Open Geospatial Consortium Inc.

Date: 2007-06-17

Reference number of this OGC® project document: OGC 07-062

Version: 0.4.0

Category: OGC Best Practices Document

Editors: Gerhard Gröger, Thomas H. Kolbe, Angela Czerwinski

Candidate OpenGIS® CityGML Implementation Specification

(City Geography Markup Language)

Document type:	OpenGIS® Engineering Report
Document subtype:	Application Schema for the Geography Markup Language 3 (GML 3.1.1)
Document stage:	OpenGIS® Best Practices Document
Document language:	English

Contents

i. Preface

This is the official CityGML logo. For current news on CityGML and information about ongoing projects and fields of research in the area of CityGML see

http://www.citygml.org

CityGML is being developed by the members of the Special Interest Group 3D of the initiative Geodata Infrastructure North-Rhine Westphalia (GDI NRW).

For further information see http://www.gdi-nrw.org/index.php?id=51&lang=eng

CityGML is assessed by the 3D Information Management (3DIM) Working Group of the OGC. It was implemented and evaluated within the OpenGIS Web Services Testbed, Phase 4 (OWS-4) in the CAD/GIS/BIM thread.

For further information see http://www.opengeospatial.org/projects/groups/3dimwg

The preparation of the English document version and the European discussion has been supported by the European Spatial Data Research Organization (EuroSDR; formerly known as OEEPE) in an EuroSDR Commission III project.

For further information see http://www.eurosdr.net

ii. Submitting organizations

The following organizations submitted this Implementation Specification to the Open Geospatial Consortium Inc.:

a) Institute for Geodesy and Geoinformation Science, Technical University Berlin
b) Institute for Geodesy and Geoinformation, University of Bonn
c) Special Interest Group 3D (SIG 3D) of the Geodata Infrastructure North-Rhine Westphalia (GDI NRW)

iii. Submission contact points

All questions regarding this submission should be directed to the editors or the participants in development:

Name	Institution	Email
Prof. Dr. Thomas H. Kolbe Claus Nagel Alexandra Stadler	Institute for Geodesy and Geoinformation Science, Technical University Berlin	kolbe@igg.tu-berlin.de nagel@igg.tu-berlin.de stadler@igg.tu-berlin.de
Dr. Gerhard Gröger Prof. Dr. Lutz Plümer Angela Czerwinski Dirk Dörschlag	Institute for Geodesy and Geoinformation, University of Bonn	groeger@ikg.uni-bonn.de pluemer@ikg.uni-bonn.de czerwinski@ikg.uni-bonn.de doerschlag@ikg.uni-bonn.de
Ulrich Gruber, Birgit Joemann Sandra Schlüter	District Administration Recklinghausen, Cadastre Department	ulrich.gruber@kreis-recklinghausen.de birgit.joemann2@kreis-re.de sandra.schlueter@kreis-re.de
Dr. Joachim Benner Dr. Klaus Leinemann	Institute for Applied Computer Science, Helmholtz Research Center Karlsruhe	benner@iai.fzk.de
Frank Bildstein	Rheinmetall Defence Electronics	bildstein.f@rheinmetall-de.com
Rüdiger Drees	T-Systems Enterprise Services GmbH, Bonn, Germany	Ruediger.Drees@t-systems.com

Andreas Kohlhaas	GIStec GmbH (formerly)	AKohlhaas@t-online.de
Frank Thiemann	Institute for Cartography and Geoinformatics, University of Hannover	Frank.Thiemann@ikg.uni-hannover.de
Martin Degen	City of Dortmund Cadastre Department	mdegen@stadtdo.de
Prof. Dr. Jürgen Döllner Haik Lorenz	Hasso Plattner Institute for Software Technology, University of Potsdam	juergen.doellner@hpi.uni-potsdam.de haik.lorenz@hpi.uni-potsdam.de
Heinrich Geerling	Architekturbüro Geerling	Heinrich@geerling.de
Dr. Frank Knospe	City of Essen Cadastre and Mapping Department	frank.knospe@amt62.essen.de
Hardo Müller	Snowflake Software Ltd., UK	Hardo.Mueller@snowflakesoftware.co.uk
Martin Rechner	rechner logistik	mail@rec-log.de
Jörg Haist Daniel Holweg	Fraunhofer Institute for Computer Graphics (IGD), Darmstadt	joerg.haist@igd.fraunhofer.de daniel.holweg@igd.fraunhofer.de
Prof. Dr. Peter A. Henning	Faculty for Computer Science University of Applied Sciences, Karlsruhe	p.henning@fh-karlsruhe.de
Carsten Rönsdorf Dave Capstick Mark Pendlington	Ordnance Survey, Great Britain	Carsten.Roensdorf@ordnancesurvey.co.uk Dave.Capstick@ordnancesurvey.co.uk Mark.Pendlington@ordnancesurvey.co.uk
Rolf Wegener Stephan Heitmann	State Cadastre and Mapping Agency of North-Rhine Westphalia	wegener@lverma.nrw.de heitmann@lverma.nrw.de
Prof. Dr. Marc-O. Löwner	Institute for Geodesy and Photogrammetry, Technical University of Braunschweig	m-o.loewner@tu-bs.de

iv. Revision history

Date	**Release**	**Editor**	**Description**
1.2.06	0.1.0	Czerwinski, Kolbe, Gröger	Initialisation of the document
22.2.06	0.1.0	Gröger, Gruber	Additions to UML diagrams
26.4.06	0.2.0	Kolbe, Gröger, Czerwinski	Release of CityGML draft specification to EuroSDR
3.6.06	0.3.0	Kolbe, Gröger, Czerwinski	Changes on property names, some attributes added. Release of CityGML specification document to OGC.
30.5.07	0.4.0	Kolbe, Gröger, Nagel, Lorenz, Benner, Czerwinski, Gruber, Schlüter, Bildstein, Drees, Löwner	Introduction of a new appearance model. Introduction of Application Domain Extensions (ADE). Minor changes to the building model. Minor changes to city object groups. The concept of TerrainIntersectionCurves (TIC) added to CityFurniture. Adapation of external code lists. Release of CityGML specification document to OGC.

v. Changes to the OGC® Abstract Specification

The OGC® Abstract Specification does not require changes to accommodate this OGC® standard.

vi. Acknowledgments

The SIG 3D wants to thank the members of the 3D Information Management (3DIM) Working Group of the OGC, especially Tim Case and Paul Cote. Further credits for careful reviewing and commenting of this document go to: John Herring, Ludvig Emgard, Bettina Petzold, Dave Capstick, Mark Pendlington, Alain Lapierre, and Frank Steggink.

Foreword

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. Open Geospatial Consortium Inc. shall not be held responsible for identifying any or all such patent rights. However, to date, no such rights have been claimed or identified.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the specification set forth in this document, and to provide supporting documentation.

Significant changes from the previous CityGML version 0.3.0 (OGC document no. 06-057r1):

- Introduction of a new appearance model;
- Introduction of Application Domain Extensions (ADE);
- Minor changes to the building model;
- Minor changes to city object groups; and
- Concept of terrain intersection curves (TIC) added to city furniture.

CityGML 0.3.0 instance documents are still valid CityGML 0.4.0 instance documents except for objects modelled as interior building installations. The approach of representing interior building installations has changed with this release of CityGML. However, the SIG 3D is not aware of existing instance documents affected by this revision. Please consult CityGML's new building model in case of necessary adaptions (cf. chapter 9.3).

Please note, that the former appearance model has been marked as deprecated and is expected to be removed in future CityGML versions. All appearance information can be losslessly converted to the new appearance model.

0 Introduction

0.1 Motivation

An increasing number of cities and companies are building virtual 3D city models for different application areas like urban planning, mobile telecommunication, disaster management, 3D cadastre, tourism, vehicle and pedestrian navigation, facility management and environmental simulations. Furthermore, in the implementation of the European Environmental Noise Directive (END, 2002/49/EC) 3D geoinformation and 3D city models play an important role.

In recent years, most virtual 3D city models have been defined as purely graphical or geometrical models, neglecting the semantic and topological aspects. Thus, these models could almost only be used for visualisation purposes but not for thematic queries, analysis tasks, or spatial data mining. Since the limited reusability of models inhibits the broader use of 3D city models, a more general modelling approach had to be taken in order to satisfy the information needs of the various application fields.

CityGML is a common semantic information model for the representation of 3D urban objects that can be shared over different applications. The latter capability is especially important with respect to the cost-effective sustainable maintenance of 3D city models, allowing the possibility of selling the same data to customers from different application fields. The targeted application areas explicitly include city planning, architectural design, tourist and leisure activities, environmental simulation, mobile telecommunication, disaster management, homeland security, real estate management, vehicle and pedestrian navigation, and training simulators.

CityGML is designed as an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is implemented as an application schema of the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange and encoding issued by the Open Geospatial Consortium (OGC) and the ISO TC211. CityGML is based on a number of standards from the ISO 191xx family, the Open Geospatial Consortium, the W3C Consortium, the Web 3D Consortium, and OASIS.

CityGML defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantical, and appearance properties. "City" is broadly defined to comprise not just built structures, but also elevation, vegetation, water bodies, "city furniture", and more. Included are generalisation hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. CityGML is applicable for large areas and small regions and can represent the terrain and 3D objects in different levels of detail simultaneously. Since either simple, single scale models without topology and few semantics or very complex multi-scale models with full topology and fine-grained semantical differentiations can be represented, CityGML enables lossless information exchange between different GI systems and users.

0.2 Historical background

CityGML has been developed since 2002 by the members of the Special Interest Group 3D (SIG 3D) of the initiative Geodata Infrastructure North Rhine-Westphalia (GDI NRW) in Germany. The SIG 3D is an open group consisting of more than 70 companies, municipalities, and research institutions from Germany, Great Britain, Switzerland, and Austria working on the development and commercial exploitation of interoperable 3D models and geovisualization. Another result of the work from the SIG 3D is the proposition of the Web 3D Service (W3DS), a 3D portrayal service that is also being discussed in the Open Geospatial Consortium (OGC Doc.No. 05-019).

A subset of CityGML has been successfully implemented and evaluated in the project "Pilot 3D" of the GDI NRW in 2005. Participants came from all over Germany and demonstrated city planning scenarios and tourist applications. Today, the official 3D city model of Berlin is based on the CityGML data model and employs CityGML as the exchange format between database, editor, and presentation systems. Also the 3D city models of Stuttgart, Bochum, Essen, Dortmund, Cologne, and Bonn are based on the CityGML model.

By the beginning of 2006, a CityGML project within EuroSDR (European Spatial Data Research) has been started aiming at the European harmonisation of 3D city modelling. From June to December 2006, CityGML was employed and evaluated in the CAD/GIS/BIM thread of the OpenGIS Web Services Testbed #4 (OWS-4).

OpenGIS® CityGML Implementation Specification

1 Scope

This document is a candidate OpenGIS Implementation Specification for the representation, storage and exchange of virtual 3D city and landscape models. CityGML is implemented as an application schema for the Geography Markup Language version 3.1.1 (GML3).

CityGML models complex and georeferenced 3D vector data along with the semantics associated with the data. In contrast to other 3D vector formats, CityGML is based on a rich, general purpose information model in addition to geometry and appearance information. For specific domain areas, CityGML also provides an extension mechanism to enrich the data with identifiable features under preservation of semantic interoperability.

Targeted application areas explicitly include urban and landscape planning; architectural design; tourist and leisure activities; 3D cadastres; environmental simulations; mobile telecommunications; disaster management; homeland security; vehicle and pedestrian navigation; training simulators and mobile robotics.

CityGML is considered a source format for 3D portraying. The semantic information contained in the model can be used in the styling process which generates computer graphics represented e.g. as a KML/COLLADA or X3D files. The appropriate OGC Portrayal Web Service for this process is the OGC Web 3D Service (W3DS).

Features of CityGML:

- Geospatial information model (ontology) for urban landscapes based on the ISO 191xx family
- GML3 representation of 3D geometries, based on the ISO 19107 model
- Representation of object surface characteristics (textures, materials)
- Taxonomies and aggregations
  - Digital Terrain Models as a combination of (including nested) triangulated irregular networks (TINs), regular rasters, break and skeleton lines, mass points
  - Sites (currently buildings; bridges and tunnels in the future)
  - Vegetation (areas, volumes and solitary objects with vegetation classification)
  - Water bodies (volumes, surfaces)
  - Transportation facilities (both graph structures and 3D surface data)
  - City furniture
  - Generic city objects and attributes
  - User-definable (recursive) grouping
- Multiscale model with 5 well-defined consecutive Levels of Detail (LOD):
  - LOD 0 – regional, landscape
  - LOD 1 – city, region
  - LOD 2 – city districts, projects
  - LOD 3 – architectural models (outside), landmarks
  - LOD 4 – architectural models (interior)
- Multiple representations in different LODs simultaneously; generalisation relations between objects in different LODs
- Optional topological connections between feature (sub)geometries
- Application Domain Extensions (ADE): Specific "hooks" in the CityGML schema allow to define application specific extensions, for example for noise pollution simulation, or to augment CityGML by properties of the new National Building Information Model Standard (NBIMS) in the U.S.

2 Conformance

XML files must be validated against the CityGML schema and fulfill all further requirements of the CityGML specification. All objects modelled in CityGML shall be modelled accordingly in any application.

3 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of OGC 07-062. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of OGC 07-062 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

The following documents are indispensable for the application of the CityGML specification. The geometry model of GML 3.1.1 is used except for some added concepts like implicit geometries (see chapter 7.2). The appearance model (see chapter 8) draws concepts from both *X3D* and *COLLADA*. Addresses are represented using the OASIS extensible address language *xAL*.

ISO 8601:2004, *Data elements and interchange formats – Information interchange – Representation of dates and times*

ISO/TS 19103:2005, *Geographic Information – Conceptual Schema Language*

ISO 19105:2000, *Geographic information – Conformance and testing*

ISO 19107:2003, *Geographic Information – Spatial Schema*

ISO 19109:2005, *Geographic Information – Rules for Application Schemas*

ISO 19111:2003, *Geographic information – Spatial referencing by coordinates*

ISO 19115:2003, *Geographic Information – Metadata*

ISO 19123:2005, *Geographic Information – Coverages*

ISO/TS 19139:2007, *Geographic Information – Metadata – XML schema implementation*

ISO/IEC 19775:2004, *X3D Abstract Specification*

OpenGIS® Abstract Specification Topic 0, *Overview, OGC document 04-084*

OpenGIS® Abstract Specification Topic 5, *The OpenGIS Feature, OGC document 99-105r2*

OpenGIS® Abstract Specification Topic 8, *Relations between Features, OGC document 99-108r2*

OpenGIS® Abstract Specification Topic 10, *Feature Collections, OGC document 99-110*

OpenGIS® Geography Markup Language Implementation Specification, *Version 3.1.1, OGC document 03-105r1*

IETF RFC 2045 & 2046, *Multipurpose Internet Mail Extensions (MIME). (November 1996)*

IETF RFC 2396, *Uniform Resource Identifiers (URI): Generic Syntax. (August 1998)*

W3C XLink, *XML Linking Language (XLink) Version 1.0. W3C Recommendation (27 June 2001)*

W3C XMLName, *Namespaces in XML. W3C Recommendation (14 January 1999)*

W3C XMLSchema-1, *XML Schema Part 1: Structures. W3C Recommendation (2 May 2001)*

W3C XMLSchema-2, *XML Schema Part 2: Datatypes. W3C Recommendation (2 May 2001)*

W3C Xpointer, *XML Pointer Language (XPointer) Version 1.0. W3C Working Draft (16 August 2002)*

W3C XML Base, *XML Base, W3C Recommendation (27 June 2001)*

W3C XML, *Extensible Markup Language (XML) 1.0 (Second Edition), W3C Recommendation (6 October 2000)*

OASIS (Organization for the Advancement of Structured Information Standards): extensible Address Language (xAL v2.0).

Khronos Group Inc.: COLLADA – Digital Asset Schema Release 1.4.1

4 Conventions

4.1 Abbreviated terms

The following abbreviated terms are used in this document:

2D	Two Dimensional
3D	Three Dimensional
AEC	Architecture, Engineering, Construction
ALKIS	German National Standard for Cadastral Information
ATKIS	German National Standard for Topographic and Cartographic Information
B-Rep	Boundary Representation
CAD	Computer Aided Design
CAAD	Computer Aided Architectural Design
COLLADA	Collaborative Design Activity
CSG	Constructive Solid Geometry
DTM	Digital Terrain Model
DXF	Drawing Exchange Format
EuroSDR	European Spatial Data Research Organisation
FM	Facility Management
GDF	Geographic Data Files
GDI NRW	Geodata Infrastructure North-Rhine Westphalia
GML	Geography Markup Language
IAI	International Alliance for Interoperability
IETF	Internet Engineering Task Force
IFC	Industry Foundation Classes
ISO	International Organization for Standardisation
LOD	Level of Detail
NBIMS	National Building Information Model Standard
OASIS	Organisation for the Advancement of Structured Information Standards
OGC	Open Geospatial Consortium
OSCRE	Open Standards Consortium for Real Estate
SIG 3D	Special Interest Group 3D of the GDI NRW
TC211	ISO Technical Committee 211
TIC	Terrain Intersection Curve
TIN	Triangulated Irregular Network
UML	Unified Modeling Language
URI	Uniform Resource Identifier
VRML	Virtual Reality Modeling Language
W3C	World Wide Web Consortium
W3DS	OGC Web 3D Service
WFS	OGC Web Feature Service
X3D	Open Standards XML-enabled 3D file format of the Web 3D Consortium
XML	Extensible Markup Language

xAL OASIS extensible Address Language

4.2 UML Notation

The CityGML specification is presented in this document in diagrams using the Unified Modeling Language (UML) static structure diagram (see Booch et al. 1997). The UML notations used in this standard are described in the diagram below (Fig. 1).

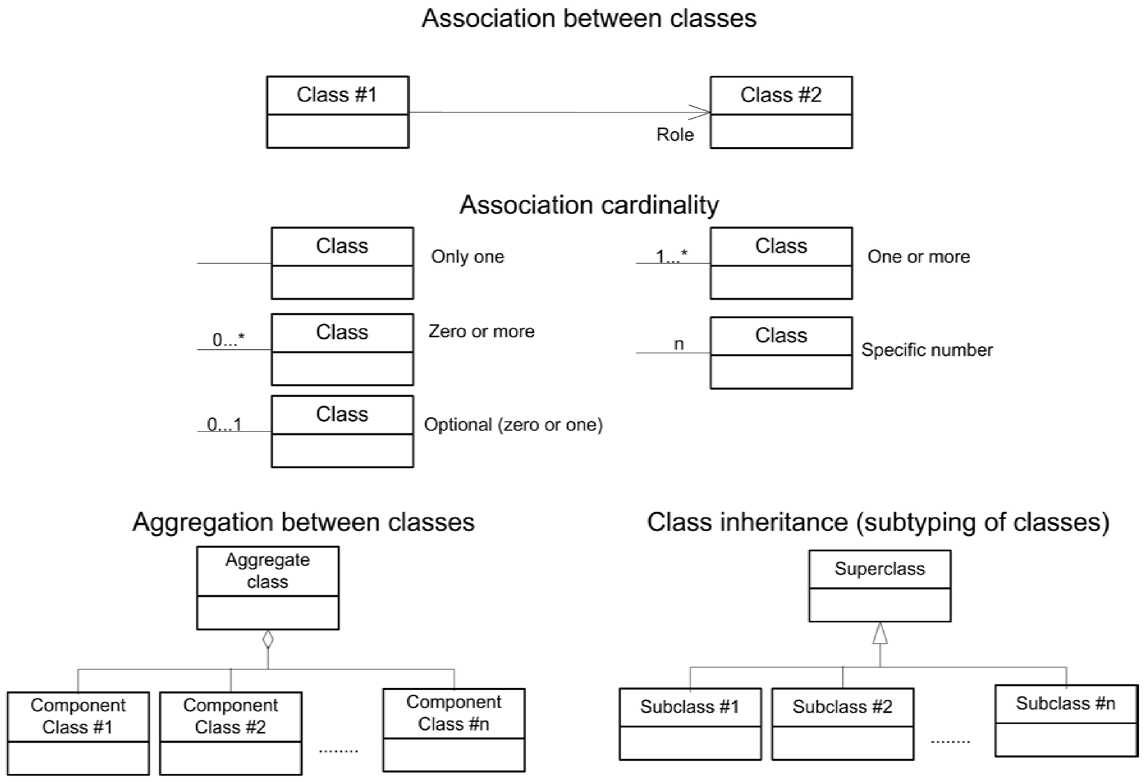


Fig. 1: UML notation (see ISO TS 19103, Geographic information - Conceptual schema language).

According to GML3 all associations between model elements in CityGML are uni-directional. Thus, associations in CityGML are navigable in only one direction. The direction of navigation is depicted by an arrowhead. In general, the context an element takes within the association is indicated by its role. The role is displayed near the target of the association. If the graphical representation is ambiguous though, the intended position of the role is clarified using a filled arrowhead as indicator.

In CityGML each feature can have geometric representations in different levels of detail (LOD). A special symbol is introduced to represent the corresponding associations between the feature and its related geometry objects. The symbol means that a separate association occurs for each LOD in the interval [a..b]. Since these associations just differ in their name they are aggregated by this notation for readability reasons. Please note, that this symbol extends the standard UML notation.

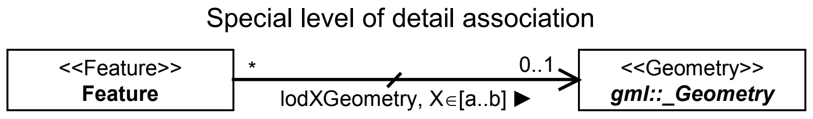


Fig. 2: UML notation: special level of detail association.

The following stereotypes are used:

<<Geometry>> represents the geometry of an object. The geometry is an identifiable and distinguishable object that is derived from the abstract GML type *AbstractGeometryType*.

<<Feature>> represents a thematic feature according to the definition in ISO 19109. A feature is an identifiable and distinguishable object that is derived from the abstract GML type *AbstractFeatureType*.

<<Object>> represents an identifiable and distinguishable object that is derived from the abstract GML type *AbstractGMLType*.

<<ExternalCodeList>> enumerates the valid attribute values (see chapter 6.5).

<<Union>> is a list of attributes. The semantics are that only one of the attributes can be present at any time.

<<PrimitiveType>> is used for representations supported by a primitive type in the implementation.

<<DataType>> is used as a descriptor of a set of values that lack identity. Data types include primitive predefined types and user-definable types. A DataType is thus a class with few or no operations whose primary purpose is to hold the abstract state of another class for transmittal, storage, encoding or persistent storage.

4.3 XML-Schema

The normative parts of the specification use the W3C XML schema language to describe the grammar of conformant CityGML data instances. XML schema is a rich language with many capabilities. While a reader who is unfamiliar with an XML schema may be able to follow the description in a general fashion, this specification is not intended to serve as an introduction to XML schema. In order to have a full understanding of this candidate specification, it is necessary for the reader to have a reasonable knowledge of XML schema.

5 Overview of CityGML

CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application schema for the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211.

The aim of the development of CityGML is to reach a common definition of the basic entities, attributes, and relations of a 3D city model. This is especially important with respect to the cost-effective sustainable maintenance of 3D city models, allowing the reuse of the same data in different application fields.

CityGML not only represents the graphical appearance of city models but specifically addresses the representation of the semantic and thematic properties, taxonomies and aggregations. CityGML includes a geometry model and a thematic model. The geometry model allows for the consistent and homogeneous definition of geometrical and topological properties of spatial objects within 3D city models (chapter 7). The base class of all objects is *CityObject*. All objects inherit the properties from *CityObject*.

The thematic model of CityGML employs the geometry model for different thematic fields like Digital Terrain Models, sites (i.e. buildings; future extensions of CityGML will also include explicit models for bridges and tunnels), vegetation (solitary objects and also areal and volumetric biotopes), water bodies, transportation facilities, and city furniture (chapter 9). Further objects, which are not explicitly modelled yet, can be represented using the concept of generic objects and attributes (chapter 6.10). In addition, extensions to the CityGML data model applying to specific application fields can be realised using the Application Domain Extensions (ADE) (chapter 6.11). Spatial objects of equal shape which appear many times at different positions like e.g. trees, can also be modelled as prototypes and used multiple times in the city model (chapter 7.2). A grouping concept allows the combination of single 3D objects, e.g. buildings to a building complex (chapter 6.7). Objects which are not geometrically modelled by closed solids can be virtually sealed in order to compute their volume (e.g. pedestrian underpasses, tunnels, or airplane hangars). They can be closed using *ClosureSurfaces* (chapter 6.3). The concept of the *TerrainIntersectionCurve* is introduced to integrate 3D objects with the Digital Terrain Model at their correct positions in order to prevent e.g. buildings from floating over or sinking into the terrain (chapter 6.4).

CityGML differentiates five consecutive Levels Of Detail (LOD), where objects become more detailed with increasing LOD regarding both their geometry and thematic differentiation (chapter 6.1). CityGML files can - but do not have to - contain multiple representations (and geometries) for each object in different LOD simultaneously. Generalisation relations allow the explicit representation of aggregated objects over different scales.

In addition to spatial properties, CityGML features can be assigned appearances. Appearances are not limited to visual data but represent arbitrary observable properties of the feature's surface such as infrared radiation, noise pollution, or earthquake-induced structural stress (chapter 8).

Furthermore, objects can have external references to corresponding objects in external datasets (chapter 6.6). Enumerative object attributes are restricted to external code lists and values defined in external, redefinable dictionaries (chapter 6.5).

6 General characteristics of CityGML

6.1 Multi-scale modelling (5 levels of detail, LOD)

CityGML supports different Levels of Detail (LOD). LODs are required to reflect independent data collection processes with differing application requirements. Further, LODs facilitate efficient visualisation and data analysis (see Fig. 3). In a CityGML dataset, the same object may be represented in different LOD simultaneously, enabling the analysis and visualisation of the same object with regard to different degrees of resolution. Furthermore, two CityGML data sets containing the same object in different LOD may be combined and integrated.

The coarsest level LOD0 is essentially a two and a half dimensional Digital Terrain Model, over which an aerial image or a map may be draped. LOD1 is the well-known blocks model comprising prismatic buildings with flat roofs. In contrast, a building in LOD2 has differentiated roof structures and thematically differentiated surfaces. Vegetation objects may also be represented. LOD3 denotes architectural models with detailed wall and roof structures, balconies, bays and projections. High-resolution textures can be mapped onto these structures. In addition, detailed vegetation and transportation objects are components of a LOD3 model. LOD4 completes a LOD3 model by adding interior structures for 3D objects. For example, buildings are composed of rooms, interior doors, stairs, and furniture.

