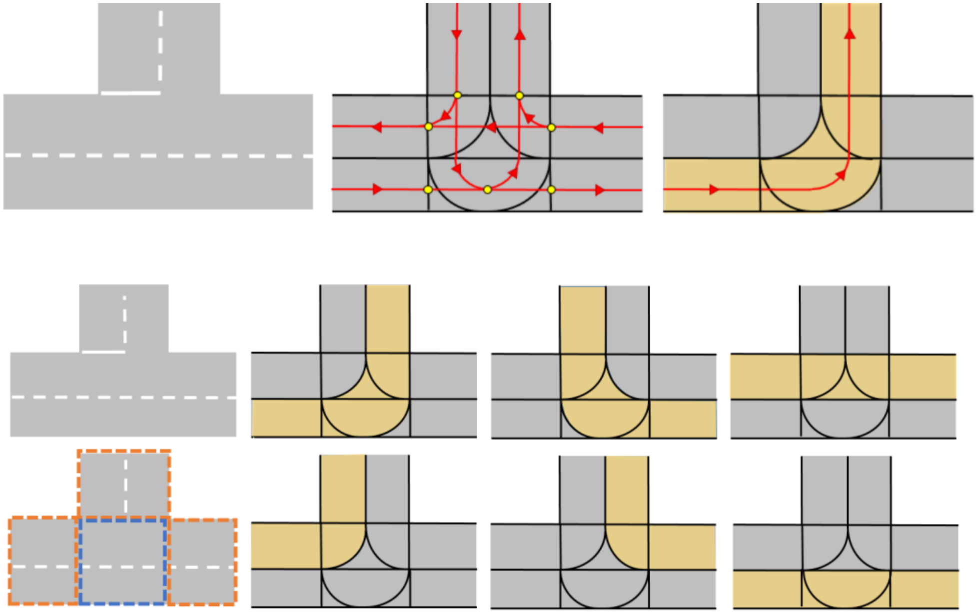
Segmenting road networks into Sections and Intersections

- Example: Melbourne

Transportation Spaces in CityGML

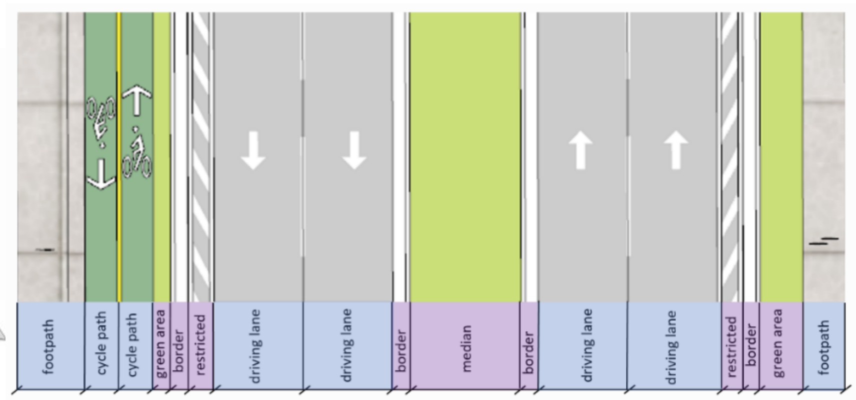
- **TrafficSpace** is a space in which traffic takes place
- Can be represented geometrically using e.g. **linear or volumetric geometries** (or geometric representation can be omitted if not required)
- Ground surfaces of **TrafficSpaces** are **TrafficAreas**





TrafficAreas and AuxiliaryTrafficAreas

- A **TrafficArea** is the ground surface of a **TrafficSpace** upon which traffic actually takes place.
- **AuxiliaryTrafficAreas** are describing further elements of the **Road**, like kerbstones, raised medians, and green areas not intended for direct traffic usage.
- Standardized attributes on function, surface material, etc.
- **Example: Section** with two carriageways segmented into **TrafficAreas** and **AuxiliaryTrafficAreas**

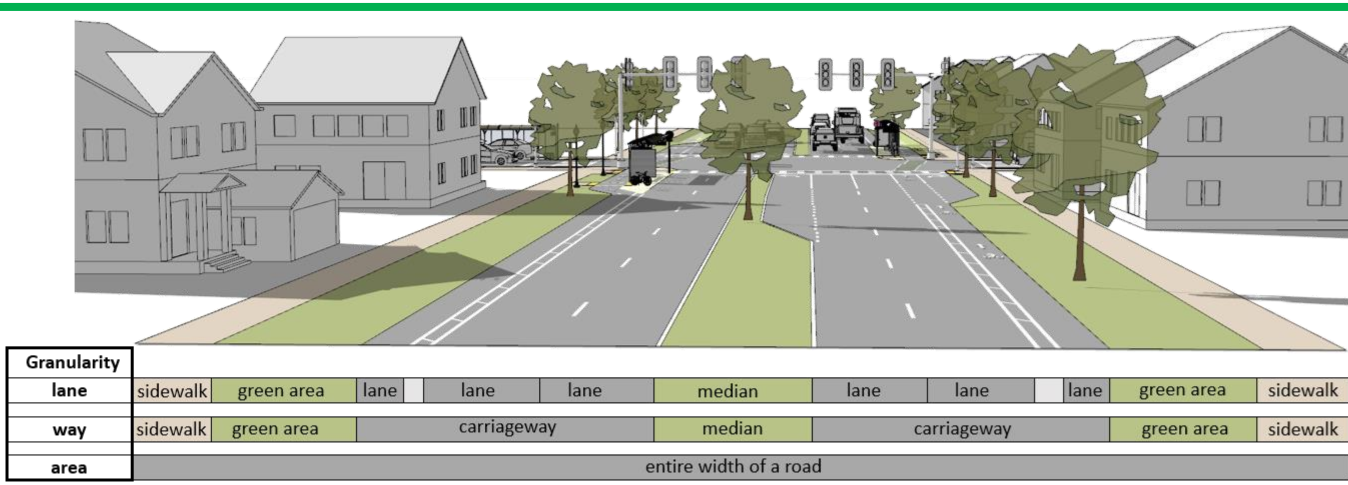


Three levels of granularity

- In **granularity ‘area’** the entire width of a **Road** is modelled with one single object.
- In **granularity ‘way’** individual objects are modelled per surface function (or traffic type). This means one object per carriageway is used.

Granularity of OpenDRIVE lane data

- In **granularity ‘lane’** each individual lane (including driving lanes for vehicles) are modelled separately.



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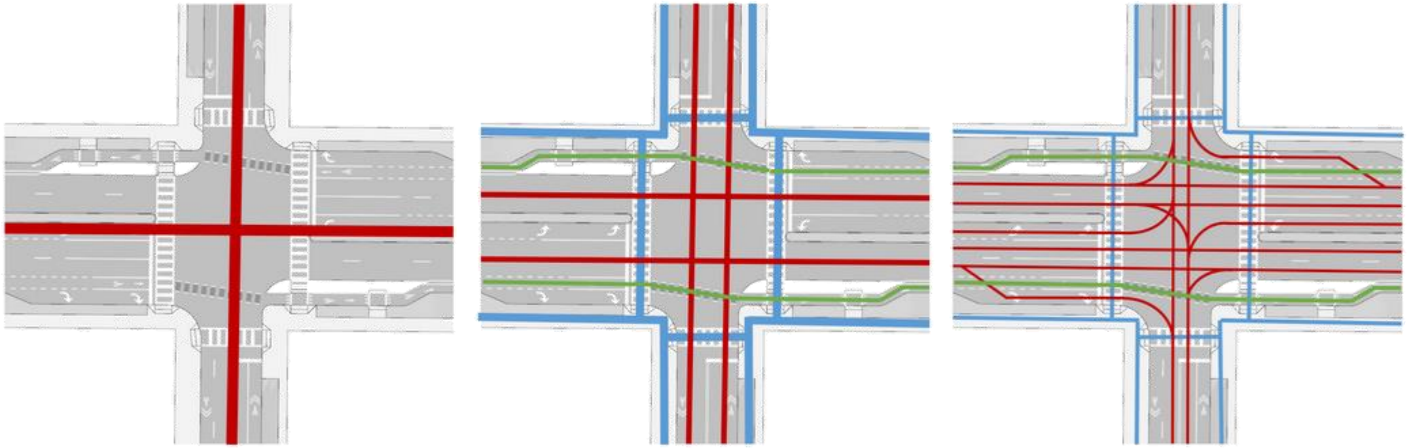
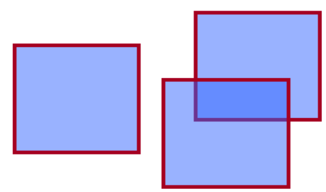


