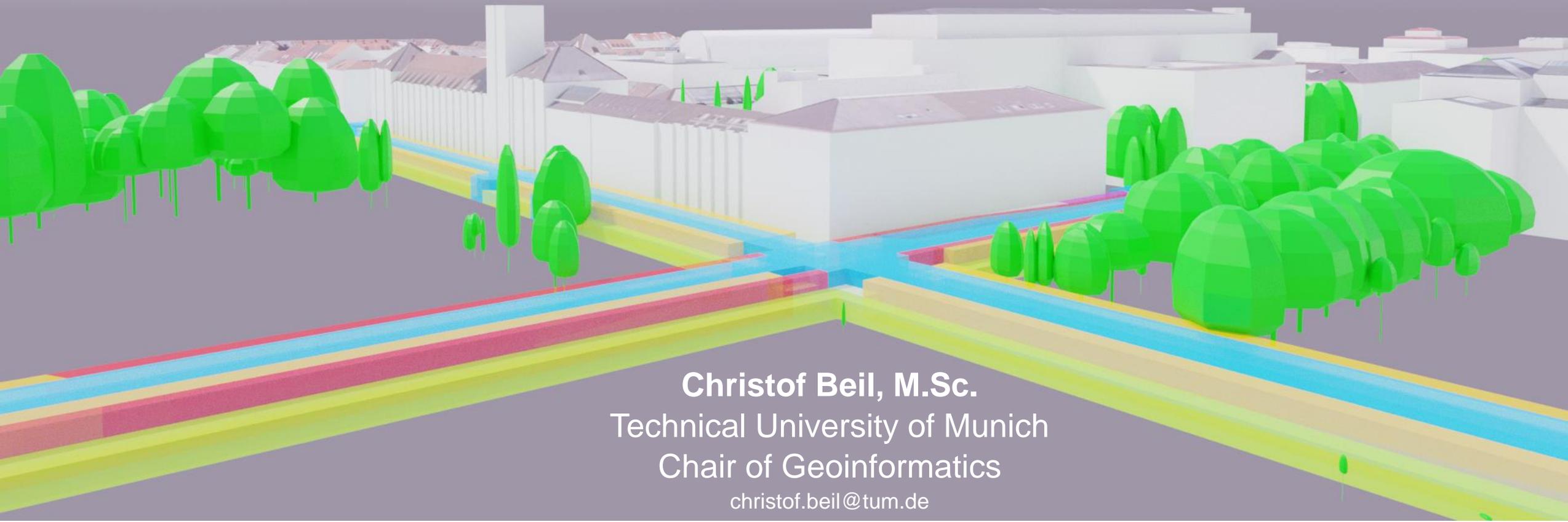


Introduction to the CityGML 3.0 Transportation Module

ASAM OpenDRIVE and OGC CityGML – A Transportation Area Concept

January 26th 2022



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Technical University of Munich

Chair of Geoinformatics

christof.beil@tum.de

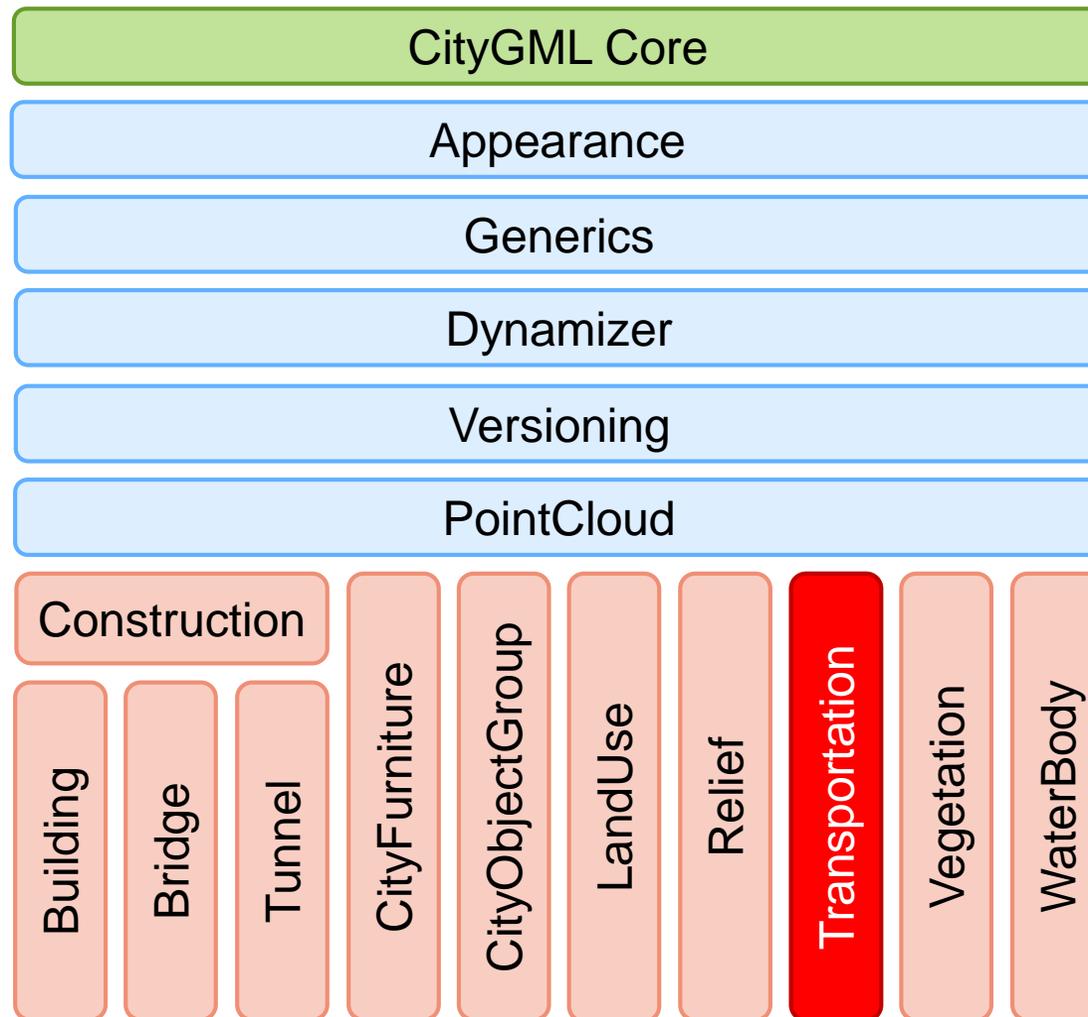
CityGML – A brief introduction

- ▶ International **OGC Standard**
- ▶ Based on **GML3**
 - GIS related Open Source tools available
 - Support for standardized Web Services (e.g. WFS)
- ▶ Commonly used for semantic **3D city modeling**
 - E.g. LoD 2 building models available for all of Germany
- ▶ 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)
- ▶ **CityGML Version 3.0 was published** in September 2021
Free download: <https://www.ogc.org/standards/citygml>



3D City Model of central Munich including buildings, vegetation and streetspace objects (visualized in the Unreal Engine)

CityGML 3.0 – Modularization



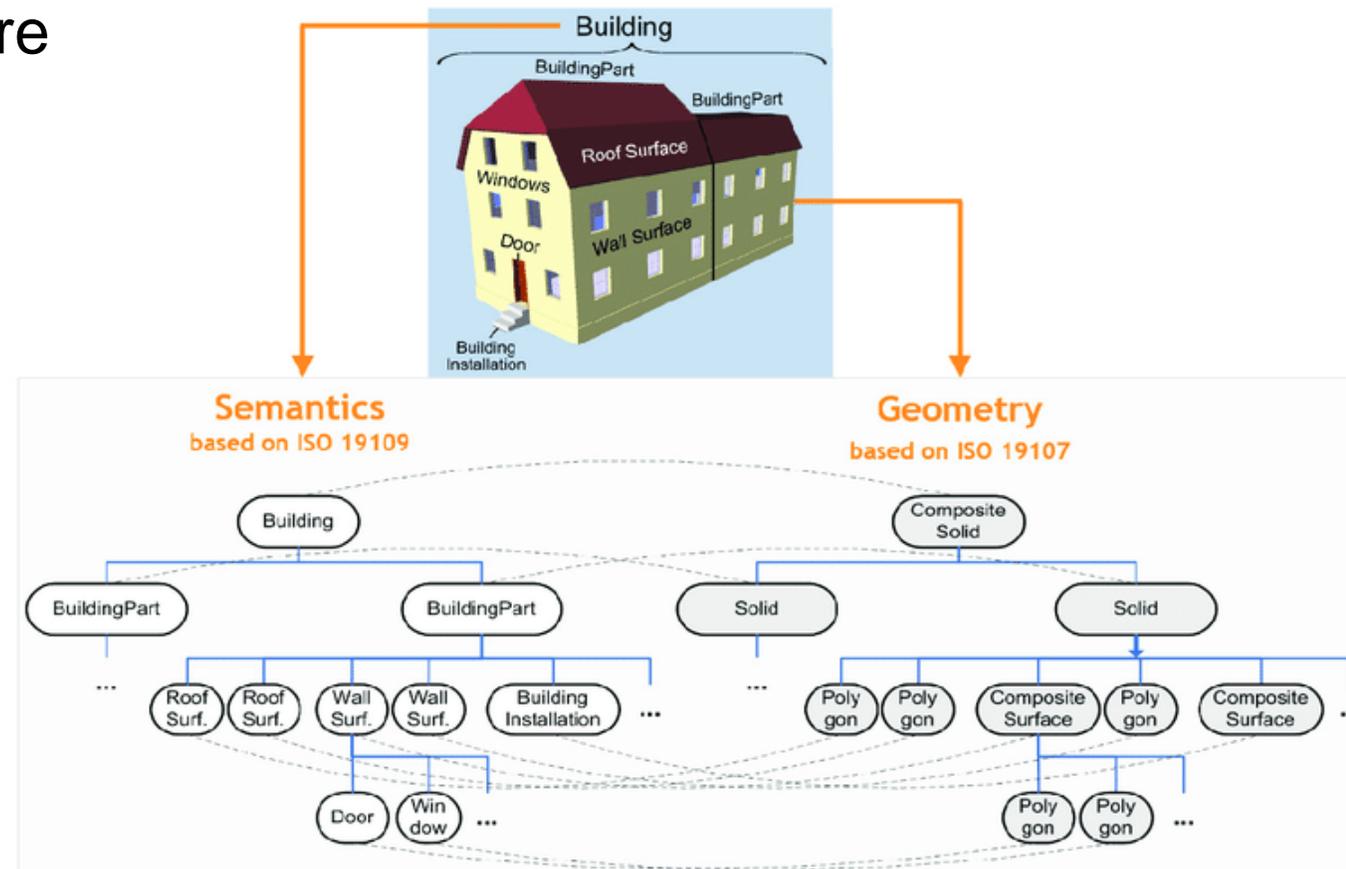
Core Module
Defines base concepts and geometries inherited by all other modules

Extension Modules
Define concepts applicable to all thematic modules

Thematic Modules
Cover a specific thematic field of virtual 3D city models

CityGML 3.0 – Hierarchical modelling structure

- ▶ Real-world objects are represented by geographic features according to the definition in ISO 19109
- ▶ Each object has a unique identifier (gml:id)
- ▶ Hierarchical structure

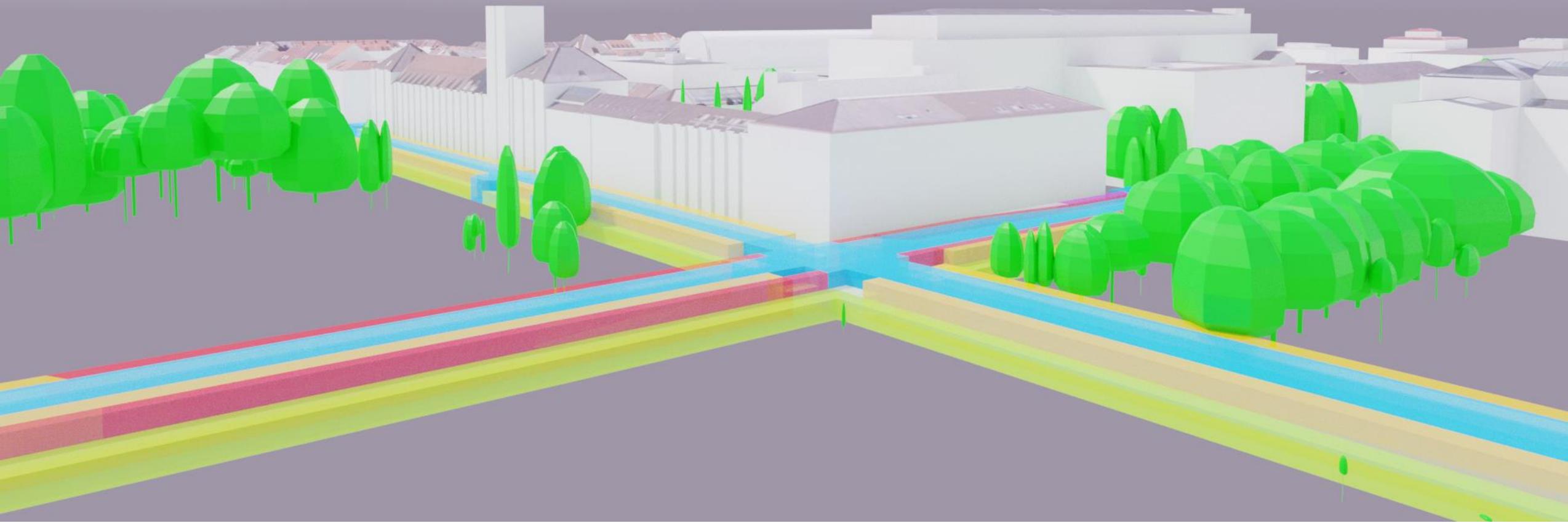


The CityGML 3.0 Transportation Module

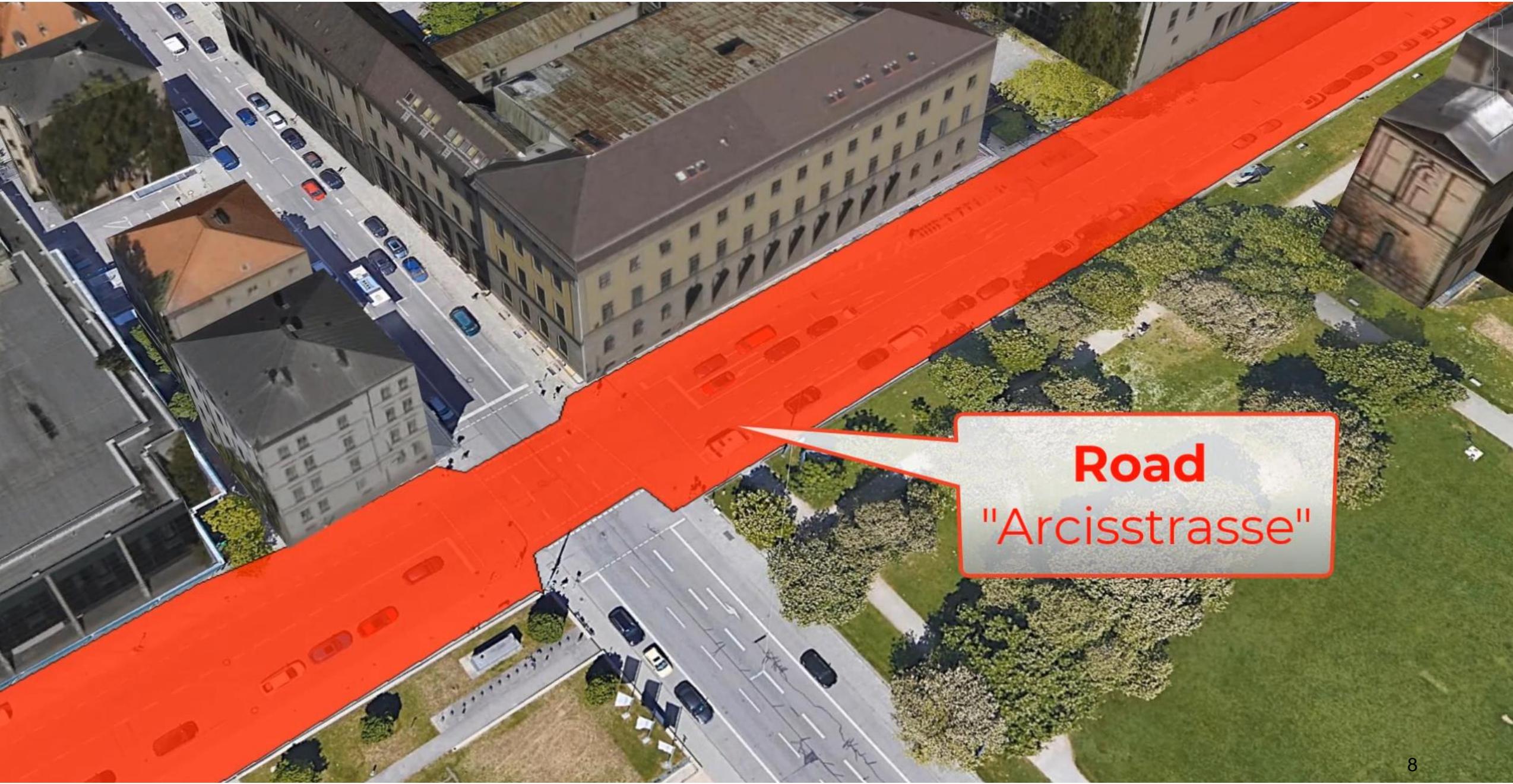
- ▶ **Revised** and **extended** concepts for modelling transportation Infrastructure in the context of semantic 3D city models
 - Concepts for **geometric and semantic segmentation**
 - Geometric representations: **linear, areal, volumetric or point cloud**
 - Concept for representing city objects using **Spaces**
 - Multiple **levels of granularity** (down to lane level)
 - New object classes such as **Markings** or **Holes**
 - **Integrated representation** for multiple transportation infrastructure (roads, railways, footpaths, waterways, etc.)
- ▶ Formally specified using UML-diagrams