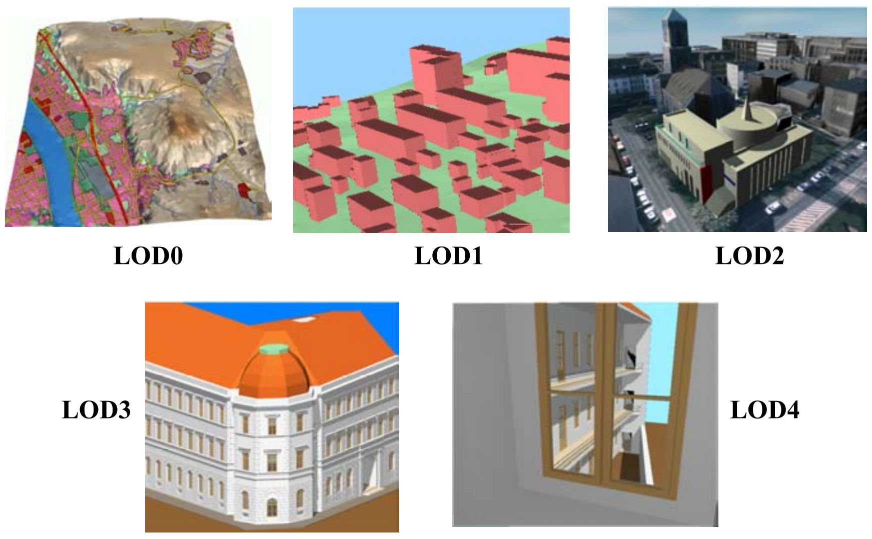


Fig. 3: The five levels of detail (LOD) defined by CityGML (source: IGG Uni Bonn)

LODs are also characterised by differing accuracies and minimal dimensions of objects (Tab. 1). The accuracy requirements given in this candidate specification are debatable and should be considered as discussion proposals. Accuracy is described as standard deviation σ of the absolute 3D point coordinates. Relative 3D point accuracy will be added in a future version of CityGML as it is typically much higher than the absolute accuracy. In LOD1, the positional and height accuracy of points must be 5m or less, while all objects with a footprint of at least 6m by 6m have to be considered. The positional and height accuracy of LOD2 must be 2m or better. In this LOD, all objects with a footprint of at least 4m × 4m have to be considered. Both types of accuracies in LOD3 are 0.5m, and the minimal footprint is 2m × 2m. Finally, the positional and height accuracy of LOD4 must be 0.2m or less. By means of these figures, the classification in five LOD may be used to assess the quality of 3D city model datasets. The LOD categorisation makes datasets comparable and provides support for their integration.

	LOD0	**LOD1**	**LOD2**	**LOD3**	**LOD4**
Model scale description	regional, landscape	city, region	city districts, projects	architectural models (outside), landmark	architectural models (interior)
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal	object blocks as	objects as	object as real	constructive

	generalisation (classification of land use)	generalised features; > 6*6m/3m	generalised features; > 4*4m/2m	features; > 2*2m/1m	elements and openings are represented
Building installations	-	-	-	representative exterior effects	real object form
Roof form/structure	no	flat	roof type and orientation	real object form	real object form
Roof overhanging parts	-	-	n.a.	n.a.	Yes
CityFurniture	-	important objects	prototypes	real object form	real object form
SolitaryVegetationObject	-	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	-	>50*50m	>5*5m	< LOD2	<LOD2
… to be continued for the other feature themes					

Tab. 1: LOD 0-4 of CityGML with its accuracy requirements (source: Albert et al. 2003).

Whereas in CityGML each object can have a different representation for every LOD, often different objects from the same LOD will be generalised to be represented by an aggregate object in a lower LOD. CityGML supports the aggregation / decomposition by providing an explicit generalisation association between any *CityObjects* (further details see UML diagram in chapter 9.1).

6.2 Coherent semantical-geometrical modelling

One of the most important design principles for CityGML is the coherent modelling of semantics and geometrical/topological properties. At the semantic level, real-world entities are represented by features, such as buildings, walls, windows, or rooms. The description also includes attributes, relations and aggregation hierarchies (part-whole-relations) between features. Thus the part-of-relationship between features can be derived at the semantic level only, without considering geometry. However, at the spatial level, geometry objects are assigned to features representing their spatial location and extent. So the model consists of two hierarchies: the semantic and the geometrical in which the corresponding objects are linked by relationships (cf. Stadler & Kolbe 2007). The advantage of this approach is that it can be navigated in both hierarchies and between both hierarchies arbitrarily, for answering thematic and/or geometrical queries or performing analyses.

If both hierarchies exist for a specific object, they must be coherent (i.e. it must be ensured that they match and fit together). For example, if a wall of a building has two windows and a door on the semantic level, then the geometry representing the wall must contain also the geometry parts of both windows and the door.

6.3 Closure surfaces

Objects, which are not modelled by a volumetric geometry, must be virtually closed in order to compute their volume (e.g. pedestrian underpasses or airplane hangars). They can be sealed using *ClosureSurfaces*. *ClosureSurfaces* are special surfaces, which are taken into account, when needed to compute volumes and are neglected, when they are irrelevant or not appropriate, for example in visualisations.

The concept of *ClosureSurfaces* is also employed to model the entrances of *subsurface objects*. Those objects like tunnels or pedestrian underpasses have to be modelled as closed solids in order to compute their volume, for example in flood simulations. The entrances to subsurface objects also have to be sealed to avoid holes in the digital terrain model (see Fig. 4). However, in close-range visualisations the entrance must be treated as open. Thus, *ClosureSurfaces* are an adequate way to model those entrances.

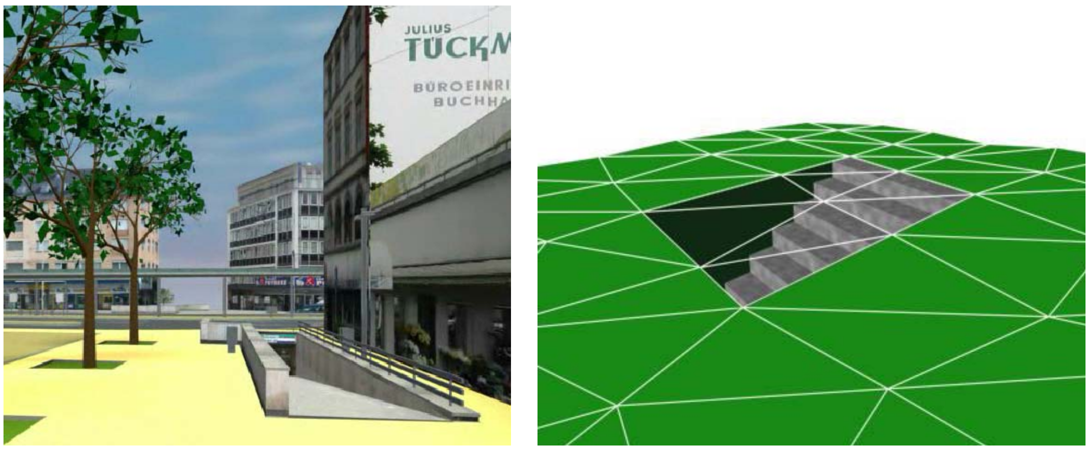


Fig. 4: Closure surfaces to seal open structures. Passages are subsurface objects (left). The entrance is sealed by a virtual *ClosureSurface,* which is both part of the DTM and the subsurface object (right) (graphic: IGG Uni Bonn).

6.4 Terrain Intersection Curve (TIC)

A crucial issue in city modelling is the integration of 3D objects and the terrain. Problems arise if 3D objects float over or sink into the terrain. This is particularly the case if terrains and 3D objects in different LOD are combined, or if they come from different providers (Kolbe and Gröger 2003). To overcome this problem, the *TerrainIntersectionCurve (TIC)* of a 3D object is introduced. These curves denote the exact position, where the terrain touches the 3D object (see Fig. 5). TICs can be applied to buildings and building parts (cf. chapter 9.3), city furniture objects (cf. chapter 9.7), and generic city objects (cf. chapter 9.10). If, for example, a building has a courtyard, the TIC consists of two closed rings: one ring representing the courtyard boundary, and one which describes the building's outer boundary. This information can be used to integrate the building and a terrain by 'pulling up' or 'pulling down' the surrounding terrain to fit the *TerrainIntersectionCurve*. The DTM may be locally warped to fit the TIC. By this means, the TIC also ensures the correct positioning of textures or the matching of object textures with the DTM. Since the intersection with the terrain may differ depending on the LOD, a 3D object may have different *TerrainIntersectionCurves* for all LOD.

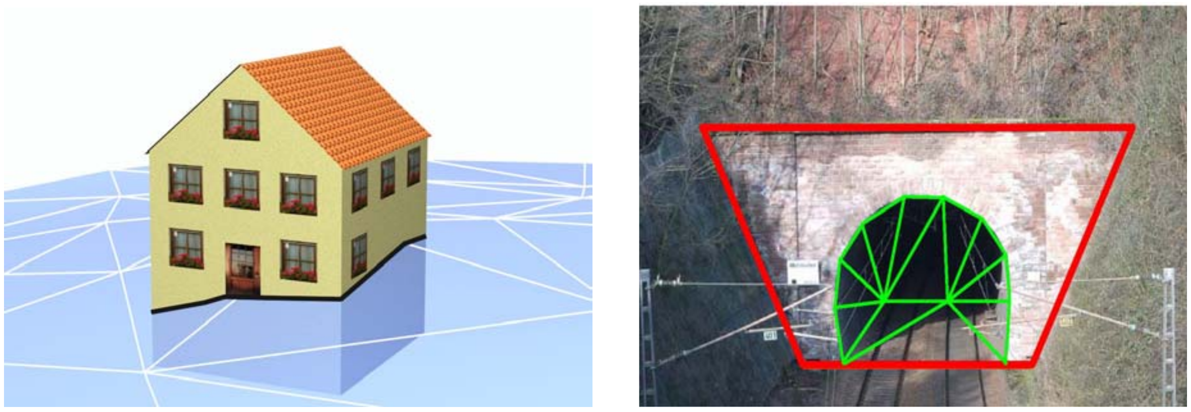


Fig. 5: *TerrainIntersectionCurve* for a building (left, black) and a tunnel object (right, white). The tunnel's hollow space is sealed by a triangulated *ClosureSurface* (graphic: IGG Uni Bonn).

6.5 Dictionaries and code lists for enumerative attributes

Attributes, which are used to classify objects, often have values that are restricted to a number of discrete values. An example is the attribute *roof type*, whose attribute values typically are saddle back roof, hip roof, semi-hip roof, flat roof, pent roof, or tent roof. If such an attribute is typed as string, misspellings or different names for the same notion obstruct interoperability. In CityGML such classifying of attributes is specified as *CodeLists* and implemented by *GML3 Dictionaries* (c.f. Cox et al. 2004). Such a structure enumerates all possible values of the attribute in an external file, ensuring that the same name is used for the same notion. In addition, the translation of attribute values into other languages is facilitated.

Dictionaries and code lists may be extended or redefined by users. They can have references to existing models. For example, room codes defined by the Open Standards Consortium for Real Estate (OSCRE) can be referenced instead of CityGML's predefined values. Likewise, classifications of buildings and building parts introduced by the National Building Information Model Standard (NBIMS) can be used alternatively.

6.6 External references

3D objects are often derived from or have relations to objects in other databases or data sets. For example, a 3D building model may have been constructed from a two-dimensional footprint in a cadastre data set, or may be derived from an architectural model (Fig. 6). The reference of a 3D object to its corresponding object in an external data set is essential, if an update must be propagated or if additional data is required, for example the name and address of a building's owner in a cadastral information system or information on antennas and doors in a facility management system. In order to supply such information, each *CityObject* may have *External References* to corresponding objects in external data sets (for the UML diagram see Fig. 20; and for XML schema definition see chapter 10.1.5). Such a reference denotes the external information system and the unique identifier of the object in this system. Both are specified as a *Uniform Resource Identifier (URI)*, which is a generic format for references to any kind of resources on the internet. The generic concept of external references allows for any CityObject an arbitrary number of links to corresponding objects in external information systems (e.g. ALKIS, ATKIS, Ordnance Survey Mastermap®, GDF, etc.).

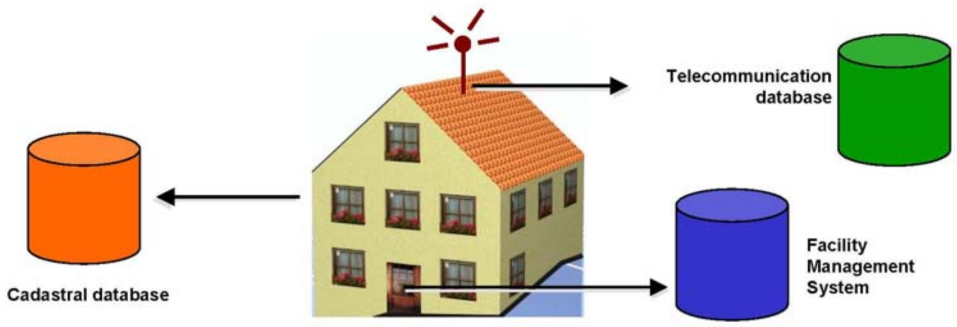


Fig. 6: External references (graphic: IGG Uni Bonn).

6.7 City object groups

The grouping concept of CityGML allows the aggregation of arbitrary city objects according to user-defined criteria, and to represent and transfer these aggregations as part of a city model (for the UML diagram see chapter 9.9; XML schema definition see chapter 10.1.4). A group may be assigned one or more names and may be further classified by specific attributes, for example, "escape route from room no. 43 in house no. 1212 in a fire scenario" as a name and "escape route" as type. Each member of the group can optionally be assigned a role name, which specifies the role this particular member plays in the group. This role name may, for example, describe the sequence number of this object in an escape route, or in the case of a building complex, denote the main building.

A group may contain other groups as members, allowing nested grouping of arbitrary depth.

6.8 Appearances

Information about a surface's appearance, i.e. observable properties of the surface, is considered an integral part of virtual 3D city models in addition to semantics and geometry. Appearance relates to any surface-based theme, e.g. infrared radiation or noise pollution, not just visual properties. Consequently, data provided by appearances can be used as input for both presentation of and analysis in virtual 3D city models.

CityGML supports feature appearances for an arbitrary number of themes per city model. Each LOD of a feature can have an individual appearance. Appearances can represent – among others – textures and georeferenced textures.

6.9 Prototypic objects / scene graph concepts

In CityGML objects of equal shape like trees and other vegetation objects, traffic lights and traffic signs can be represented as prototypes which are instantiated multiple times at different locations (Fig. 7). The geometry of prototypes is defined in local coordinate systems. Every instance is represented by a reference to the prototype, a base point in the world coordinate reference system and a transformation matrix that facilitates scaling, rotation, and translation of the prototype. The principle is adopted from the concept of scene graphs used in computer graphics standards like VRML and X3D. As the GML3 geometry model does not provide support for scene graph concepts, it is implemented as an extension to the GML3 geometry model (for further description see chapter 7.2).

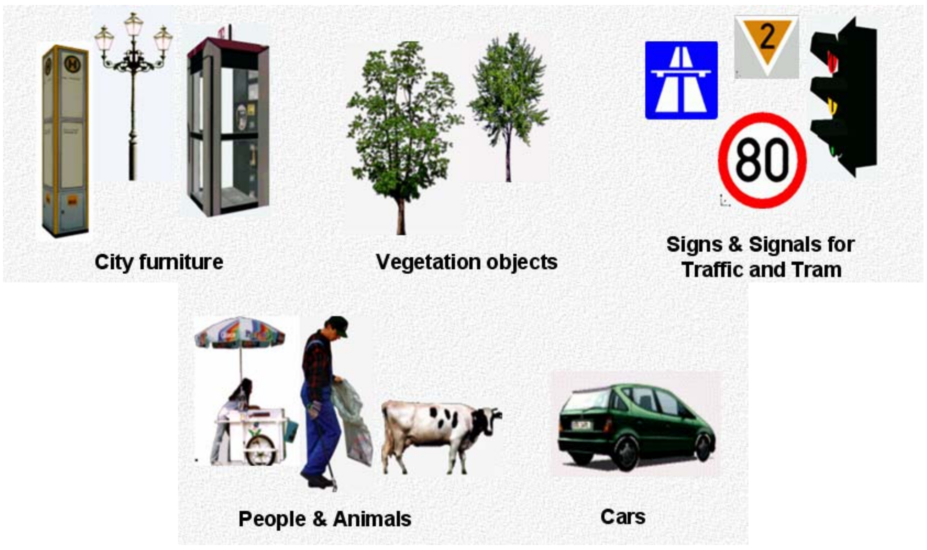


Fig. 7: Examples of prototypic shapes (source: Rheinmetall Defence Electronics).

6.10 Generic city objects and attributes

CityGML was designed as a universal topographic information model that defines object types and attributes which are useful for a broad range of applications. In practical applications the objects within specific 3D city models will most likely contain attributes which are not explicitly modelled in CityGML. Moreover, there might be 3D objects which are not covered by the thematic classes of CityGML. CityGML provides two different concepts to support the exchange of such data: 1) generic objects and attributes, and 2) application domain extensions (see chapter 6.11).

The concept of generic objects (*GenericCityObject*) and attributes (*CityObjectGenericAttribute*) allows the extension of CityGML applications during runtime, i.e. any CityObject may be extended by additional attributes, whose names, datatypes, and values can be provided by a running application without any change of the CityGML XML schema. The corresponding UML diagram is given in chapter 9.10 and the XML schema definition in chapter 10.1.3.

The current version of CityGML does not include explicit thematic models for bridges, tunnels, and walls. They will be added in a future version. In the meantime, these objects should be stored or exchanged using generic objects and attributes.

6.11 Application Domain Extensions (ADE)

Application Domain Extensions (ADE) specify additions to the CityGML data model. Such additions comprise the introduction of new properties to existing CityGML classes like e.g. the number of habitants of a building or the definition of new object types. The difference between ADEs and generic objects and attributes is, that an ADE has to be defined in an extra XML schema definition file with its own namespace. This file has to explicitly import the CityGML schema.

The advantage of this approach is that the extension is formally specified. Extended CityGML instance documents can be validated against the CityGML and the respective ADE schema. ADEs can be defined (and even standardised) by information communities which are interested in specific application fields. More than one ADE can be actively used in the same dataset (further description cf. chapter 9.11).

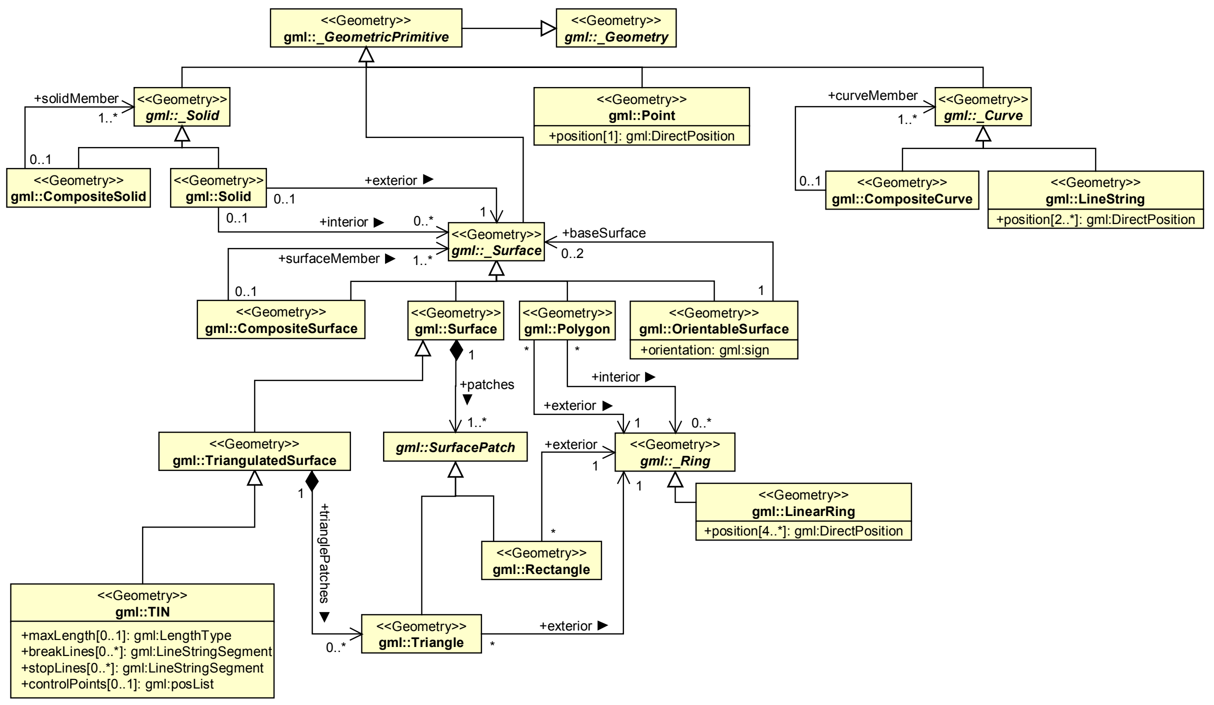
Recently, a first ADE for noise pollution simulation has been developed, which is employed in the simulation of environmental noise dispersion according to the Environmental Noise Directive of the European Commission (2002/49/EC). Annex E (chapter 11.5) shows and explains the CityGML Noise ADE as an example.

7 Spatial model

Spatial properties of CityGML features are represented by objects of GML3's geometry model. This model is based on the standard ISO 19107 'Spatial Schema' (Herring 2001), representing 3D geometry according to the well-known *Boundary Representation* (B-Rep, cf. Foley et al. 1995). CityGML actually uses only a subset of the GML3 geometry package, defining a profile of GML3. This subset is depicted in Fig. 8 and Fig. 9. Furthermore, GML3's explicit Boundary Representation is extended by scene graph concepts, which allow the representation of the geometry of features with the same shape implicitly and thus more space efficiently (chapter 7.2).

7.1 Geometric-topological model

The geometry model of GML 3 consists of primitives, which may be combined to form complexes, composite geometries or aggregates. For each dimension, there is a geometrical primitive: a zero-dimensional object is a *Point*, a one-dimensional a *_Curve*, a two-dimensional a *_Surface*, and a three-dimensional a *_Solid* (Fig. 8). Each geometry can have its own coordinate reference system. A solid is bounded by surfaces and a surface by curves. In CityGML, a curve is restricted to be a straight line, thus only the GML3 class *LineString* is used. Surfaces in CityGML are represented by *Polygons*, which define a planar geometry, i.e. the boundary and all interior points are required to be located in one single plane.



<<Geometry>> gml::_GeometricPrimitive
<<Geometry>> gml::_Geometry
+solidMember
1..*
<<Geometry>> gml::_Solid
<<Geometry>> gml::Point
+position[1]: gml:DirectPosition
+curveMember
1..*
<<Geometry>> gml::_Curve
0..1
<<Geometry>> gml::CompositeSolid
<<Geometry>> gml::Solid
0..1
+exterior ▶
0..1
+interior ▶
0..*
1
<<Geometry>> gml::_Surface
+baseSurface
0..2
+surfaceMember ▶
1..*
0..1
<<Geometry>> gml::CompositeCurve
<<Geometry>> gml::LineString
+position[2..*]: gml:DirectPosition
0..1
1
<<Geometry>> gml::CompositeSurface
<<Geometry>> gml::Surface
<<Geometry>> gml::Polygon
<<Geometry>> gml::OrientableSurface
+orientation: gml:sign
1
+patches ▼
1..*
*
*
+interior ▶
+exterior ▶
1
0..*
<<Geometry>> gml::TriangulatedSurface
gml::SurfacePatch
+exterior
1
<<Geometry>> gml::_Ring
1
<<Geometry>> gml::LinearRing
+position[4..*]: gml:DirectPosition
1
+trianglePatches ▼
*
<<Geometry>> gml::Rectangle
<<Geometry>> gml::TIN
+maxLength[0..1]: gml:LengthType
+breakLines[0..*]: gml:LineStringSegment
+stopLines[0..*]: gml:LineStringSegment
+controlPoints[0..1]: gml:posList
0..*
<<Geometry>> gml::Triangle
*
+exterior ▶

Fig. 8: UML diagram of CityGML's geometry model (subset and profile of GML3): Primitives and Composites.

Combined geometries can be aggregates, complexes or composites of primitives (see illustration in Fig. 10). In an *Aggregate*, the spatial relationship between components is not restricted. They may be disjoint, overlapping, touching, or disconnected. GML3 provides a special aggregate for each dimension, a *MultiPoint*, a *MultiCurve, a MultiSurface* or a *MultiSolid* (see Fig. 9). In contrast to aggregates, a *Complex* is topologically structured: its parts must be disjoint, must not overlap and are allowed to touch, at most, at their boundaries or share parts of their boundaries. A *Composite* is a special complex provided by GML3. It can only contain elements of the same dimension. Its elements must be disjoint as well, but they must be topologically connected along their boundaries. *A Composite* can be a *CompositeSolid,* a *CompositeSurface, or CompositeCurve.* (c.f. Fig. 8).

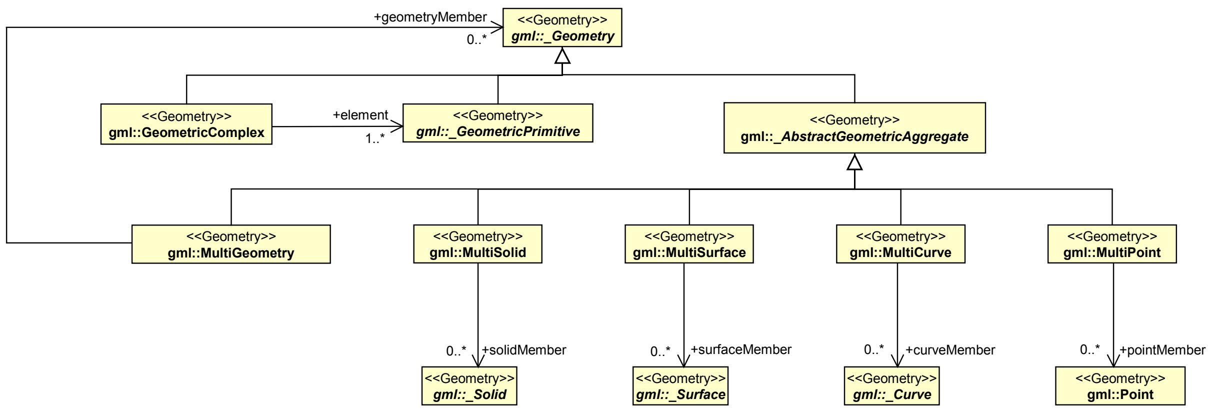

+geometryMember
0..*
<<Geometry>> gml::_Geometry
<<Geometry>> gml::GeometricComplex
+element
1..*
<<Geometry>> gml::_GeometricPrimitive
<<Geometry>> gml::_AbstractGeometricAggregate
<<Geometry>> gml::MultiGeometry
<<Geometry>> gml::MultiSolid
<<Geometry>> gml::MultiSurface
<<Geometry>> gml::MultiCurve
<<Geometry>> gml::MultiPoint
0..* +solidMember
0..* +surfaceMember
0..* +curveMember
0..* +pointMember
<<Geometry>> gml::_Solid
<<Geometry>> gml::_Surface
<<Geometry>> gml::_Curve
<<Geometry>> gml::Point

Fig. 9: UML diagram of CityGML's geometry model: Complexes and Aggregates

An *OrientableSurface* is a surface with an explicit orientation, i.e. two sides, front and back, can be distinguished. This may be used to assign textures to specific sides of a surface, or to distinguish the exterior and the interior side of a surface when bounding a solid. Please note, that Curves and Surfaces have a default orientation in GML which results from the order of the defining points. Thus, an OrientableSurface only has to be used, if the orientation of a given GML geometry has to be reversed.