Geometry

- ISO 19107:2003 Geographic information - Spatial schema
- Geometry Types most relevant for Transportation Module
  - GM_Point
  - GM_MultiPoint
  - **GM_MultiCurve**
  - **GM_MultiSurface**
  - GM_Solid
  - GM_Object



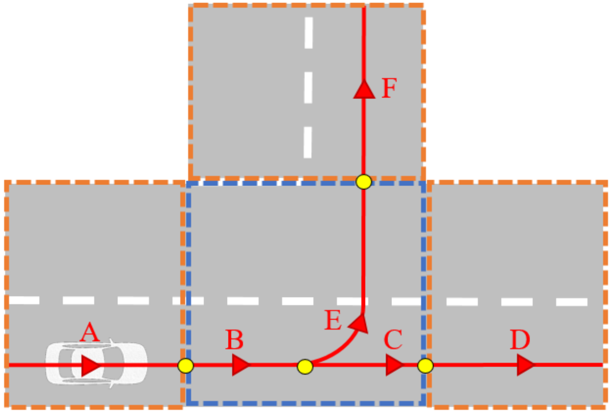
<<CodeList>>
GM_CurveInterpolation

+ linear
+ geodesic
+ circularArc3Points
+ circularArc2PointWithBulge
+ elliptical
+ clothoid
+ conic
+ polynomialSpline
+ cubicSpline
+ rationalSpline

- Nearly all geometries use 3D coordinates
- Coordinates always have to be given with respect to a coordinate reference system (CRS)

Topology

- Predecessor / Successor Concept
- Traffic direction attribute
- Useful for routing / navigation applications

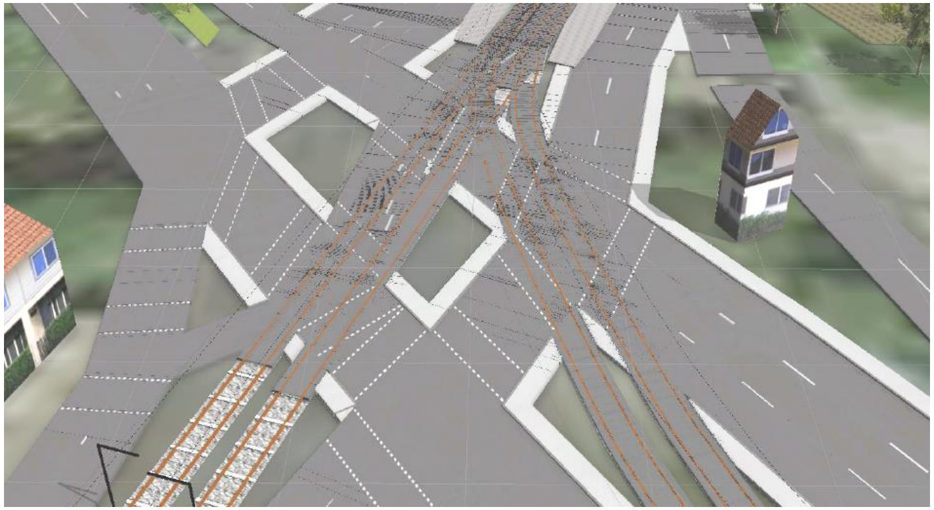


TrafficSpace	Predecessor	Successor(s)
A		B
B	A	E, C
C	B	D
D	C	
E	B	F
F	E	

- Linking concept for non-redundant representations (e.g. XLinks)
  - Geometry shared by different semantic objects only needs to be represented once

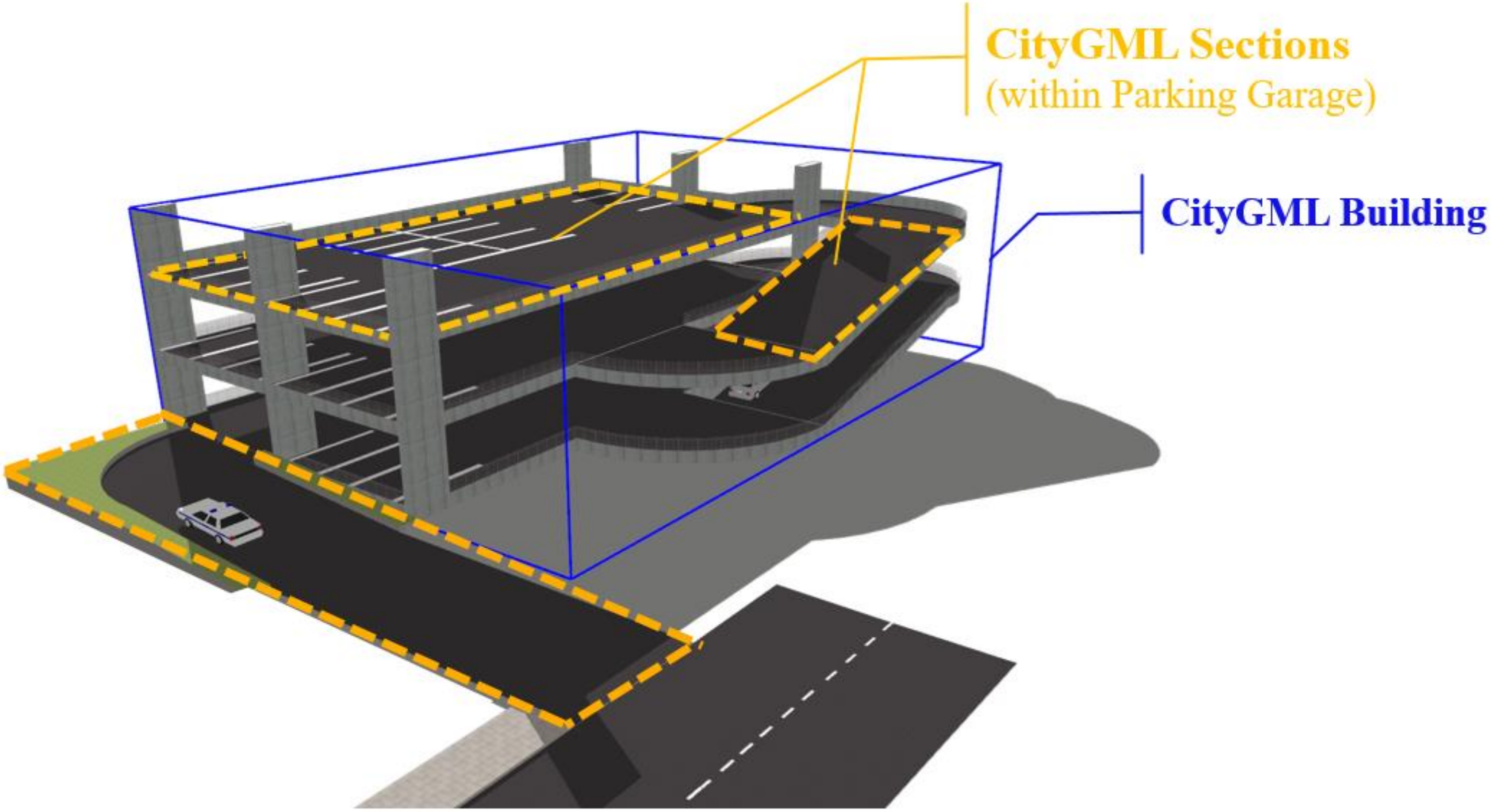
Integration of multiple Transportation types

- Concepts apply to Road, Railway and Waterway infrastructure
- Combined and non-redundant geometric and semantic modelling of multiple transportation infrastructure possible
- **Consistent**, **integrated** and **complete 3D city model**



Roads within Buildings (Parking garage)

- Transportation networks and *Roads* can reach into *Buildings* (e.g. within a parking garage)