Semantic Concepts

for modelling the streetspace with CityGML 3.0

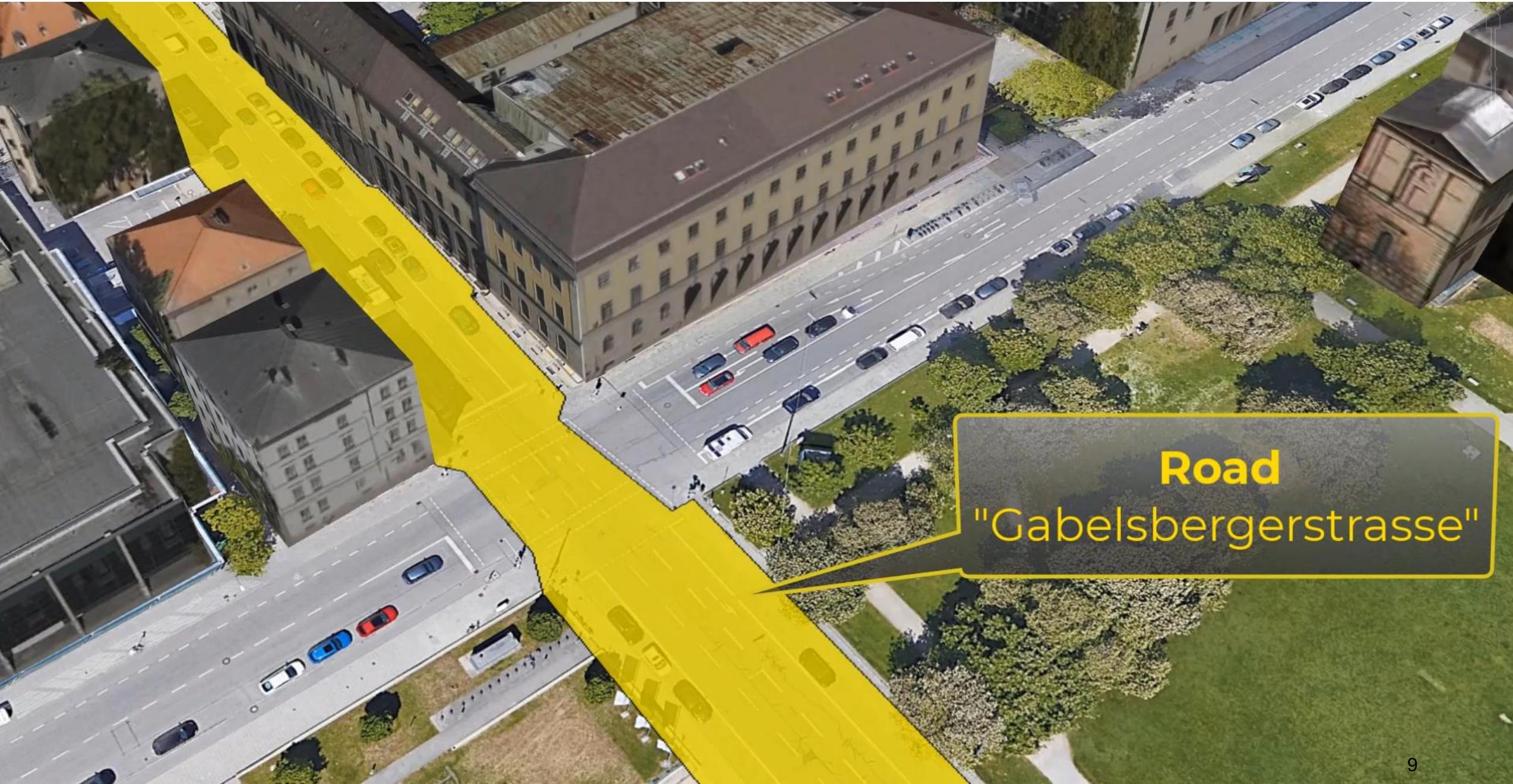


Segmenting street networks into Road objects

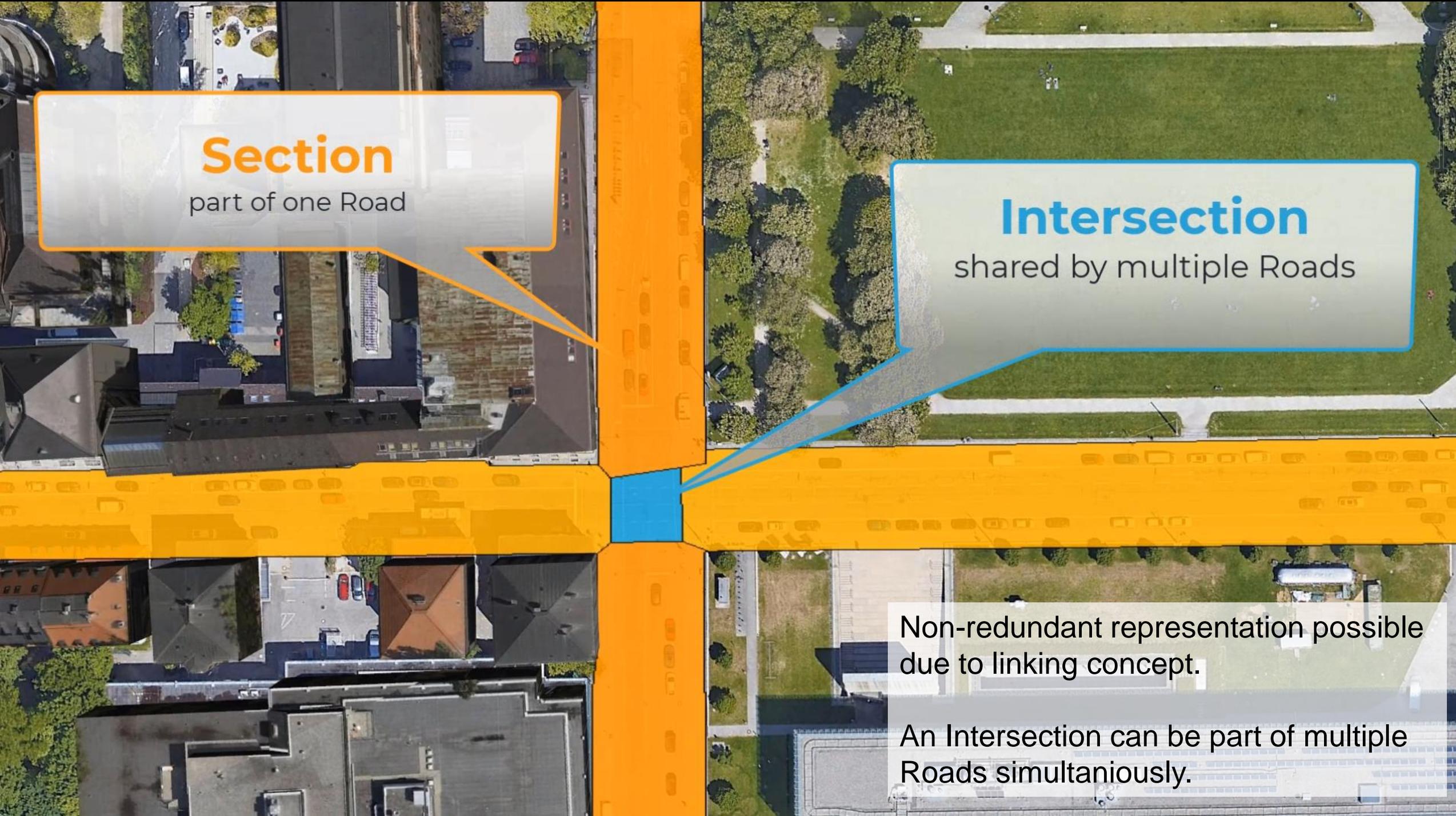


Road
"Arcisstrasse"

Segmenting street networks into Road objects



Road
"Gabelsbergerstrasse"

An aerial photograph of a city street intersection. A yellow semi-transparent road overlay is centered on the street, with a blue semi-transparent intersection point at the center. The background shows buildings, trees, and a grassy area.

Section

part of one Road

Intersection

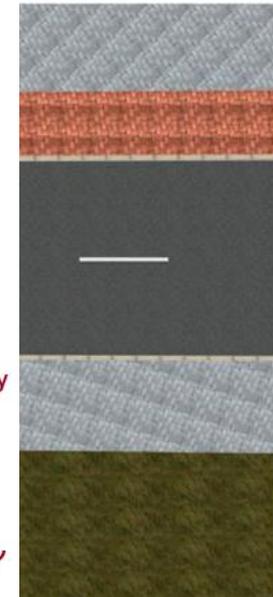
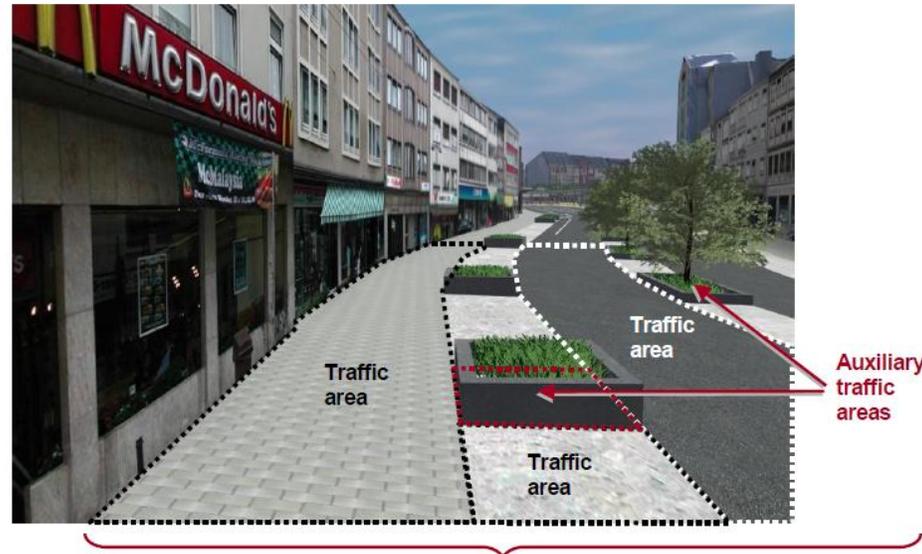
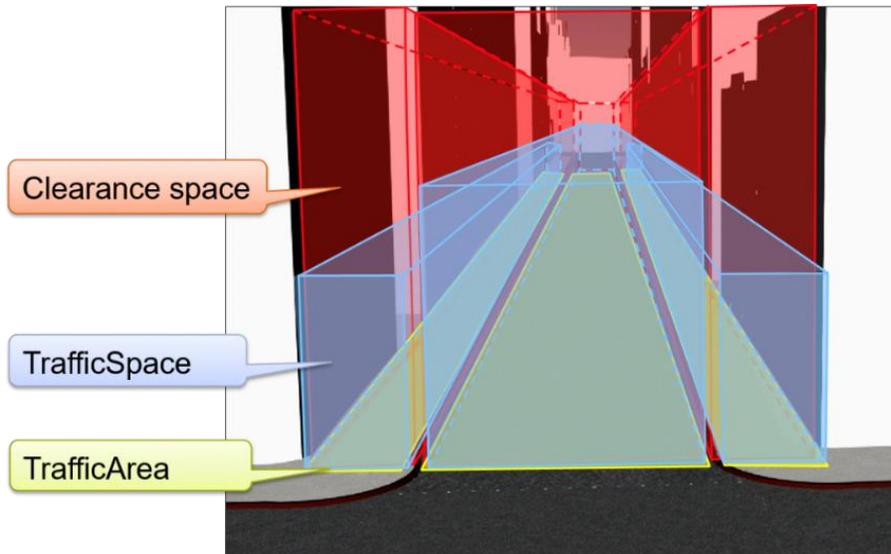
shared by multiple Roads

Non-redundant representation possible due to linking concept.

An Intersection can be part of multiple Roads simultaneously.

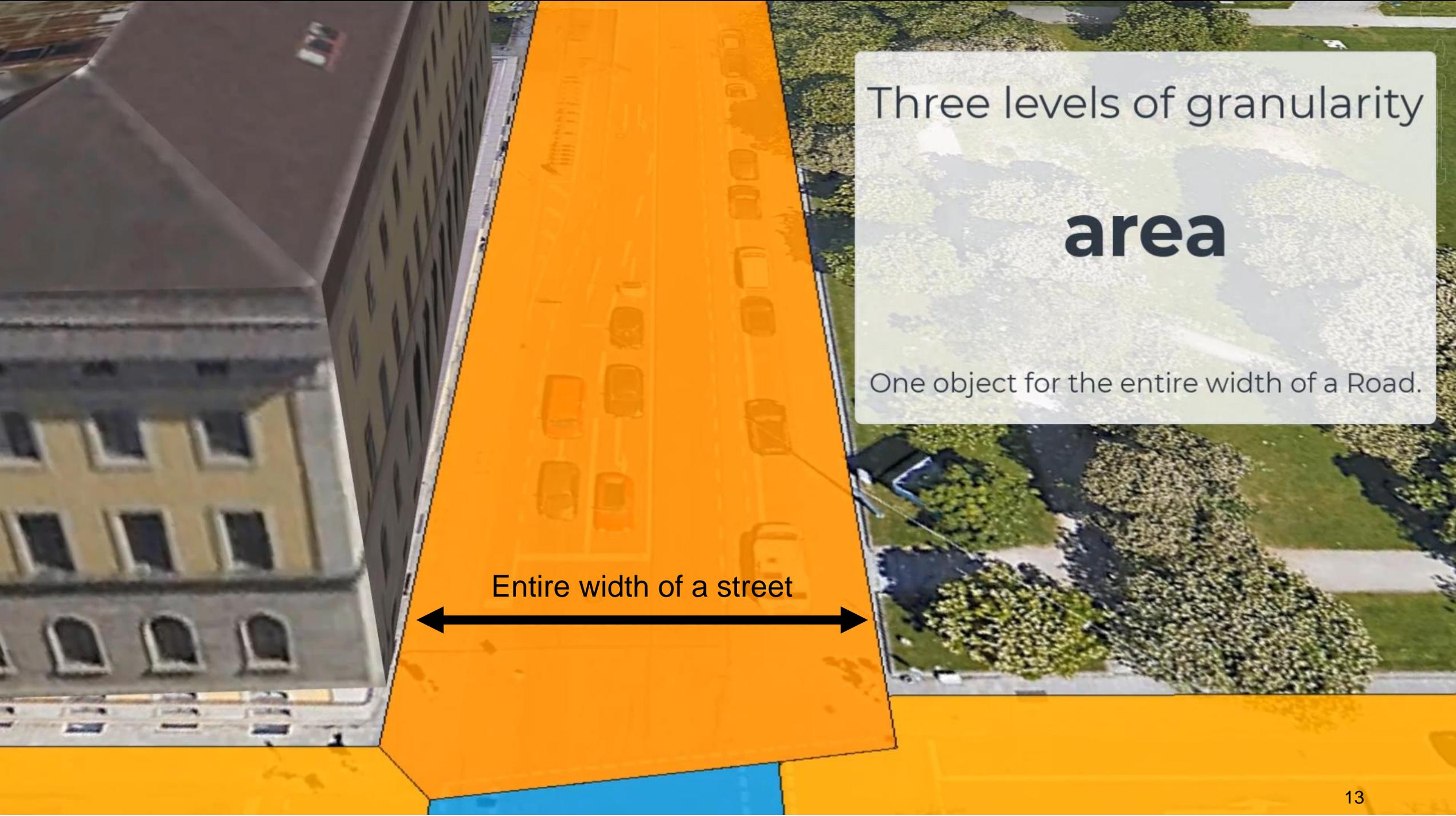
Further segmentation of Sections and Intersections