TriangulatedSurfaces are special surfaces, which specify triangulated irregular networks often used to represent the terrain. While a *TriangulatedSurface* is a composition of explicit *Triangles*, the subclass *TIN* is used to represent a triangulation in an implicit way by a set of control points, defining the nodes of the triangles. The triangulation may be reconstructed using standard triangulation methods (Delaunay triangulation). In addition, break lines and stop lines define characteristic contour characteristics of the terrain.

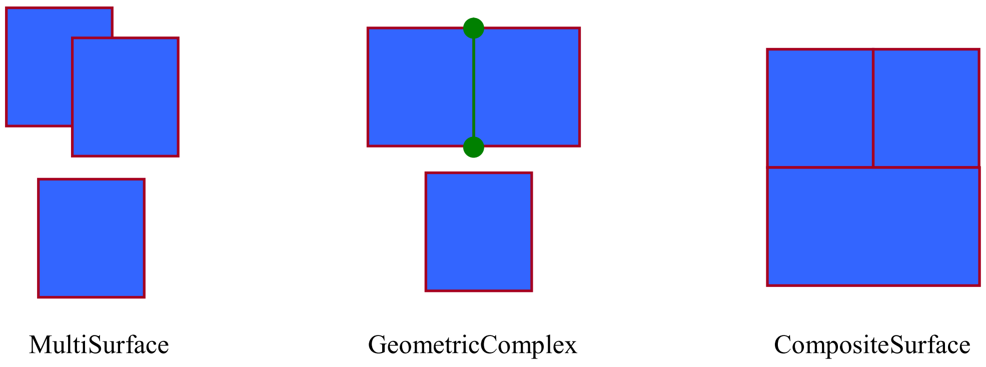


Fig. 10: Combined geometries.

The GML3 composite model realises a recursive aggregation schema for every primitive type of the corresponding dimension. This aggregation schema allows the definition of nested aggregations (hierarchy of components). For example, a building geometry (*CompositeSolid*) can be composed of the house geometry (*CompositeSolid*) and the garage geometry (*Solid*), while the house's geometry is further decomposed into the roof geometry (*Solid*) and the geometry of the house body (*Solid*).

CityGML provides the explicit modelling of topology, for example the sharing of geometry objects between features or other geometries. One part of space is represented only once by a geometry object and is referenced by all features or more complex geometries which are defined or bounded by this geometry object. Thus redundancy is avoided and explicit topological relations between parts are maintained. Basically, there are three cases. First, two features may be defined spatially by the same geometry. For example, if a path is both a transportation feature and a vegetation feature, the surface geometry defining the path is referenced both by the transportation object and by the vegetation object. Second, geometry may be shared between a feature and another geometry. A geometry defining a wall of a building may be referenced twice: by the solid geometry defining the geometry of the building, and by the wall feature. Third, two geometries may reference the same geometry, which is in the boundary of both. For example, a building and an adjacent garage may be represented by two solids. The surface describing the area where both solids touch may be represented only once and it is referenced by both solids. As it can be seen from Fig. 11, this requires partitioning of the respective surfaces. In general, Boundary Representation only considers visible surfaces. However, to make topological adjacency explicit and to allow the possibility of deletion of one part of a composed object without leaving holes in the remaining aggregate touching elements are included. Whereas touching is allowed, permeation of objects is not in order to avoid the multiple representation of the same space. However, the use of topology in CityGML is optional.

In order to implement topology, CityGML uses the XML concept of *XLinks* provided by GML. Each geometry object that should be shared by different geometric aggregates or different thematic features is assigned an unique identifier, which may be referenced by a GML geometry property using a *href* attribute. CityGML does not deploy the built-in topology package of GML3, which provides separate topology objects accompanying the geometry. This kind of topology is very complex and elaborate. Nevertheless, it lacks flexibility when data sets, which might include or neglect topology, should be covered by the same data model. The XLink topology is simple and flexible and nearly as powerful as the explicit GML3 topology model. However, a disadvantage of the XLink topology is that navigation between topologically connected objects can only be performed in one direction (from an aggregate to its components), not (immediately) bidirectional as it is the case for GML's built-in topology. An example for CityGML's topology representation is given in the dataset listed in chapter 11.4.1.

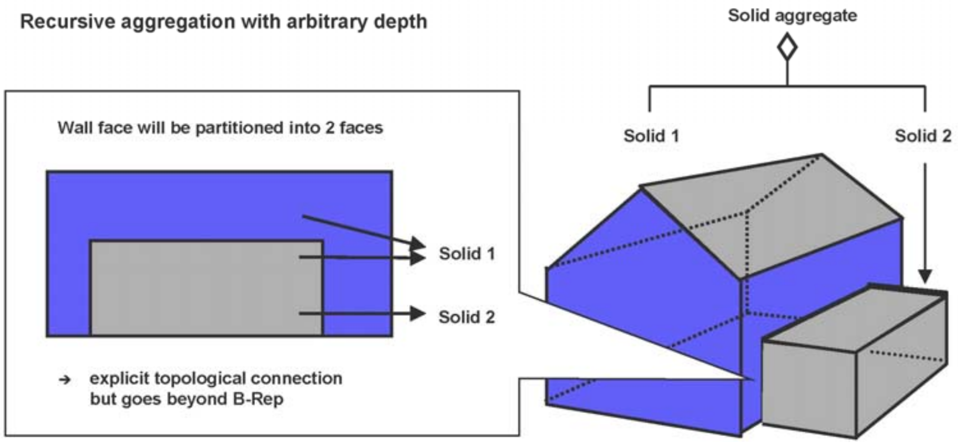

Recursive aggregation with arbitrary depth
Solid aggregate
Wall face will be partitioned into 2 faces
Solid 1
Solid 2
Solid 1
Solid 2
→ explicit topological connection but goes beyond B-Rep

Fig. 11: Recursive aggregation of objects and geometries in CityGML (graphic: IGG Uni Bonn).

The following excerpt of a CityGML example file defines a *gml:Polygon* with an id *wallSurface4711*, which is part of the geometry property *lod2Surface* of a building. Another building being adjacent to the first building references this polygon in its geometry property.

```
<building>
........
   <lod2Solid>
   ........
         <gml:surfaceMember>
            <gml:Polygon gml:id="wallSurface4711">
               <gml:exterior>
                  <gml:LinearRing>
                     <gml:pos srsDimension="3">32.0 31.0 2.5</gml:pos>
                     ........
                  </gml:LinearRing>
               </gml:exterior>
            </gml:Polygon>
         <gml:surfaceMember>
   ...........
   </lod2Solid>
..............
</building>
..............
<building>
...............
   <lod2Solid>
      <gml:surfaceMember xlink:href="#wallSurface4711"/>
   .................
   </lod2Solid>
</building>
```

7.2 Implicit geometries, prototypic objects, scene graph concepts

The concept of implicit geometries is an enhancement of the geometry model of GML3. It is used in CityGML's vegetation model, for city furniture and generic objects (see chapters 9.6, 9.7 and 9.10). The UML diagram is depicted in Fig. 12, the corresponding XML schema definition is provided in chapter 10.2.2.

An implicit geometry is a geometric object, where the shape is stored only once as a prototypical geometry, for example a tree or other vegetation object, a traffic light or a traffic sign. This prototypic geometry object is re-used or referenced many times, wherever the corresponding feature occurs in the 3D city model. Each occurrence is represented by a link to the prototypic shape geometry (in a local cartesian coordinate system), by a transformation matrix that is multiplied with each 3D coordinate of the prototype, and by an anchor point denoting the base point of the object in the world coordinate reference system. This reference point also defines the CRS to which the world coordinates belong after the application of the transformation. In order to determine the absolute coordinates of an implicit geometry, the anchor point coordinates have to be added to the matrix multiplication results. The transformation matrix accounts for the intended rotation, scaling, and local translation of the prototype. It is a 4x4 matrix that is multiplied with the prototype coordinates using homogeneous coordinates, i.e. (x,y,z,1). This way even a projection might be modelled by the transformation matrix.

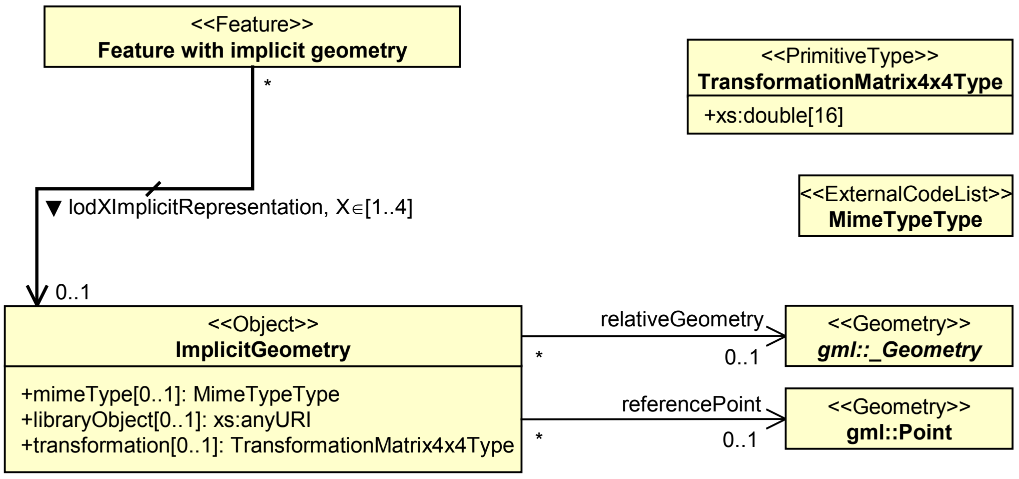

<<Feature>>
Feature with implicit geometry
*
<<PrimitiveType>>
TransformationMatrix4x4Type
+xs:double[16]
▼ lodXImplicitRepresentation, X∈[1..4]
<<ExternalCodeList>>
MimeTypeType
0..1
<<Object>>
ImplicitGeometry
+mimeType[0..1]: MimeTypeType
+libraryObject[0..1]: xs:anyURI
+transformation[0..1]: TransformationMatrix4x4Type
relativeGeometry
*
0..1
<<Geometry>>
gml::_Geometry
referencePoint
*
0..1
<<Geometry>>
gml::Point

Fig. 12: UML diagram of *ImplicitGeometries*.

The reason for using the concept of implicit geometries in CityGML is space efficiency. Since the shape of, for example, trees of the same species can be treated as identical, it would be inefficient to model the detailed geometry of each of the large number of trees explicitly. The concept of implicit geometries is similar to the well known concept of *primitive instancing* used for the representation of *scene graphs* in the field of computer graphics (Foley et al. 1995).

The term *Implicit geometry* refers to the principle that a geometry object with a complex shape can be simply represented by a base point and a transformation, implicitly unfolding the object's shape at a specific location in the world coordinate system.

The shape of an *ImplicitGeometry* can be represented in an external file with a proprietary format, e.g. a VRML file, a DXF file, or a 3D Studio MAX file. The reference to the implicit geometry can be specified by an URI pointing to a local or remote file, or even to an appropriate web service. Alternatively, the shape can be defined by a GML3 geometry object. This has the advantage that it can be stored or exchanged inline within the CityGML dataset. Typically, the shape of the geometry is defined in a local coordinate system where the origin lies within or near to the object's extent. If the shape is referenced by an URI, also the MIME type of the denoted object has to be specified (e.g. "model/vrml" for VRML models or "model/x3d+xml" for X3D models).

The implicit representation of 3D object geometry has some advantages compared to the explicit modelling, which represents the objects using absolute world coordinates. It is more space-efficient, and thus more extensive scenes can be stored or handled by a system. The visualisation is accelerated since 3D graphics cards support the scene graph concept. Furthermore, the usage of different shape versions of objects is facilitated, e.g. different seasons, since only the library objects have to be exchanged (see example in Fig. 40 on page 67).

ImplicitGeometryType

```
<xs:complexType name="ImplicitGeometryType">
  <xs:complexContent>
    <xs:extension base="gml:AbstractGMLType">
      <xs:sequence>
        <xs:element name="mimeType" type="MimeTypeType" minOccurs="0" />
        <xs:element name="transformationMatrix" type="TransformationMatrix4x4Type" minOccurs="0" />
        <xs:element name="libraryObject" type="xs:anyURI" minOccurs="0" />
        <xs:element name="relativeGMLGeometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="referencePoint" type="gml:PointPropertyType" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="ImplicitGeometry" type="ImplicitGeometryType" substitutionGroup="gml:_GML" />
```

An example for an implicit geometry is given by the following city furniture object (c.f. section 9.7), which is represented by a geometry in LOD 2:

```
<CityFurniture>
  <class>1000</class>   <!-- "traffic"; declared in external code list (CityFurnitureClassType) in annex A -->
  <function>1080</function>  <!-- "traffic light"; declared in external code list (CityFurnitureFunctionType) in annex A -->
  <lod2ImplicitRepresentation>
    <ImplicitGeometry>
      <mimeType>model/vrml</mimeType>
      <libraryObject>
        http://www.some-3d-library.com/3D/furnitures/TrafficLight434.wrl
      </libraryObject>
      <referencePoint>
        <gml:Point srsName="urn:ogc:def:crs,crs:EPSG:6.12:31467,crs:EPSG:6.12:5783">
          <gml:pos srsDimension="3">5793898.77 3603845.54 44.8</gml:pos>
        </gml:Point>
      </referencePoint>
    </ImplicitGeometry>
  </lod2ImplicitRepresentation>
</CityFurniture>
```

The shape of the geometry of the traffic light (city furniture with class “1000” and function “1080” according to the external code lists proposed in annex A) is defined by a VRML file which is specified by a URL. This library object, which is defined in a local coordinate system, is transformed to its actual location by adding the coordinates of the reference point.

The following clip of a CityGML file provides a more complex example for an implicit geometry:

```
<CityFurniture>
  <class>1000</class>   <!-- "traffic"; declared in external code list (CityFurnitureClassType) in annex A -->
  <function>1080</function>  <!-- "traffic light"; declared in external code list (CityFurnitureFunctionType) in annex A -->
  <lod2ImplicitRepresentation>
    <ImplicitGeometry>
      <mimeType>model/vrml</mimeType>
      <transformationMatrix>
        0.866025    -0.5    0    0.7
        0.5    0.866025    0    0.8
        0    0    1    0
        0    0    0    1
      </transformationMatrix>
      <libraryObject>
        http://www.some-3d-library.com/3D/furnitures/TrafficLight434.wrl
      </libraryObject>
      <referencePoint>
        <gml:Point srsName="urn:ogc:def:crs,crs:EPSG:6.12:31467,crs:EPSG:6.12:5783">
          <gml:pos srsDimension="3">5793898.77 3603845.54 44.8</gml:pos>
        </gml:Point>
      </referencePoint>
    </ImplicitGeometry>
  </lod2ImplicitRepresentation>
</CityFurniture>
```

In addition to the first example, a transformation matrix is specified. It is a homogeneous matrix, serialized in a row major fashion, i.e. the first four entries in the list denote the first row of the matrix, etc. The matrix combines a translation by the vector (0.7, 0.8, 0) – the origin of the local reference system is not the center of the object – and a rotation around the z-axis by 30 degrees (*cos(30) = 0.866025* and *sin(30) = 0.5*). This rotation is necessary to align the traffic light with respect to a road. The actual position of the traffic light is computed as follows:

1. each point of the VRML file (with homogeneous coordinates) is multiplied by the transformation matrix;
2. for each resulting point, the reference point $(5793898.77, 3603845.54, 44.8, 1)^T$ is added, yielding the actual geometry of the city furniture.

External code lists

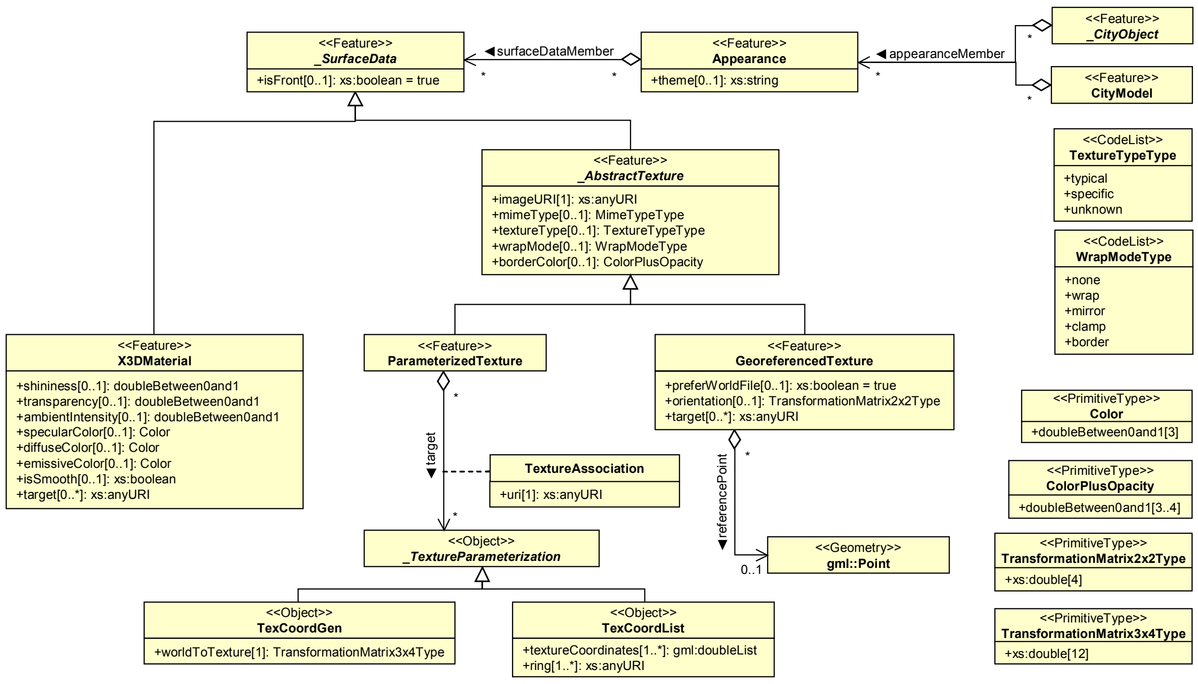
The ImplicitGeometry model introduces the following types, whose valid values are explicitly enumerated in an external code list (cf. chapter 6.5 and chapter 11.1):

- MimeTypeType

8 Appearance model

In addition to spatial properties, CityGML features have *appearances* – observable properties of the feature's surface. Appearances are not limited to visual data but represent arbitrary categories called *themes* such as infrared radiation, noise pollution, or earthquake-induced structural stress. Each LOD can have an individual appearance for a specific theme. An appearance is composed of data for each surface object, i.e. *surface data*. A single surface object may have surface data for multiple themes. Similarly, surface data can be shared by multiple surface objects (e.g. road paving). Finally, surface data values can either be constant across a surface or depend on the exact location within the surface.

In CityGML's appearance model, themes are represented by an identifier only. The appearance of a city model for a given theme is defined by a set of *Appearance* objects referencing this theme. Thus, the *Appearance* objects belonging to the same theme compose a virtual group. They may be included in different places within a CityGML dataset. Furthermore a single CityGML dataset may contain several themes. An *Appearance* object collects surface data relevant for a specific theme either for individual features or the whole city model in any LOD. Surface data is represented by objects of class *_SurfaceData* and its descendents with each covering the whole area of a surface geometry. The relation between surface data and surface objects is expressed by an *URI* (*Uniform Resource Identifier*) link from a *_SurfaceData* object to an object of type *gml:AbstractSurfaceType* or type *gml:MultiSurface*. The UML diagram in Fig. 13 illustrates CityGML's appearance model.



<<Feature>> _SurfaceData
+isFront[0..1]: xs:boolean = true
◀surfaceDataMember
*
*
<<Feature>> Appearance
+theme[0..1]: xs:string
◀appearanceMember
*
*
<<Feature>> _CityObject
*
<<Feature>> CityModel
<<CodeList>> TextureTypeType
+typical
+specific
+unknown
<<CodeList>> WrapModeType
+none
+wrap
+mirror
+clamp
+border
<<Feature>> _AbstractTexture
+imageURI[1]: xs:anyURI
+mimeType[0..1]: MimeTypeType
+textureType[0..1]: TextureTypeType
+wrapMode[0..1]: WrapModeType
+borderColor[0..1]: ColorPlusOpacity
<<Feature>> X3DMaterial
+shininess[0..1]: doubleBetween0and1
+transparency[0..1]: doubleBetween0and1
+ambientIntensity[0..1]: doubleBetween0and1
+specularColor[0..1]: Color
+diffuseColor[0..1]: Color
+emissiveColor[0..1]: Color
+isSmooth[0..1]: xs:boolean
+target[0..*]: xs:anyURI
<<Feature>> ParameterizedTexture
*
▼target
TextureAssociation
+uri[1]: xs:anyURI
*
<<Feature>> GeoreferencedTexture
+preferWorldFile[0..1]: xs:boolean = true
+orientation[0..1]: TransformationMatrix2x2Type
+target[0..*]: xs:anyURI
*
▼referencePoint
0..1
<<Geometry>> gml::Point
<<PrimitiveType>> Color
+doubleBetween0and1[3]
<<PrimitiveType>> ColorPlusOpacity
+doubleBetween0and1[3..4]
<<PrimitiveType>> TransformationMatrix2x2Type
+xs:double[4]
<<PrimitiveType>> TransformationMatrix3x4Type
+xs:double[12]
<<Object>> _TextureParameterization
<<Object>> TexCoordGen
+worldToTexture[1]: TransformationMatrix3x4Type
<<Object>> TexCoordList
+textureCoordinates[1..*]: gml:doubleList
+ring[1..*]: xs:anyURI

Fig. 13: UML diagram of CityGML's appearance model.

A constant surface property is modelled as material. A surface property, which depends on the location within the surface, is modelled as texture. Each surface object can have both a material and a texture per theme and side. This allows for providing both a constant approximation and a complex measurement of a surface's property simultaneously. An application is responsible for choosing the appropriate property representation for its task (e.g. analysis or rendering). A specific mixing is not defined since this is beyond the scope of CityGML. If a surface object is to receive multiple textures or materials, each texture or material requires a separate theme. The mixing of themes or their usage is not defined within CityGML and left to the application.

8.1 *Relation between appearances, features and geometry*

Despite the close relation between surface data and surface, surface data is stored separately in the feature to preserve the original GML geometry model. Instead of surface data being an attribute of the respective target surface geometry object, each surface data object maintains a set of URIs specifying the *gml:id*s of the target surface objects (of type *gml:AbstractSurfaceType* or *gml:MultiSurface*). In case of a composite or aggregate target surface, the surface data object is assigned to all contained surfaces. Other target types such as features, solids, or *gml:AbstractSurfacePatchType* (which includes *gml:Triangle*) are invalid, even though the XML schema language cannot formally express constrains on URI target types. For the exact mapping function of surface data values to a surface patch refer to the respective surface data type description.

The limitation of valid target types to *gml:AbstractSurfaceType* and *gml:MultiSurface* excluding *gml:Abstract-SurfacePatchType* is based on the GML geometry model and its use in CityGML. In general, GML surfaces are represented using subclasses of *gml:AbstractSurfaceType*. Such surfaces are required to be continuous. A *gml:MultiSurface* does not need to fulfill this requirement and consequently is no *gml:AbstractSurfaceType* (cf. 7.1). Since captured real-world surfaces often cannot be guaranteed to be continuous, CityGML allows for *gml:MultiSurface* to represent a feature's boundary in various places as an alternative to a continuous surface. To treat such surfaces similarly to a *gml:CompositeSurface*, surface data objects are allowed to link to *gml:Multi-Surface* objects. The exclusion of *gml:AbstractSurfacePatchType* as valid target type results from its specifica-tion as a root class without *gml:AbstractGMLType* being its parent class. Thus, a *gml:AbstractSurfacePatchType* (which includes *gml:Triangle* and *gml:Rectangle*) cannot receive a *gml:id* and cannot be referenced.

Each surface object can have per theme at most one active front-facing material, one active back-facing material, one active front-facing texture, and one active back-facing texture. If multiple surface data objects of the same category and theme are assigned to a surface object, one is chosen to become active. Multiple indirect assign-ments due to nested surface definitions are resolved by overwriting, e.g. the front-facing material of a *gml:Polygon* becomes active by overwriting the front-facing material of the parental *gml:CompositeSurface*. Multiple direct assignments, i.e. a surface object's *gml:id* is referenced multiple times within a theme, are re-solved implementation-dependently by choosing exactly one of the conflicting surface data objects. Thus, multiple direct assignments within a theme should be avoided.

Each CityObject feature can store surface data. Thus, surface data is arranged in the feature hierarchy of a CityGML dataset. Surface data then links to its target surface using URIs. Even though the linking mechanism permits arbitrary links across the feature hierarchy to another feature's surface, it is recommended to follow the principle of locality: Surface data should be stored such that the linked surfaces only belong to the containing CityObject feature and its children. "Global" surface data should be stored with the city model. Adhering to the locality principle also ensures that CityObjects retrieved from a WFS will contain the respective appearance information.

8.2 Appearance and SurfaceData

The feature class *Appearance* defines a container for surface data objects. It provides the *theme* that all contained surface data objects are related to. All appearance objects with the same theme in a CityGML file are considered a group. Surface data objects are stored in the *surfaceDataMember* property. They can be used in multiple themes simultaneously as remote properties.

The feature class *_SurfaceData* is the base class for materials and textures. Its only element is the boolean flag *isFront*, which determines the side a surface data object applies to.

Please note, that all classes of the appearance model support CityGML's ADE mechanism (cf. chapters 6.11 and 9.11). The hooks for application specific extensions are realized by the elements "*_GenericApplicationPropertyOf…*".

AppearanceType, AppearancePropertyType

```
<xs:complexType name="AppearanceType">
  <xs:complexContent>
    <xs:extension base="gml:AbstractFeatureType">
      <xs:sequence>
        <xs:element name="theme" type="xs:string" minOccurs="0"/>
        <xs:element name="surfaceDataMember" type="SurfaceDataPropertyType" minOccurs="0" maxOccurs="unbounded"/>
        <xs:element ref="_GenericApplicationPropertyOfAppearance" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
```

```
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="appearanceMember" type="AppearancePropertyType" substitutionGroup="gml:featureMember"/>
<!-- ======================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAppearance" type="xs:anyType" abstract="true"/>
<!-- ====================================================================================== -->
<xs:complexType name="AppearancePropertyType">
   <xs:complexContent>
      <xs:extension base="gml:FeaturePropertyType">
         <xs:sequence minOccurs="0">
            <xs:element name="Appearance" type="AppearanceType"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
```

AbstractSurfaceDataType, _SurfaceData, SurfaceDataAssociationType

```
<xs:complexType name="AbstractSurfaceDataType">
   <xs:complexContent>
      <xs:extension base="gml:AbstractFeatureType">
         <xs:sequence>
            <xs:element name="isFront" type="xs:boolean" default="true" minOccurs="0"/>
            <xs:element ref="_GenericApplicationPropertyOfAbstractSurfaceData" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="_SurfaceData" type="AbstractSurfaceDataType" abstract="true" substitutionGroup="gml:_Feature"/>
<!-- ======================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAbstractSurfaceData" type="xs:anyType" abstract="true"/>
<!-- ====================================================================================== -->
<xs:complexType name="SurfaceDataPropertyType">
   <xs:sequence minOccurs="0">
      <xs:element ref="_SurfaceData" minOccurs="0"/>
   </xs:sequence>
   <xs:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xs:complexType>
```

8.3 Material

Materials define light reflection properties being constant for a whole surface object. The definition of the class *X3DMaterial* is adopted from the X3D and COLLADA specification (cf. X3D, COLLADA specification). *diffuseColor* defines the color of diffusely reflected light. *specularColor* defines the color of a directed reflection. *emissiveColor* is the color of light generated by the surface. All colors use RGB values with red, green, and blue between 0 and 1. Transparency is defined separately using the *transparency* element where 0 stands for fully opaque and 1 for fully transparent. *ambientIntensity* defines the minimum percentage of *diffuseColor* that is visible regardless of light sources. *shininess* controls the sharpness of the specular highlight. 0 produces a soft glow while 1 results in a sharp highlight. *isSmooth* gives a hint for normal interpolation. If this boolean flag is set to true, vertex normals should be used for shading (Gouraud shading). Otherwise, normals should be constant for a surface patch (flat shading).