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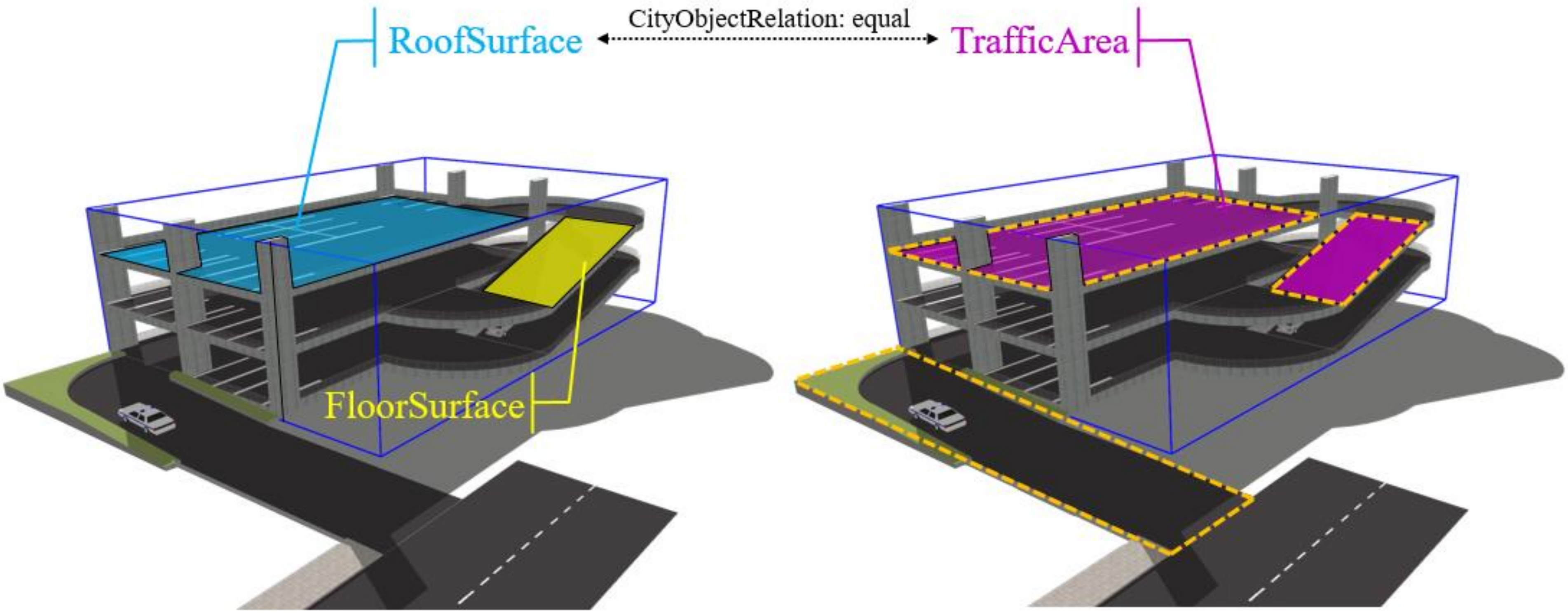
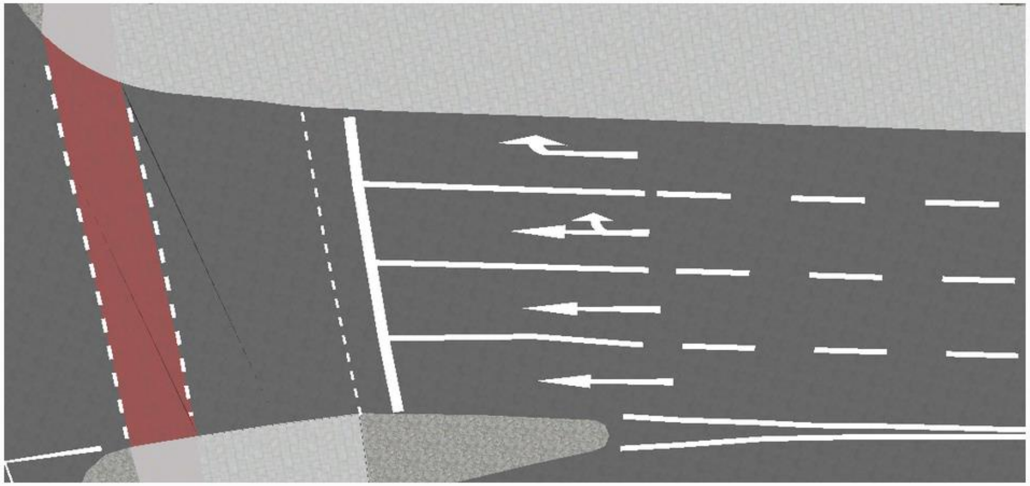


Other relevant CityGML objects

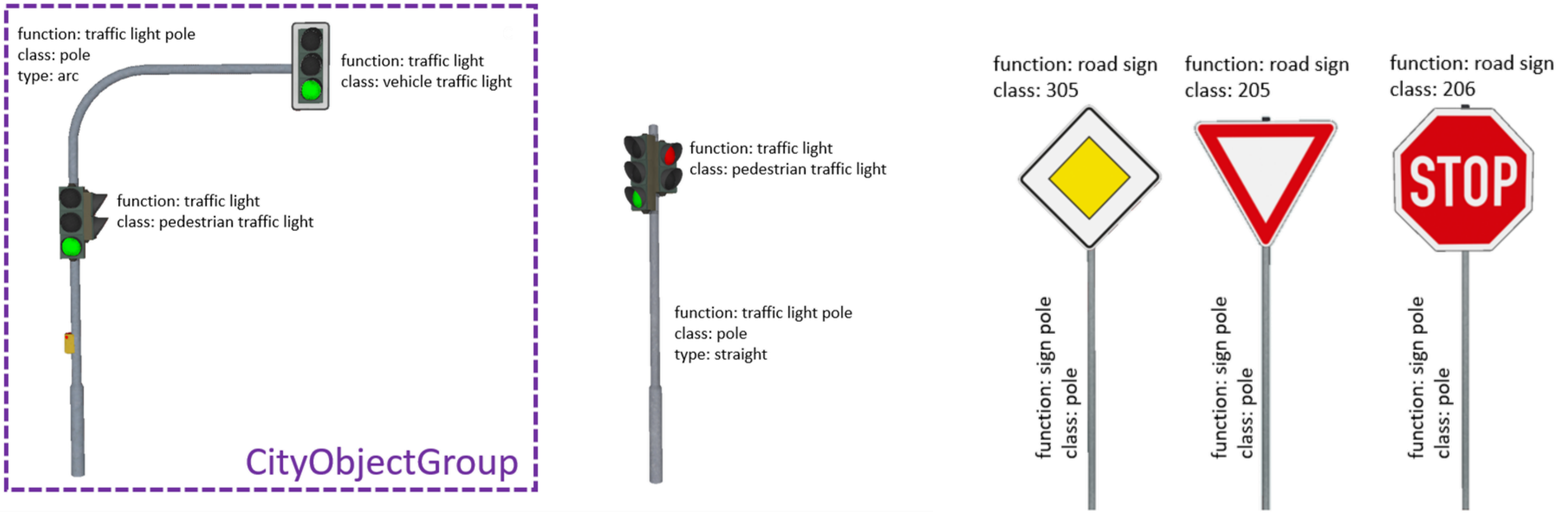
- **Markings**
  - Visible pattern on a transportation area relevant to the structuring or restriction of traffic
  - E.g. using explicit (polygonal) geometries
  - Each marking can be related to a specific lane
  - Attributive information on function (e.g. stop line, arrow straight, etc.) can be contained



Other relevant CityGML objects

▸ CityFurniture

- Object or piece of equipment installed in the outdoor environment for various purposes (e.g. street signs, traffic signals, street lamps, benches, trash bins, bike racks, etc.)
- Traffic signs / lights can be related to individual lanes
- Implicit or explicit geometries (point / surfaces geometries or actual 3D models)