- ▶ Sections / Intersections can consist of **TrafficSpaces** and **AuxiliaryTrafficSpaces**
- ▶ **TrafficSpace** is a space in which traffic takes place
- ▶ An **AuxiliaryTrafficSpace** is used to represent e.g. green areas
- ▶ A **TrafficArea** is the ground surface of a TrafficSpace
- ▶ Individual class, function, usage attributes



TrafficArea	Auxiliary TrafficArea	Function
		footpath
		cyclepath
		kerbstone
		driving lane
		road marking
		driving lane
		kerbstone
		footpath
		green area

Section (City of Solingen, IGG Uni Bonn)

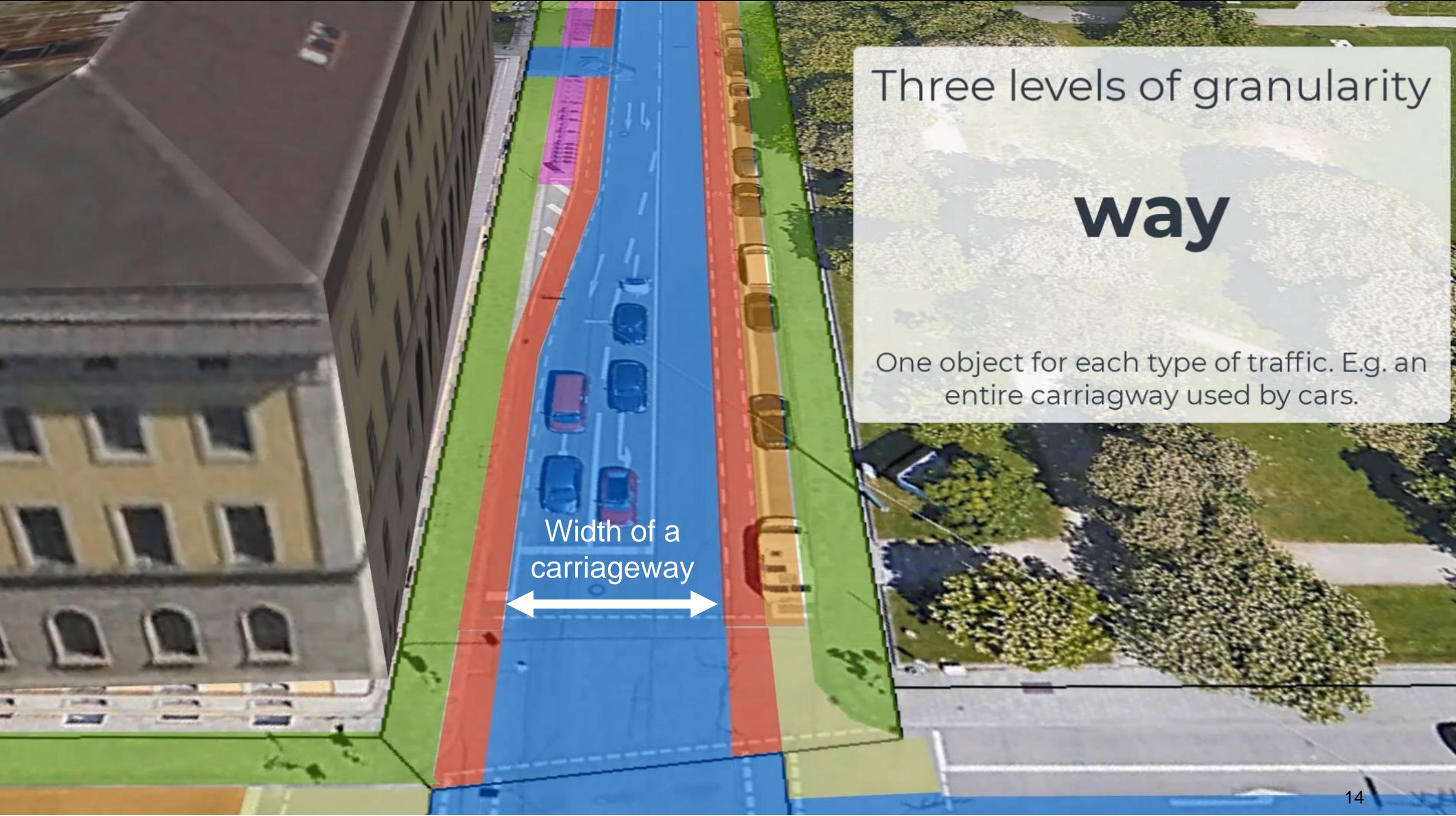


Three levels of granularity

area

One object for the entire width of a Road.

Entire width of a street



Three levels of granularity

way

One object for each type of traffic. E.g. an entire carriageway used by cars.

Width of a carriageway

Three levels of granularity

lane

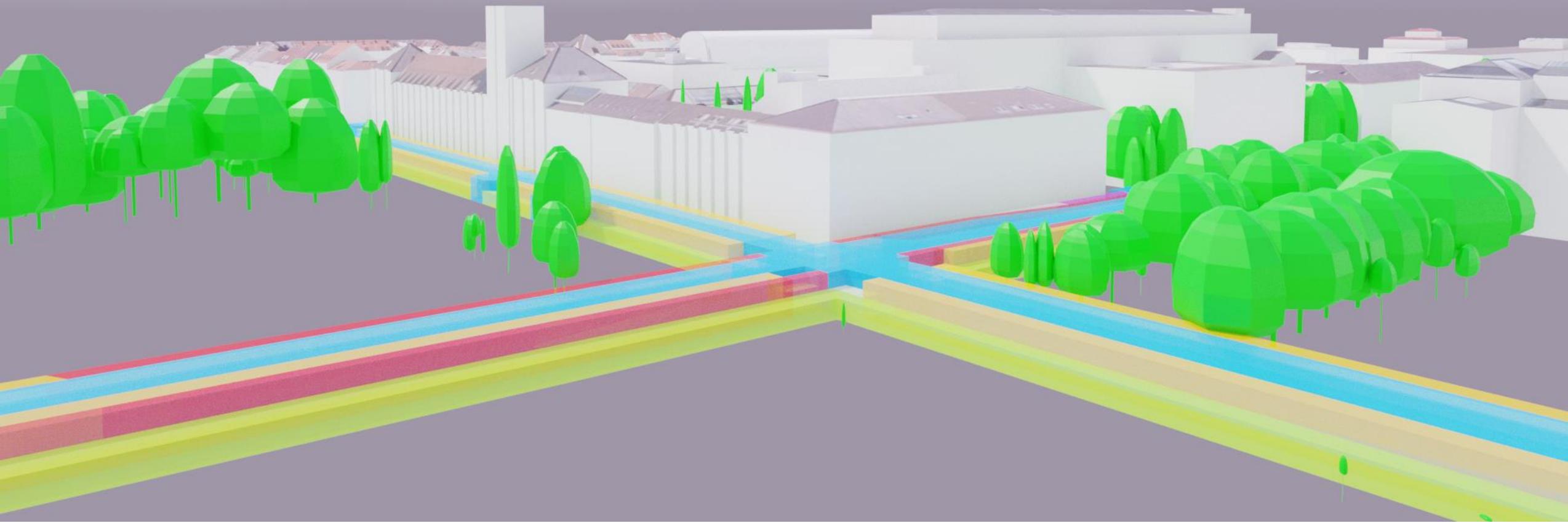
One object for each individual lane.

Individual lanes



Geometric representations

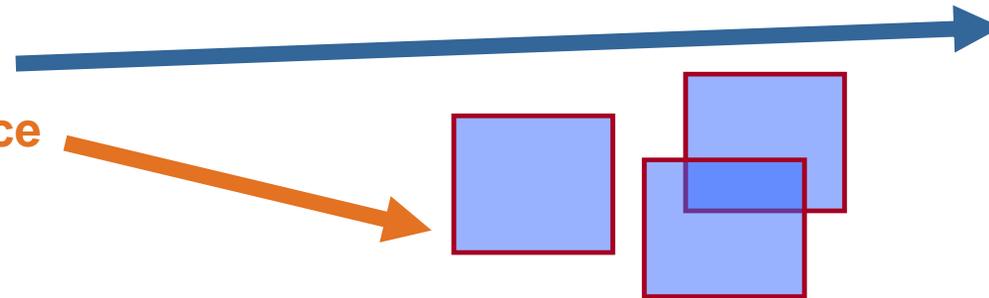
for modelling the streetspace with CityGML 3.0



Available Geometries

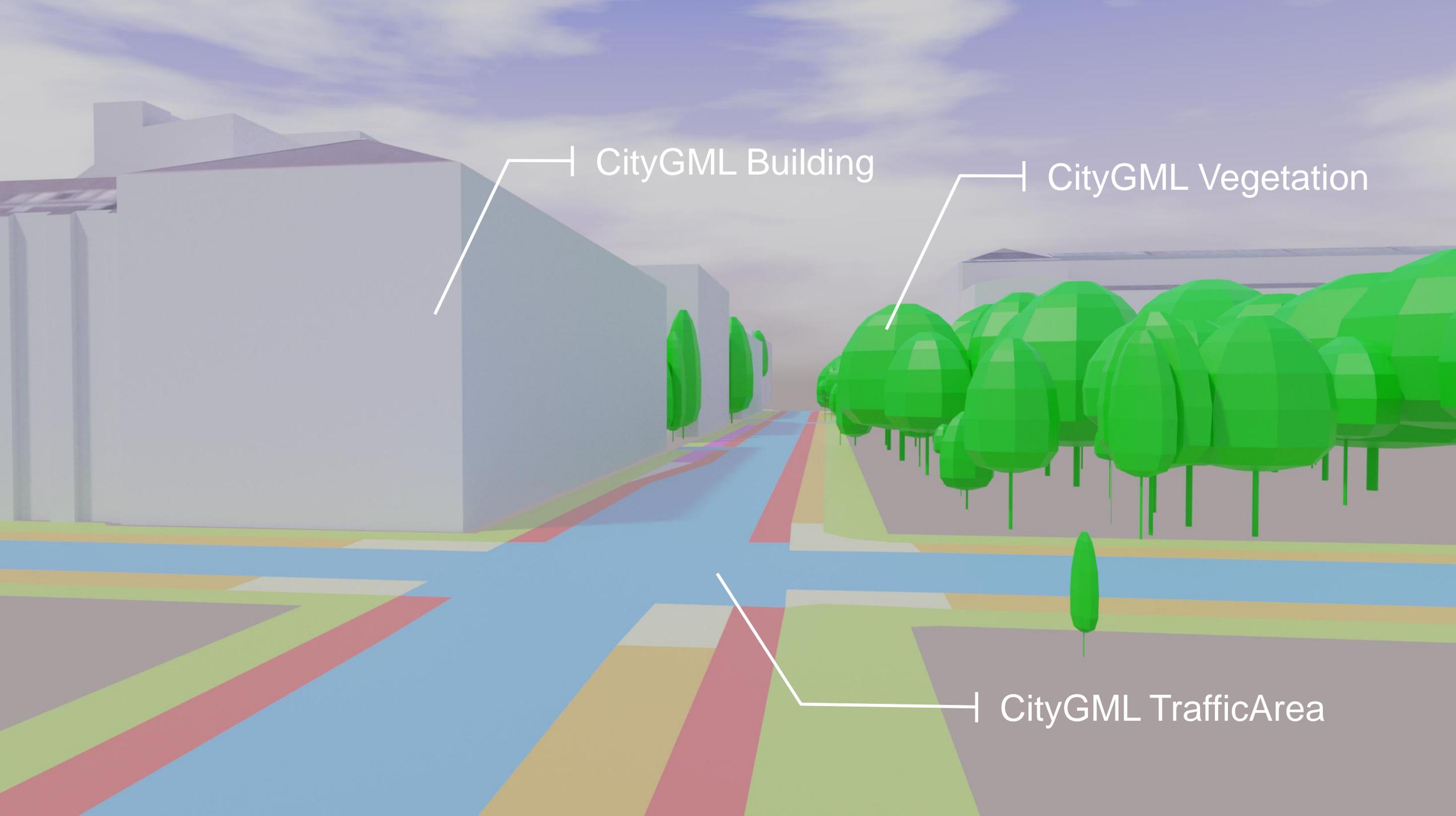
- ▶ ISO 19107:2003 Geographic information - Spatial schema
- ▶ Geometry types most relevant for Transportation Module

- 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

- ▶ Fully supported in GIS and spatial databases
- ▶ Nearly all geometries use 3D coordinates
- ▶ Coordinates with respect to a Coordinate Reference System (CRS)
- ▶ Local 3D cartesian CS are also supported (important for BIM or CAD data integration)



CityGML Building

CityGML Vegetation

CityGML TrafficArea

Concept for modeling Spaces

Spaces can be represented using different geometries

- volumetric
- areal
- linear
- point clouds

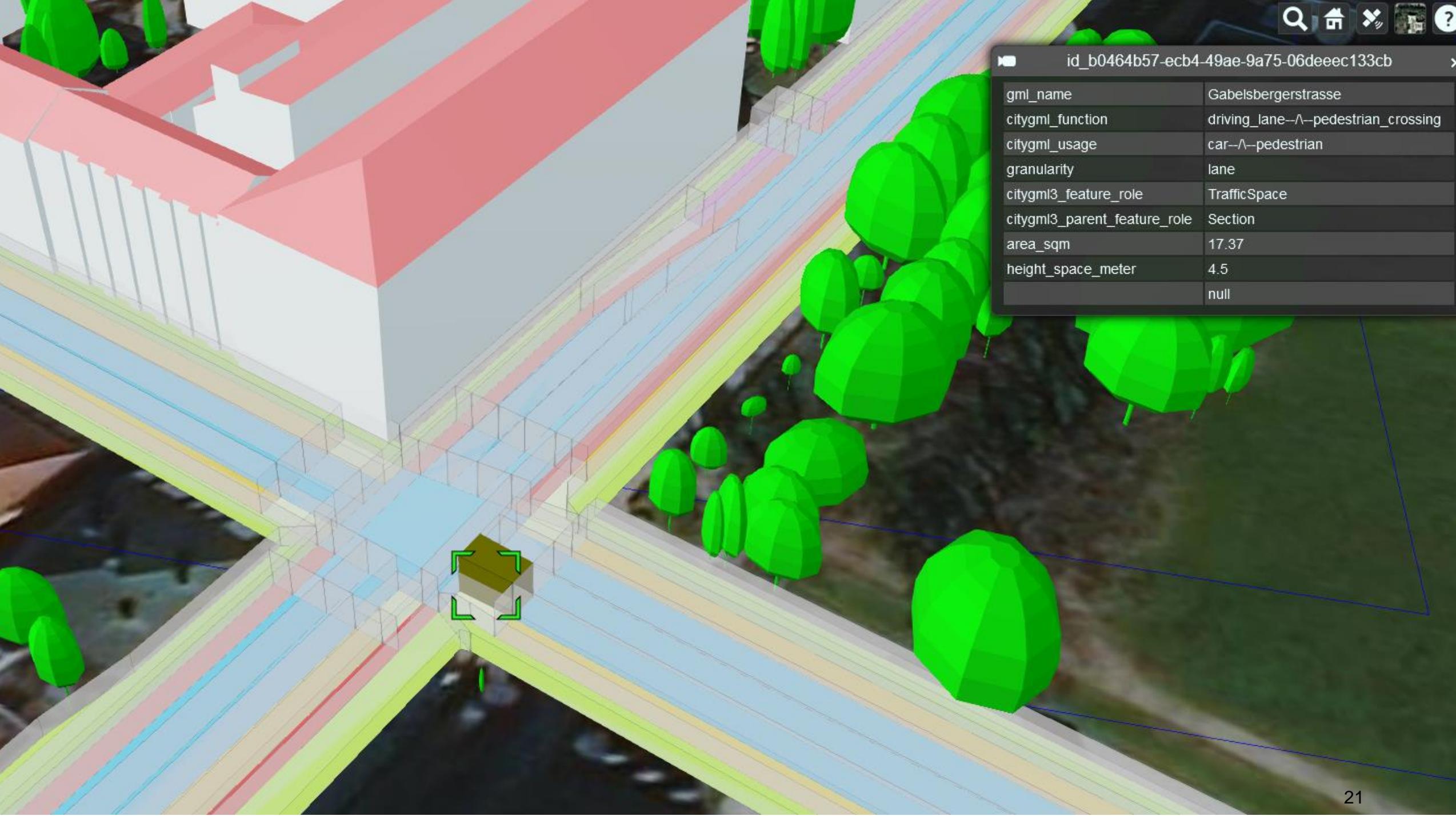
CityGML TrafficSpace
Space in which traffic takes place