Target surfaces are specified using *target* elements. Each element contains the URI of one target surface object (of type *gml:AbstractSurfaceType* or *gml:MultiSurface*).

X3DMaterialType, X3DMaterial

```
<xs:complexType name="X3DMaterialType">
   <xs:complexContent>
      <xs:extension base="AbstractSurfaceDataType">
         <xs:sequence>
            <xs:element name="ambientIntensity" type="doubleBetween0and1" minOccurs="0"/>
            <xs:element name="diffuseColor" type="Color" minOccurs="0"/>
            <xs:element name="emissiveColor" type="Color" minOccurs="0"/>
            <xs:element name="specularColor" type="Color" minOccurs="0"/>
            <xs:element name="shininess" type="doubleBetween0and1" minOccurs="0"/>
            <xs:element name="transparency" type="doubleBetween0and1" minOccurs="0"/>
            <xs:element name="isSmooth" type="xs:boolean" minOccurs="0"/>
            <xs:element name="target" type="xs:anyURI" minOccurs="0" maxOccurs="unbounded"/>
            <xs:element ref="_GenericApplicationPropertyOfX3DMaterial" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="X3DMaterial" type="X3DMaterialType" substitutionGroup="_SurfaceData"/>
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfX3DMaterial" type="xs:anyType" abstract="true"/>
```

8.4 *Texture and texture mapping*

The base class for textures is *_AbstractTexture*. Textures in CityGML are always raster-based 2D textures. The raster image is specified by *imageURI* using a URI and can be an arbitrary image data resource, even a preformatted request for a web service. The image data format can be defined using standard MIME types in the *mimeType* element.

Textures can be qualified by the attribute *textureType*. The *textureType* differentiates between textures, which are specific for a certain object (*specific*) and prototypic textures being typical for that object surface (*typical)*. Textures may also be classified as *unknown*.

The specification of texture wrapping is adopted from the COLLADA standard. Texture wrapping is required when accessing a texture outside the underlying image raster. *wrapMode* can have one of five values (Fig. 14 illustrates the effect of these wrap modes):

1. *none* – the resulting color is fully transparent
2. *wrap* – the texture is repeated
3. *mirror* – the texture is repeated and mirrored
4. *clamp* – the texture is clamped to its edges
5. *border* – the resulting color is specified by the *borderColor* element (RGBA)

In wrap mode *mirror*, the texture image is repeated both in horizontal and in vertical direction to fill the texture space similar to wrap mode *wrap*. Unlike *wrap*, each repetition results from flipping the previous texture part along the repetition direction. This behaviour removes the edge correspondence constraint for wrapped textures and always results in a seamless texture.

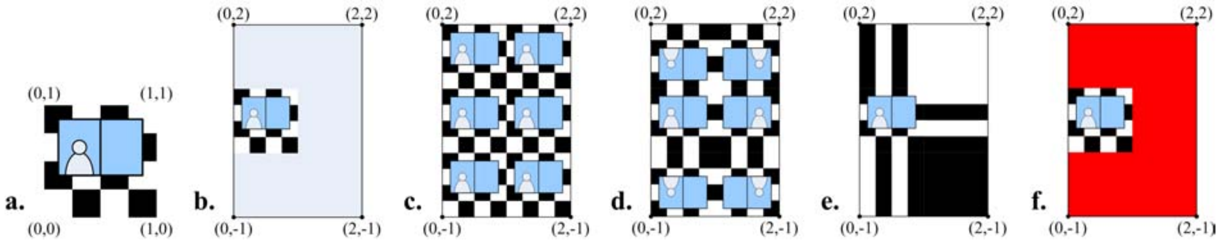


Fig. 14: A texture (a) applied to a facade using different wrap modes: (b) none, (c) wrap, (d) mirror, (e) clamp and (f) border. The border color is red. The numbers denote texture coordinates (image: Hasso-Plattner-Institute).

AbstractTextureType, _Texture, WrapModeType, TextureTypeType

```
<xs:complexType name="AbstractTextureType">
   <xs:complexContent>
      <xs:extension base="AbstractSurfaceDataType">
         <xs:sequence>
            <xs:element name="imageURI" type="xs:anyURI"/>
            <xs:element name="mimeType" type="MimeTypeType" minOccurs="0"/>
            <xs:element name="textureType" type="TextureTypeType" minOccurs="0"/>
            <xs:element name="wrapMode" type="WrapModeType" minOccurs="0"/>
            <xs:element name="borderColor" type="ColorPlusOpacity" minOccurs="0"/>
            <xs:element ref="_GenericApplicationPropertyOfAbstractTexture" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
```

```
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_Texture" type="AbstractTextureType" abstract="true" substitutionGroup="_SurfaceData"/>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAbstractTexture" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:simpleType name="WrapModeType">
  <xs:restriction base="xs:string">
    <xs:enumeration value="none"/>
    <xs:enumeration value="wrap"/>
    <xs:enumeration value="mirror"/>
    <xs:enumeration value="clamp"/>
    <xs:enumeration value="border"/>
  </xs:restriction>
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:simpleType name="TextureTypeType">
  <xs:restriction base="xs:string">
    <xs:enumeration value="specific" />
    <xs:enumeration value="typical" />
    <xs:enumeration value="unknown" />
  </xs:restriction>
</xs:simpleType>
```

_AbstractTexture is further specialised according to the texture parameterisation, i.e. the mapping function from a location on the surface to a location in the texture image. CityGML uses the notion of texture space, where the texture image always occupies the region $[0,1]^2$ regardless of the actual image size or aspect ratio. The lower left image corner is located at the origin. The mapping function must be known for each surface object to receive texture.

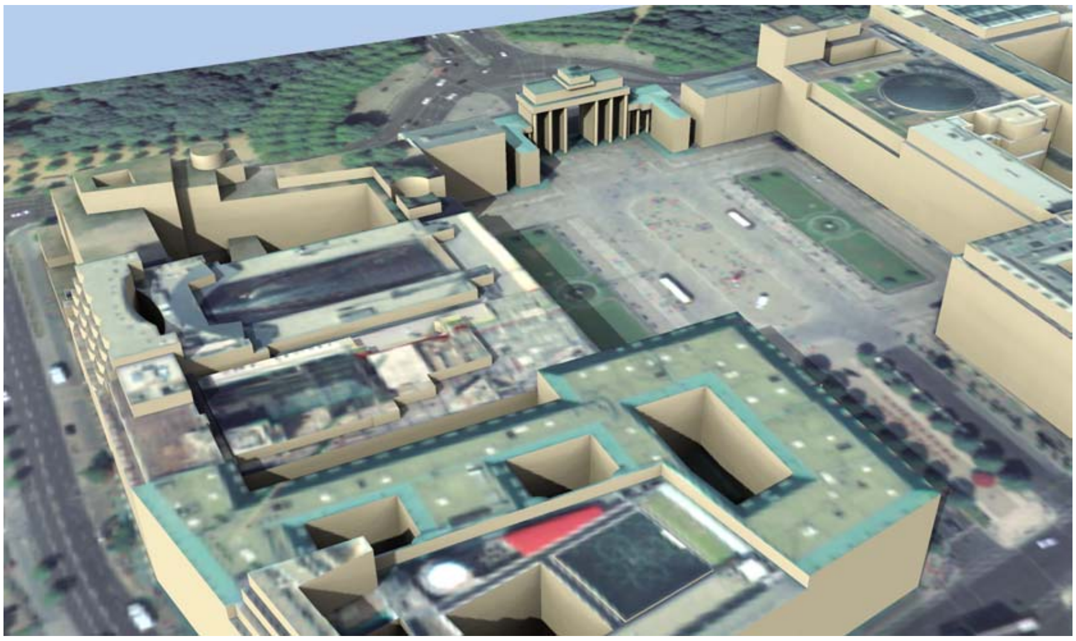


Fig. 15: A georeferenced texture applied to ground and roof surfaces (source: Senate of Berlin, Hasso-Plattner-Institute).

The class *GeoreferencedTexture* describes a texture that uses a planimetric projection. Consequently, it does not make sense to texture vertical surfaces using a *GeoreferencedTexture*. Such a texture has a unique mapping function which is usually provided with the image file (e.g. georeferenced TIFF) or as a separate ESRI world file. The search order for an external georeference is determined by the boolean flag *preferWorldFile*. If this flag is set to true (its default value), a world file is looked for first and only if it is not found the georeference from the image data is used. If *preferWorldFile* is false, the world file is used only if no georeference from the image data is available.

Alternatively, CityGML allows for inline specification of a georeference similar to a world file. This internal georeference specification always takes precedence over any external georeference. *referencePoint* defines the location of the lower left image corner in world space. Since *GeoreferencedTexture* uses a planimetric projection, *referencePoint* is two-dimensional. *orientation* defines the rotation and scaling of the image in form of a

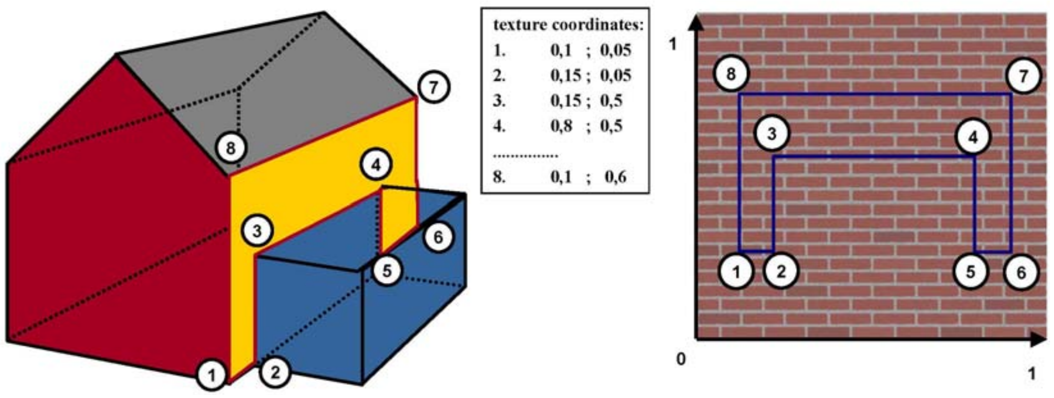
2x2 matrix (a list of 4 doubles in row-major order). The CRS of this transformation is identical to the *referencePoint*'s CRS. A planimetric point $(x,y)^T$ is transformed to a point $(s,t)^T$ in texture space using the formula $(s,t)^T = M \cdot (x,y)^T + P_R$ with M denoting *orientation* and P_R denoting *referencePoint*.

If neither an internal or an external georeference is given the *GeoreferencedTexture* is invalid. Each target surface object is specified by an URI in a *target* element. All target surface objects share the mapping function defined by the georeference. No other mapping function is allowed. Please note, that the *gml:boundedBy* property inherited from *gml:AbstractFeatureType* could be set to the bounding box of valid image data to allow for spatial queries. Fig. 15 shows a georeferenced texture applied to the ground and all roof surfaces.

GeoreferencedTextureType, GeoreferencedTexture

```
<xs:complexType name="GeoreferencedTextureType">
  <xs:complexContent>
    <xs:extension base="AbstractTextureType">
      <xs:sequence>
        <xs:element name="preferWorldFile" type="xs:boolean" default="true" minOccurs="0"/>
        <xs:element name="referencePoint" type="gml:PointPropertyType" minOccurs="0"/>
        <xs:element name="orientation" type="TransformationMatrix2x2Type" minOccurs="0"/>
        <xs:element name="target" type="xs:anyURI" minOccurs="0" maxOccurs="unbounded"/>
        <xs:element ref="_GenericApplicationPropertyOfGeoreferencedTexture" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="GeoreferencedTexture" type="GeoreferencedTextureType" substitutionGroup="_Texture"/>
<!-- ====================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfGeoreferencedTexture" type="xs:anyType" abstract="true"/>
<!-- ====================================================================================== -->
<xs:simpleType name="TransformationMatrix2x2Type">
  <xs:restriction base="gml:doubleList">
    <xs:minLength value="4"/>
    <xs:maxLength value="4"/>
  </xs:restriction>
</xs:simpleType>
```

The class *ParameterizedTexture* describes a texture with target-dependent mapping function. The mapping is defined by subclasses of class *_TextureParameterization* as a property of the link to the target surface object. Each target surface object is specified as URI in the *uri* attribute of a separate *target* element. Since *target* implements *gml:AssociationType*, it allows referencing to a remote *_TextureParameterization* object (using the *xlink:href* attribute), e.g. for sharing a mapping function between targets or textures in different themes. The mapping function can either use the concept of texture coordinates (through class *TexCoordList*) or a transformation matrix from world space to texture space (through class *TexCoordGen*).



texture coordinates:

1.	0,1 ;	0,05
2.	0,15 ;	0,05
3.	0,15 ;	0,5
4.	0,8 ;	0,5
....		
8.	0,1 ;	0,6

Fig. 16: Positioning of textures using texture coordinates (image: IGG Uni Bonn).

Texture coordinates are applicable only to polygonal surfaces, whose boundaries are described by *gml:LinearRing* (e.g. *gml:Triangle*, *gml:Polygon*, or a *gml:MultiSurface* consisting of *gml:Polygon*s). They define an explicit mapping of a surface's boundary points to points in texture space, i.e. each boundary point must receive a corresponding coordinate pair in texture space (for the notion of coordinates, refer to ISO 19111). These coordinates are not restricted to the [0,1] interval. Texture coordinates for interior surface points are planarly interpolated from the boundary's texture coordinates. Fig. 16 shows an example.

Texture coordinates for a target surface object are specified using class *TexCoordList* as a texture parameterization object in the texture's *target* property. Each *gml:LinearRing* composing the boundary of the target surface object (which also might be a *gml:CompositeSurface*, *gml:MultiSurface*, or *gml:TriangularSurface*) requires its own set of texture coordinates. A set of texture coordinates is specified using the *textureCoordinates* element of class *TexCoordList*. Thus, a *TexCoordList* contains as many *textureCoordinate* elements as the target surface object contains *gml:LinearRing*s. *textureCoordinate*'s mandatory attribute *ring* provides the *gml:id* of the respective ring. The content is an ordered list of double values where each two values define a texture coordinate pair. The list contains one pair per ring point with the pairs' order corresponding to the ring points' order.

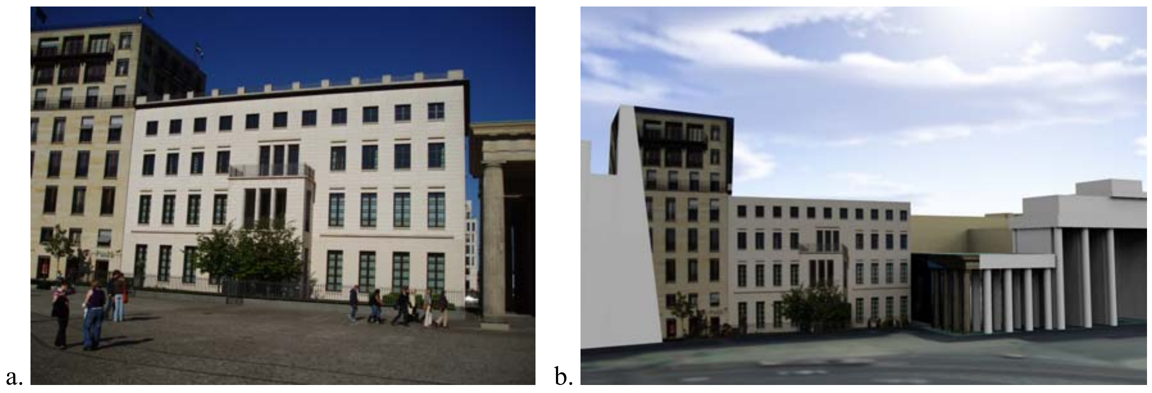


Fig. 17: Projecting a photograph (a) onto multiple facades (b) using the *worldToTexture* transformation. The photograph does not cover the left facade completely. Thus, the texture appears to be clipped. Texture wrapping is set to "*none*" (source: Senate of Berlin, Hasso-Plattner-Institute).

Alternatively, the mapping function can comprise a 3x4 transformation matrix specified by class *TexCoordGen*. The transformation matrix, specified by the *worldToTexture* element, defines a linear transformation from a spatial location (in homogeneous coordinates) to texture space. The use of homogeneous coordinates facilitates perspective projections as transformation, e.g. for projecting a photograph into a city model (cf. Fig. 17). Texture coordinates $(s,t)^T$ are calculated from a space location $(x,y,z)^T$ as $(s,t)^T = (s'/q', t'/q')^T$ with $(s',t',q')^T = M \cdot (x,y,z,1)^T$. *M* denotes the 3x4 transformation matrix. Compared to a general 4x4 transformation, the resulting *z* component is ignored. Thus, the respective matrix row is omitted. Additionally, the *worldToTexture* element uses the *gml:SRSReferenceGroup* attributes to define its CRS. A location in world space has to be first transformed into this CRS before the transformation matrix can be applied.

The following construction results in a *worldToTexture* transformation that mimics the process of taking a photograph by projecting a location in world space (in the city model) to a location in texture space:

$$M = \underbrace{\begin{pmatrix} 0.5 & 0 & 0.5 \\ 0 & 0.5 & 0.5 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Adjustment to texture space}} \cdot \underbrace{\begin{pmatrix} 2f/w & 0 & 0 & 0 \\ 0 & 2f/h & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}}_{\text{Perspective projection}} \cdot \underbrace{\begin{pmatrix} r_x & r_y & r_z & 0 \\ u_x & u_y & u_z & 0 \\ d_x & d_y & d_z & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Camera orientation}} \cdot \underbrace{\begin{pmatrix} 1 & 0 & 0 & -P_x \\ 0 & 1 & 0 & -P_y \\ 0 & 0 & 1 & -P_z \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Camera location}}$$

In this formula, f denotes the focal length; w and h represent the image sensor's physical dimensions; $\vec{r}$, $\vec{u}$, and $\vec{d}$ define the camera's frame of reference as right, up and directional unit vectors expressed in world coordinates; and *P* stands for the camera's location in world space. Fig. 18 sketches this setting.

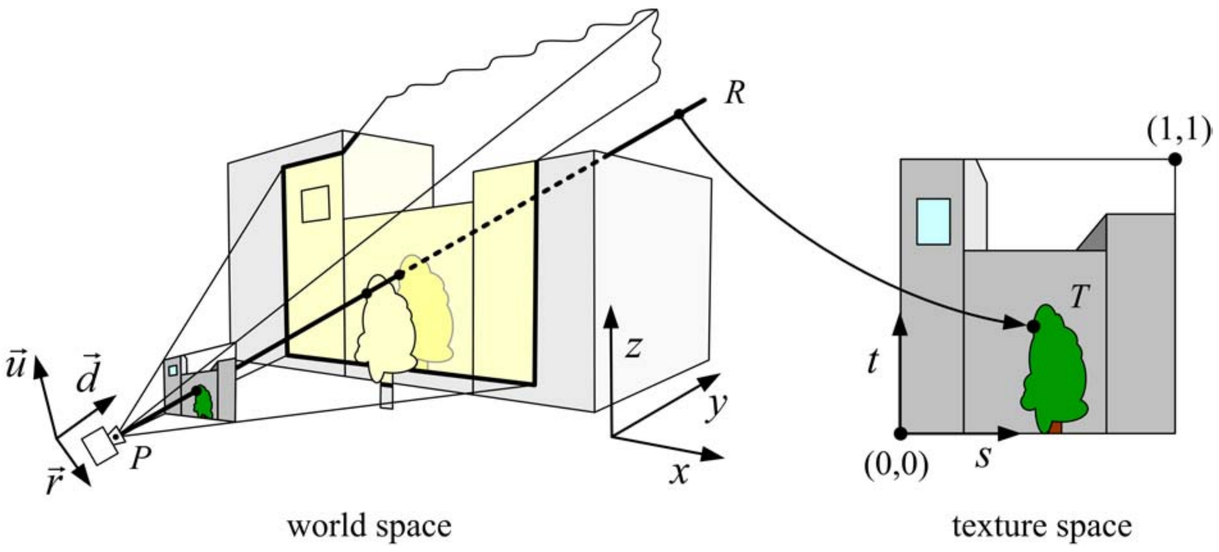


Fig. 18: Projective texture mapping. All points on a ray *R* starting from the projection center *c* are mapped to the same point *T* in texture space (image: Hasso-Plattner-Institute, IGG TU Berlin).

Alternatively, if the 3x4 camera matrix M_P is known (e.g. through a calibration and registration process), it can easily be adopted for use in *worldToTexture*. M_P is derived from intrinsic and extrinsic camera parameters (interior and exterior orientation) and transforms a location in world space to a pixel location in the image. Assuming the upper left image corner has pixel coordinates (0,0), the complete transformation to texture space coordinates can be written as (width$_{\text{image}}$ and height$_{\text{image}}$ denote the image size in pixels):

$$M = \begin{pmatrix} 1/width_{image} & 0 & 0 \\ 0 & -1/height_{image} & 1 \\ 0 & 0 & 1 \end{pmatrix} \cdot M_P$$

Please note, that *worldToTexture* cannot compensate for radial or other non-linear distortions introduced by a real camera lens.

Another use of *worldToTexture* is texturing a facade with complex geometry without specifying texture coordinates for each *gml:LinearRing*. Instead, only the facade's aggregated surface becomes the texture target using a *TexCoordGen* as parameterization. Then, *worldToTexture* effectively encodes an orthographic projection of world space into texture space. For the special case of a vertical facade this transformation is given by:

$$M = \underbrace{\begin{pmatrix} 1/width_f & 0 & 0 & 0 \\ 0 & 1/height_f & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Scaling to texture space}} \cdot \underbrace{\begin{pmatrix} -n_y & n_x & 0 & 0 \\ 0 & 0 & 1 & 0 \\ n_x & n_y & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Facade orientation}} \cdot \underbrace{\begin{pmatrix} 1 & 0 & 0 & -F_x \\ 0 & 1 & 0 & -F_y \\ 0 & 0 & 1 & -F_z \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Facade location}}$$

This equation assumes $\vec{n}$ denoting the facade's overall normal vector (normalized, pointing outward, and being parallel to the ground), *F* denoting the facade's lower left point, and *width$_f$* and *height$_f$* specifying the facade's dimensions in world units. For the general case of an arbitrary normal vector the facade orientation matrix assumes a form similar to the camera orientation matrix:

$$M = \begin{pmatrix} 1/width_f & 0 & 0 & 0 \\ 0 & 1/height_f & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} r_x & r_y & r_z & 0 \\ u_x & u_y & u_z & 0 \\ n_x & n_y & n_z & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 & -F_x \\ 0 & 1 & 0 & -F_y \\ 0 & 0 & 1 & -F_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \text{with} \quad \begin{array}{l} \vec{r} = \dfrac{(0 \;\; 0 \;\; 1)^T \times \vec{n}}{\left\|(0 \;\; 0 \;\; 1)^T \times \vec{n}\right\|} \\ \vec{u} = \vec{n} \times \vec{r} \end{array}$$

ParameterizedTextureType, ParameterizedTexture, TextureAssociationType

```
<xs:complexType name="ParameterizedTextureType">
  <xs:complexContent>
    <xs:extension base="AbstractTextureType">
      <xs:sequence>
```

```
            <xs:element name="target" type="TextureAssociationType" minOccurs="0" maxOccurs="unbounded"/>
            <xs:element ref="_GenericApplicationPropertyOfParameterizedTexture" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="ParameterizedTexture" type="ParameterizedTextureType" substitutionGroup="_Texture"/>
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfParameterizedTexture" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:complexType name="TextureAssociationType">
   <xs:sequence minOccurs="0">
      <xs:element ref="_TextureParameterization"/>
   </xs:sequence>
   <xs:attribute name="uri" type="xs:anyURI" use="required"/>
   <xs:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xs:complexType>
```

TextureParameterizationType, TexCoordListType, TexCoordGenType

```
<xs:complexType name="TextureParameterizationType" abstract="true">
   <xs:complexContent>
      <xs:extension base="gml:AbstractGMLType">
         <xs:sequence>
            <xs:element ref="_GenericApplicationPropertyOfTextureParameterization" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_TextureParameterization" type="TextureParameterizationType" abstract="true" substitutionGroup="gml:_Object"/>
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfTextureParameterization" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:complexType name="TexCoordListType">
   <xs:complexContent>
      <xs:extension base="TextureParameterizationType ">
         <xs:sequence>
            <xs:element name="textureCoordinates" maxOccurs="unbounded">
               <xs:complexType>
                  <xs:simpleContent>
                     <xs:extension base="gml:doubleList">
                        <xs:attribute name="ring" type="xs:anyURI" use="required"/>
                     </xs:extension>
                  </xs:simpleContent>
               </xs:complexType>
            </xs:element>
            <xs:element ref="_GenericApplicationPropertyOfTexCoordList" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="TexCoordList" type=" TexCoordListType" substitutionGroup="_TextureParameterization "/>
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfTexCoordList" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:complexType name="TexCoordGenType">
   <xs:complexContent>
      <xs:extension base="TextureParameterizationType ">
         <xs:sequence>
            <xs:element name="worldToTexture">
               <xs:complexType>
                  <xs:simpleContent>
                     <xs:extension base="TransformationMatrix3x4Type">
                        <xs:attributeGroup ref="gml:SRSReferenceGroup"/>
                     </xs:extension>
                  </xs:simpleContent>
               </xs:complexType>
            </xs:element>
            <xs:element ref="_GenericApplicationPropertyOfTexCoordGen" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
```

```
</xs:complexType>
<!-- ================================================================================ -->
<xs:element name="TexCoordGen" type=" TexCoordGenType" substitutionGroup="_TextureParameterization "/>
<!-- ================================================================================ -->
<xs:element name="_GenericApplicationPropertyOfTexCoordGen" type="xs:anyType" abstract="true"/>
<!-- ================================================================================ -->
<xs:simpleType name="TransformationMatrix3x4Type">
  <xs:restriction base="gml:doubleList">
    <xs:minLength value="12"/>
    <xs:maxLength value="12"/>
  </xs:restriction>
</xs:simpleType>
```

8.5 Related concepts

The notion of appearance clearly relates to the generic coverage approach (cf. ISO 19123 and OGC Abstract specification, Topic 6). Surface data can be described as discrete or continuous coverage over a surface as two-dimensional domain with a specific mapping function. Such an implementation requires the extension of GML coverages (as of version 3.1) by suitable mapping functions and specialisation for valid domain and range sets. For reasons of simplicity and comprehensibility both in implementation and usage, CityGML does not follow this approach, but relies on textures and materials as well-known surface property descriptions from the field of computer graphics (cf. X3D, COLLADA specification, Foley et al.). Textures and materials store data as color using an appropriate mapping. If such a mapping is impractical, data storage can be customised using ADEs. A review of coverages for appearance modelling is considered for CityGML beyond version 1.0.0.