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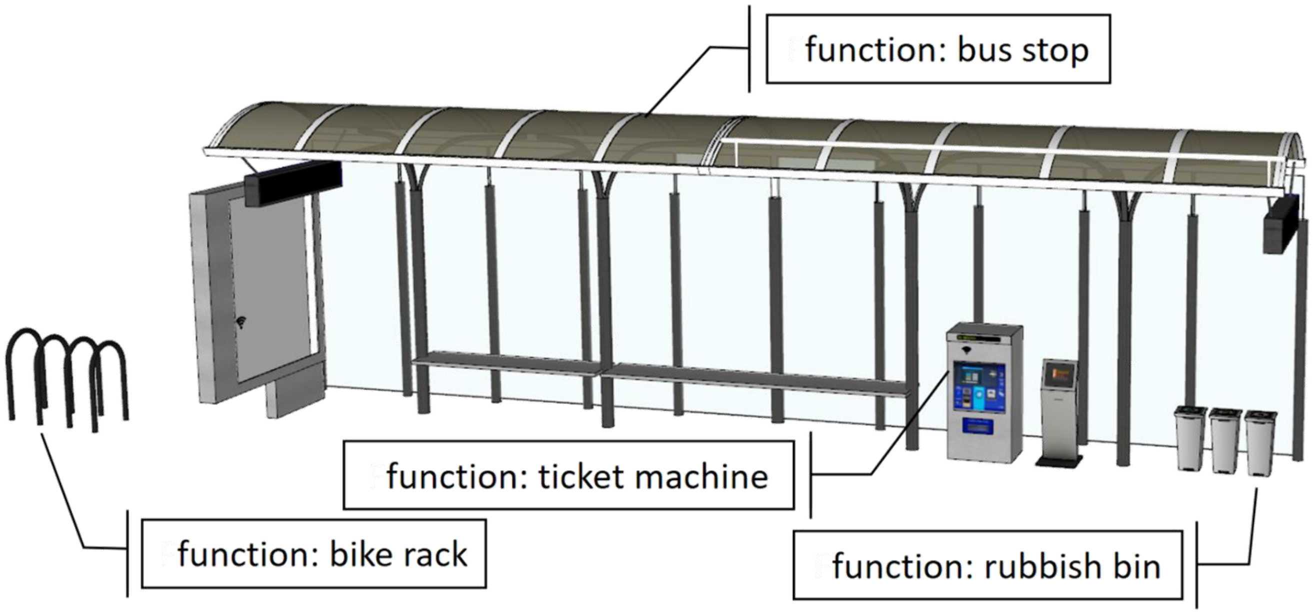


Other relevant CityGML objects

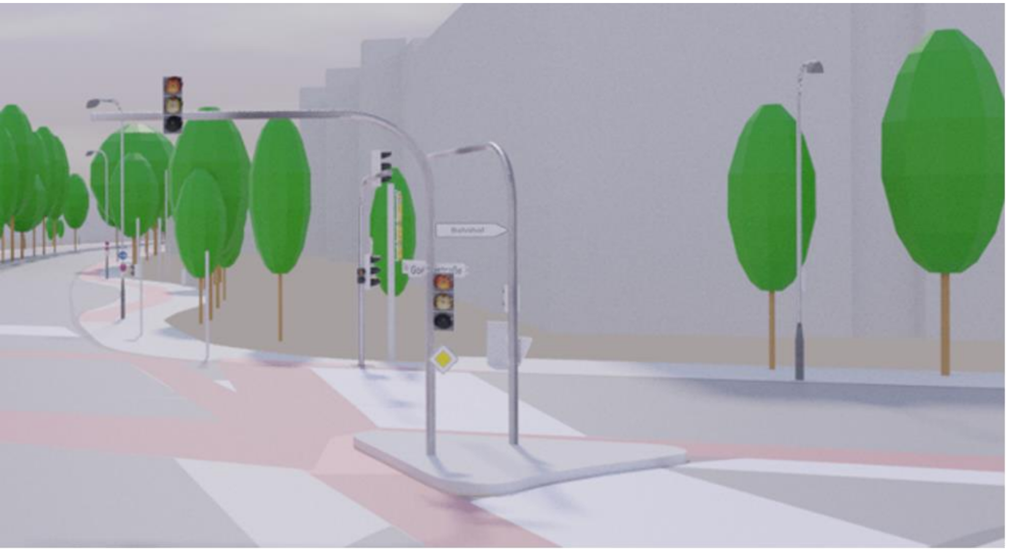
- **Holes**
  - Openings in the surface of a street, road, or plaza, such as road damage, manholes, or gullies

Other relevant CityGML objects

- **Squares**
- Transportation space for unrestricted movement of vehicles, bicycles and/or pedestrians
- Includes plazas as well as large sealed surfaces such as parking lots or gas stations

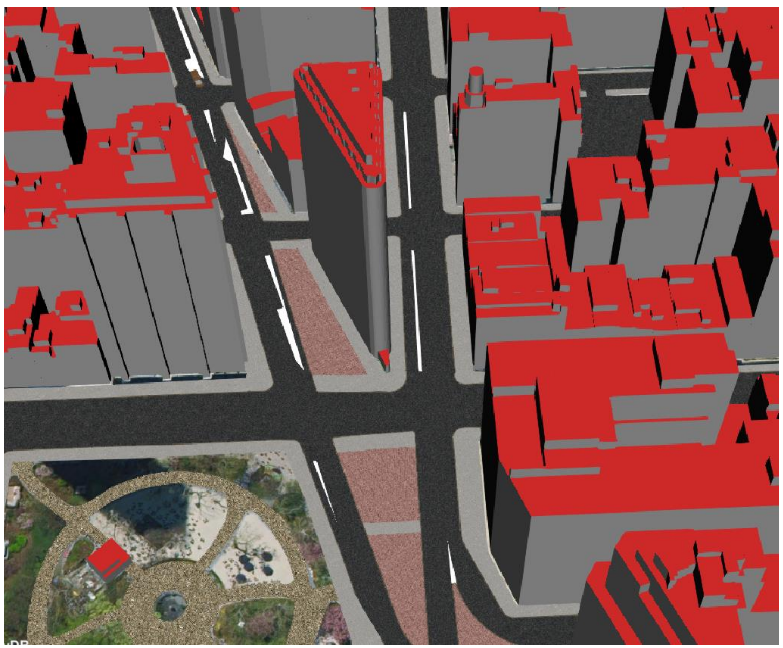
Other relevant CityGML obejcts

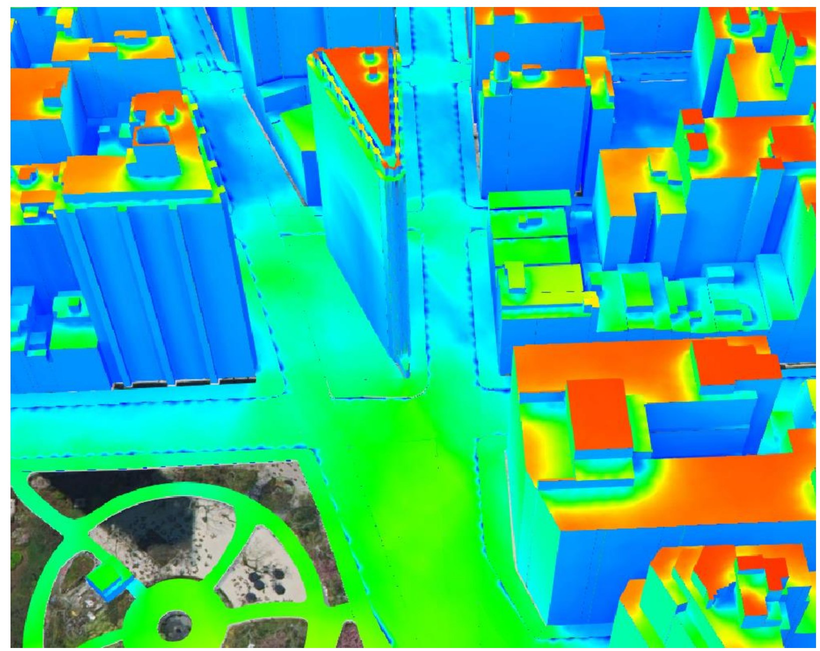
- **Vegetation**
  - Solitary vegetation objects, such as trees, bushes and ferns, or vegetation areas that are covered by plants of a given species or a typical mixture of plant species, such as forests, steppes and wet meadows