Potential conflict
Class: ClearanceSpace

CityGML TrafficArea
Ground surface of each TrafficSpace

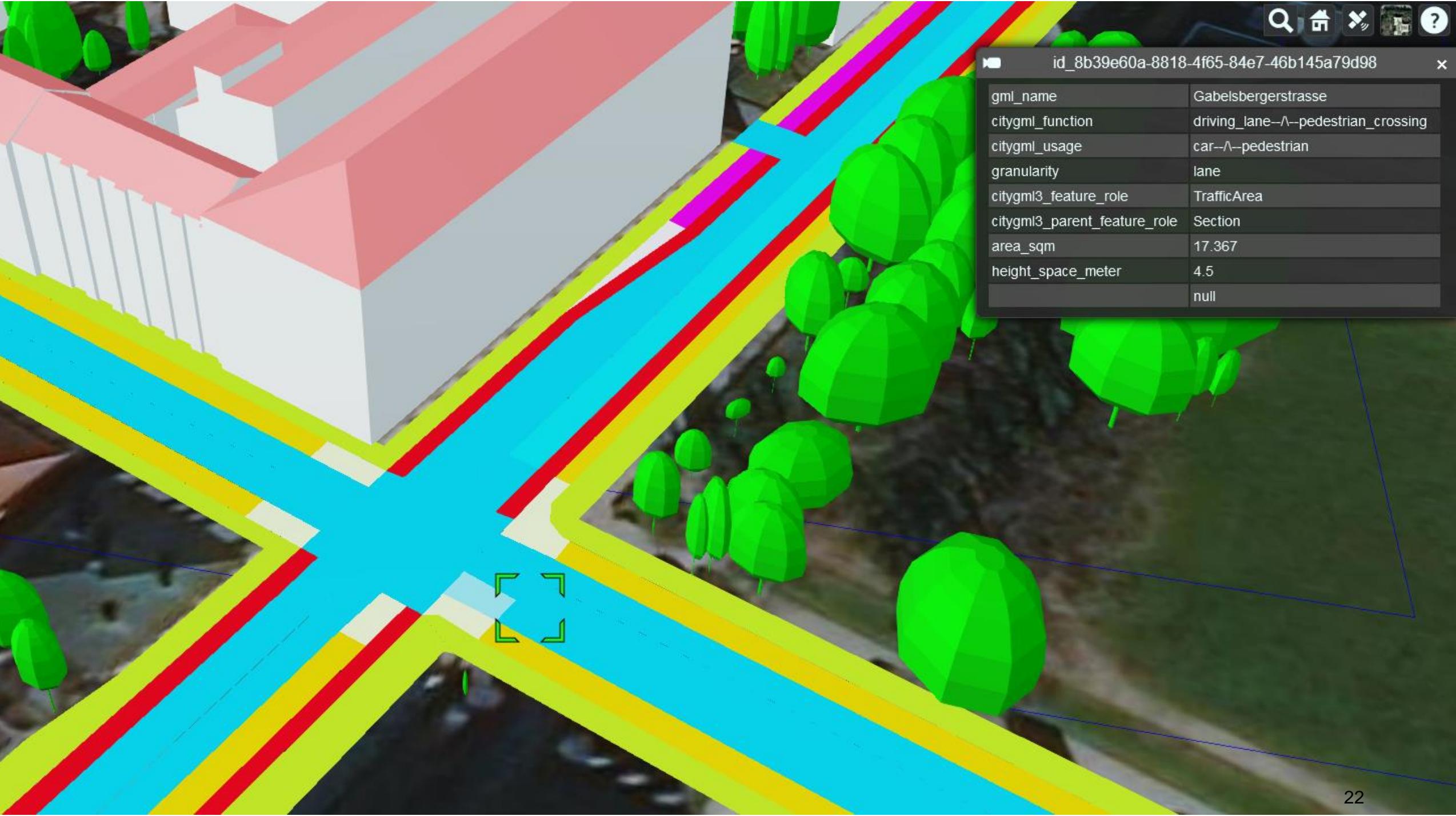
4,5 m

2,5 m

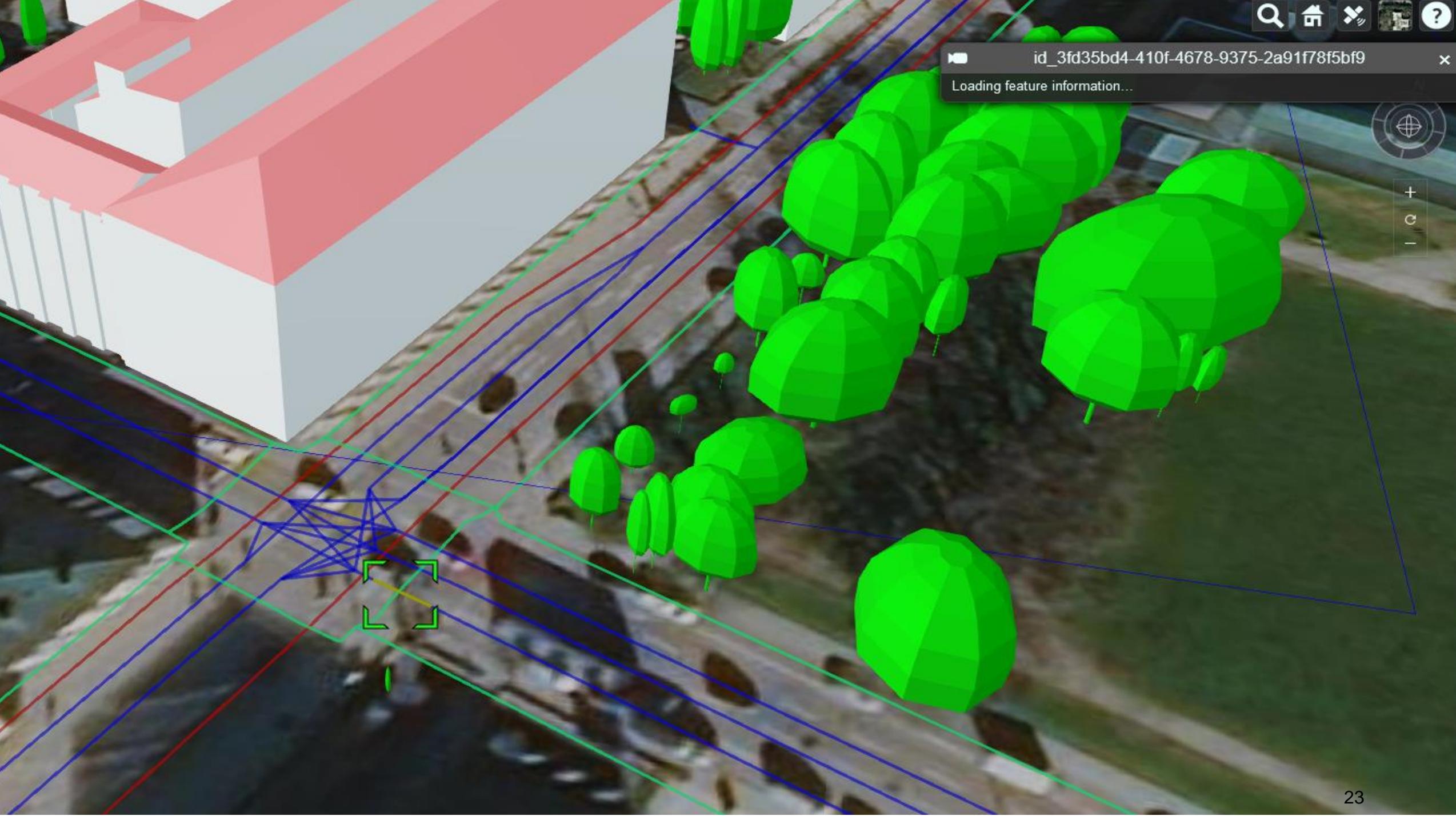


id_b0464b57-ecb4-49ae-9a75-06deec133cb

gml_name	Gabelsbergerstrasse
citygml_function	driving_lane--^--pedestrian_crossing
citygml_usage	car--^--pedestrian
granularity	lane
citygml3_feature_role	TrafficSpace
citygml3_parent_feature_role	Section
area_sqm	17.37
height_space_meter	4.5
	null



id_8b39e60a-8818-4f65-84e7-46b145a79d98	
gml_name	Gabelsbergerstrasse
citygml_function	driving_lane-Λ-pedestrian_crossing
citygml_usage	car-Λ-pedestrian
granularity	lane
citygml3_feature_role	TrafficArea
citygml3_parent_feature_role	Section
area_sqm	17.367
height_space_meter	4.5
	null



id_3fd35bd4-410f-4678-9375-2a91f78f5bf9
Loading feature information...

Three levels of granularity

- ▶ Granularity = **area** (one TrafficSpace for the entire per street width)

areal / surface representation



graph-based / linear representation



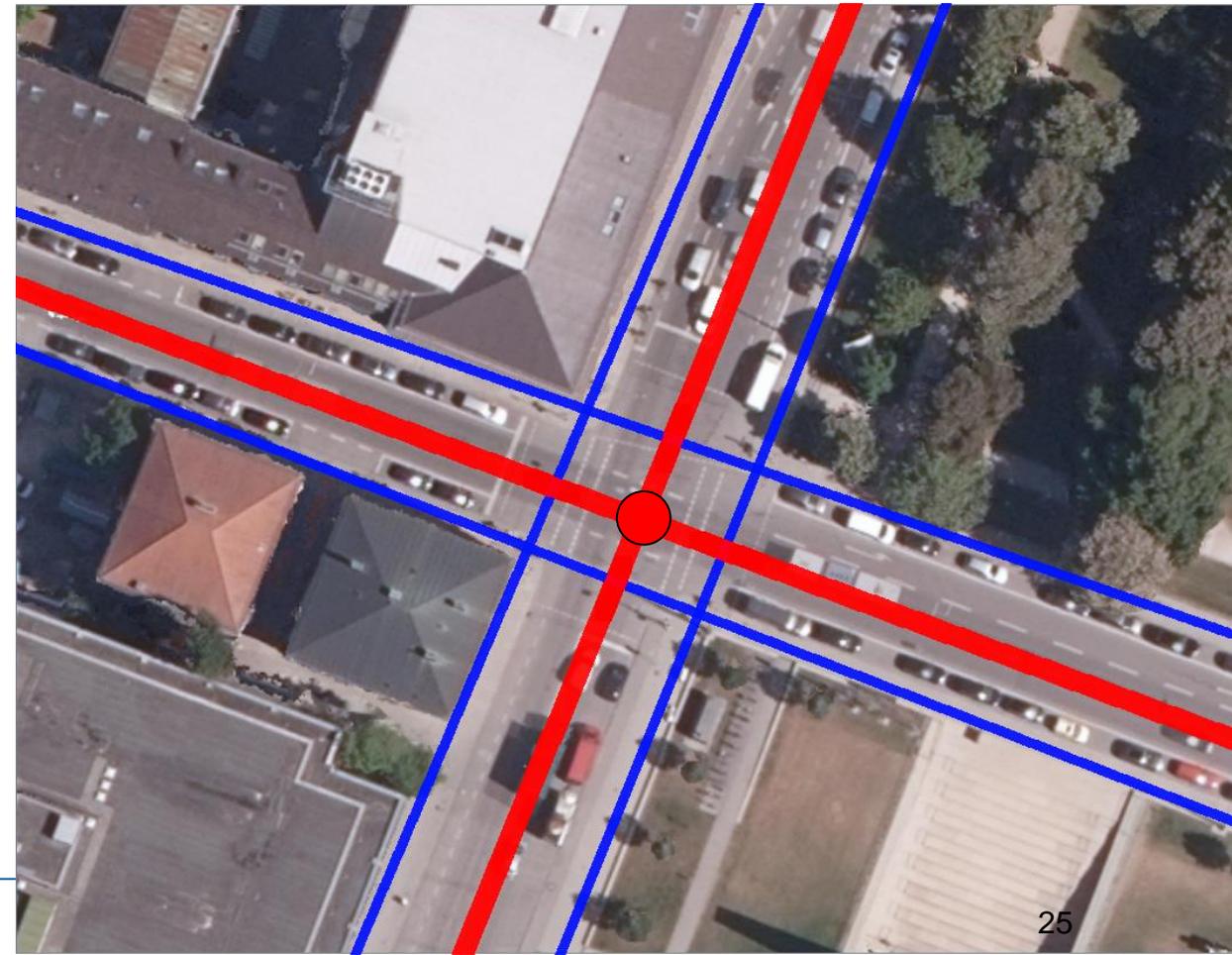
Three levels of granularity

- ▶ Granularity = **way** (one TrafficSpace per traffic type)

areal / surface representation



graph-based / linear representation



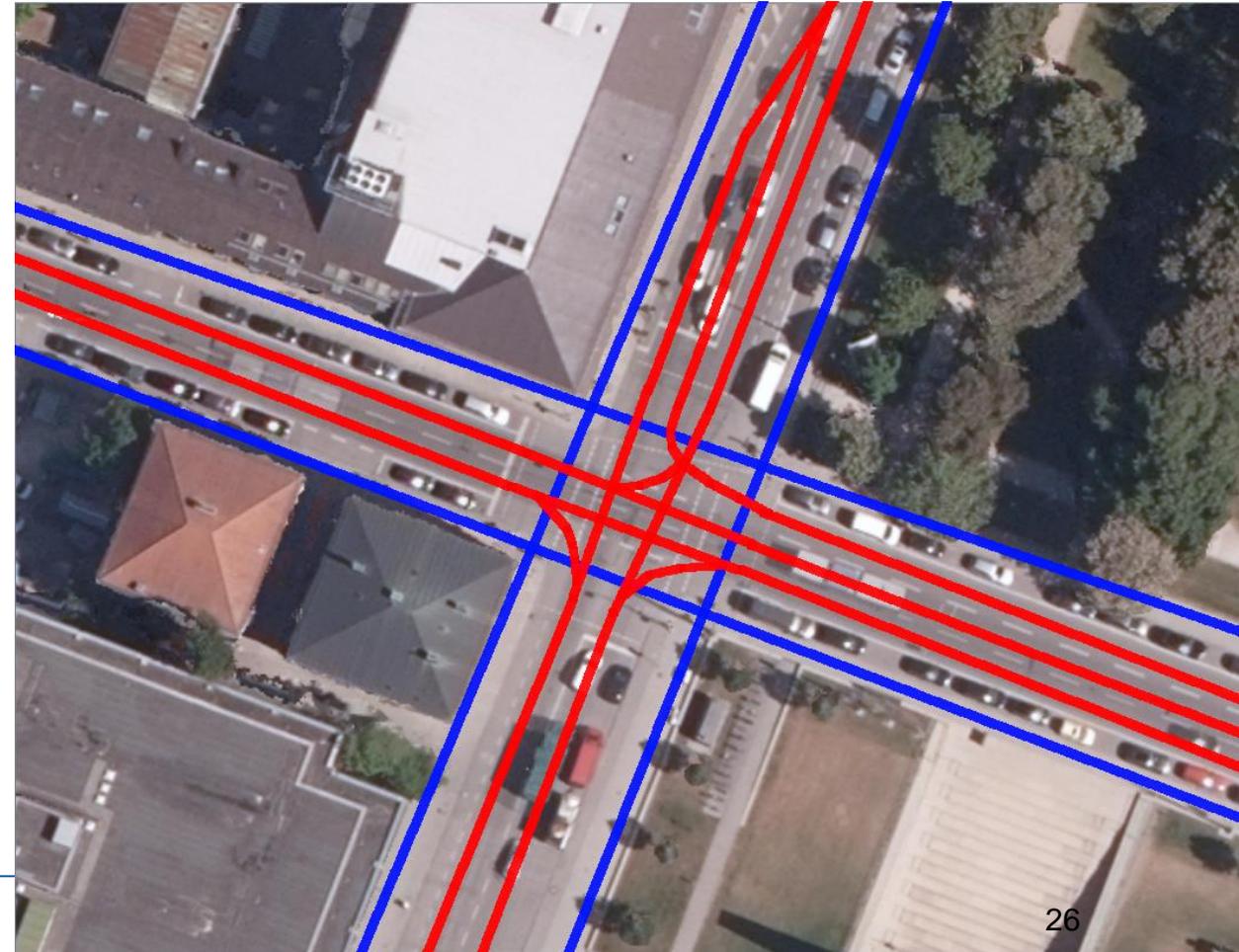
Three levels of granularity

- ▶ Granularity = **lane** (one TrafficSpace per lane)