Appearance is also related to portrayal. Portrayal describes the composition and symbolisation of a digital model's image, i.e. presentation, while appearance encodes observations of the real object's surface, i.e. data. Even though being based on graphical terms such as textures and materials, surface data is not limited to being input for portrayal, but similarly serves as input or output for analyses on a feature's surface. Consequently, CityGML does not define mixing or composition of themes for portrayal purposes. Portrayal is left to viewer applications or styling specification languages such as OGC Styled Layer Descriptors (SLD) or OGC Symbology Encoding (SE).

8.6 Material model in previous CityGML versions [deprecated]

Since GML3 has no built-in concept for the representation of surface materials, previous versions of CityGML extend the GML3 geometry model by the new class *TexturedSurface*, which allows for assigning appearance properties (colors, shininess, transparency) and textures to 3D surfaces. The definition of the appearance properties is adopted from the X3D specification.

This approach for appearance modelling has been deprecated due to inherent limitations and is expected to be removed in future. Appearances information contained in a *TexturedSurface* can be losslessly converted to the new appearance model.

Each surface or composite surface can be specialized to a *TexturedSurface*, which can be assigned *Materials* (*colors, shininess, transparency*) or *SimpleTextures*. Fig. 19 depicts the UML diagram, for XML schema definition see chapter 10.2.1.

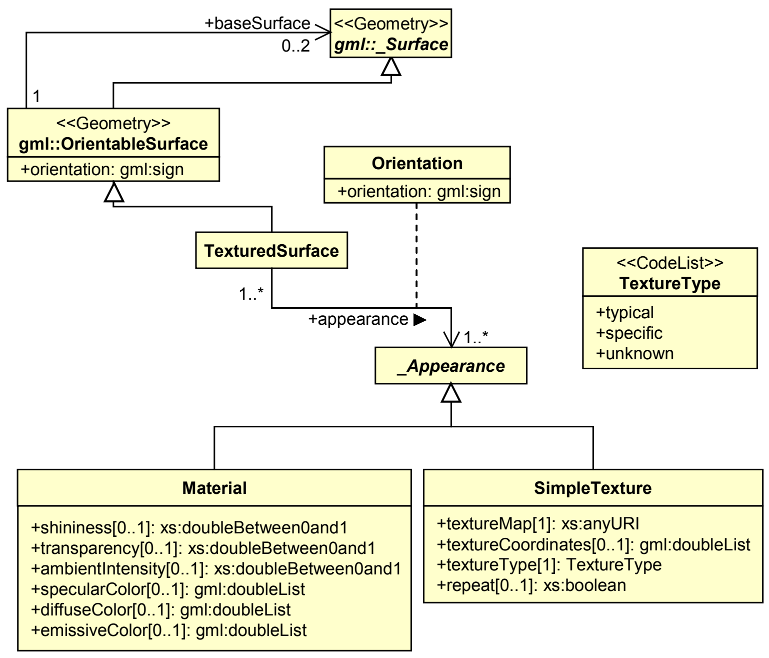

+baseSurface
0..2
<<Geometry>>
gml::_Surface
1
<<Geometry>>
gml::OrientableSurface
+orientation: gml:sign
Orientation
+orientation: gml:sign
TexturedSurface
1..*
+appearance ▶
1..*
_Appearance
<<CodeList>>
TextureType
+typical
+specific
+unknown
Material
+shininess[0..1]: xs:doubleBetween0and1
+transparency[0..1]: xs:doubleBetween0and1
+ambientIntensity[0..1]: xs:doubleBetween0and1
+specularColor[0..1]: gml:doubleList
+diffuseColor[0..1]: gml:doubleList
+emissiveColor[0..1]: gml:doubleList
SimpleTexture
+textureMap[1]: xs:anyURI
+textureCoordinates[0..1]: gml:doubleList
+textureType[1]: TextureType
+repeat[0..1]: xs:boolean

Fig. 19: UML diagram of CityGML's material model. Please note, that this approach for appearance modelling is marked as deprecated and is expected to be removed in future CityGML versions.

The concept of positioning textures on surfaces complies with the 3D computer graphics standard X3D (web 3D 2004), a successor of VRML97. CityGML adds the class *TexturedSurface* to the geometry model of GML3 because there has been no appropriate texturing concept in ISO 19107 and in GML3.

A texture is specified as a raster image referenced by an *URI* (*Uniform Resource Identifier*) and can be an arbitrary resource, even on the internet. Textures are positioned by employing the concept of *texture coordinates*, i.e. each texture coordinate matches with exactly one 3D coordinate of the *TexturedSurface* (Fig. 16). The use of texture coordinates allows an exact positioning and trimming of the texture on the surface geometry.

The color of a surface is defined by RGB values. These have to be in the range of 0 to 1. The *frontOpacity* and the *backOpacity* define the level of *transparency* of each surface. Their values have also to be in the range of 0 to 1, where 1 means completely covering and 0 denotes a completely transparent surface. The colors can be differentiated in *diffuseColor* (color when illuminated by a source of light), *emissiveColor* (color when self-illuminating) and *specularColor/shininess* (color for shiny surfaces).

Textures can be qualified by the attribute *textureType*. The *textureType* differentiates between textures which are specific for a certain object (*specific*) and prototypic textures being typical for that object surface (*typical)*. Textures may also be classified as *unknown*.

_Appearance is derived from *gml:AbstractGMLType* to be referenced in an *appearance* property. The attribute *gml:id* is inherited, whose value may be referenced by a XLink. *_Appearance* is the upper class of *Material* and *SimpleTexture*.

TexturedSurfaceType, TexturedSurface

```
<xs:complexType name="TexturedSurfaceType">
  <xs:complexContent>
    <xs:extension base="gml:OrientableSurfaceType">
      <xs:sequence>
        <xs:element ref="appearance" maxOccurs="unbounded" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ============================================================================ -->
<xs:element name="TexturedSurface" type="TexturedSurfaceType" substitutionGroup="gml:OrientableSurface" />
<!-- ============================================================================ -->
<xs:element name="appearance" type="_AppearancePropertyType" />
<!-- ============================================================================ -->
<xs:complexType name="_AppearancePropertyType">
  <xs:sequence>
```

```
    <xs:element ref="_Appearance" minOccurs="0" />
  </xs:sequence>
  <xs:attribute name="orientation" type="gml:SignType" default="+" />
  <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
</xs:complexType>
```

TexturedSurface may have one or more appearance properties, which can either be a Material (Color,...) or a Texture. The *_Appearance* element can either be represented inline as an element of this type or by an XLink reference to a remote *_Appearance* element. Either the reference or the contained element must be given, but neither both or none. The side of the surface the *_Appearance* refers to is given by the orientation attribute of the appearance property element, which refers to the corresponding sign attribute of the orientable surface: + means the side with positive orientation and - the side with negative orientation.

_AppearanceType, _Appearance

```
<xs:complexType name="_AppearanceType" abstract="true">
  <xs:complexContent>
    <xs:extension base="gml:AbstractGMLType" />
  </xs:complexContent>
</xs:complexType>
<!-- ======================================================================================== -->
<xs:element name="_Appearance" type="_AppearanceType" abstract="true" substitutionGroup="gml:_GML" />
```

MaterialType, Material

```
<xs:complexType name="MaterialType">
  <xs:complexContent>
    <xs:extension base="_AppearanceType">
      <xs:sequence>
        <xs:element name="shininess" type="doubleBetween0and1" minOccurs="0" />
        <xs:element name="transparency" type="doubleBetween0and1" minOccurs="0" />
        <xs:element name="ambientIntensity" type="doubleBetween0and1" minOccurs="0" />
        <xs:element name="specularColor" type="Color" minOccurs="0" />     <!-- Color is a list of 3 double values ranging from 0 to 1-->
        <xs:element name="diffuseColor" type="Color" minOccurs="0" />
        <xs:element name="emissiveColor" type="Color" minOccurs="0" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ======================================================================================= -->
<xs:element name="Material" type="MaterialType" substitutionGroup="_Appearance" />
<!-- ======================================================================================== -->
```

SimpleTextureType, SimpleTexture

```
<xs:complexType name="SimpleTextureType">
  <xs:complexContent>
    <xs:extension base="_AppearanceType">
      <xs:sequence>
        <xs:element name="textureMap" type="xs:anyURI" />
        <xs:element name="textureCoordinates" type="gml:doubleList" />
        <xs:element name="textureType" type="TextureTypeType" minOccurs="0" />
        <xs:element name="repeat" type="xs:boolean" minOccurs="0" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ======================================================================================== -->
<xs:element name="SimpleTexture" type="SimpleTextureType" substitutionGroup="_Appearance" />
```

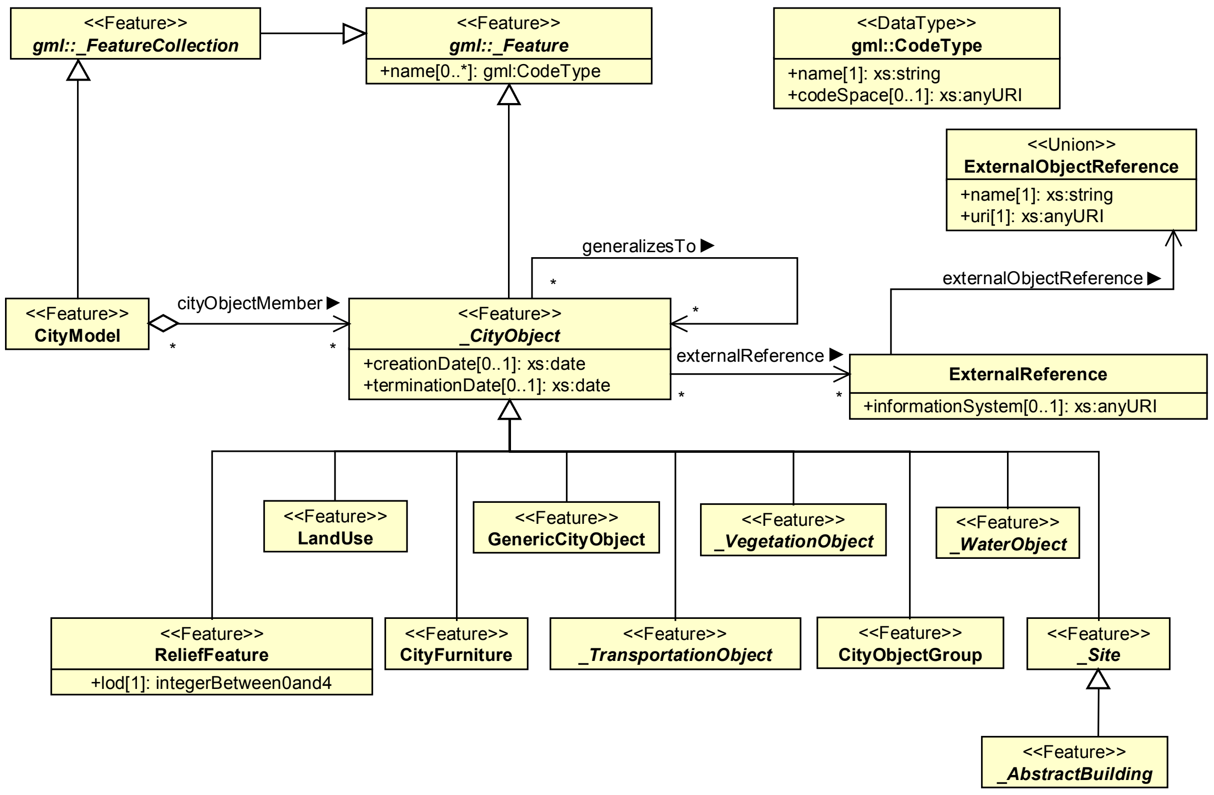
9 Thematic model

The thematic model of CityGML consists of the class definitions for the most important types of objects within virtual 3D city models. These classes have been identified to be either required or be important in many different application areas in the sense of a core model. Most thematic classes are (transitively) derived from the basic classes *Feature* and *FeatureCollection*, the basic notions defined in ISO 19109 and GML3 for the representation of spatial objects and their aggregations. Features contain spatial as well as non-spatial attributes which are mapped to GML3 feature properties with corresponding data types. Geometric properties are represented as associations to the geometry classes described in chapter 7. The thematic model also comprises different types of interrelationships between *Feature* classes like aggregations, generalizations and associations.

The aim of the explicit modelling is to reach a high degree of semantic interoperability between different applications. By specifying the thematic concepts and their semantics along with their mapping to UML and GML3 different applications can rely on a well-defined set of *Feature* types, attributes and data types with a standardised meaning or interpretation. In order to allow also for the exchange of objects and/or attributes that are not explicitly modelled in CityGML, the concepts of *GenericCityObjects* and *GenericAttributes* have been introduced (see chapter 9.10).

9.1 Top level classes

Fig. 20 presents the top level class hierarchy of the thematic model in CityGML. The base class of all thematic classes is *CityObject*, which provides a creation and a termination date for the management of histories of features as well as external references to the same object in other data sets (XML schema definition see chapter 10.1.2). *CityObject* is a subclass of the GML class *Feature*, thus it inherits metadata (e.g. information about the lineage, quality aspects, accuracy) and names from *Feature* and its super classes. A *CityObject* may have multiple names, which are optionally qualified by a *codeSpace*. This enables the differentiation between, for example, an official name from a popular name or names in different languages (c.f. the name property of GML objects, Cox et al. 2004).



<<Feature>> gml::_FeatureCollection
<<Feature>> gml::_Feature
+name[0..*]: gml:CodeType
<<DataType>> gml::CodeType
+name[1]: xs:string
+codeSpace[0..1]: xs:anyURI
<<Union>> ExternalObjectReference
+name[1]: xs:string
+uri[1]: xs:anyURI
generalizesTo ▶
externalObjectReference ▶
cityObjectMember ▶
<<Feature>> CityModel
<<Feature>> _CityObject
+creationDate[0..1]: xs:date
+terminationDate[0..1]: xs:date
externalReference ▶
ExternalReference
+informationSystem[0..1]: xs:anyURI
<<Feature>> LandUse
<<Feature>> GenericCityObject
<<Feature>> _VegetationObject
<<Feature>> _WaterObject
<<Feature>> ReliefFeature
+lod[1]: integerBetween0and4
<<Feature>> CityFurniture
<<Feature>> _TransportationObject
<<Feature>> CityObjectGroup
<<Feature>> _Site
<<Feature>> _AbstractBuilding

Fig. 20: UML diagram of the top level class hierarchy of CityGML. The bracketed numbers following the attribute names denote its multiplicity: the minimal and maximal number of occurrences of the attribute per object. For example, a *name* is optional (0) in the class *_Feature* or may occur multiple times (star symbol), while a *_CityObject* has none or at most one *creationDate*. A *ReliefFeature* has exactly one occurrence of the attribute *LOD*.

The subclasses of *CityObject* comprise the different thematic fields of a city model: the terrain, the coverage by land use objects, transportation, vegetation, water bodies and sites, in particular buildings. The class *CityFurniture* is used to represent traffic lights, traffic signs, flower buckets, or similar objects. The class *GenericCityObject* allows the modelling of features, which are not covered explicitly by the CityGML schema. In the future, sites will be completed by further subclasses like tunnel, bridge, excavation, wall or embankment. At present, these objects have to be represented by *GenericObjects* (see chapters 6.10 and 9.10).

Thematic classes have further subclasses with relations, attributes and geometry. Features of the specialized subclasses of *CityObject* may be aggregated to a single *CityModel*, which is a feature collection with optional metadata.

Generally, each feature has the attributes *class*, *function* and *usage*, unless it is stated otherwise. The *class* attribute can occur only once, while the attributes *usage* and *function* can be used multiple times. The *class* attribute describes the classification of the objects, e.g. road, track, railway, or square. The attribute *function* contains the purpose of the object, like national highway or county road, while the attribute *usage* may define if an object is e.g. navigable or usable for pedestrians.

_CityObjectType, _CityObject

```
<xs:complexType name="_CityObjectType" abstract="true">
  <xs:complexContent>
    <xs:extension base="gml:AbstractFeatureType">
      <xs:sequence>
        <xs:element name="creationDate" type="xs:date" minOccurs="0" />
        <xs:element name="terminationDate" type="xs:date" minOccurs="0" />
        <xs:element name="externalReference" type="ExternalReferenceType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element ref="_genericAttribute" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="generalizesTo" type="GeneralizationRelationType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element ref="appearanceMember" minOccurs="0" maxOccurs="unbounded"/>
        <xs:element ref="_GenericApplicationPropertyOfCityObject" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="_CityObject" type="_CityObjectType" abstract="true" substitutionGroup="gml:_Feature" />
<!-- ====================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfCityObject" type="xs:anyType" abstract="true"/>
```

The generalisation relation may be used to relate features, which represent the same real-world object in different Levels-of-Detail, i.e. a feature and its generalized counterpart(s). The direction of this relation is from the feature to the corresponding generalised feature.

Every *CityObject* may be assigned an arbitrary number of generic attributes. Further details on generic attributes (including the UML diagram) are given in chapter 9.10.

CityModelType, CityModel

```
<xs:complexType name="CityModelType">
  <xs:complexContent>
    <xs:extension base="gml:AbstractFeatureCollectionType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfCityModel" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="CityModel" type="CityModelType" substitutionGroup="gml:_FeatureCollection" />
<!-- ====================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfCityModel" type="xs:anyType" abstract="true"/>
```

cityObjectMember, appearanceMember

```
<xs:element name="cityObjectMember" type="gml:FeaturePropertyType" substitutionGroup="gml:featureMember"/>
<!-- ====================================================================================== -->
```

```
<xs:element name="appearanceMember" type="AppearancePropertyType" substitutionGroup="gml:featureMember"/>
```

The definition of *cityObjectMember* and *appearanceMember* allows for an arbitrary or even mixed sequence of *CityObject* features and *Appearance* features (cf. chapter 8) within a *CityModel* feature collection.

_SiteType, _Site

```
<xs:complexType name="_SiteType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfSite" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_Site" type="_SiteType" abstract="true" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfSite" type="xs:anyType" abstract="true"/>
```

_Site is intended as the abstract superclass for buildings, facilities, etc. Future extension of CityGML (e.g. bridges or tunnels) would be modelled as subclasses of *_Site*. As subclass of *_CityObject*, a *_Site* inherits all attributes and relations, in particular the id, names, external references, generic attributes and generalisation relations.

ExternalReferenceType

```
<xs:complexType name="ExternalReferenceType">
  <xs:sequence>
    <xs:element name="informationSystem" type="xs:anyURI" minOccurs="0" />
    <xs:element name="externalObject" type="ExternalObjectReferenceType" />
  </xs:sequence>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:complexType name="ExternalObjectReferenceType">
  <xs:choice>
    <xs:element name="name" type="xs:string" />
    <xs:element name="uri" type="xs:anyURI" />
  </xs:choice>
</xs:complexType>
```

An *ExternalReference* defines a hyperlink to a corresponding object in another information system, for example in the German cadastre (ALKIS), the German topographic information system (ATKIS), or the Ordnance Survey Mastermap®. The reference consists of the name of the external information system, represented by an URI, and the reference of the external object, given either by a string or by an URI. If the informationSystem element is missing in the ExternalReference, the ExternalObjectReference must be an URI.

GeneralizationRelationType

```
<xs:complexType name="GeneralizationRelationType">
  <xs:complexContent>
    <xs:restriction base="gml:AssociationType">
      <xs:sequence minOccurs="0">
        <xs:element ref="gml:_Feature" />
      </xs:sequence>
      <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
    </xs:restriction>
  </xs:complexContent>
</xs:complexType>
```

9.2 *Digital Terrain Model (DTM)*

An essential part of a city model is the terrain. In CityGML, the terrain is represented by the class *ReliefFeature* in LOD 0-4 (Fig. 21 depicts the UML diagram, for XML schema definition see chapter 10.4.8). A *ReliefFeature* consists of one or more entities of the class *ReliefComponent.* Its validity may be restricted to a certain area defined by an optional *validity extent polygon*. As *ReliefFeature* and *ReliefComponent* are derivatives of *CityObject,* the corresponding attributes and relations are inherited. The class *ReliefFeature* is associated with different concepts of terrain representations which can coexist. The terrain may be specified as a regular raster or grid (*RasterRelief)*, as a TIN (Triangulated Irregular Network, *TINReflief*), by break lines (*BreaklineRelief)*, or by mass points *(MasspointRelief*). The four types are implemented by the corresponding GML3 classes: grids by *RectifiedGridCoverages,* break lines by *Curves,* mass points by *Points* and TINs either by *TriangulatedSurfaces* or by GML3 *TINs*. In case of *TriangulatedSurfaces*, the triangles are given explicitly while in case of GML3 *TINs* only 3D points are represented, where the triangulation can be reconstructed by standard methods (Delaunay triangulation, cf. Okabe et al. 1992). Break lines are represented by 3D curves. Mass points are simply a set of 3D points.

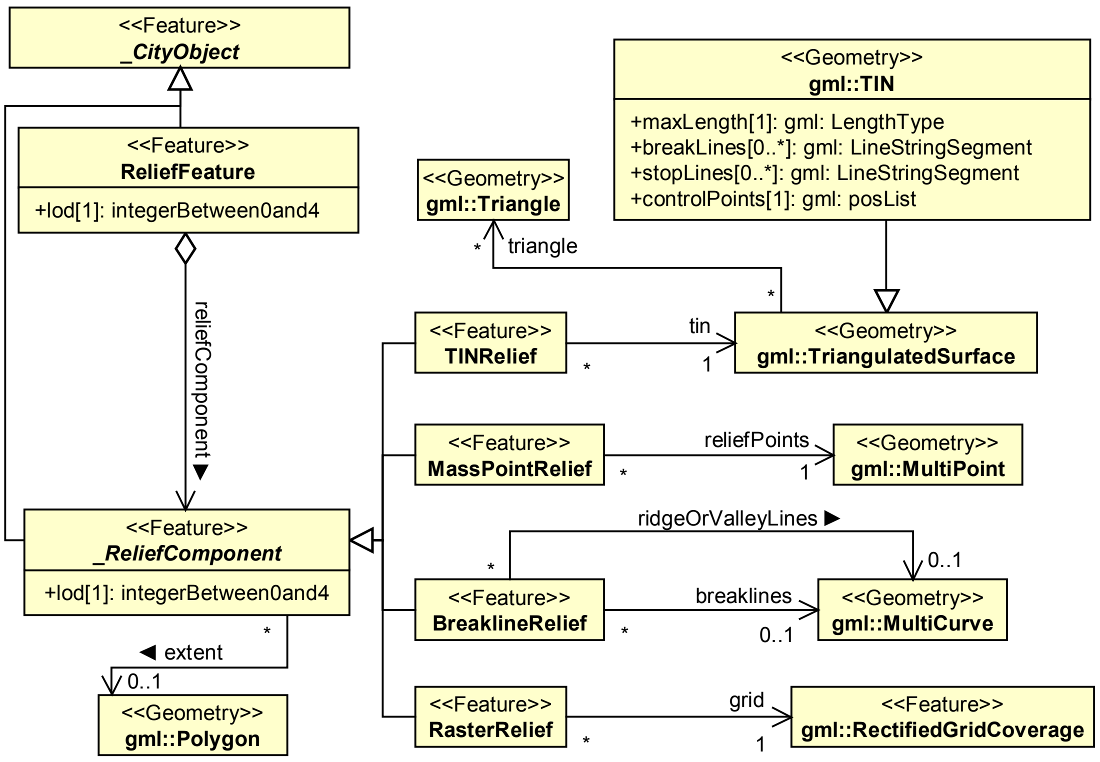


Fig. 21: UML diagram of the Digital Terrain Model in CityGML.

In a CityGML dataset the four terrain types may be combined in different ways, yielding a high flexibility. First, each type may be represented in different levels of detail, reflecting different accuracies or resolutions. Second, a part of the terrain can be described by the combination of multiple types, for example by a raster and break lines, or by a TIN and break lines. In this case, the break lines must share the geometry with the triangles. Third, neighboring regions may be represented by different types of terrain models. To facilitate this combination, each terrain object is provided with a spatial attribute denoting its *extent of validity* (Fig. 22). In most cases, the extent of validity of a regular raster dataset corresponds to its bounding box. This validity extent is represented by a 2D footprint polygon, which may have holes. This concept enables, for example, the modelling of a terrain by a coarse grid, where some distinguished regions are represented by a detailed, high-accuracy TIN. The boundaries between both types are given by the extent attributes of the corresponding terrain objects.

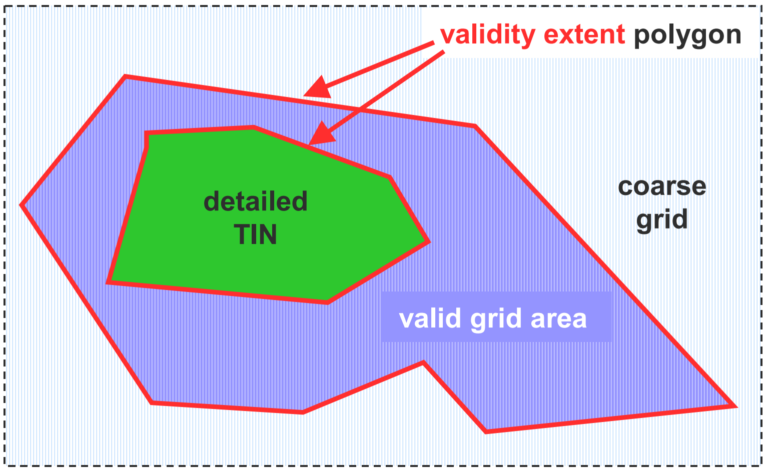


Fig. 22: Nested DTMs in CityGML using validity extent polygons (graphic: IGG Uni Bonn).

Accuracy and resolution of the DTM are not necessarily dependent on those of the building model. Hence, there is the possibility to integrate building models with higher LOD to a DTM with lower accuracy or resolution.

This approach interacts with the concept of *TerrainIntersectionCurves TIC* (see chapter 6.4). The TIC can be used like break lines to adjust the DTM to different building models and hence to ensure a consistent representation of the DTM. If necessary, a retriangulation may have to be processed. A TIC can also be derived by the individual intersection of the DTM and the building model.

ReliefFeature and its *ReliefComponents* both have an *lod* attribute denoting the corresponding level of detail. In most cases, the LOD of a *ReliefFeature* matches the LOD of its *ReliefComponents*. However, it is also allowed to specify a *ReliefFeature* with a high LOD which consists of *ReliefComponents* where some of them can have a LOD lower than that of the aggregating *ReliefFeature*. The idea is that, for example, for a LOD 3 scene it might be sufficient to use a regular grid in LOD 2 with certain higher precision areas defined by *ReliefComponents* in LOD 3. The LOD 2 grid and the LOD 3 components can easily be integrated using the concept of the validity extent polygon. Therefore, although some of the *ReliefComponents* would have been classified to a lower LOD, the whole *ReliefFeature* would be appropriate to use with other LOD 3 models which is indicated by setting its *lod* value to 3.