Appearance

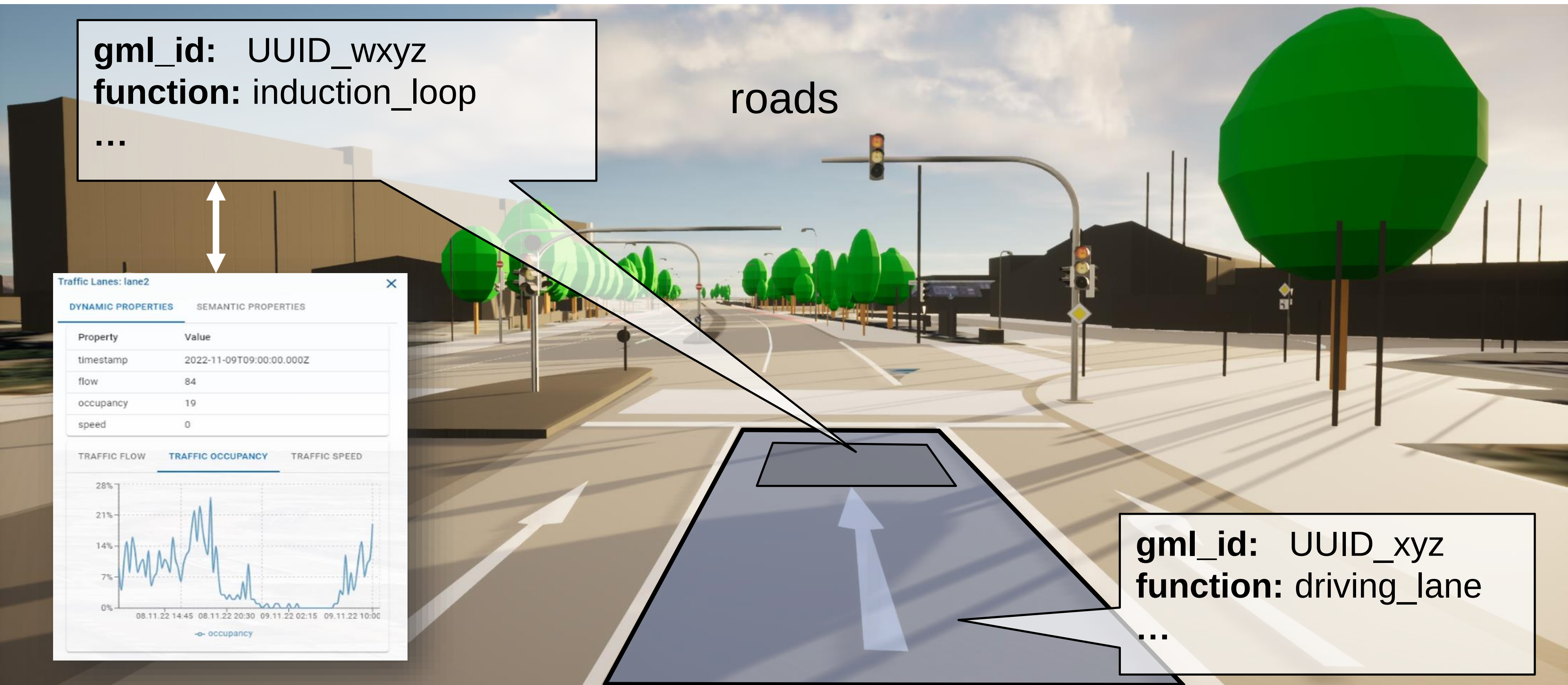
- Colors / textures can be associated with city objects
- E.g. material definitions from the X3D and COLLADA standards
- Single surface geometry object may have surface data for multiple themes (arbitrary categories, e.g. solar irradiation)





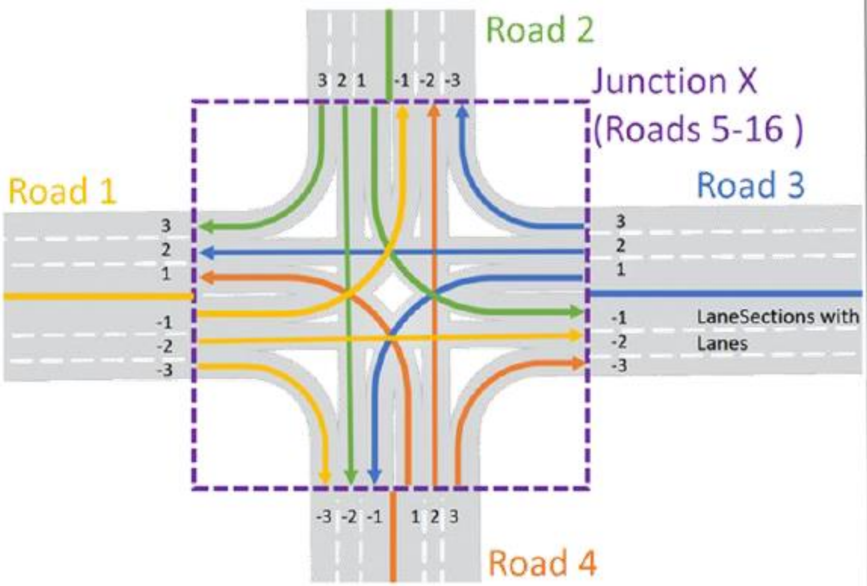
Representing time-depentent properties using Dynamizers

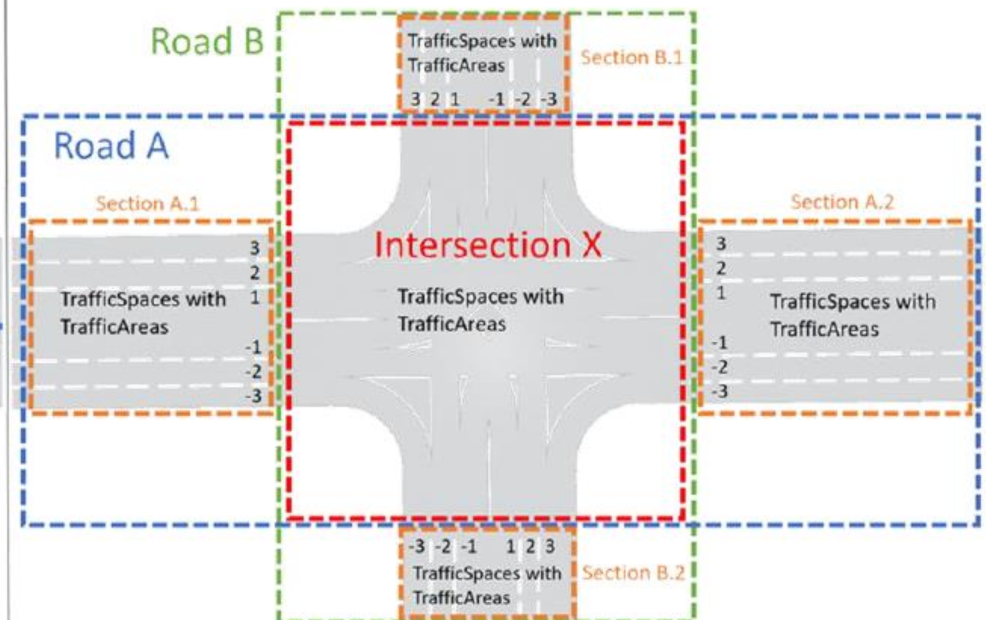
- **Dynamizer**
- Concepts that enables representation of time-varying data for city object properties as well as for integrating sensors with 3D city models.



Comparison of OpenDRIVE and CityGML

OpenDRIVE Standard Roads / Roads within a Junction || **CityGML** Roads with Sections / and Intersection





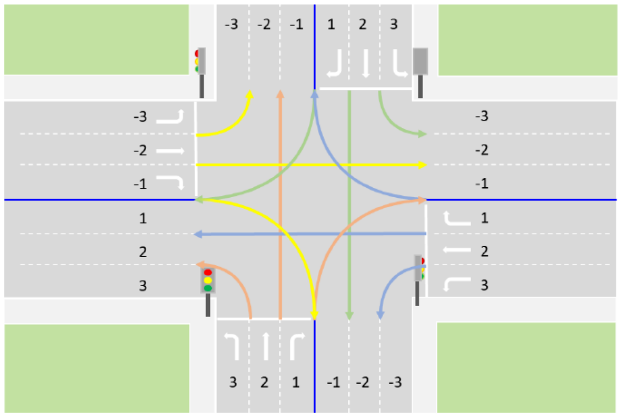
Referenceline-based (parametric) redundant and overlapping geometries and data gaps

Surface-based (explicit coordinates) and non-redundant without overlapping geometries or gaps