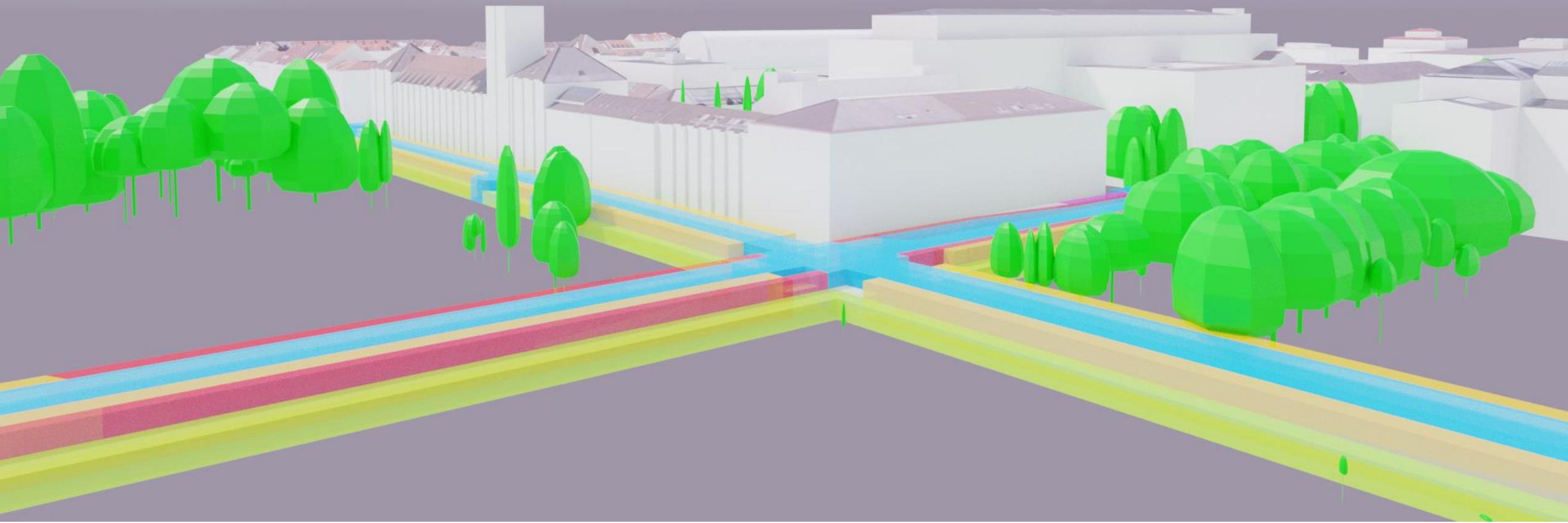
areal / surface representation



graph-based / linear representation

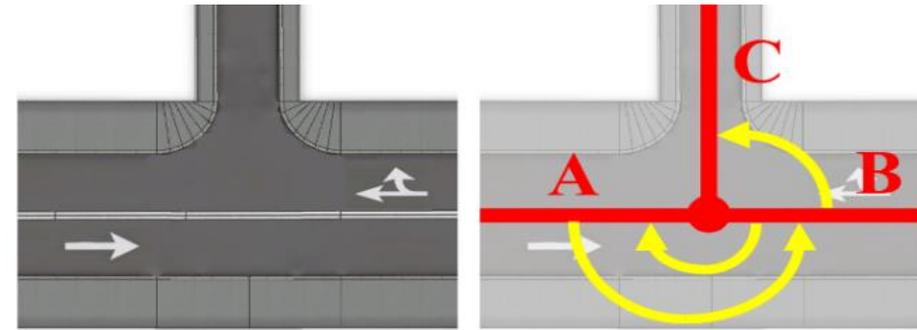


Topological concepts for modelling the streetspace with CityGML 3.0



Topological concepts

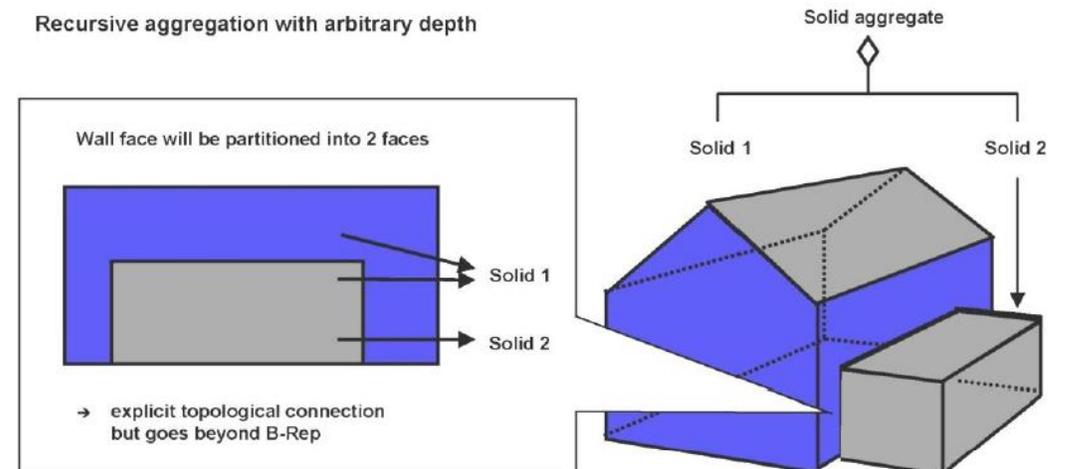
- ▶ TrafficSpaces can contain information on predecessors / successors



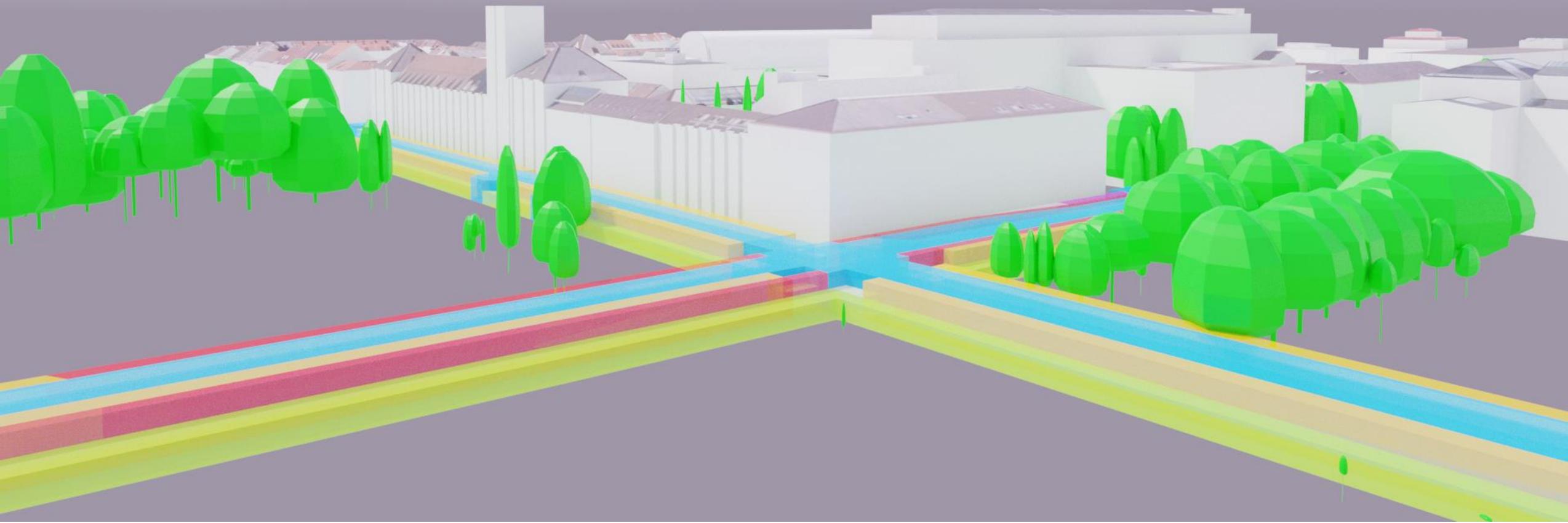
	Predecessor	Successor
A	B	B
B	A	A, C
C	B	-

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

Recursive aggregation with arbitrary depth



Integrated representation of multiple transportation infrastructure



Integrated representation of different traffic types

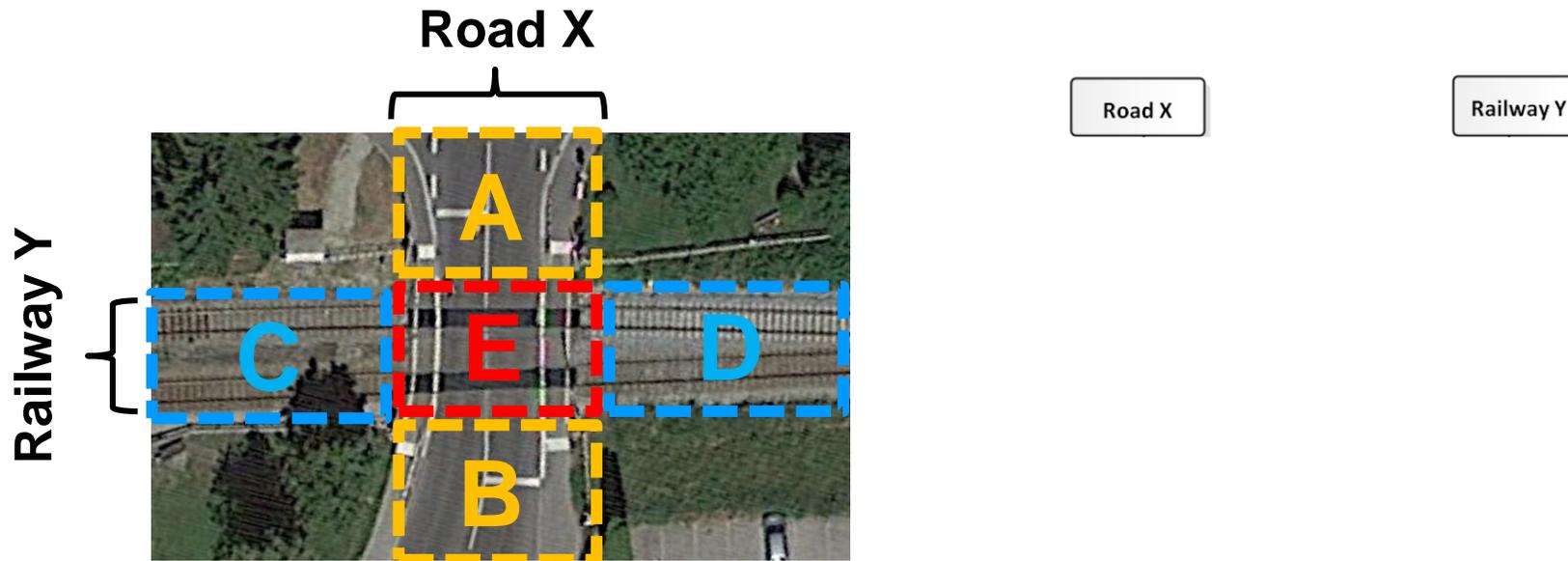
- ▶ Concepts apply to Roads, Railways, Waterways
- ▶ **Combined representation** with **non-redundant** semantics / geometry



- ▶ **Consistent, integrated** and **standardized** for an **entire 3D city model**
- ▶ Relevant for several applications in the context of digital urban twins and smart cities

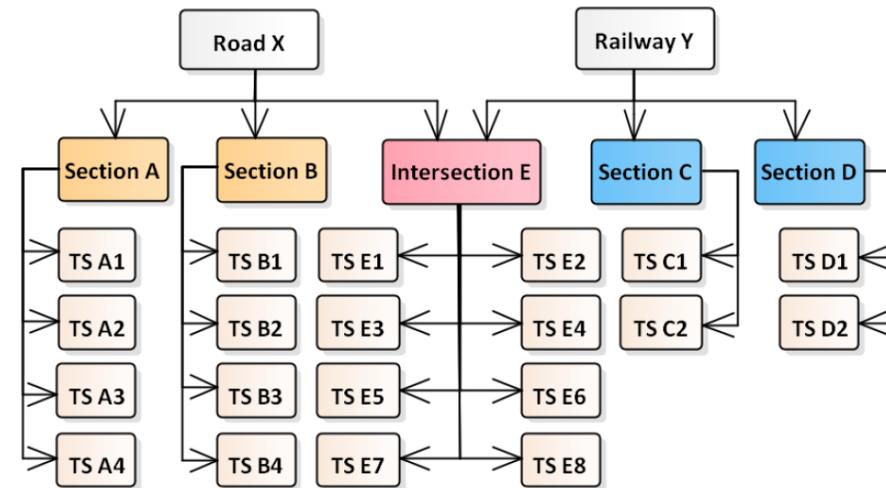
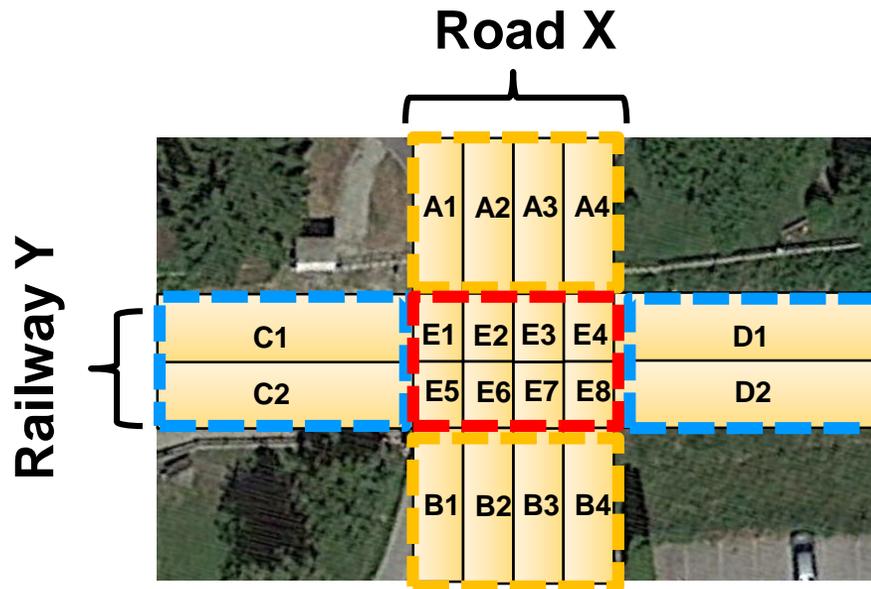
Integrated representation of different traffic types

- ▶ Concepts apply to Roads, Railways, Waterways
- ▶ E.g.: Railway crossing
 - Combined representation of Road and Railway objects with a shared Intersection