ReliefFeatureType, ReliefFeature

```
<xs:complexType name="ReliefFeatureType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="lod" type="integerBetween0and4"/>
        <xs:element name="reliefComponent" type="ReliefComponentPropertyType" maxOccurs="unbounded"/>
        <xs:element ref="_GenericApplicationPropertyOfReliefFeature" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="ReliefFeature" type="ReliefFeatureType" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfReliefFeature" type="xs:anyType" abstract="true"/>
```

_ReliefComponentType, _ReliefComponent

```
<xs:complexType name="_ReliefComponentType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="lod" type="integerBetween0and4" />
        <xs:element name="extent" type="gml:PolygonPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfReliefComponent" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================= -->
<xs:element name="_ReliefComponent" type="_ReliefComponentType" abstract="true" substitutionGroup="_CityObject"/>
<!-- ============================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfReliefComponent" type="xs:anyType" abstract="true"/>
```

TINReliefType, TINRelief

```
<xs:complexType name="TINReliefType">
  <xs:complexContent>
    <xs:extension base="_ReliefComponentType">
      <xs:sequence>
        <xs:element name="tin" type="tinPropertyType" />
        <xs:element ref="_GenericApplicationPropertyOfTinRelief" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================= -->
<xs:element name="TINRelief" type="TINReliefType" substitutionGroup="_ReliefComponent" />
<!-- ============================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTinRelief" type="xs:anyType" abstract="true"/>
<!-- ============================================================================================= -->
<xs:complexType name="tinPropertyType">
  <xs:complexContent>
    <xs:restriction base="gml:AssociationType">
      <xs:sequence minOccurs="0">
        <xs:element ref="gml:TriangulatedSurface" />
      </xs:sequence>
      <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
    </xs:restriction>
  </xs:complexContent>
</xs:complexType>
```

The geometry of a *TINRelief* is defined by the GML geometry class *gml:TriangulatedSurface*. This allows either the explicit provision of a set of triangles (*gml:TriangulatedSurface*) or specifying of only the control points, break and stop lines using the subclass *gml:Tin* of *gml:TriangulatedSurface*. In the latter case, an application that processes an instance document containing a *gml:Tin* has to reconstruct the triangulated surface by the application of a constrained Delaunay triangulation algorithm (cf. Okabe et al. 1992).

RasterReliefType, RasterRelief

```
<xs:complexType name="RasterReliefType">
  <xs:complexContent>
    <xs:extension base="_ReliefComponentType">
      <xs:sequence>
        <xs:element name="grid" type="gridPropertyType" />
        <xs:element ref="_GenericApplicationPropertyOfRasterRelief" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================= -->
<xs:element name="RasterRelief" type="RasterReliefType" substitutionGroup="_ReliefComponent" />
<!-- ============================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfRasterRelief" type="xs:anyType" abstract="true"/>
<!-- ============================================================================================= -->
<xs:complexType name="gridPropertyType">
  <xs:complexContent>
    <xs:restriction base="gml:AssociationType">
      <xs:sequence minOccurs="0">
        <xs:element ref="gml:RectifiedGridCoverage" />
      </xs:sequence>
      <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
    </xs:restriction>
  </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================= -->
<xs:element name="Elevation" type="gml:LengthType" substitutionGroup="gml:_Object" />
```

MassPointReliefType, MassPointRelief

```
<xs:complexType name="MassPointReliefType">
  <xs:complexContent>
    <xs:extension base="_ReliefComponentType">
      <xs:sequence>
        <xs:element name="reliefPoints" type="gml:MultiPointPropertyType" />
        <xs:element ref="_GenericApplicationPropertyOfMassPointRelief" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="MassPointRelief" type="MassPointReliefType" substitutionGroup="_ReliefComponent" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfMassPointRelief" type="xs:anyType" abstract="true"/>
```

BreaklineReliefType, BreaklineRelief

```
<xs:complexType name="BreaklineReliefType">
  <xs:complexContent>
    <xs:extension base="_ReliefComponentType">
      <xs:sequence>
        <xs:choice>
          <xs:element name="ridgeOrValleyLines" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="breaklines" type="gml:MultiCurvePropertyType" minOccurs="0" />
        </xs:choice>
        <xs:element ref="_GenericApplicationPropertyOfBreaklineRelief" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="BreaklineRelief" type="BreaklineReliefType" substitutionGroup="_ReliefComponent" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfBreaklineRelief" type="xs:anyType" abstract="true"/>
```

The geometry of a *BreakLineRelief* can be composed of break lines and ridge/valley lines. Whereas break lines indicate abrupt changes of terrain slope, ridge/valley lines in addition mark a change of the sign of the terrain slope gradient. A *BreakLineRelief* must have at least one of the two properties.

9.3 Building model

The building model is the most detailed thematic concept of CityGML. It allows the representation of thematic and spatial aspects of buildings, building parts and installations in four levels of detail, LOD1 to LOD4. Fig. 23 provides examples of 3D city models for each LOD.

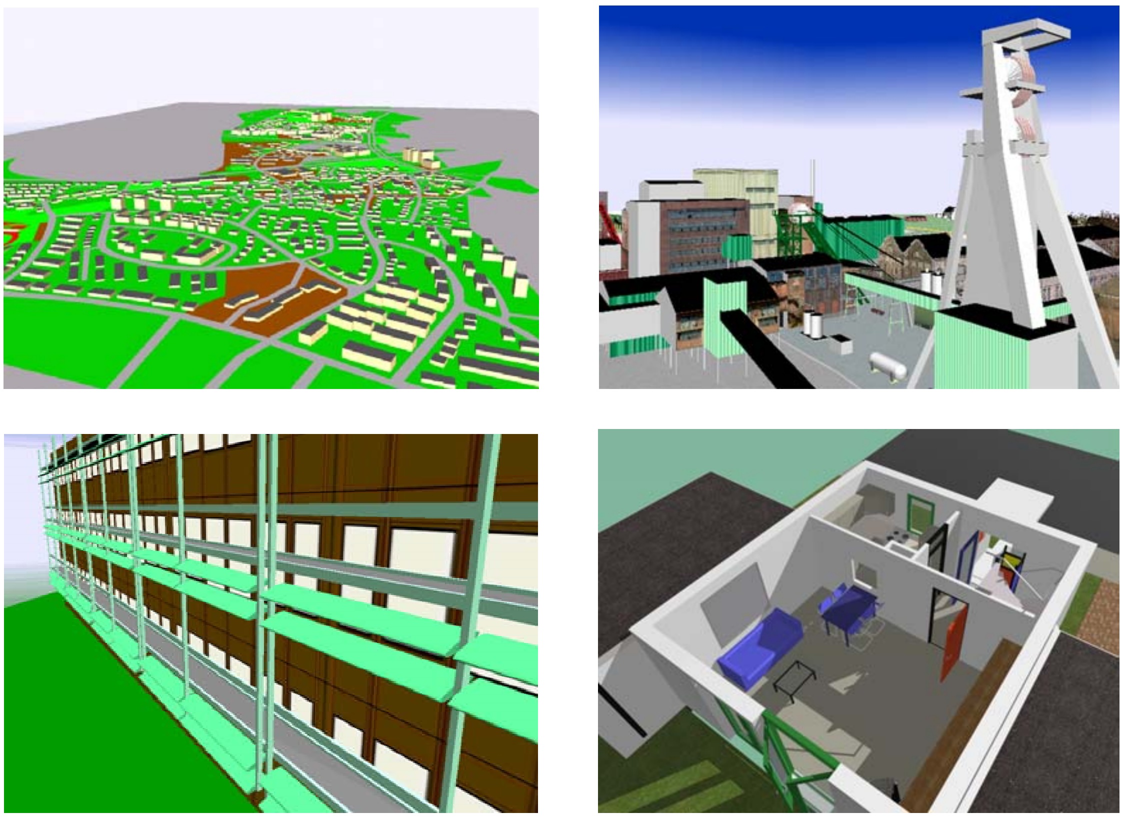
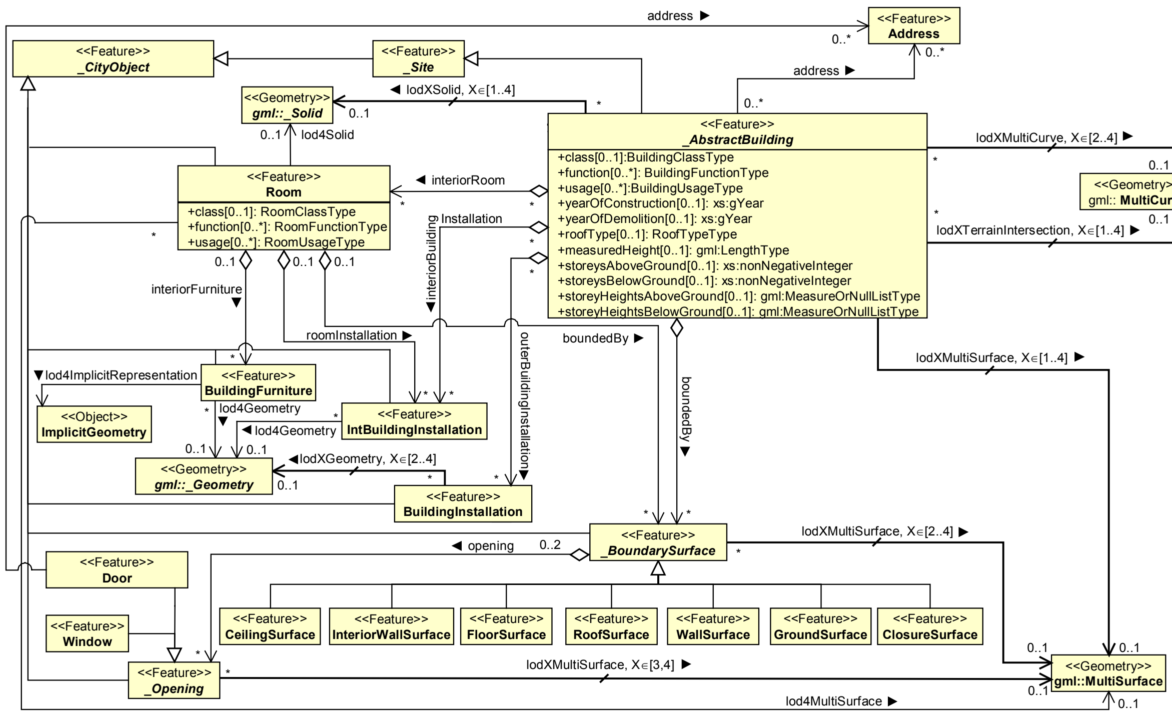


Fig. 23: Examples for city or building models in LOD1 (upper left), LOD2 (upper right), LOD3 (lower left), and LOD4 (lower right) (source: District of Recklinghausen, m-g-h ingenieure+architekten GmbH).

The UML diagram of the building model is depicted in Fig. 24 and Fig. 25, for the XML schema definition see chapter 9.3.1 and following. The pivotal class of the model is *_AbstractBuilding*, which is a subclass of the thematic class *Site* (and transitively of the root class *_CityObject*). *_AbstractBuilding* is specialised either to a *Building* or to a *BuildingPart*. Since an *_AbstractBuilding* consists of *BuildingParts*, which again are *_AbstractBuildings*, an aggregation hierarchy of arbitrary depth may be realised. *_AbstractBuilding* is a subclass of the root class *_CityObject*. Thus, the relation to the class *ExternalReference* (see chapter 6.6) and the possibility to assign *GenericAttributes* is inherited (see chapter 6.10).

Building complexes, which consist of a number of distinct buildings like a factory site or hospital complex, should be aggregated using the concept of *CityObjectGroups* (see chapter 6.7). The main building of the complex can be denoted by providing "main building" as the role name of the corresponding object.

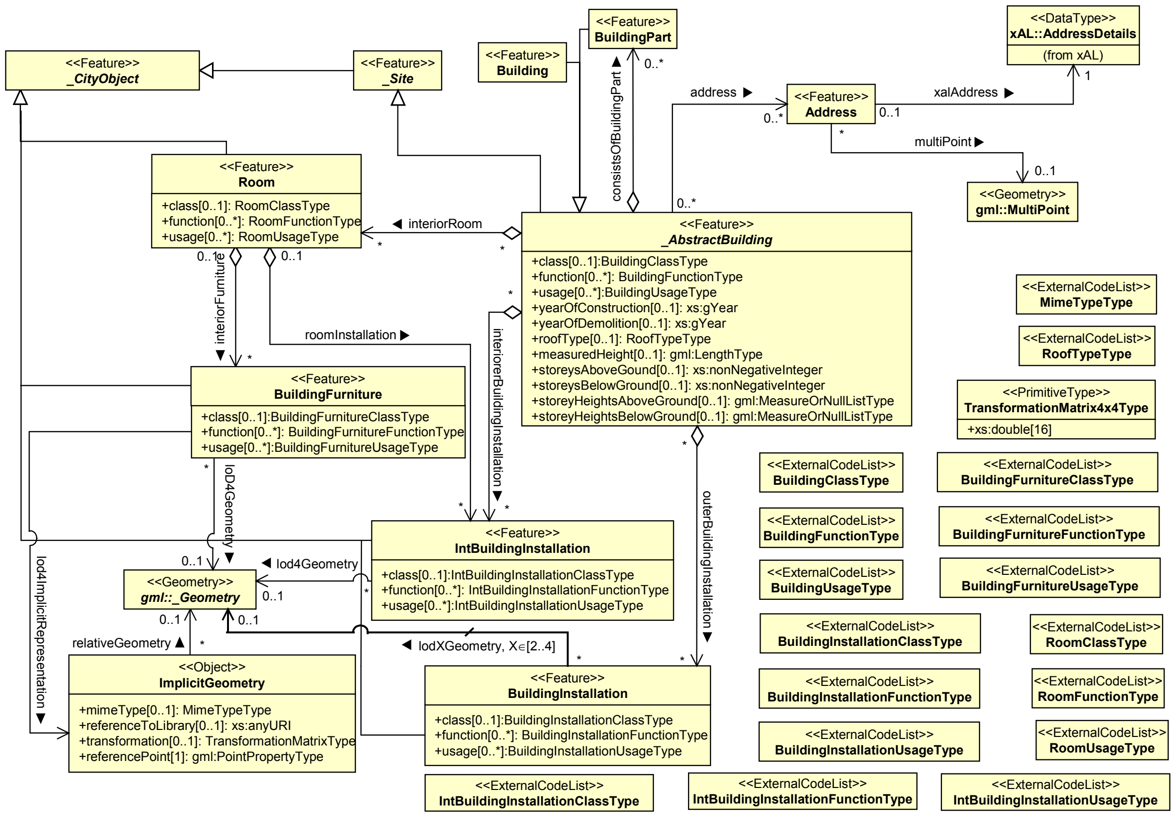
Both classes *Building* and *BuildingPart* inherit the attributes of *_AbstractBuilding*: the class of the building, the function (e.g. residential, public, or industry), the usage, the year of construction, the year of demolition, the roof type, the measured height, and the number and individual heights of the storeys above and below ground. This set of parameters is suited for roughly reconstructing the three-dimensional shape of a building and can be provided by cadastral systems. Furthermore, *Addresses* can be assigned to *Buildings* or *BuildingParts*.



<<Feature>> _CityObject
<<Feature>> _Site
<<Feature>> Address
<<Geometry>> gml::_Solid
<<Feature>> _AbstractBuilding
+class[0..1]:BuildingClassType
+function[0..*]: BuildingFunctionType
+usage[0..*]:BuildingUsageType
+yearOfConstruction[0..1]: xs:gYear
+yearOfDemolition[0..1]: xs:gYear
+roofType[0..1]: RoofTypeType
+measuredHeight[0..1]: gml:LengthType
+storeysAboveGround[0..1]: xs:nonNegativeInteger
+storeysBelowGround[0..1]: xs:nonNegativeInteger
+storeyHeightsAboveGround[0..1]: gml:MeasureOrNullListType
+storeyHeightsBelowGround[0..1]: gml:MeasureOrNullListType
<<Feature>> Room
+class[0..1]: RoomClassType
+function[0..*]: RoomFunctionType
+usage[0..*]: RoomUsageType
<<Geometry>> gml:: MultiCurve
<<Feature>> BuildingFurniture
<<Object>> ImplicitGeometry
<<Feature>> IntBuildingInstallation
<<Geometry>> gml::_Geometry
<<Feature>> BuildingInstallation
<<Feature>> _BoundarySurface
<<Feature>> Door
<<Feature>> Window
<<Feature>> _Opening
<<Feature>> CeilingSurface
<<Feature>> InteriorWallSurface
<<Feature>> FloorSurface
<<Feature>> RoofSurface
<<Feature>> WallSurface
<<Feature>> GroundSurface
<<Feature>> ClosureSurface
<<Geometry>> gml::MultiSurface
address ▶
lodXSolid, X∈[1..4]
lod4Solid
interiorRoom
interiorBuilding Installation
lodXMultiCurve, X∈[2..4] ▶
lodXTerrainIntersection, X∈[1..4] ▶
interiorFurniture
roomInstallation ▶
boundedBy ▶
lodXMultiSurface, X∈[1..4] ▶
▼lod4ImplicitRepresentation
lod4Geometry
lodXGeometry, X∈[2..4]
outerBuildingInstallation
opening
lodXMultiSurface, X∈[2..4] ▶
lodXMultiSurface, X∈[3,4] ▶
lod4MultiSurface ▶

Fig. 24: UML diagram of CityGML's building model, part 1: pivotal class *AbstractBuilding, Room,* and thematic surfaces.

The geometric representation and semantic structure of an *_AbstractBuilding* is shown in Fig. 24. The model is successively refined from LOD1 to LOD4. Therefore, not all components of a building model are represented equally in each LOD and not all aggregation levels are allowed in each LOD. In CityGML, all object classes are associated to the LODs with respect to the minimum acquisition criteria for each LOD (cf. chapter 6.1). An object can be represented simultaneously in different LODs by providing distinct geometries for the corresponding LODs.



<<Feature>> _CityObject
<<Feature>> _Site
<<Feature>> Building
<<Feature>> BuildingPart
<<Feature>> Address
<<DataType>> xAL::AddressDetails
(from xAL)
<<Geometry>> gml::MultiPoint
<<Feature>> Room
+class[0..1]: RoomClassType
+function[0..*]: RoomFunctionType
+usage[0..*]: RoomUsageType
<<Feature>> _AbstractBuilding
+class[0..1]:BuildingClassType
+function[0..*]: BuildingFunctionType
+usage[0..*]:BuildingUsageType
+yearOfConstruction[0..1]: xs:gYear
+yearOfDemolition[0..1]: xs:gYear
+roofType[0..1]: RoofTypeType
+measuredHeight[0..1]: gml:LengthType
+storeysAboveGound[0..1]: xs:nonNegativeInteger
+storeysBelowGround[0..1]: xs:nonNegativeInteger
+storeyHeightsAboveGround[0..1]: gml:MeasureOrNullListType
+storeyHeightsBelowGround[0..1]: gml:MeasureOrNullListType
<<Feature>> BuildingFurniture
+class[0..1]:BuildingFurnitureClassType
+function[0..*]: BuildingFurnitureFunctionType
+usage[0..*]:BuildingFurnitureUsageType
<<Feature>> IntBuildingInstallation
+class[0..1]:IntBuildingInstallationClassType
+function[0..*]: IntBuildingInstallationFunctionType
+usage[0..*]:IntBuildingInstallationUsageType
<<Geometry>> gml::_Geometry
<<Object>> ImplicitGeometry
+mimeType[0..1]: MimeTypeType
+referenceToLibrary[0..1]: xs:anyURI
+transformation[0..1]: TransformationMatrixType
+referencePoint[1]: gml:PointPropertyType
<<Feature>> BuildingInstallation
+class[0..1]:BuildingInstallationClassType
+function[0..*]: BuildingInstallationFunctionType
+usage[0..*]:BuildingInstallationUsageType
<<ExternalCodeList>> MimeTypeType
<<ExternalCodeList>> RoofTypeType
<<PrimitiveType>> TransformationMatrix4x4Type
+xs:double[16]
<<ExternalCodeList>> BuildingClassType
<<ExternalCodeList>> BuildingFurnitureClassType
<<ExternalCodeList>> BuildingFunctionType
<<ExternalCodeList>> BuildingFurnitureFunctionType
<<ExternalCodeList>> BuildingUsageType
<<ExternalCodeList>> BuildingFurnitureUsageType
<<ExternalCodeList>> BuildingInstallationClassType
<<ExternalCodeList>> RoomClassType
<<ExternalCodeList>> BuildingInstallationFunctionType
<<ExternalCodeList>> RoomFunctionType
<<ExternalCodeList>> BuildingInstallationUsageType
<<ExternalCodeList>> RoomUsageType
<<ExternalCodeList>> IntBuildingInstallationClassType
<<ExternalCodeList>> IntBuildingInstallationFunctionType
<<ExternalCodeList>> IntBuildingInstallationUsageType
consistsOfBuildingPart
address ▶
xalAddress ▶
multiPoint ▶
interiorRoom
interiorFurniture
roomInstallation ▶
interiorBuildingInstallation
outerBuildingInstallation
lod4ImplicitRepresentation
lodD4Geometry
lod4Geometry
relativeGeometry
lodXGeometry, X∈[2..4]

Fig. 25: UML diagram of CityGML's building model, part 2: *Building, BuildingPart, BuildingInstallation, IntBuildingInstallation, BuildingFurniture*, and *Address.*

In LOD1, a building model consists of a geometric representation of the building volume. Optionally, a *MultiCurve* representing the *TerrainIntersectionCurve* (see chapter 6.4) can be specified. This geometric representation is refined in LOD2 by additional *MultiSurface* and *MultiCurve* geometries, used for modelling architectural details like a roof overhang, columns, or antennas. In LOD2 and higher LODs the outer facade of a building can also be differentiated semantically by the classes *_BoundarySurface* and *BuildingInstallation*. A *_BoundarySurface* is a part of the building's exterior shell with a special function like wall (*WallSurface*), roof (*RoofSurface*), ground plate (*GroundSurface*) or *ClosureSurface*. The *BuildingInstallation* class is used for building elements like balconies, chimneys, dormers or outer stairs, strongly affecting the outer appearance of a building. A *BuildingInstallation* may have the attributes *class*, *function* and *usage* (c.f. Fig. 25).

In LOD3, the openings in *_BoundarySurface* objects (doors and windows) can be represented as thematic objects. In LOD4, the highest level of resolution, also the interior of a building, composed of several rooms, is represented in the building model by the class *Room*. This enlargement allows a virtual accessibility of buildings, e.g. for visitor information in a museum ("Location Based Services"), the examination of accommodation standards or the presentation of daylight illumination of a building. The aggregation of rooms according to arbitrary, user defined criteria (e.g. for defining the rooms corresponding to a certain storey) is achieved by employing the general grouping concept provided by CityGML (see chapter 9.3.6). Interior installations of a building, i.e. objects within a building which (in contrast to furniture) cannot be moved, are represented by the class *IntBuildingInstallation*. If an installation is attached to a specific room (e.g. radiators or lamps), they are associated with the *Room* class, otherwise (e.g. in case of rafters or pipes) with *_AbstractBuilding*. A *Room* may have the attributes *class*, *function* and *usage* referenced to external code lists (chapter 9.3.7 and 11.1). The *class* attribute allows a classification of rooms with respect to the stated function, e.g. commercial or private rooms, and occurs only once. The *function* attribute is intended to express the main purpose of the room, e.g. living room, kitchen. The attribute *usage* can be used if the way the object is actually used differs from the function. Both attributes can occur multiple times.

The visible surface of a room is represented geometrically as a *Solid* or *MultiSurface*. Semantically, the surface can be structured into specialised *_BoundarySurfaces*, representing floor (*FloorSurface*), ceiling (*CeilingSurface*), and interior walls (*InteriorWallSurface*). Room furniture, like tables and chairs, can be represented in the CityGML building model with the class *BuildingFurniture*. A *BuildingFurniture* may have the attributes *class*, *function* and *usage*.

An example of a CityGML dataset for *SimpleBuildings* can be found in chapter 11.4.1.

9.3.1 Building and building part

BuildingType, Building

```
<xs:complexType name="BuildingType">
  <xs:complexContent>
    <xs:extension base="_AbstractBuildingType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfBuilding" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="Building" type="BuildingType" substitutionGroup="_AbstractBuilding" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfBuilding" type="xs:anyType" abstract="true"/>
```

The *Building* class is one of the two subclasses of *AbstractBuilding*. If a building only consists of one (homogeneous) part, this class shall be used. A building composed of structural segments differing in, for example the number of storeys or the roof type has to be separated into one *Building* having one or more additional *BuildingParts* (see Fig. 26). The geometry and non-spatial properties of the central part of the building should be represented in the aggregating *Building* feature.

BuildingPartType, BuildingPart

```
<xs:complexType name="BuildingPartType">
  <xs:complexContent>
```

```
    <xs:extension base="_AbstractBuildingType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfBuildingPart" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="BuildingPart" type="BuildingPartType" substitutionGroup="_AbstractBuilding" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfBuildingPart" type="xs:anyType" abstract="true"/>
```

The class *BuildingPart* is derived from *AbstractBuilding*. It is used to model a structural part of a building (see Fig. 26).

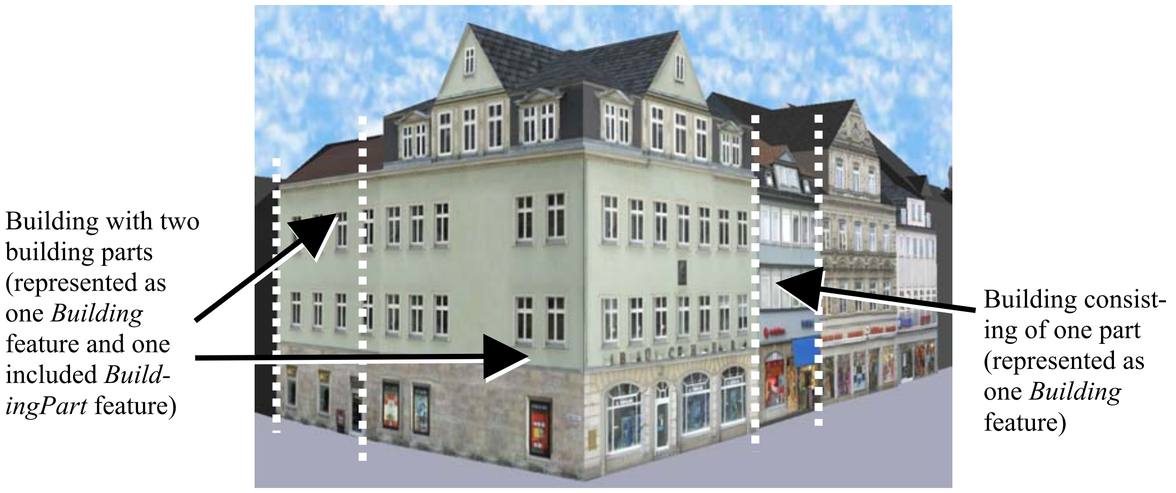

Building with two building parts (represented as one *Building* feature and one included *BuildingPart* feature)
Building consisting of one part (represented as one *Building* feature)

Fig. 26: Examples of buildings consisting of one and two building parts (source: City of Coburg).