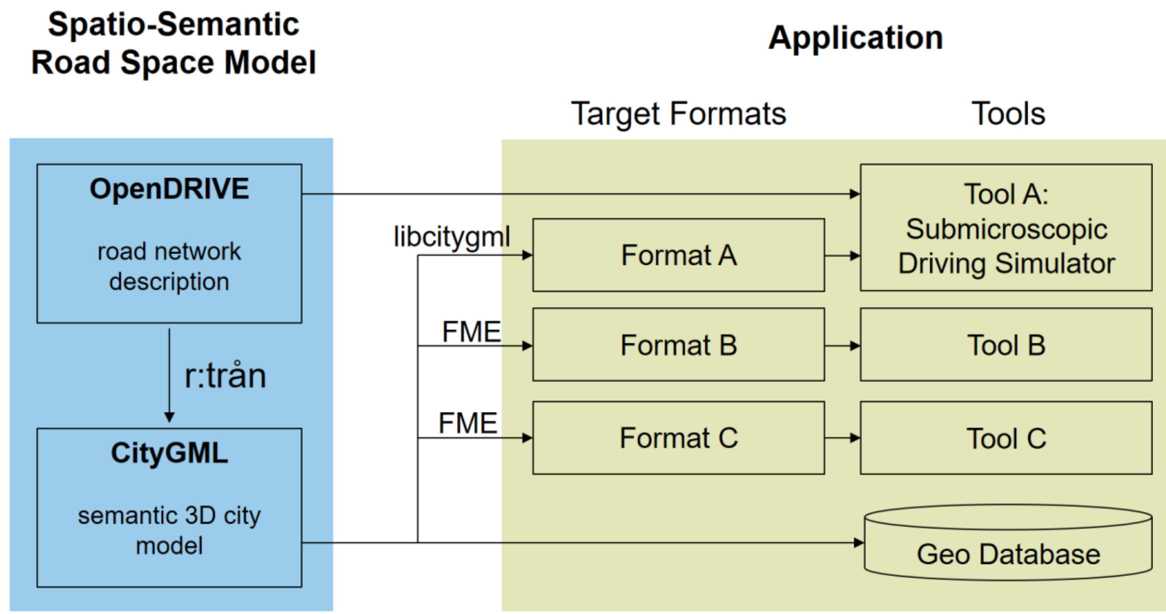
Open source OpenDRIVE to CityGML converter