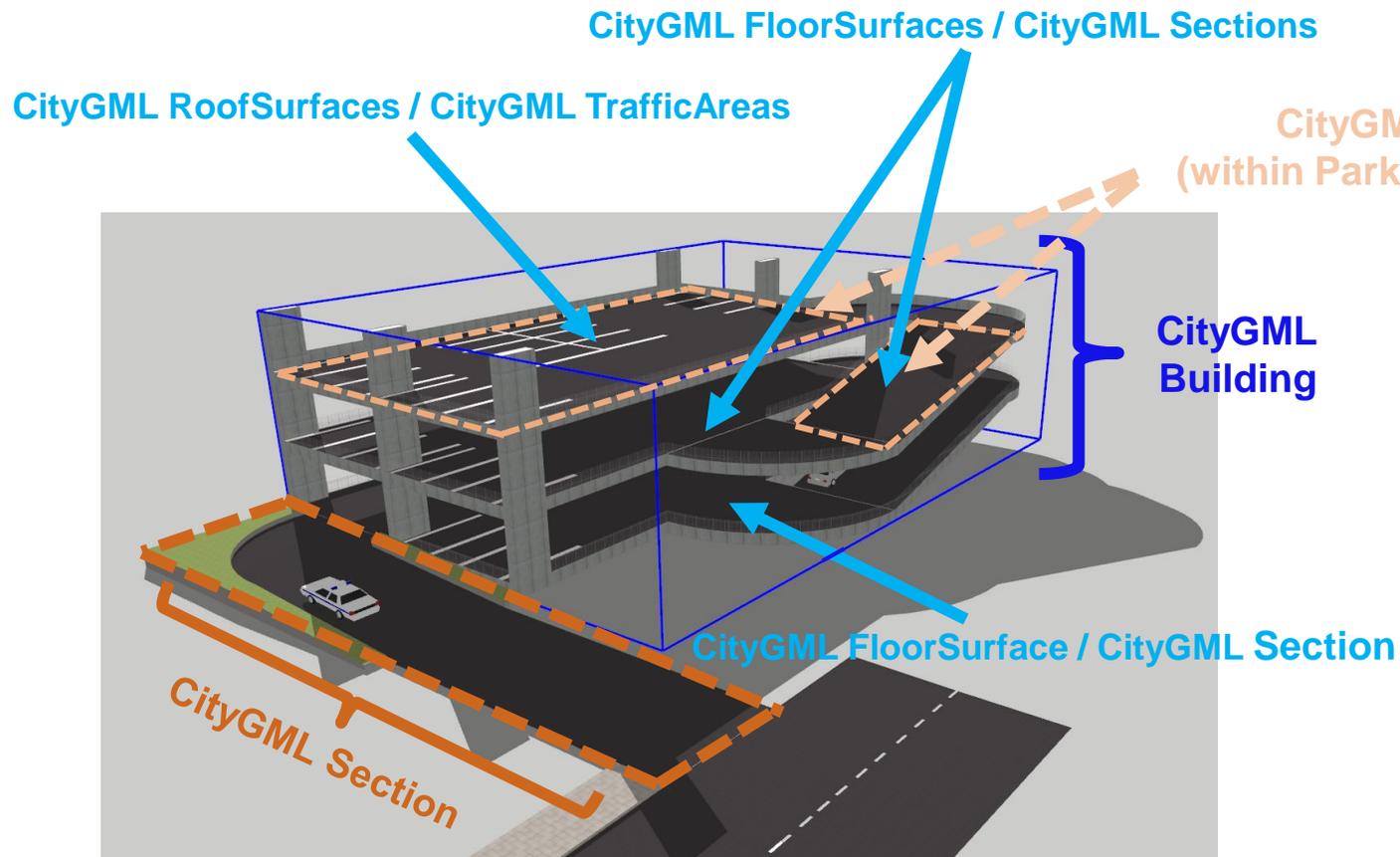
Integrated representation of different traffic types

- ▶ Concepts apply to Roads, Railways, Waterways
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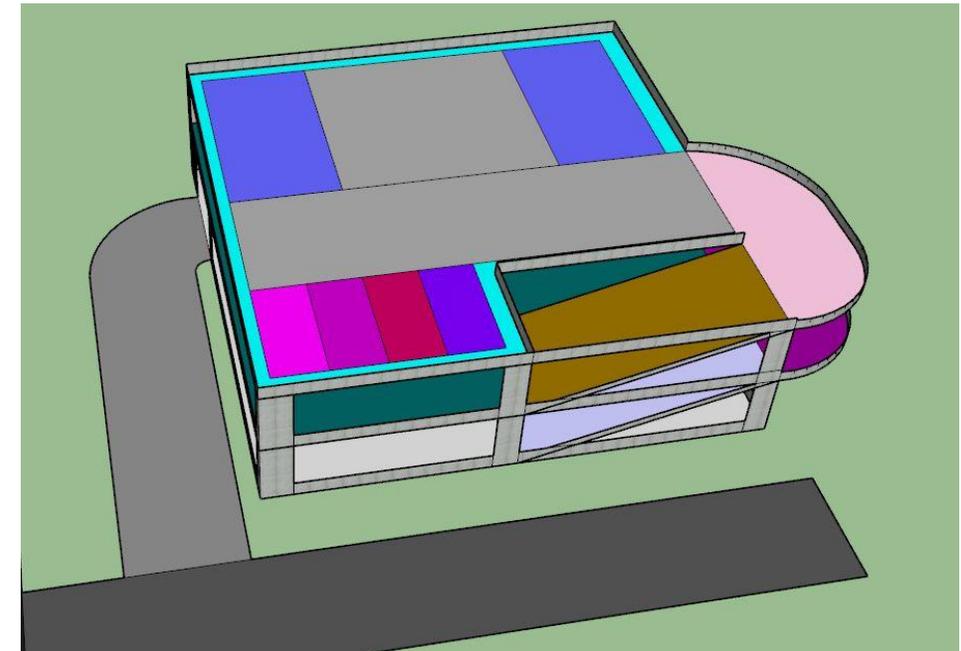


Integrated representation of different object types

- ▶ Combined representation of Buildings and Transportation infrastructure
- ▶ E.g: Parking garage



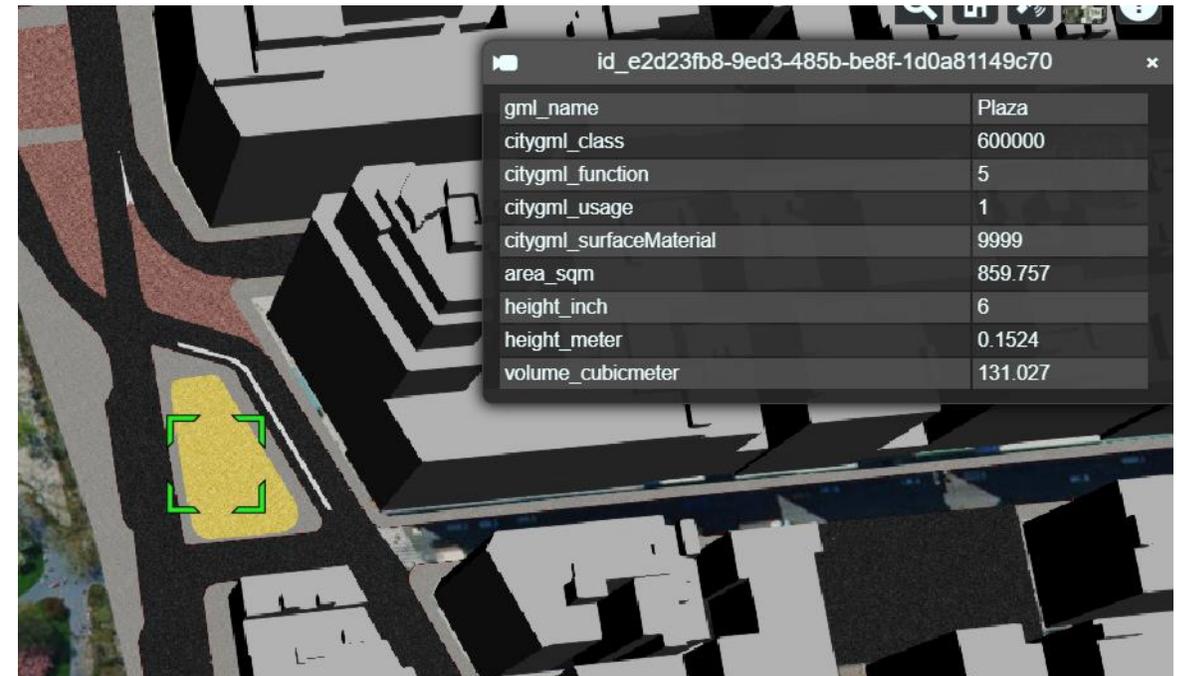
CityGML Sections
(within Parking garage)



Additional classes of the CityGML3.0 Transportation Module

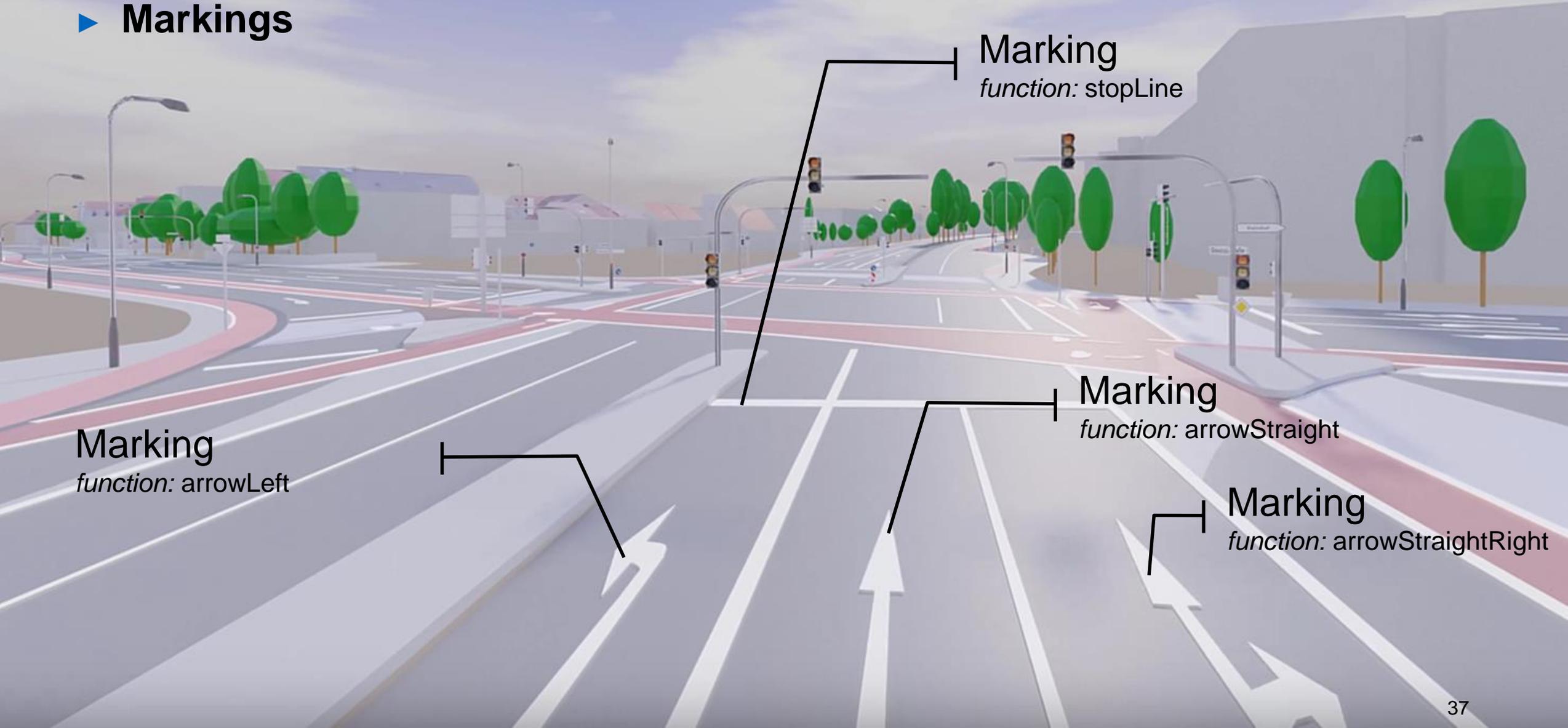
► Square

- Large, sealed surfaces (e.g. public places or parking lots)
- Not segmented into Sections / Intersections
- Can contain individual TrafficSpaces / AuxiliaryTrafficSpaces



New classes of the CityGML3.0 Transportation Module

► Markings



Marking
function: arrowLeft

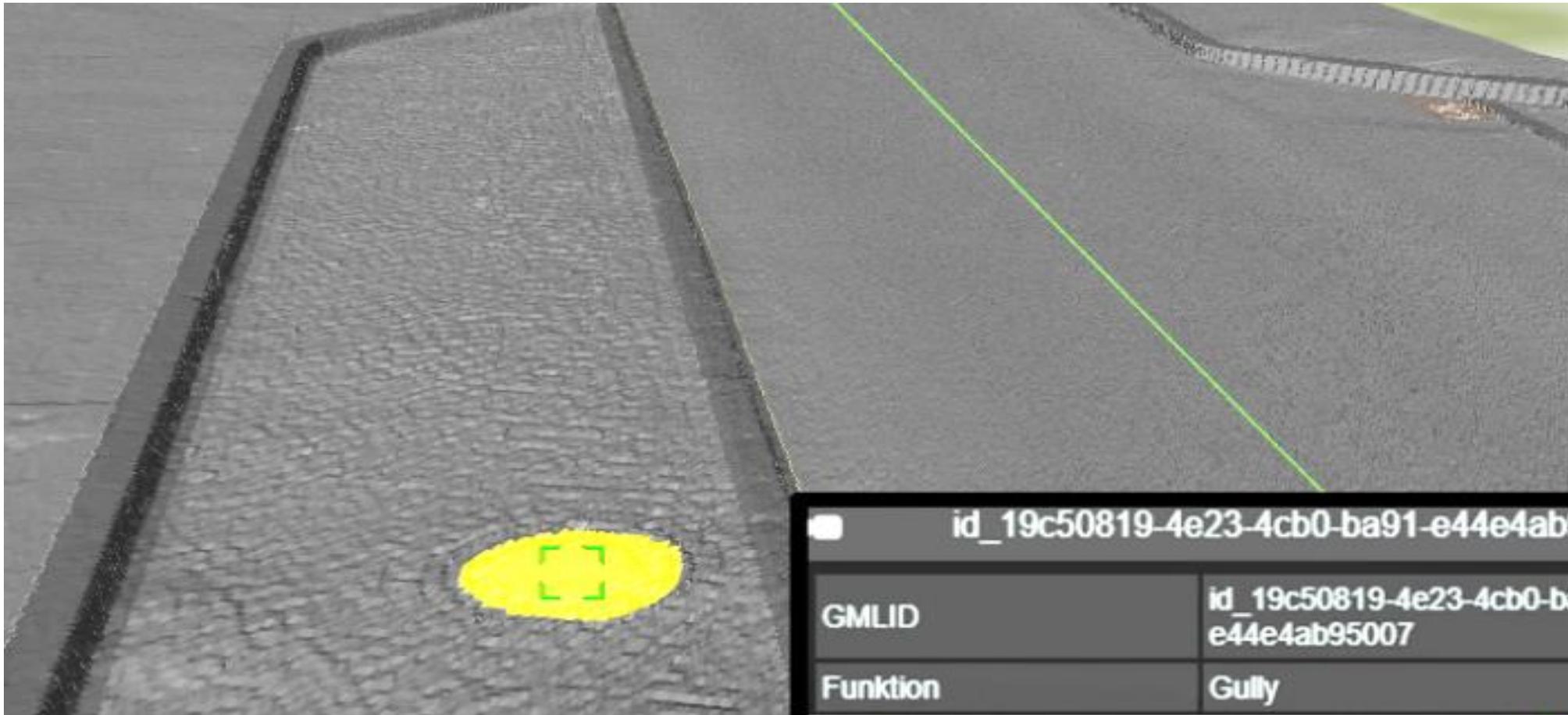
Marking
function: stopLine

Marking
function: arrowStraight

Marking
function: arrowStraightRight

New classes of the CityGML3.0 Transportation Module

- ▶ **Holes:** e.g. drains or road damage



Extending CityGML

▶ CityGML Application Domain Extension (ADE)

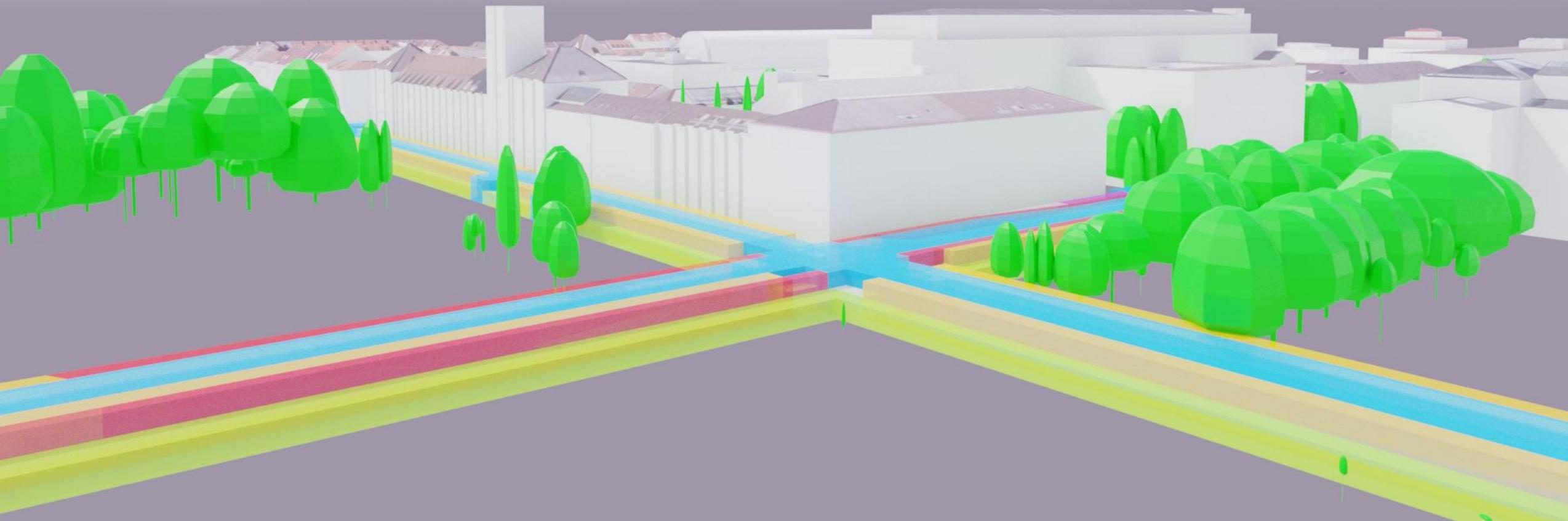
- Build in CityGML mechanism
- Augment data model with additional concepts required by use-case (e.g. new properties or object types)
- Advantage: Extension is formally specified
- Existing CityGML ADEs
 - Energy ADE
 - Noise ADE
 - UtilityNetwork ADE

▶ Potential “CityGML OpenDRIVE ADE”

- Add missing concepts (Linear Referencing, Parameterization etc.)