_AbstractBuildingType, _AbstractBuilding

```
<xs:complexType name="_AbstractBuildingType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_SiteType">
      <xs:sequence>
          <xs:element name="class" type="BuildingClassType" minOccurs="0" />
          <xs:element name="function" type="BuildingFunctionType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="usage" type="BuildingUsageType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="yearOfConstruction" type="xs:gYear" minOccurs="0" />
          <xs:element name="yearOfDemolition" type="xs:gYear" minOccurs="0" />
          <xs:element name="roofType" type="RoofTypeType" minOccurs="0" />
          <xs:element name="measuredHeight" type="gml:LengthType" minOccurs="0" />
          <xs:element name="storeysAboveGround" type="xs:nonNegativeInteger" minOccurs="0" />
          <xs:element name="storeysBelowGround" type="xs:nonNegativeInteger" minOccurs="0" />
          <xs:element name="storeyHeightsAboveGround" type="gml:MeasureOrNullListType" minOccurs="0" />
          <xs:element name="storeyHeightsBelowGround" type="gml:MeasureOrNullListType" minOccurs="0" />
          <xs:element name="lod1Solid" type="gml:SolidPropertyType" minOccurs="0" />
          <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
          <xs:element name="lod1TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="lod2Solid" type="gml:SolidPropertyType" minOccurs="0" />
          <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
          <xs:element name="lod2MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="lod2TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="outerBuildingInstallation" type="BuildingInstallationPropertyType" minOccurs="0"
                                   maxOccurs="unbounded" />
          <xs:element name="interiorBuildingInstallation" type="IntBuildingInstallationPropertyType" minOccurs="0"
                                   maxOccurs="unbounded" />
          <xs:element name="boundedBy" type="BoundarySurfacePropertyType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="lod3Solid" type="gml:SolidPropertyType" minOccurs="0" />
          <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
          <xs:element name="lod3MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="lod3TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="lod4Solid" type="gml:SolidPropertyType" minOccurs="0" />
          <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
          <xs:element name="lod4MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="lod4TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
          <xs:element name="interiorRoom" type="InteriorRoomPropertyType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="consistsOfBuildingPart" type="BuildingPartPropertyType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="address" type="AddressPropertyType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element ref="_GenericApplicationPropertyOfAbstractBuilding" minOccurs="0" maxOccurs="unbounded"/>
        </xs:sequence>
      </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ==================================================================================== -->
<xs:element name="_AbstractBuilding" type="_AbstractBuildingType" abstract="true" substitutionGroup="_Site" />
<!-- ==================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfAbstractBuilding" type="xs:anyType" abstract="true"/>
```

The abstract class *_AbstractBuilding* contains properties for building attributes, purely geometric representations, and geometric/semantic representations of the building or building part on different levels of detail. The attributes describe:

a) The classification of the building or building part (*class*), the different functions (*function*), and the usage (*usage*). The permitted values for these property types are specified in a separate XML file, using the dictionary concept of GML3.
b) The year of construction (*yearOfConstruction*) and the year of demolition (*yearOfDemolition*) of the building or building part. These attributes can be used to describe the chronology of the building development within a city model. The points of time refer to real world time.
c) The roof type of the building or building part (*roofType*). The permitted values for the *RoofTypeType* are specified in a separate XML-File, using the dictionary concept of GML.
d) The measured relative height (*measuredHeight*) of the building or building part ridge line (highest point).
e) The number of storeys above (*storeyAboveGround*) and below (*storeyBelowGround*) ground level.
f) The list of storey heights above (*storeyHeightsAboveGround*) and below (*storeyHeightsBelowGround*) ground level. The first value in a list denotes the height of the nearest storey wrt. to the ground level and last value the height of the farthest.

Spanning the different levels of detail, the building model differs in the complexity and granularity of the geometric representation and the thematic structuring of the model into components with a special semantic meaning. This is illustrated in Fig. 27, showing the same building in four different LODs. The class *_AbstractBuilding* has a number of properties which are associated with certain LODs.

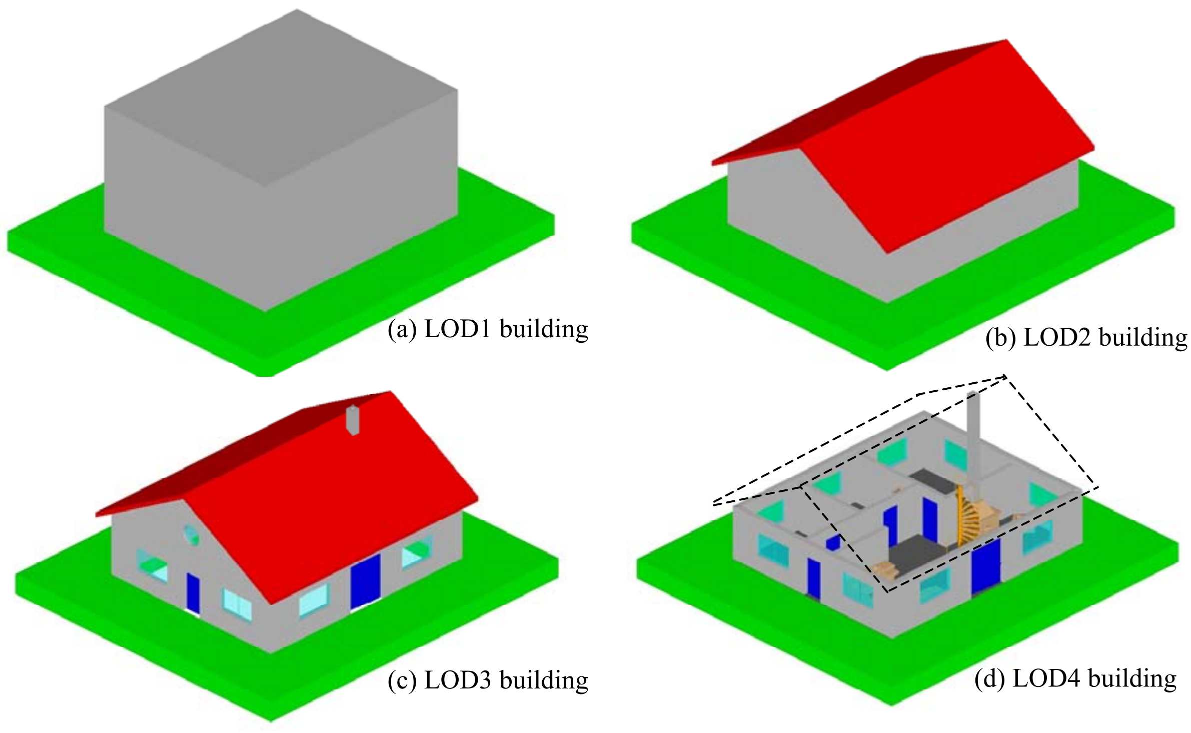


Fig. 27: Building model in LOD1 – LOD4 (source: Research Center Karlsruhe).

Tab. 2 shows the correspondence of the different geometric and semantic themes of the building model to LODs. In each LOD, the volume of a building can be expressed by a *SolidGeometry* and/or a *MultiSurfaceGeometry*. The definition of a 3D Terrain Intersection Curve (TIC), used to integrate buildings from different sources with the Digital Terrain Model, is also possible in all four LODs. The TIC can – but does not have to – build closed rings around the building or building parts.

In LOD1 (see Fig. 27 a), the different structural entities of a building are aggregated to simple blocks and not differentiated in detail. The volumetric and surface parts of the exterior building shell are identical and only one of the corresponding properties (*lod1Solid* or *lod1MultiSurface*) must be used.

In LOD2 and higher levels of detail, the exterior shell of a building is not only represented geometrically as *SolidGeometry* and/or *MultiSurfaceGeometry*, it can also be composed of semantic objects. The base class for all objects semantically structuring the building shell is *_BoundarySurface* (see chapter 9.3.2), which is associated with a *MultiSurfaceGeometry*. If in a building model both a geometric representation of the exterior shell as volume or surface model and a semantic representation by means of thematic *_BoundarySurfaces* exist, the geometric representation must not explicitly define the geometry, but has to reference the *MultiSurfaceGeometry* of the *_BoundarySurfaces*.

Geometric / semantic theme	**Property type**	**LOD 1**	**LOD 2**	**LOD 3**	**LOD 4**
Volume part of the building shell	*gml:SolidType*	•	•	•	•
Surface part of the building shell	*gml:MultiSurfaceType*	•	•	•	•
Terrain Intersection Curve	*gml:MultiCurveType*	•	•	•	•
Curve part of the building shell	*gml:MultiCurveType*		•	•	•
BoundarySurfaces (chapter 9.3.2)	*_BoundarySurfaceType*		•	•	•
Outer building installations (chapter 9.3.3)	*BuildingInstallationType*		•	•	•
Openings (chapter 9.3.4)	*_OpeningType*			•	•
Rooms *(*chapter 9.3.5*)*	*RoomType*				•
Interior building installations (chapter 9.3.5)	*IntBuildingInstallationType*				•

Tab. 2: Semantic themes of the class *AbstractBuilding*.

Apart from *BuildingParts*, smaller features of the building ("outer building installations") can also strongly affect the building characteristic. These features are modelled by the class *BuildingInstallation* (see chapter 9.3.3). Typical candidates for this class are chimneys (see Fig. 27 c), dormers (see Fig. 26), balconies, outer stairs, or antennas. *BuildingInstallations* may only be included in LOD2 models, if their extents exceed the minimum dimensions as specified in chapter 6.1. For the geometrical representation of the class *BuildingInstallation*, an arbitrary geometry object from the GML subset shown in Fig. 8 can be used.

The class *_AbstractBuilding* has no additional properties for LOD3. Besides the higher requirements on geometric precision and smaller minimum dimensions, the main difference of LOD2 and LOD3 buildings concerns the class *_BoundarySurface* (see chapter 9.3.2). In LOD3, openings in a building corresponding with windows or doors (see Fig. 27 c) are modelled by the (abstract) class *_Opening* and the derived classes *Window* and *Door* (see chapter 9.3.4).

With respect to the exterior building shell, the LOD4 data model is identical to that of LOD3. But LOD4 provides for a possibility to describe the interior structure of a building with the classes *IntBuildingInstallation* and *Room* (see chapter 9.3.5).

AddressType, Address

```
<xs:complexType name="AddressType">
  <xs:complexContent>
    <xs:extension base="gml:AbstractFeatureType">
      <xs:sequence>
```

```
        <xs:element name="xalAddress" type="xalAddressPropertyType" />
        <xs:element name="multiPoint" type="gml:MultiPointPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfAddress" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="Address" type="AddressType" substitutionGroup="gml:_Feature" />
<!-- ========================================================================================= -->
<xs:complexType name="xalAddressPropertyType">
  <xs:sequence>
    <xs:element ref="xAL:AddressDetails" />
  </xs:sequence>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAddress" type="xs:anyType" abstract="true"/>
```

Each *Building* or *BuildingPart* feature may be assigned zero or more addresses. Addresses are modelled as GML features having one address property and an optional *multiPoint* property, which allows specification of the exact positions of the building entrances that are associated with the corresponding address. The point coordinates can be 2D or 3D. Modelling addresses as features has the advantage that GML3's method of representing features by reference (using XLinks) can be applied. This means, that addresses might be bundled as an address FeatureCollection that is stored within an external file or that can be served by an external Web Feature Service. The *address* property elements within the CityGML file then would not contain the address information inline but only references to the corresponding external features.

The address information is specified using the *xAL address standard* issued by the OASIS consortium (OASIS 2003), which provides a generic schema for all kinds of international addresses. Therefore, the structure of the child element of the *xALAddress* property has to follow the OASIS xAL schema. Listing 1 and Listing 2 give examples for the representation of German and British addresses in xAL. Generally, if a CityGML instance document contains address information, the namespace prefix "xal:" should be declared in the root element and must refer to "urn:oasis:names:tc:ciq:xsdschema:xAL:2.0". An example showing a complete CityGML building including an address element is provided in chapter 11.4.1.

```
<!-- Bussardweg 7, 76356 Weingarten, Germany -->
<xal:AddressDetails>
  <xal:Country>
    <xal:CountryName>Germany</xal:CountryName>
    <xal:Locality Type="City">
      <xal:LocalityName>Weingarten</xal:LocalityName>
      <xal:Thoroughfare Type="Street">
        <xal:ThoroughfareName>Bussardweg</xal:ThoroughfareName>
        <xal:ThoroughfareNumber>7</xal:ThoroughfareNumber>
      </xal:Thoroughfare>
      <xal:PostalCode>
        <xal:PostalCodeNumber>76356</xal:PostalCodeNumber>
      </xal:PostalCode>
    </xal:Locality>
  </xal:Country>
</xal:AddressDetails>
```

Listing 1: Example for a German address in xAL format.

```
<!-- 46 Brynmaer Road Battersea LONDON, SW11 4EW United Kingdom -->
<xal:AddressDetails>
  <xal:Country>
    <xal:CountryName>United Kingdom</xal:CountryName>
    <xal:Locality Type="City">
      <xal:LocalityName>LONDON</xal:LocalityName>
      <xal:DependentLocality Type="District">
        <xal:DependentLocalityName>
          BATTERSEA
        </xal:DependentLocalityName>
        <xal:Thoroughfare>
          <xal:ThoroughfareName>BRYNMAER ROAD</xal:ThoroughfareName>
          <xal:ThoroughfareNumber>46</xal:ThoroughfareNumber>
        </xal:Thoroughfare>
      </xal:DependentLocality>
      <xal:PostalCode>
        <xal:PostalCodeNumber>SW11 4EW</xal:PostalCodeNumber>
      </xal:PostalCode>
    </xal:Locality>
  </xal:Country>
</xal:AddressDetails>
```

Listing 2: Example for a British address in xAL format (source: http://xml.coverpages.org/xnal.html).

9.3.2 Boundary surfaces

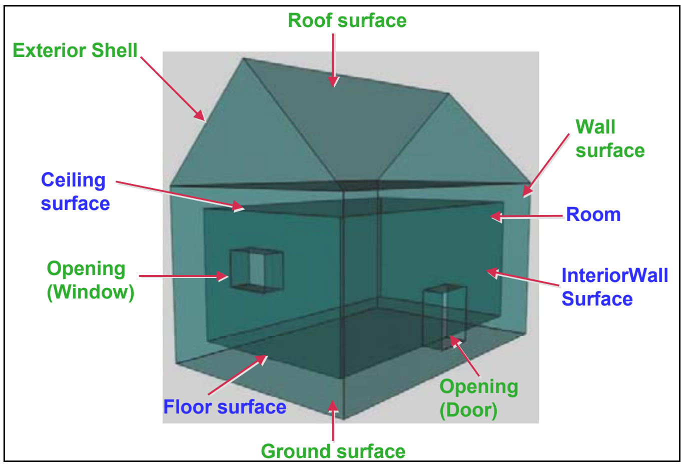
_BoundarySurfaceType, _BoundarySurface

```
<xs:complexType name="_BoundarySurfaceType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="opening" type="OpeningPropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element ref="_GenericApplicationPropertyOfBoundarySurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_BoundarySurface" type="_BoundarySurfaceType" abstract="true" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfBoundarySurface" type="xs:anyType" abstract="true"/>
```

_BoundarySurface is the (abstract) base class for several thematic classes, structuring the exterior shell of a building and the visible surface of a room. It is a subclass of *_CityObject* and thus inherits all properties like the GML3 standard feature properties (*gml:name* etc.) and the CityGML specific properties like *GenericAttributes* and *ExternalReferences*. From *_BoundarySurface*, the thematic classes *RoofSurface, WallSurface, GroundSurface, ClosureSurface, FloorSurface, InteriorWallSurface,* and *CeilingSurface* are derived. The thematic classification of building surfaces is illustrated in Fig. 28 and subsequently specified.

For each LOD between 2 and 4, the geometry of a *_BoundarySurface* may be defined by a different *MultiSurfaceGeometry*. In LOD2, this surface geometry must be simply connected, which means that the components of the *MultiSurface* (e.g. *gml:Polygon*) must not have inner holes (*gml:interior*).

In LOD3 and LOD4, a *_BoundarySurface* may reference *_Openings* (see 9.3.4) like doors and windows. If the geometric location of *_Openings* topologically lies within a surface component (e.g. *gml:Polygon*) of the *MultiSurfaceGeometry,* these *_Openings* must be represented as holes within that surface. A hole is represented by an interior ring within the corresponding surface geometry object. If such an opening is sealed by a *Door*, a *Window*, or a *ClosureSurface*, their outer boundary may consist of the same points as the inner ring (denoting the hole) of the surrounding surface. However, the points have to be specified in reverse order (exterior boundaries counter-clockwise and interior boundaries clockwise when looking in opposite direction of the surface's normal vector). The embrasure surfaces of an *Opening* belong to the relevant adjacent *_BoundarySurface*. If, for example a door seals the *Opening*, the embrasure surface on the one side of the door belongs to the *InteriorWallSurface* and on the other side to the *WallSurface* (Fig. 28 on the right).



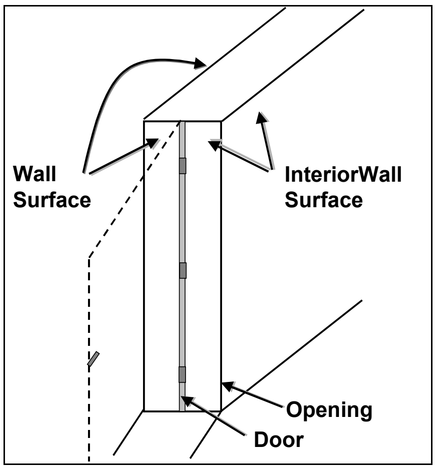


Fig. 28: Classification of *BoundarySurfaces* (left), in particular for *Openings* (right) (graphic: IGG Uni Bonn).

RoofSurfaceType, RoofSurface

```
<xs:complexType name="RoofSurfaceType">
  <xs:complexContent>
    <xs:extension base="_BoundarySurfaceType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfRoofSurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="RoofSurface" type="RoofSurfaceType" substitutionGroup="_BoundarySurface" />
```

```
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfRoofSurface" type="xs:anyType" abstract="true"/>
```

The major roof parts of a building or building part are expressed by the class *RoofSurface*. Secondary parts of a roof with a specific semantic meaning like dormers or chimneys should be modelled as *BuildingInstallations*.

WallSurfaceType, WallSurface

```
<xs:complexType name="WallSurfaceType">
   <xs:complexContent>
      <xs:extension base="_BoundarySurfaceType">
         <xs:sequence>
            <xs:element ref="_GenericApplicationPropertyOfWallSurface" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </ xs:extension >
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="WallSurface" type="WallSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfWallSurface" type="xs:anyType" abstract="true"/>
```

All parts of the building facade visible from the outside are modelled by the class *WallSurface*.

GroundSurfaceType, GroundSurface

```
<xs:complexType name="GroundSurfaceType">
   <xs:complexContent>
      <xs:extension base="_BoundarySurfaceType">
         <xs:sequence>
            <xs:element ref="_GenericApplicationPropertyOfGroundSurface" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="GroundSurface" type="GroundSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfGroundSurface" type="xs:anyType" abstract="true"/>
```

The ground plate of a building or building part is modelled by the class *GroundSurface*. The polygon defining the ground plate is congruent with the building's footprint. However, the surface normal of the ground plate is pointing downwards.

ClosureSurfaceType, ClosureSurface

```
<xs:complexType name="ClosureSurfaceType">
   <xs:complexContent>
      <xs:extension base="_BoundarySurfaceType">
         <xs:sequence>
            <xs:element ref="_GenericApplicationPropertyOfClosureSurface" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="ClosureSurface" type="ClosureSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfClosureSurface" type="xs:anyType" abstract="true"/>
```

An opening in a building not filled by a door or window can be sealed by a virtual surface called *ClosureSurface* (see chapter 6.3). Hence, buildings with open sides like a barn or a hangar, can be virtually closed in order to be able to compute their volume. *ClosureSurfaces* are also used in the interior building model. If two rooms with a different function (e.g. kitchen and living room) are directly connected without a separating door, a *ClosureSurface* should be used to separate or connect the volumes of both rooms.

FloorSurfaceType, FloorSurface

```
<xs:complexType name="FloorSurfaceType">
  <xs:complexContent>
    <xs:extension base="_BoundarySurfaceType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfFloorSurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="FloorSurface" type="FloorSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfFloorSurface" type="xs:anyType" abstract="true"/>
```

The class *FloorSurface* must only be used in the LOD4 interior building model for modelling the floor of a room.

InteriorWallSurfaceType, InteriorWallSurface

```
<xs:complexType name="InteriorWallSurfaceType">
  <xs:complexContent>
    <xs:extension base="_BoundarySurfaceType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfInteriorWallSurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="InteriorWallSurface" type="InteriorWallSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfInteriorWallSurface" type="xs:anyType" abstract="true"/>
```

The class *InteriorWallSurface* must only be used in the LOD4 interior building model for modelling the visible surfaces of the room walls.

CeilingSurfaceType, CeilingSurface

```
<xs:complexType name="CeilingSurfaceType">
  <xs:complexContent>
    <xs:extension base="_BoundarySurfaceType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfCeilingSurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="CeilingSurface" type="CeilingSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfCeilingSurface" type="xs:anyType" abstract="true"/>
```

The class *CeilingSurface* must only be used in the LOD4 interior building model for modelling the ceiling of a room.

9.3.3 Outer building installations

BuildingInstallationType, BuildingInstallation

```
<xs:complexType name="BuildingInstallationType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="BuildingInstallationClassType" minOccurs="0" />
        <xs:element name="function" type="BuildingInstallationFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="BuildingInstallationUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfBuildingInstallation" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="BuildingInstallation" type="BuildingInstallationType" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfBuildingInstallation" type="xs:anyType" abstract="true"/>
```

A *BuildingInstallation* is an outer component of a building which has not the significance of a *BuildingPart*, but which strongly affects the outer characteristic of the building. Examples are chimneys, stairs, antennas, balconies or attached roofs above stairs and paths. A *BuildingInstallation* optionally has attributes *class*, *function* and *usage*. The attribute *class* - which can only occur once - represents a general classification of the installation. With the attributes *function* and *usage*, nominal and real functions of a building installation can be described. For all three attributes the list of feasible values is specified in a GML dictionary. For the geometrical representation of a *BuildingInstallation*, an arbitrary geometry object from the GML subset shown in Fig. 8 can be used.

9.3.4 Openings

_OpeningType, _Opening

```
<xs:complexType name="_OpeningType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfOpening" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_Opening" type="_OpeningType" abstract="true" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfOpening" type="xs:anyType" abstract="true"/>
```

The class *_Opening* is the (abstract) base class for semantically decribing openings like doors or windows in outer or inner walls. Openings only exist in models of LOD3 or LOD4. Each *_Opening* is associated with a *MultiSurfaceGeometry*.

WindowType, Window

```
<xs:complexType name="WindowType">
  <xs:complexContent>
    <xs:extension base="_OpeningType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfWindow" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="Window" type="WindowType" substitutionGroup="_Opening" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWindow" type="xs:anyType" abstract="true"/>
```

The class *Window* is used for modelling windows in the exterior shell of a building, or hatches between adjacent rooms. The formal difference between the classes *Window* and *Door* is that – in normal cases – *Windows* are not specifically intended for the transit of people or vehicles.

DoorType, Door

```
<xs:complexType name="DoorType">
  <xs:complexContent>
    <xs:extension base="_OpeningType">
      <xs:sequence>
        <xs:element name="address" type="AddressPropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element ref="_GenericApplicationPropertyOfDoor" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="Door" type="DoorType" substitutionGroup="_Opening" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfDoor" type="xs:anyType" abstract="true"/>
```

The class *Door* is used for modelling doors in the exterior shell of a building, or between adjacent rooms. Doors can be used by people to enter or leave a building or room. In contrast to a *ClosureSurface* a door may be closed, blocking the transit of people. A *Door* may be assigned zero or more addresses.

9.3.5 Building Interior

RoomType, Room

```
<xs:complexType name="RoomType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="RoomClassType" minOccurs="0" />
        <xs:element name="function" type="RoomFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="RoomUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod4Solid" type="gml:SolidPropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="boundedBy" type="BoundarySurfacePropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="interiorFurniture" type="InteriorFurniturePropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="roomInstallation" type="IntBuildingInstallationPropertyType" minOccurs="0"
                          maxOccurs="unbounded" />
        <xs:element ref="_GenericApplicationPropertyOfRoom" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="Room" type="RoomType" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfRoom" type="xs:anyType" abstract="true"/>
```

A *Room* is a semantic object for modelling the free space inside a building. It should be closed (if necessary by using *ClosureSurfaces*) and the geometry normally will be described by a solid (*lod4Solid*). However, if the topological correctness of the boundary cannot be guaranteed, the geometry can alternatively be given as a *MultiSurface* (*lod4MultiSurface*). The surface normals of the outer shell of a GML solid must point outwards. This is important to consider when *Room* surfaces should be assigned *_Appearances*. In this case, textures and colors must be placed on the backside of the corresponding surfaces in order to be visible from the inside of the room (use the *orientation* attribute of the *appearance* property element).

In addition to the geometrical representation, different parts of the visible surface of a room can be modelled by specialised *BoundarySurfaces* (*FloorSurface*, *CeilingSurface*, *InteriorWallSurface*, see chapter 9.3.2).

A special task is the modelling of passages between adjacent rooms. The room solids are topologically connected by the surfaces representing hatches, doors or closure surfaces that seal open doorways. Rooms are defined as being adjacent, if they have common *Openings* or *ClosureSurfaces*. The surface that represents the opening geometrically is part of the boundaries of the solids of both rooms, or the opening is referenced by both rooms on the semantic level. This adjacency implies an accessibility graph, which can be employed to determine the spread of e.g. smoke or gas, but which can also be used to compute escape routes using classical shortest path algorithms (see Fig. 29).

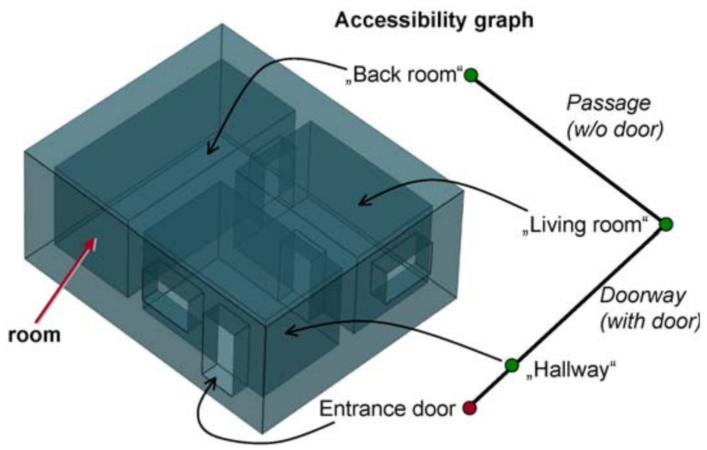


Fig. 29: Accessibility graph derived from topological adjacencies of room surfaces (graphic: IGG Uni Bonn).

BuildingFurnitureType, BuildingFurniture

```
<xs:complexType name="BuildingFurnitureType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="BuildingFurnitureClassType" minOccurs="0" />
        <xs:element name="function" type="BuildingFurnitureFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="BuildingFurnitureUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfBuildingFurniture" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ===================================================================================== -->
<xs:element name="BuildingFurniture" type="BuildingFurnitureType" substitutionGroup="_CityObject" />
<!-- ===================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfBuildingFurniture" type="xs:anyType" abstract="true"/>
```

Rooms may have *BuildingFurnitures* and *IntBuildingInstallations*. A *BuildingFurniture* is a movable part of a room, such as a chair or furniture. *BuildingFurniture* is modelled in the same way as *CityFurniture* (c.f. chapter 9.7).