https://rtron.io/

Parametric OpenDRIVE

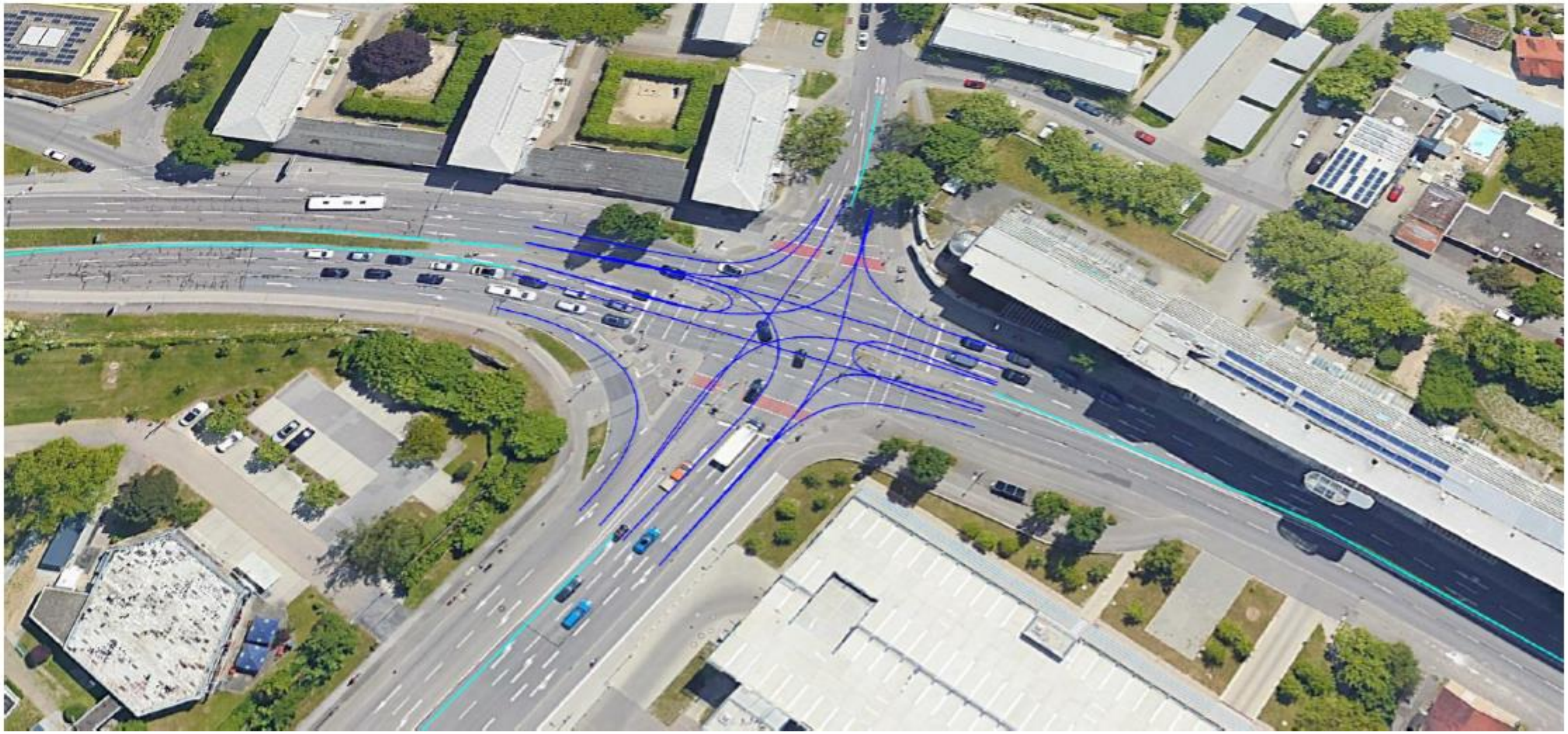


Semantic 3D city model
with explicit coordinates

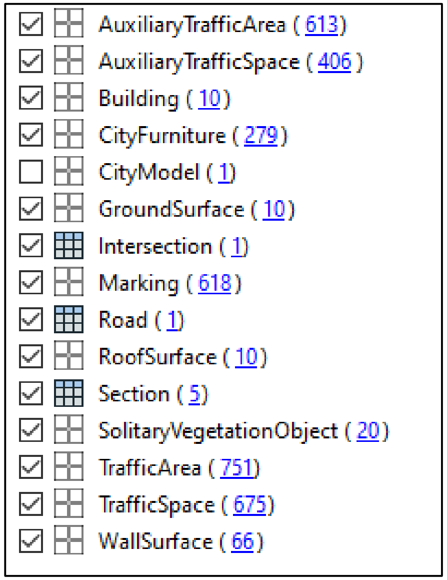


CityGML 3.0 from OpenDRIVE

- OpenDRIVE data created by 3DMappingSolutions GmbH
  Intersection in Ingolstadt

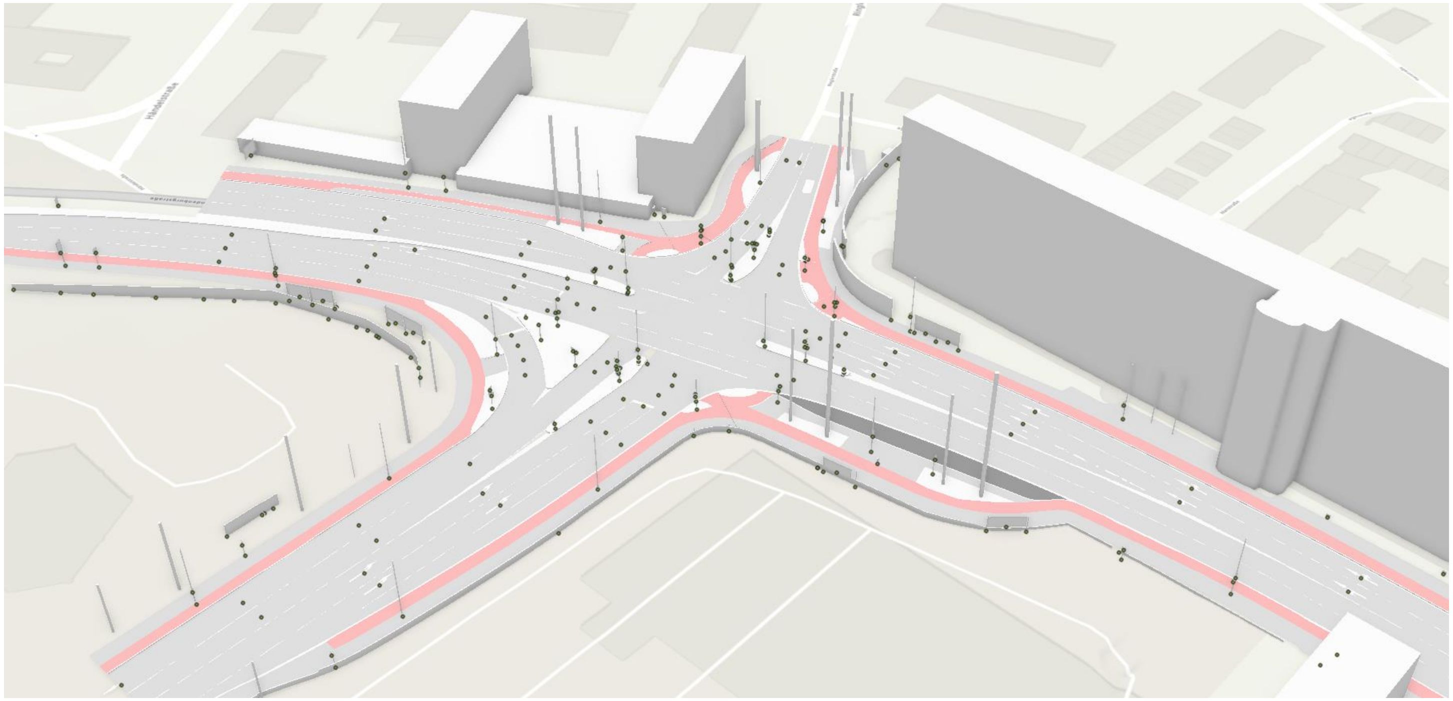


CityGML 3.0 from OpenDRIVE



Converted from OpenDRIVE to CityGML 3.0 using r:tron

Containes overlaps and redundant geometries due to the original data structure



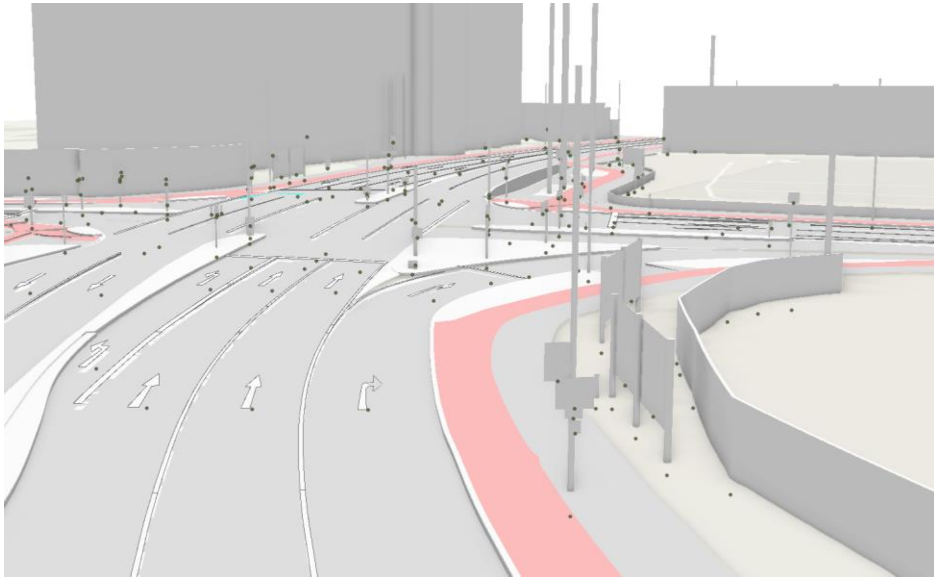
CityGML 3.0 aus OpenDRIVE

CityFurniture
- Poles
- Traffic signs
- Traffic lights
- Barriers
- etc.

Vegetation
- Trees
- Information on height, diameter, etc

Information on signs / traffic lights and trees is (in some cases) abstracted with points containing attributes on type-subtype etc.

This can be substituted with actual 3D sign models etc.



CityGML 3.0 Streetspace Modeling Example 1

- Streetspace model of Ingolstadt automatically generated from OpenDRIVE data and visualized in the UnrealEngine

https://www.youtube.com/watch?v=t5UXEVQcMj4

CityGML 3.0 Streetspace Modeling Example 2

- Digital Twin Munich: Web-based traffic simulation visualization combined with a semantic 3D city model

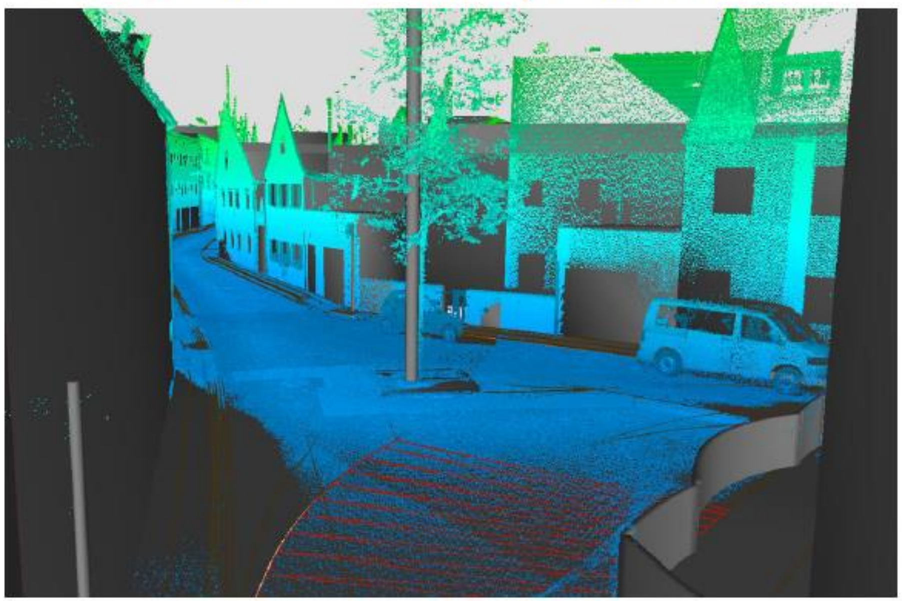
https://www.youtube.com/watch?v=GDf7U8vgyzc

CityGML 3.0 Streetspace Modeling Example 3

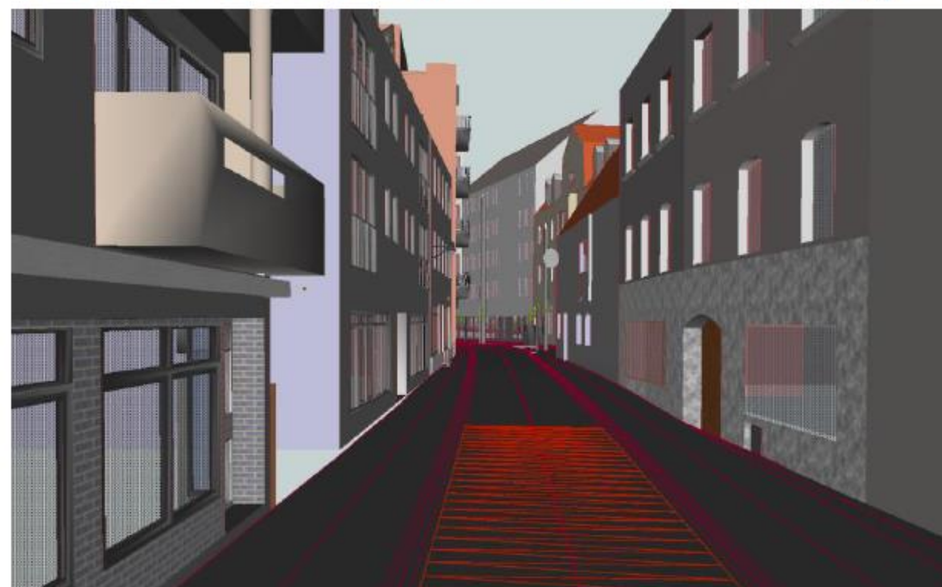
- Dataset examples:
  https://github.com/savenow/lod3-road-space-models

Easy combination of multiple (geo-referenced) datasets

Road model and point cloud



Road model and LOD3 buildings



Common Misunderstandings about CityGML

- ***CityGML is just an exchange format***
  - **NO!** - It is in the first place a conceptual schema on how to represent 3D city models in an interoperable, integrative, and multi-application supportive way
  - Due to historic reasons the normative part of CityGML is its encoding as a GML application schema (there was no standards category for semantic data models in OGC back in 2006 – only abstract or implementation specifications by then)
  - There are alternative mappings of the CityGML conceptual model onto other platforms like spatial databases, JSON, and Graph DB
- ***CityGML is a visualization format***
  - **NO!** – CityGML puts focus on the representation of spatio-semantic characteristics of 3D city and landscape features (Ontology)
  - However, visualizations e.g. in 3DTiles, i3S, X3D, glTF, COLLADA, KML, OpenFlight can easily be generated from CityGML