Link to interactive Demos
<http://go.tum.de/300369>

Demos and examples for semantic 3D streetspace models



Link to interactive demos
<http://go.tum.de/300369>

Complex intersection in Ingolstadt



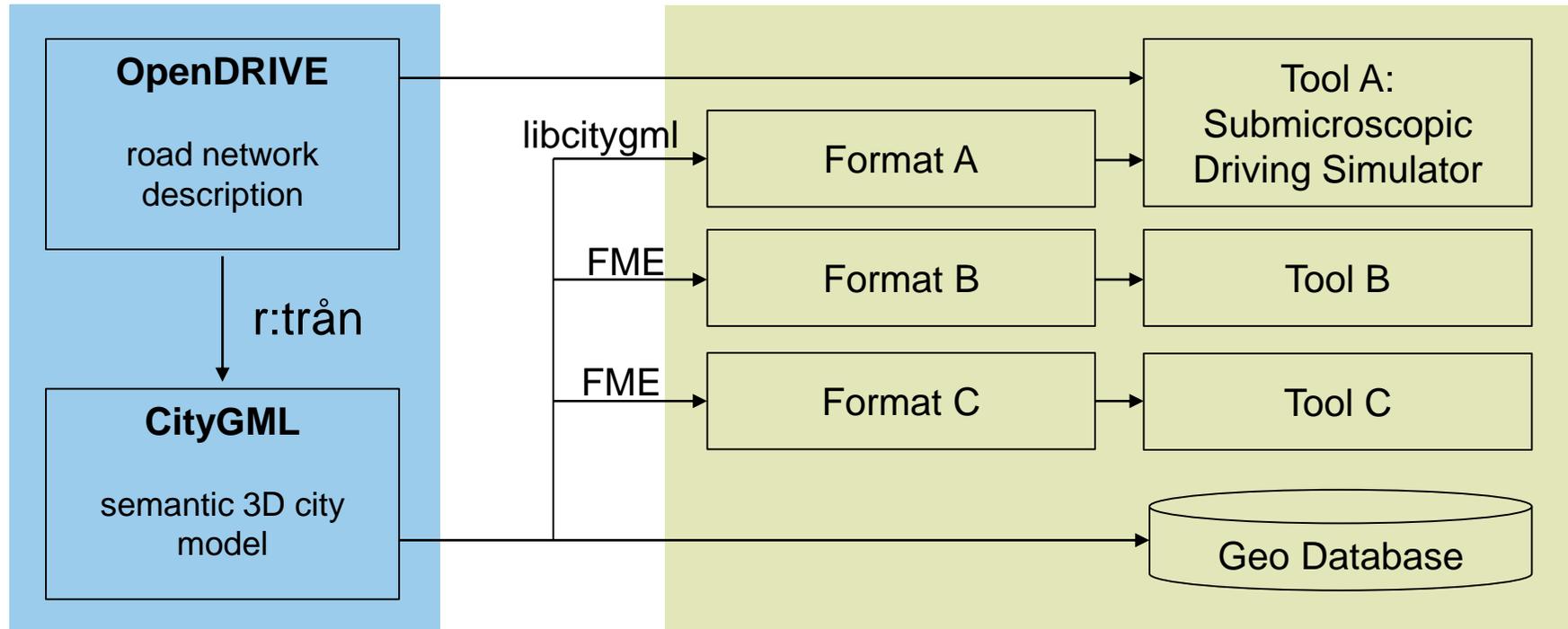
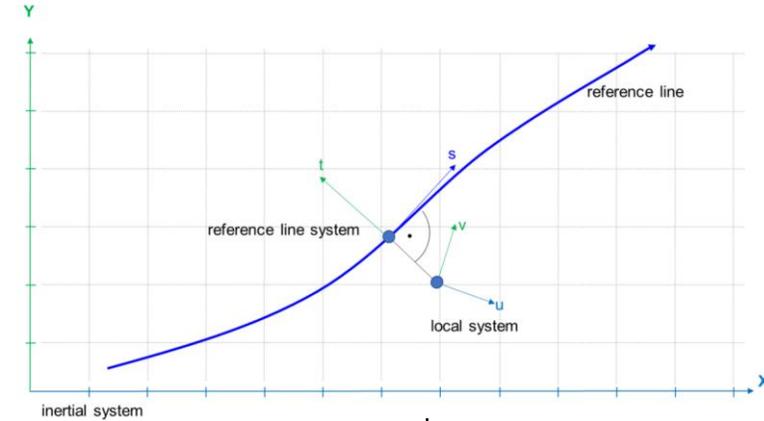
Derived from OpenDRIVE data using the Open Source OpenDRIVE to CityGML converter r:trån - <https://rtron.io>

Rendered in the Unreal Engine

Open Source OpenDRIVE to CityGML converter r:trån

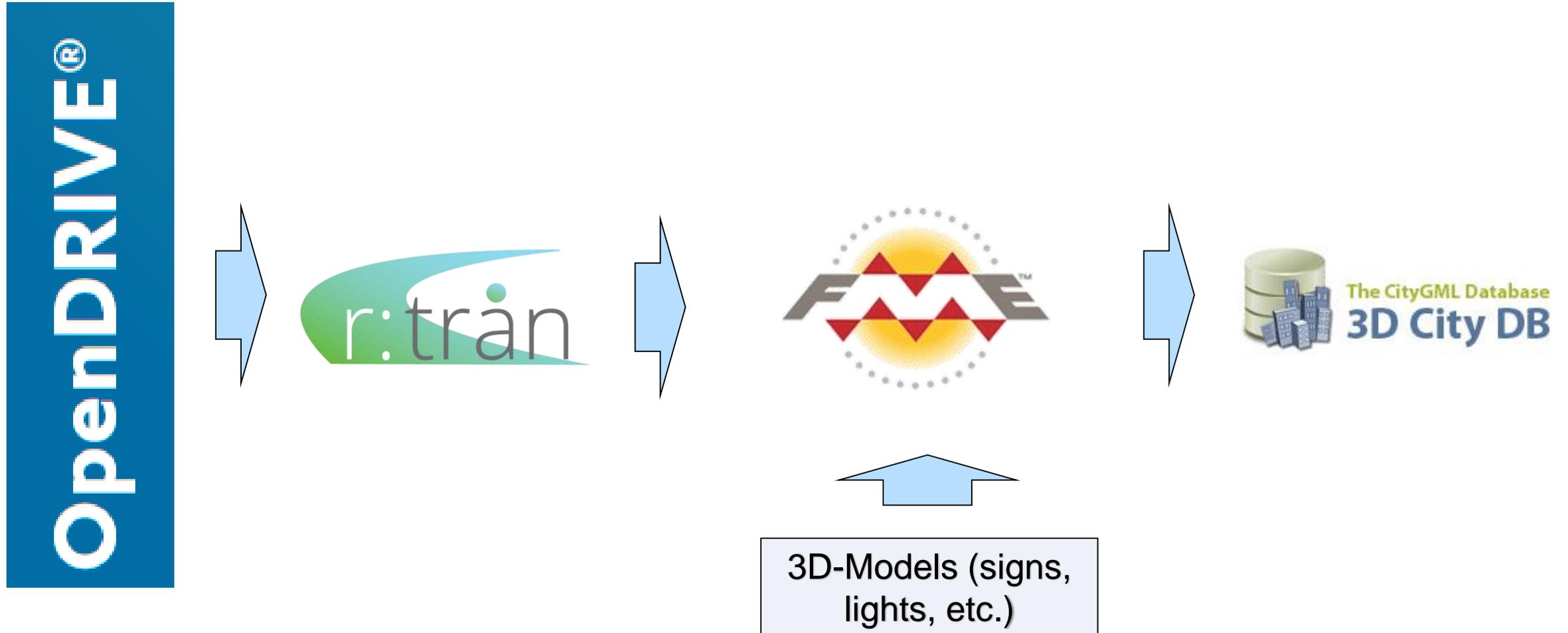
Spatio-Semantic Road Space Model

Application



Schwab, Beil, Kolbe (2020)

Workflow: Detailed 3D streetspace model in Ingolstadt



3DCityDatabase



▶ 3DCityDB:

- Free 3D geo-database to store, represent, and manage virtual 3D city models
<https://www.3dcitydb.org/3dcitydb/>

▶ Importer / Exporter Tool:

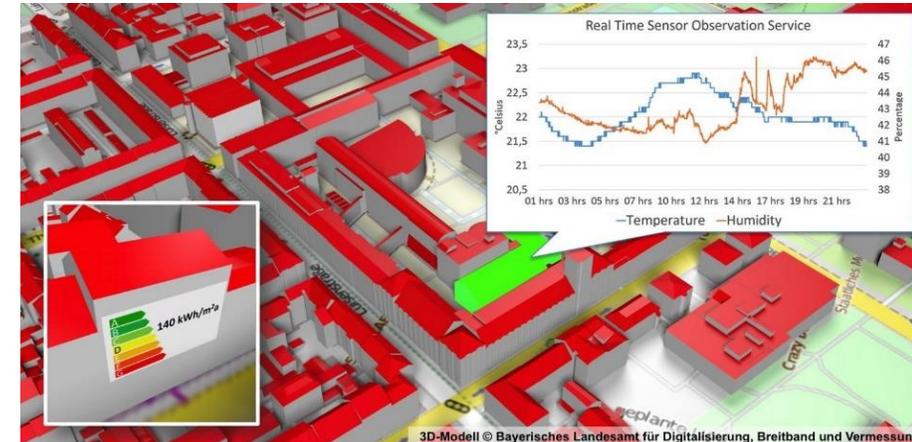
- Import: CityGML data (currently version 2.0, soon: CityGML 3.0)
- Export: CityGML, KML, COLLADA and glTF formats
 - Including tiling strategies

▶ Web Feature Service

- Web-based access to the 3D city objects

▶ 3DCityDB-Web-Map-Client

- Interactive 3D visualization based on Cesium virtual globe



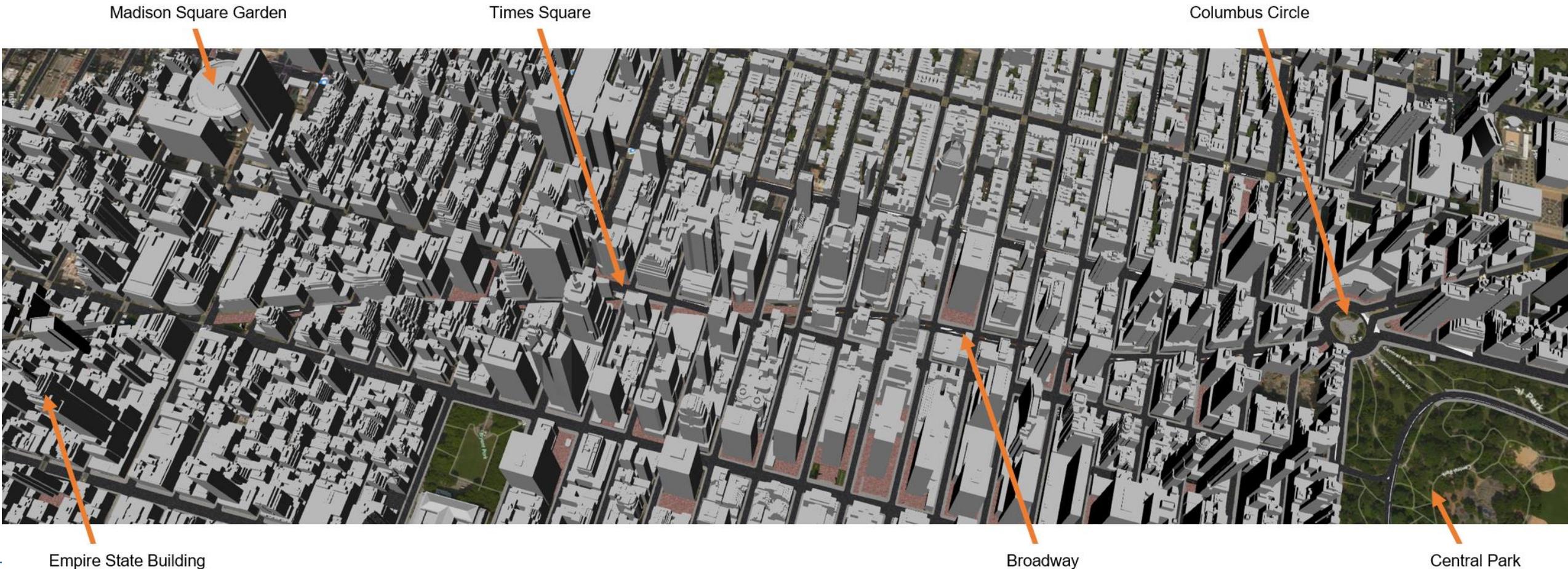
Complex intersection in Ingolstadt – Derived from OpenDRIVE data



Streetspace model for the entire city of New York

Link to interactive demos
<http://go.tum.de/300369>

- ▶ Over 500'000 individual objects (roadbeds, sidewalks, etc.)
- ▶ Derived from Open Data (NYC Open Data Portal)

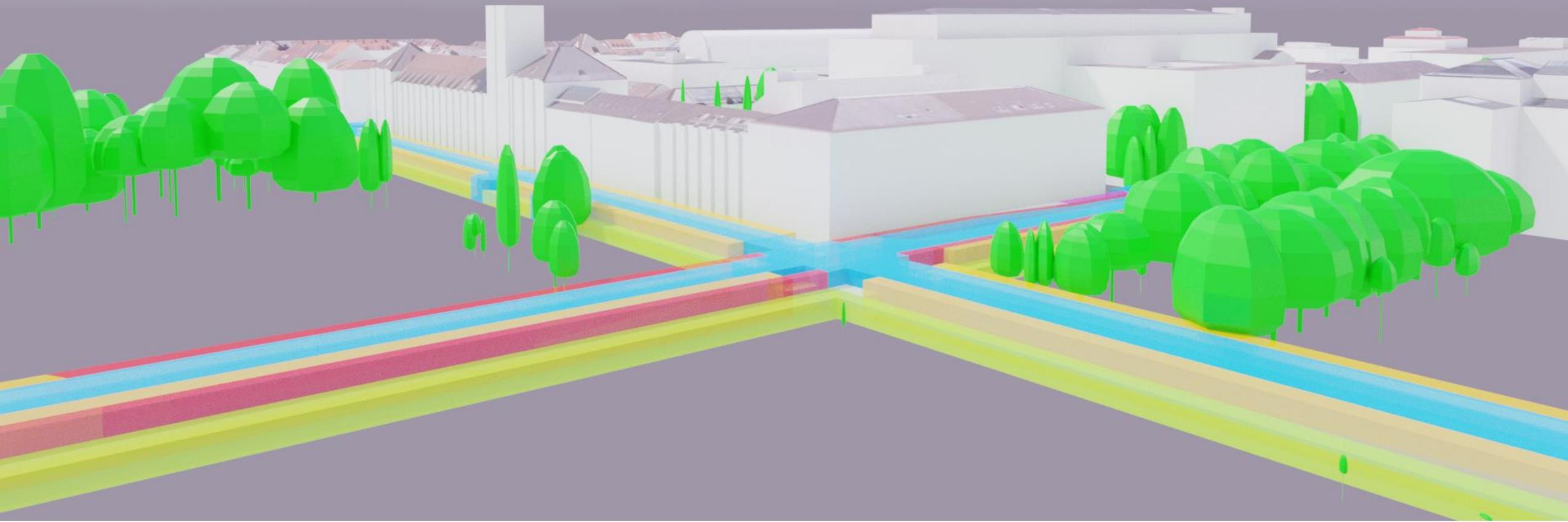


Empire State Building

Broadway

Central Park

Applications for semantic 3D streetspace models



Applications for semantic 3D streetspace models

► Infrastructure Planning and Management:

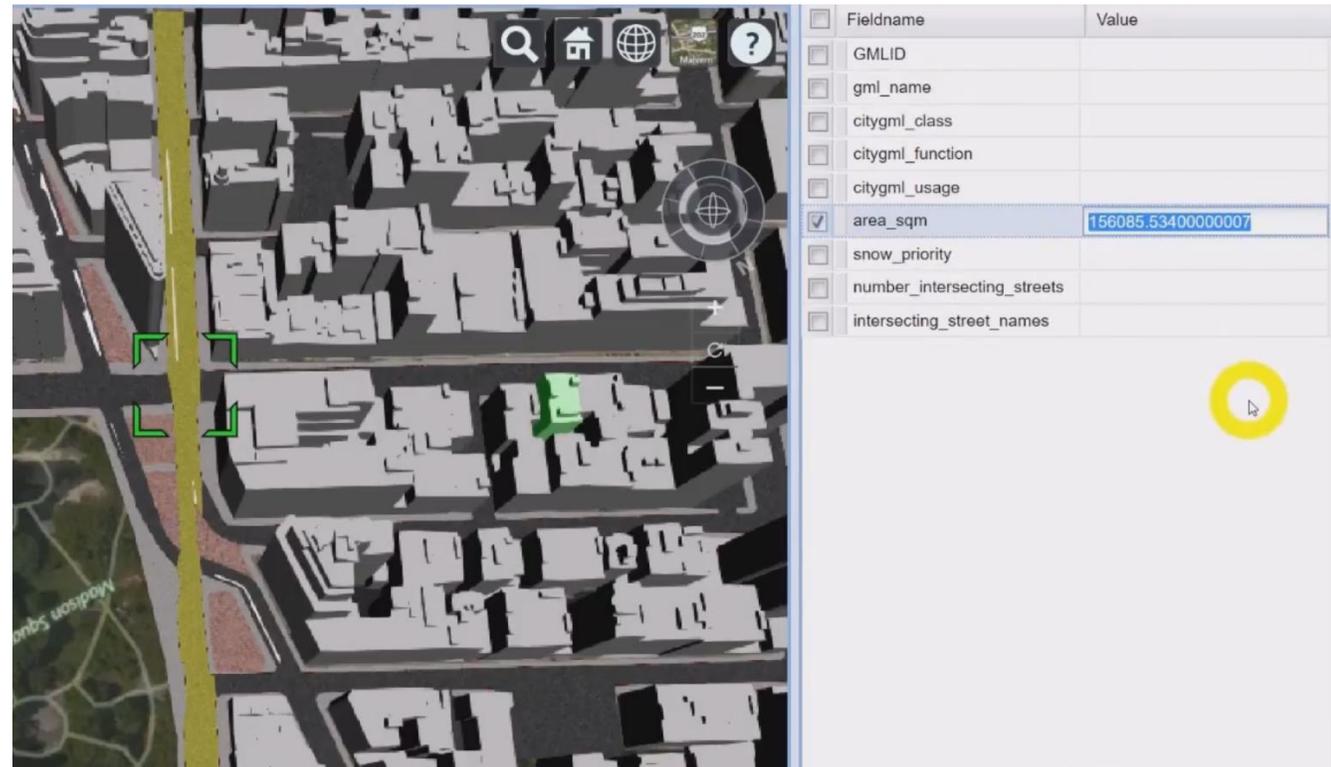
- Asset management
- Maintenance
- Road condition analysis

► Automotive Analysis:

- Driving dynamics
- Driving simulation (driver training)
- Traffic simulation
- Autonomous driving

► Spatial Analysis:

- Visibility analysis
- Solar irradiation analysis for solar energy production and urban heat island effects



Beil & Kolbe (2017)

Applications for semantic 3D streetspace models

► Infrastructure Planning and Management:

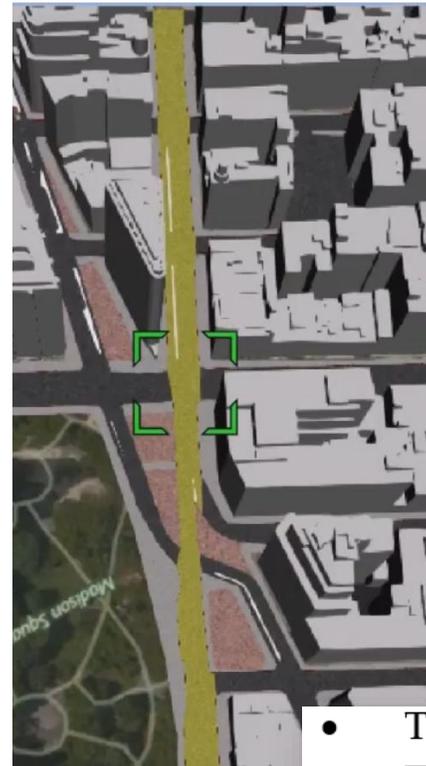
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<input type="checkbox"/>	Fieldname	Value
<input type="checkbox"/>	GMLID	
<input type="checkbox"/>	gml_name	
<input type="checkbox"/>	citygml_class	
<input type="checkbox"/>	citygml_function	
<input type="checkbox"/>	citygml_usage	
<input checked="" type="checkbox"/>	area_sqm	156085.53400000007
<input type="checkbox"/>	snow_priority	
<input type="checkbox"/>	number_intersecting_streets	
<input type="checkbox"/>	intersecting_street_names	

- Total roadbed area: 273.198 m²
- Total intersection area: 156.085 m²
- Pavement rating = 6: 43.395 m²
- Pavement rating = 8-10: 136.322 m²

Applications for semantic 3D streetspace models

▶ Infrastructure Planning and Management:

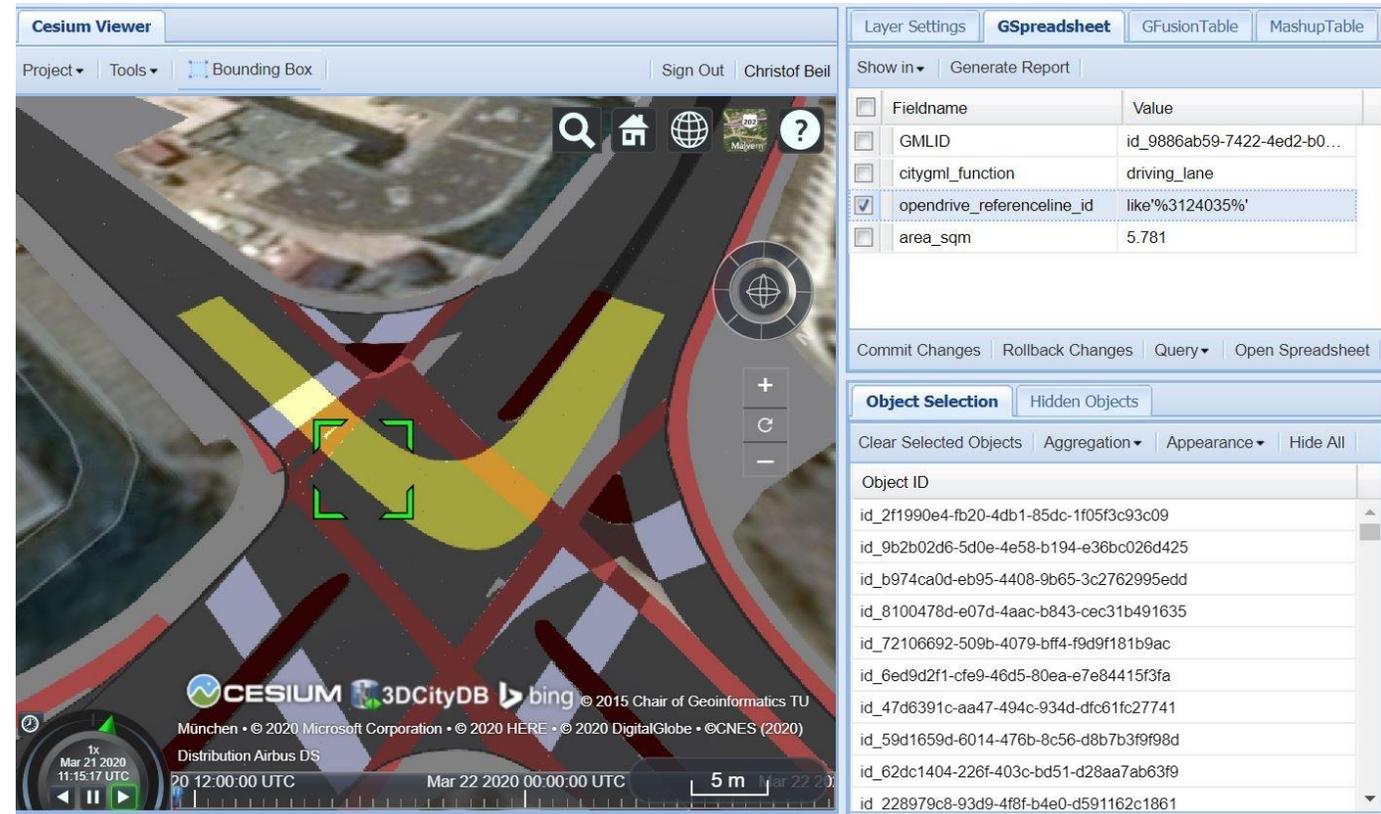
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- Visibility analysis
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Beil & Kolbe (2020a)

Applications for semantic 3D streetspace models

► Infrastructure Planning and Management:

- Asset management
- Maintenance
- Road condition analysis

► Automotive Analysis:

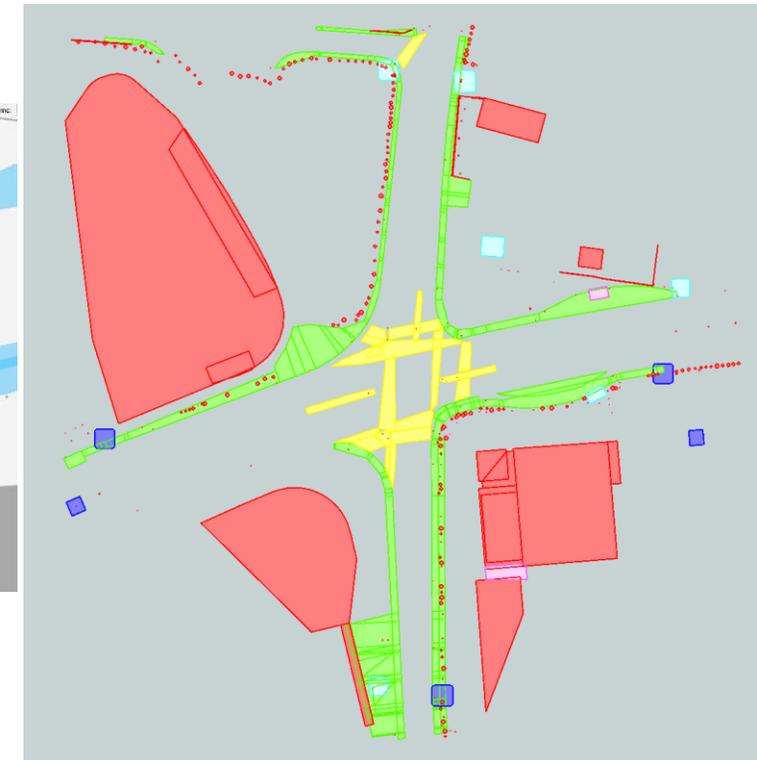
- Driving dynamics
- Driving simulation (driver training)
- Traffic simulation
- Autonomous driving

► Spatial Analysis:

- Visibility analysis
- Solar irradiation analysis for solar energy production and urban heat island effects

Pedestrian simulation tool: MomentUM

Base-Map with information on sidewalks, pedestrian crossings and obstacles derived from CityGML data.



Schwab, Beil, Kolbe (2020)

Applications for semantic 3D streetspace models

► Infrastructure Planning and Management:

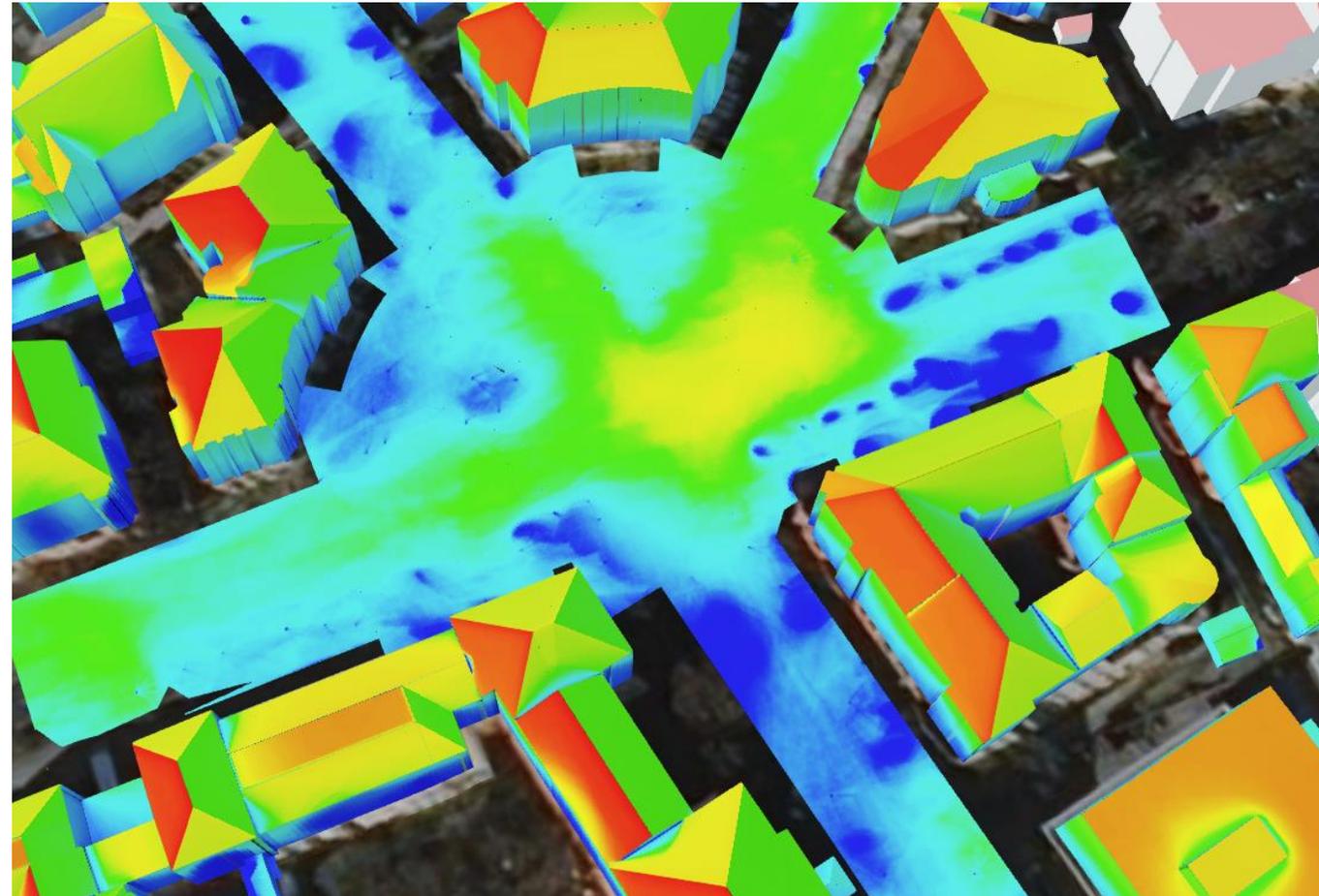
- Asset management
- Maintenance
- Road condition analysis

► Automotive Analysis:

- Driving dynamics
- Driving simulation (driver training)
- Traffic simulation
- Autonomous driving

► Spatial Analysis:

- Visibility analysis
- Solar irradiation analysis for solar energy production and urban heat island effects



Conclusion

- ▶ Concepts on **Semantics, Geometry, Topology** and **Appearance**
 - 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)
 - New object classes such as **Markings** or **Holes**
 - **Integrated representation** for multiple transportation infrastructure (roads, railways, footpaths, waterways, etc.)
- ▶ Multiple **applications** in the context of **digital urban twins** and **smart cities**
- ▶ Potential for extending the conceptual model
 - **Potential CityGML OpenDRIVE ADE**

Relevant links

- ▶ CityGML3.0 Standard Download
<https://www.ogc.org/standards/citygml>
- ▶ CityGML3.0 Encodings GitHub Repository
<https://github.com/opengeospatial/CityGML-3.0Encodings>
- ▶ 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/>

References

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