(Some) Advantages of CityGML compared to (pure) visualization formats

- Extensive semantic, topological, temporal and geometric concepts
- Geo-referenced data (important for large infrastructure objects where the Earth's curvature cannot be neglected)
- Easy combination with other (geo-referenced) data
- Many cities worldwide model their 3D city models according to CityGML
- Database solution available (3DCityDB)
  - Spatial indices on the data
  - Spatio-semantic queries and analysis
- Searchability of objects and semantic information
  - Number intersection types
  - Relations between signs of a certain type next to vegtation
  - Road layout identification
- Association of sensor observations with semantic 3D models

Extending CityGML

- CityGML extension mechanisms
  1. **Generic classes and attributes**
  2. **Application Domain Extensions (ADE)**

     Formally specified augment data model with additional concepts required by use-case (e.g. new properties or object types)

- Models can be enriched with additional information (generic attributes) very easily
  - Reflective information
  - Number of recognitions by vehicles
  - Speed limit
  - Intersection type
  - …

CityGML subsets

- CityGML is application independent and used by multiple disciplines and is useful to several communities
- Thus, CityGML contains many concepts and a powerful but complex data model

However,

- “Implementations may employ a subset of constructs according to their specific information needs.” [CityGML 3.0 specification, 2021]
- Suggestion: Subset of relevant objects and concepts
  - Only used subset required to OpenDRIVE community

Conclusion

- **Revised** and **extended** concepts for modelling transportation Infrastructure in the context of semantic 3D city models
  - Concepts for **geometric and semantic segmentation**
  - Geometric representations: **linear, areal, volumetric or point cloud**
  - Concept for representing city objects using **Spaces**
  - Multiple **levels of granularity** (down to lane level)
  - **Integrated representation** for multiple transportation infrastructure (roads, railways, footpaths, waterways, etc.)
  - Including detailed information bicycle paths and pedestrian areas
- A number of use cases benefit from these concepts

Relevant links

- CityGML3.0
  https://www.ogc.org/standards/citygml
- Guideline explaining CityGML 3.0 Transportation Module
  https://tum-gis.github.io/road2citygml3/
- Interactive Streetspace Demos
  https://wiki.tum.de/display/gisproject/Online+Demo+Collection
- Data Downloads
  https://wiki.tum.de/display/gisproject/Download+Section
- 3DCityDB
  https://www.3dcitydb.org/3dcitydb/
- Open Source Converter r:trån: OpenDRIVE to CityGML
  https://rtron.io/

Resources on CityGML

- CityGML 2.0 Standard [Gröger, Kolbe, Nagel, Häfele 2012]
  https://www.ogc.org/standards/citygml

- T. H. Kolbe, 2009: Representing and Exchanging 3D City Models with CityGML. In: Lee, Zlatanova (eds.), 3D Geo-Information Sciences, Springer
  https://mediatum.ub.tum.de/node?id=1145752

- B. Willenborg, M. Sindram, T. H. Kolbe, 2017: Applications of 3D City Models for a better understanding of the Built Environment. In: Behnisch, Meinel (eds.): Trends in Spatial Analysis and Modelling. Springer
  https://mediatum.ub.tum.de/node?id=1348882

- List of worldwide Open Data 3D city models in CityGML („Awesome CityGML“):
  https://github.com/OloOcki/awesome-citygml

- F. Biljecki, K. Kumar, C. Nagel, 2018: CityGML Application Domain Extension (ADE): overview of developments. Open geospatial data, softw. stand. 3, 13
  https://doi.org/10.1186/s40965-018-0055-6

Resources on CityGML 3.0

- CityGML 3.0 Conceptual Model + UML Diagrams + Discussions
  https://github.com/opengeospatial/CityGML-3.0CM

- CityGML 3.0 XML Schema Files, Test datasets
  https://github.com/opengeospatial/CityGML-3.0Encodings

- IFC → CityGML 3.0 FME Workspace
  https://github.com/tum-gis/ifc-to-citygml3

- T. Kutzner, K. Chaturvedi, T. H. Kolbe, 2020: CityGML 3.0: New Functions Open Up New Applications. PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science, 2020, 19
  http://dx.doi.org/10.1007/s41064-020-00095-z

- C. Beil, R. Ruhdorfer, T. Coduro, T. H. Kolbe, 2020: Detailed Streetspace Modelling for Multiple Applications: Discussions on the Proposed CityGML 3.0 Transportation Model. ISPRS International Journal of Geo-Information 9 (10)
  https://www.mdpi.com/2220-9964/9/10/603

Additional Information

Alternative CityGML Encodings (1)

- **CityJSON** is a JSON-based exchange format for CityGML city models (www.cityjson.org)
  - issued as an „OGC Community Standard“
  - originally developed by TU Delft
  - there is some software support (e.g. different tools by TU Delft, 3DCityDB, FME, citygml4j, etc.)
- **3DCityDB** is a spatial/relational database schema for the storage and management of CityGML city models (www.3dcitydb.org)
  - developed by the Chair of Geoinformatics at TU Munich in cooperation with the companies virtualcitySYSTEMS and M.O.S.S.
  - Open Source implementation for PostGIS and Oracle Spatial
  - in productive use worldwide in many cities, countries and in research projects; sometimes embedded in commercial systems

Alternative CityGML Encodings (2)

- **OWL / RDF** schemas for the use and analysis of CityGML city models in the Semantic Web / Linked Data. There are two separate developments:
  - Ontology of the Univ. of Geneva (Prof. Gilles Falquet, Prof. Claudine Métral): http://cui.unige.ch/isi/icle-wiki/ontologies and http://cui.unige.ch/isi/onto//citygml2.0.owl
  - **CityOWL** Ontology of the Univ. of Lyon (LIRIS, Group of Prof. Gilles Gesquière): https://github.com/VCityTeam/UD-Graph

- Alternative encodings do not necessarily support the full model scope of CityGML
  - e.g. some limitations with CityJSON, and not directly compatible with OGC services like WFS; but more compact and simpler encoding compared to XML-based encoding, simpler processing e.g. in web browsers

The CityGML Ecosystem

- **CityGML is based on GML** and is thus compatible with many OGC web services standards, e.g.
  - **Web Feature Service** – Access (read, write, modify) entire 3D city models, individual objects and their components
  - **Web Processing Service** – generic interface for encapsulating functions (e.g. data transformations, AI analyses, etc.)
  - **3D Portrayal Service** – Visualization of 3D models (derivation of 3D visualization formats)
- For all services there are different implementations / products (both commercial and Open Source)
- These web services are in turn compatible with the **OGC Catalog Service for the Web (CS/W)** specification
- Comprehensive basis for **Smart City developments**

3D City Database

https://www.3dcitydb.org
https://github.com/3dcitydb

- Open Source software package for the efficient storage, management, and visualization of CityGML-based 3D city models

- **Development cooperation**
  - Chair of Geoinformatics at TUM (Lead)
  - virtualcitySYSTEMS GmbH, Berlin
  - M.O.S.S. Computer Grafik System GmbH, Taufkirchen

- **Development status (**current version: 4.2.0**)**
  - full support of CityGML 1.0.0 and 2.0.0
  - Oracle/PostGIS relational database schema + Import/Export tool with a graphical user interface and a command line interface
  - offers a Web Feature Services 2.0 according to the OGC standard
  - V5.0 currently under development → support of CityGML 3.0

Working with / Visualization of CityGML Datasets

- **FZKViewer** [KIT Karlsruhe, free software]
  https://www.iai.kit.edu/english/1648.php
- **eveBIM** [CSTB France, free software]
  https://www.evebim.fr/telechargement/
- **3DCityDB + 3DCityDB Web Viewer** [TU Munich / VCS / MOSS, Open Source software]
  https://www.3dcitydb.org
- **Azul for MacOS** [TU Delft, Open Source software]
  https://github.com/tudelft3d/azul
- **FME Data Inspector** [Safe Software, commercial]
  https://www.safe.com/fme/fme-desktop/
- **ArcGIS Interoperability Extension** [ESRI, commercial]
  http://www.esri.com/software/arcgis/extensions/datainteroperability

Extract / Transform / Load (ETL) for CityGML

- **HALE Studio** [wetransform, Open Source software]
  https://github.com/halestudio/hale
- **Feature Manipulation Engine** [Safe Software, commercial]
  https://www.safe.com/fme/fme-desktop/
- **GDAL GML Application Schema** [Open Source software]
  https://gdal.org/drivers/vector/gmlas.html
- **Deegree** [lat/lon GmbH, Open Source software]
  https://github.com/deegree/deegree3
- **CityGML tools** [citygml4j, Open Source software]
  https://github.com/citygml4j/citygml-tools