IntBuildingInstallationType, IntBuildingInstallation

```
<xs:complexType name="IntBuildingInstallationType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="IntBuildingInstallationClassType" minOccurs="0" />
        <xs:element name="function" type="IntBuildingInstallationFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="IntBuildingInstallationUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfIntBuildingInstallation" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ===================================================================================== -->
<xs:element name="IntBuildingInstallation" type="IntBuildingInstallationType" substitutionGroup="_CityObject" />
<!-- ===================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfIntBuildingInstallation" type="xs:anyType" abstract="true"/>
```

An *IntBuildingInstallation* is an object inside a building with a specialized function or semantic meaning. In contrast to *BuildingFurniture*, *IntBuildingInstallations* are permanently attached to the building structure and cannot be moved. Typical examples are interior stairs, railings, radiators or pipes. Objects of the class *IntBuildingInstallation* can either be associated with a room (class *Room*), or with the complete building / building part (class *_AbstractBuilding*, see chapter 9.3.1). An *IntBuildingInstallation* optionally has attributes *class*, *function* and *usage*. The attribute *class,* which can only occur once, represents a general classification of the internal building component. With the attributes *function* and *usage*, nominal and real functions of a building installation can be described. For all three attributes the list of feasible values is specified in a GML dictionary. For the geometrical representation of an *IntBuildingInstallation*, an arbitrary geometry object from the GML subset shown in Fig. 8 can be used.

9.3.6 Modelling building storeys using CityObjectGroups

CityGML does not provide a specific concept for the representation of storeys as it is available in the AEC/FM standard IFC (IAI 2006). However, a storey can be represented as an explicit aggregation of all building features on a certain height level using CityGML's notion of *CityObjectGroups* (cf. chapter 9.9). This would include *Rooms*, *Doors*, *Windows*, *IntBuildingInstallations* and *BuildingFurniture*. If thematic surfaces like walls and interior walls should also be associated to a specific storey, this might require the vertical fragmentation of these surfaces (one per storey), as in virtual 3D city models they typically span the whole façade.

In order to model building storeys with CityGML's generic grouping concept, a nested hierarchy of *CityGMLGroup* objects has to be used. On the first level, all semantic objects belonging to a specific storey are grouped. The attributes of the corresponding *CityObjectGroup* object are set as follows:

- The *class* attribute shall be assigned the value "*building separation*".
- The *function* attribute shall be assigned the value "*lodXStorey*" with X between 1 and 4 in order to denote that this group represents a storey wrt. a specific LOD.
- The storey name or number can be stored in the *gml:name* property.

On the second level, the *CityGMLGroup* objects representing different storeys are grouped itself. By using the generic aggregation concept of *CityGMLGroup,* the "storeys group" is associated with the corresponding *Building* or *BuildingPart* object. The *class* attribute of the storeys group shall be assigned the value "*building storeys*".

9.3.7 External code lists

The building model introduces the following types, whose valid values are explicitly enumerated in an external code list (cf. chapter 6.5 and Annex A):

- BuildingClassType
- BuildingFunctionType
- BuildingUsageType
- RoofTypeType
- BuildingInstallationClassType
- BuildingInstallationFunctionType
- BuildingInstallationUsageType
- IntBuildingInstallationClassType
- IntBuildingInstallationFunctionType
- IntBuildingInstallationUsageType
- BuildingFurnitureClassType
- BuildingFurnitureFunctionType
- BuildingFurnitureUsageType
- RoomClassType
- RoomFunctionType
- RoomUsageType

9.4 Water bodies

Waters have always played an important role in urbanisation processes and cities were built preferably at rivers and places where landfall seemed to be easy. Obviously, water is essential for human alimentation and sanitation. Water bodies present the most economical way of transportation and are barriers at the same time, that avoid instant access to other locations. Bridging waterways caused the first efforts of construction and resulted in high-tech bridges of today. The landscapes of many cities are dominated by water, which directly relates to 3D city models. Furthermore, water bodies are important for urban life as subject of recreation and possible hazards as e.g. floods.

The distinct character of water bodies compared with the permanence of buildings, roadways, and terrain is considered in this thematic model. Water bodies are dynamic surfaces. Tides occur regularly, but irregular events predominate with respect to natural forces, for example flood events. The visible water surface changes in height and its covered area with the necessity to model its semantics and geometry distinct from adjacent objects like terrain or buildings.

This first modelling approach of water bodies fulfils the requirements of 3D city models. It does not inherit any hydrological or other dynamic aspects. In these terms it does not claim to be complete. However, the semantic and geometric description given here allows further enhancements of dynamics and conceptually different descriptions.

The water bodies model represents the thematic aspects and three-dimensional geometry of rivers, canals, lakes, and basins. In the LOD 2-4 water bodies are bounded by distinct thematic surfaces. These surfaces are the obligatory *WaterSurface*, defined as the boundary between water and air, the optional *WaterGroundSurface*, defined as the boundary between water and underground (e.g. DTM or floor of a 3D basin object), and zero or more *WaterClosureSurfaces*, defined as virtual boundaries between different water bodies or between water and the end of a modelled region (see Fig. 30). A dynamic element may be the *WaterSurface* to represent temporarily changing situations of tidal flats.

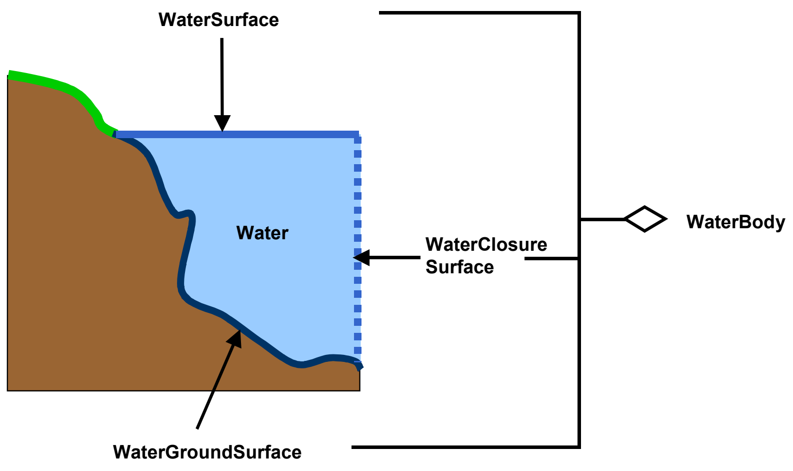


Fig. 30: Illustration of a water body defined in CityGML (graphic: IGG Uni Bonn).

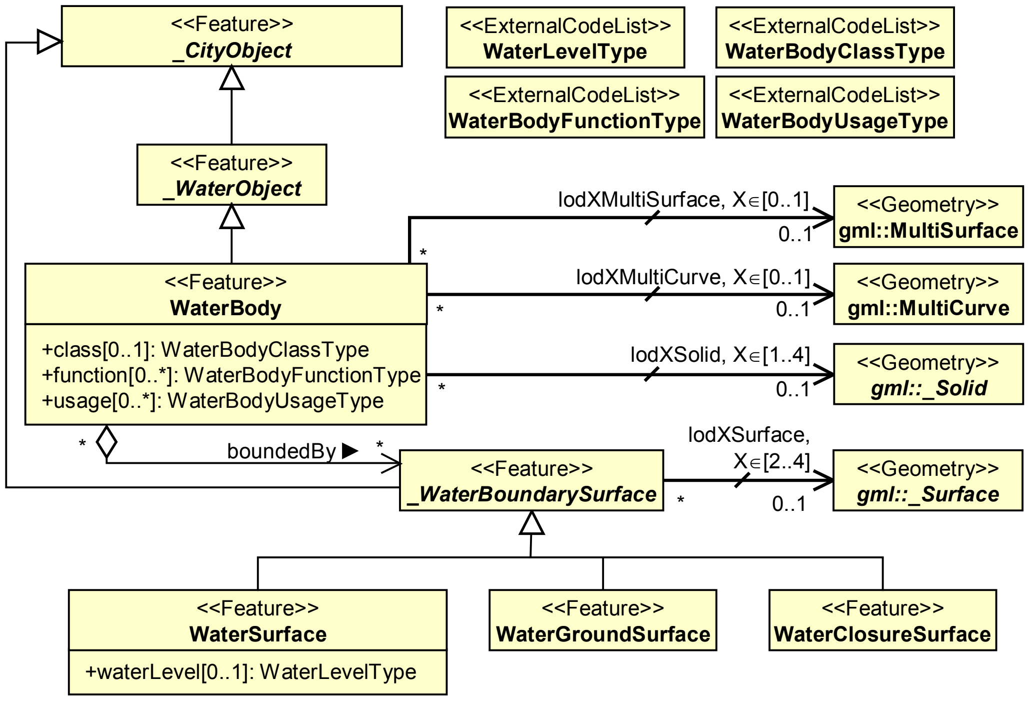
The UML diagram of the water body model is depicted in Fig. 31, for XML schema definition see below and chapter 10.4.5.

Every *WaterBody* object may have the attributes *class*, *function* and *usage* referencing to external code lists (c.f. chapter 9.4.3 and 11.1). The attribute *class* defines the classification of the object, e.g. lake, river, or fountain and can occur only once. The attribute *function* contains the purpose of the object like, for example national waterway or public swimming, while the attribute *usage* defines the actual usages, e.g. whether the water body is navigable. The latter two attributes can occur multiple times.

WaterBody is a subclass of *_WaterObject* and thus of the root class *_CityObject*. The class *_WaterObject* can be differentiated in further subclasses of water objects in the future. The geometrical representation of the *WaterBody* varies through the different levels of detail. Since *WaterBody* is a subclass of *_CityObject* and hence a feature, it inherits the attribute *gml:name*. The *WaterBody* can be differentiated semantically by the class

_WaterBoundarySurface. A *_WaterBoundarySurface* is a part of the water body's exterior shell with a special function like *WaterSurface*, *WaterGroundSurface* or *WaterClosureSurface*. As with any *_CityObject*, *WaterBody* objects as well as *WaterSurface*, *WaterGroundSurface*, and *WaterClosureSurface* may be assigned *External-References* and *GenericAttributes* (c.f. chapter 6.6, 6.10).

The optional attribute *waterLevel* of a *WaterSurface* can be used to describe the water level, for which the given 3D surface geometry was acquired. This is especially important when the water body is influenced by the tide. The allowed values are defined in the respective external code list.



<<Feature>> _CityObject
<<ExternalCodeList>> WaterLevelType
<<ExternalCodeList>> WaterBodyClassType
<<ExternalCodeList>> WaterBodyFunctionType
<<ExternalCodeList>> WaterBodyUsageType
<<Feature>> _WaterObject
lodXMultiSurface, X∈[0..1]
0..1
*
<<Geometry>> gml::MultiSurface
<<Feature>> WaterBody
+class[0..1]: WaterBodyClassType
+function[0..*]: WaterBodyFunctionType
+usage[0..*]: WaterBodyUsageType
lodXMultiCurve, X∈[0..1]
<<Geometry>> gml::MultiCurve
lodXSolid, X∈[1..4]
<<Geometry>> gml::_Solid
boundedBy ▶
lodXSurface, X∈[2..4]
<<Feature>> _WaterBoundarySurface
<<Geometry>> gml::_Surface
<<Feature>> WaterSurface
+waterLevel[0..1]: WaterLevelType
<<Feature>> WaterGroundSurface
<<Feature>> WaterClosureSurface

Fig. 31: UML diagram of the water body model in CityGML.

Both LOD0 and LOD1 represent a low level of illustration and high grade of generalization. Here the rivers are modelled as *MultiCurve* geometry and brooks are omitted. Seas, oceans and lakes with significant extent are represented as a *MultiSurface* (Fig. 31). Every *WaterBody* may be assigned a combination of geometries of different types. Linear water bodies are represented as a network of 3D curves. Each curve is composed of straight line segments, where the line orientation denotes the flow direction (water flows from the first point of a curve, e.g. a *gml:LineString,* to the last). Areal objects like lakes or seas are represented by 3D surface geometries of the water surface.

Starting from LOD1 water bodies may also be modelled as water filled volumes represented by *Solids*. If a water body is represented by a *Solid* in LOD2 or higher, the surface geometries of the corresponding thematic *Water-ClosureSurface*, *WaterGroundSurface*, and *WaterSurface* objects must coincide with the exterior shell of the *Solid*. This can be ensured, if for one LOD X the respective *lodXSurface* elements (where *X* is between 2 and 4) of *WaterClosureSurface*, *WaterGroundSurface*, and *WaterSurface* do not redundantly define *gml:Polygons,* but instead reference the corresponding polygons (using XLink) within the *CompositeSurface* that defines the exterior shell of the *Solid*.

LOD2 to LOD4 demand a higher grade of detail and therefore any *WaterBody* will be outlined by thematic surfaces or a solid composed of the surrounding thematic surfaces.

The special UML notations for LOD associations mean that there exists one association for each of the listed LOD (cf. chapter 4.2). Every object of the class *WaterSurface, WaterClosureSurface*, and *WaterGroundSurface* must have at least one associated surface geometry. This means, that every *WaterSurface, WaterClosureSurface*, and *WaterGroundSurface* feature within a CityGML instance document must contain at least one of the following properties: *lod2Surface*, *lod3Surface*, *lod4Surface*.

The water body model implicitly includes the concept of *TerrainIntersectionCurves* (TIC), e.g. to specify the exact intersection of the DTM with the 3D geometry of a *WaterBody* or to adjust a *WaterBody* or *WaterSurface* to the surrounding DTM (see chapter 6.4). The rings defining the *WaterSurface* polygons implicitly delineate the intersection of the water body with the terrain or basin.

9.4.1 Water body

_WaterObjectType, _WaterObject

```
<xs:complexType name="_WaterObjectType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfWaterObject" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="_WaterObject" type="_WaterObjectType" substitutionGroup="_CityObject" />
<!-- ====================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterObject" type="xs:anyType" abstract="true"/>
```

WaterBodyType, WaterBody

```
<xs:complexType name="WaterBodyType">
  <xs:complexContent>
    <xs:extension base="_WaterObjectType">
      <xs:sequence>
        <xs:element name="class" type="WaterBodyClassType" minOccurs="0" />
        <xs:element name="function" type="WaterBodyFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="WaterBodyUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod0MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
        <xs:element name="lod0MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod1MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
        <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod1Solid" type="gml:SolidPropertyType" minOccurs="0" />
        <xs:element name="lod2Solid" type="gml:SolidPropertyType" minOccurs="0" />
        <xs:element name="lod3Solid" type="gml:SolidPropertyType" minOccurs="0" />
        <xs:element name="lod4Solid" type="gml:SolidPropertyType" minOccurs="0" />
        <xs:element name="boundedBy" type="BoundedByWaterSurfacePropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element ref="_GenericApplicationPropertyOfWaterBody" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="WaterBody" type="WaterBodyType" substitutionGroup="_WaterObject" />
<!-- ====================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterBody " type="xs:anyType" abstract="true"/>
```

9.4.2 Boundary surfaces

With respect to different functions and characteristics three boundary classes for water are defined to build a solid or composite surface geometry (Fig. 30).

1. Boundary class “Air to Water”. The *WaterSurface* is mandatory to the model and usually is registered using photogrammetric analysis or mapping exploration. The representation may vary due to tidal flats or changing water levels, which can be reflected by including different static water surfaces having different *waterLevels* (*WaterLevelType)*, as for example highest flooding event, mean sea level, or minimum water level, given in an external code list. This offers the opportunity to describe significant water surfaces due to levels that are important for certain representations e.g. in tidal zones.
2. Boundary class “Water to Ground”. The *WaterGroundSurface* may be known by sonar exploration or other depth measurements. Also part of the ground surface is the boundary “Water to Building”. The ground surface might be identical to the underwater terrain model, but also describes the contour to other underwater objects. The usefulness of this concept arises from the existence of water defence buildings like sluices, sills, flood barrage or tidal power stations. The use of *WaterGroundSurface* as boundary layer to buildings is

relevant in urban situations, where buildings enclose the defined water completely such as fountains and swimming pools. Together, the *WaterSurface* and *WaterGroundSurface* enclose the *WaterBody* as a volume.

3. Boundary class “Water to Water”. The *WaterClosureSurface* is an optional feature that comes in use, when the union of the *WaterSurfaces* and *WaterGroundSurfaces* of a water body does not define a closed volume. The *WaterClosureSurface* is then used to complete the enclosure of water volumes and to separate water volumes from those where only the surface is known. This might occur, where the cross section and ground surface of rivers is partly available during its course.

_WaterBoundarySurfaces shall only be included as parts of corresponding *WaterBody* objects and may not be used as stand-alone objects within a CityGML model.

_WaterBoundarySurfaceType, _WaterBoundarySurface

```
<xs:complexType name="_WaterBoundarySurfaceType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="lod2Surface" type="gml:SurfacePropertyType" minOccurs="0" />
        <xs:element name="lod3Surface" type="gml:SurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4Surface" type="gml:SurfacePropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfWaterBoundarySurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_WaterBoundarySurface" type="_WaterBoundarySurfaceType" abstract="true" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterBoundarySurface" type="xs:anyType" abstract="true"/>
```

WaterSurfaceType, WaterSurface

```
<xs:complexType name="WaterSurfaceType">
  <xs:complexContent>
    <xs:extension base="_WaterBoundarySurfaceType">
      <xs:sequence>
        <xs:element name="waterLevel" type="WaterLevelType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfWaterSurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="WaterSurface" type="WaterSurfaceType" substitutionGroup="_WaterBoundarySurface" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterSurface" type="xs:anyType" abstract="true"/>
```

WaterGroundSurfaceType, WaterGroundSurface

```
<xs:complexType name="WaterGroundSurfaceType">
  <xs:complexContent>
    <xs:extension base="_WaterBoundarySurfaceType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfWaterGroundSurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="WaterGroundSurface" type="WaterGroundSurfaceType" substitutionGroup="_WaterBoundarySurface" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterGroundSurface" type="xs:anyType" abstract="true"/>
```

WaterClosureSurfaceType, WaterClosureSurface

```
<xs:complexType name="WaterClosureSurfaceType">
  <xs:complexContent>
```

```
    <xs:extension base="_WaterBoundarySurfaceType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfWaterClosureSurface" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="WaterClosureSurface" type="WaterClosureSurfaceType" substitutionGroup="_WaterBoundarySurface" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterClosureSurface" type="xs:anyType" abstract="true"/>
```

9.4.3 External code lists

The water bodies model introduces the following types, whose valid values are explicitly enumerated in an external code list (cf. chapter 6.5 and Annex A):

- WaterLevelType
- WaterBodyClassType
- WaterBodyFunctionType
- WaterBodyUsageType

9.5 Transportation objects

The transportation model of CityGML is a multi-functional, multi-scale model focusing on thematic and functional as well as on geometrical/topological aspects. Transportation features are represented as a linear network in LOD0. Starting from LOD1, all transportation features are geometrically described by 3D surfaces. The areal modelling of transportation features allows for the application of geometric route planning algorithms. This can be useful to determine constrictions and manoeuvres required along a transportation route. This information can also be employed for trajectory planning of mobile robots in the real world or the automatic placement of avatars (virtual people) or vehicle models in 3D visualizations and training simulators.

The main class is *TransportationComplex*, which represents, for example, a road, a track, a railway, or a square. Fig. 32 illustrates the four different thematic classes.

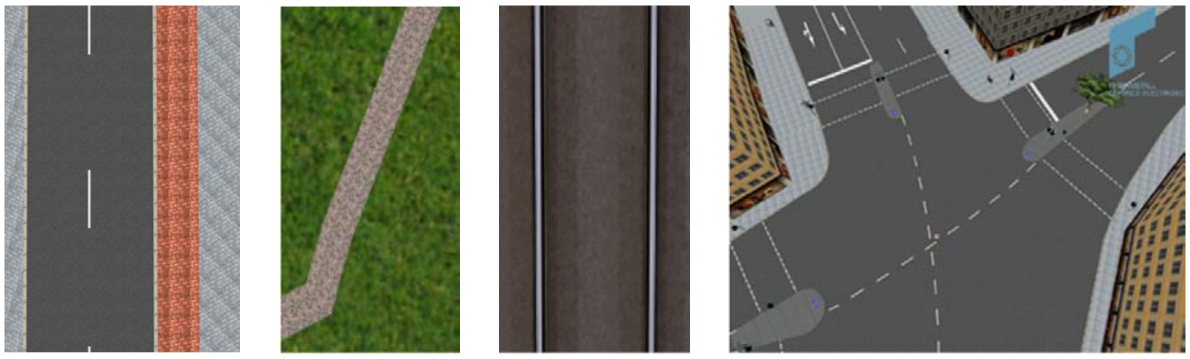


Fig. 32: Representations of *TransportationComplex* (from left to right: examples of road, track, rail, and square) (source: Rheinmetall Defence Electronics).

A *TransportationComplex* is composed of the parts *TrafficArea* and *AuxiliaryTrafficArea*. Fig. 33 depicts an example for a LOD2 *TransportationComplex* configuration within a virtual 3D city model. The *Road* consists of several *TrafficAreas* for the sidewalks, road lanes, parking lots, and of *AuxiliaryTrafficAreas* below the raised flower beds.

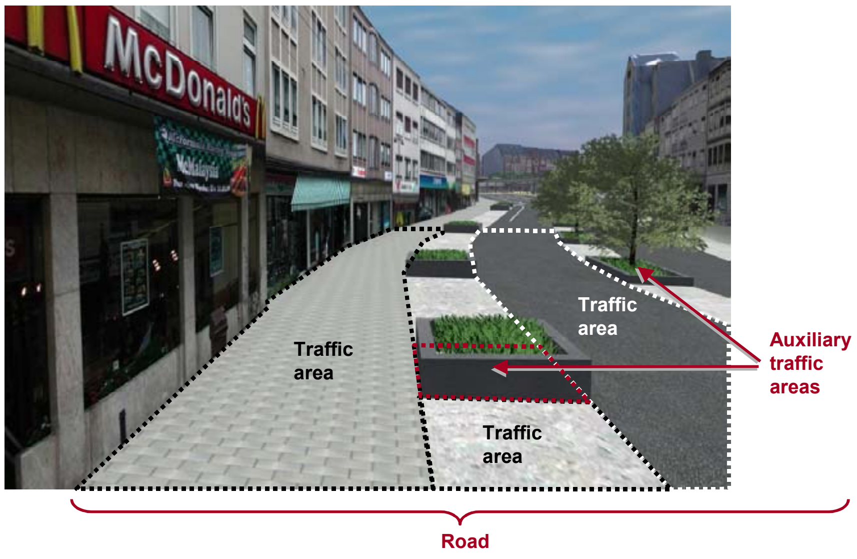
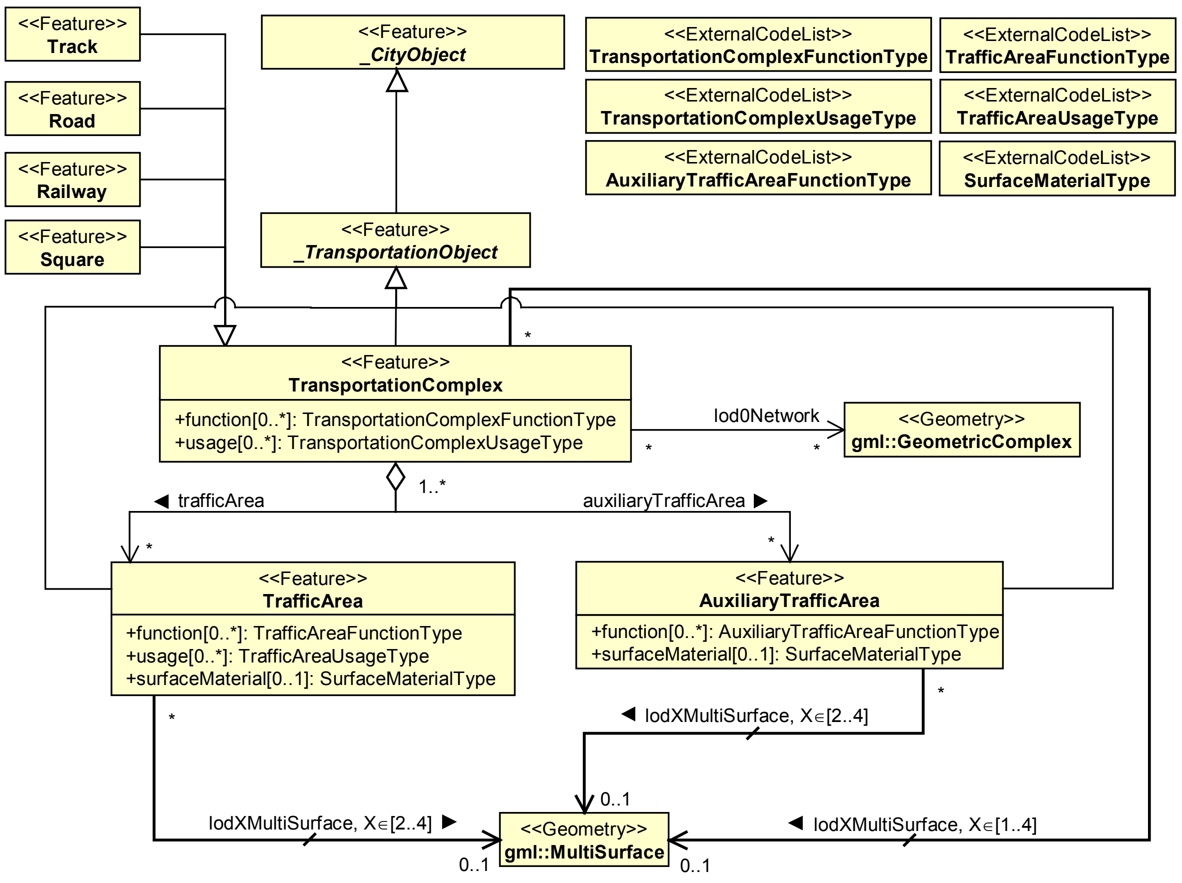


Fig. 33: Example for the representation of a *TransportationComplex* in LOD2 in CityGML: a road, which is the aggregation of *TrafficAreas* and *AuxiliaryTrafficAreas* (source: City of Solingen, IGG Uni Bonn).

Fig. 34 depicts the UML diagram of the transportation model, for XML schema definition see chapter 10.4.3.



<<Feature>> Track
<<Feature>> Road
<<Feature>> Railway
<<Feature>> Square
<<Feature>> _CityObject
<<Feature>> _TransportationObject
<<ExternalCodeList>> TransportationComplexFunctionType
<<ExternalCodeList>> TrafficAreaFunctionType
<<ExternalCodeList>> TransportationComplexUsageType
<<ExternalCodeList>> TrafficAreaUsageType
<<ExternalCodeList>> AuxiliaryTrafficAreaFunctionType
<<ExternalCodeList>> SurfaceMaterialType
<<Feature>> TransportationComplex
+function[0..*]: TransportationComplexFunctionType
+usage[0..*]: TransportationComplexUsageType
lod0Network
<<Geometry>> gml::GeometricComplex
trafficArea
auxiliaryTrafficArea
1..*
<<Feature>> TrafficArea
+function[0..*]: TrafficAreaFunctionType
+usage[0..*]: TrafficAreaUsageType
+surfaceMaterial[0..1]: SurfaceMaterialType
<<Feature>> AuxiliaryTrafficArea
+function[0..*]: AuxiliaryTrafficAreaFunctionType
+surfaceMaterial[0..1]: SurfaceMaterialType
lodXMultiSurface, X∈[2..4]
lodXMultiSurface, X∈[2..4]
lodXMultiSurface, X∈[1..4]
<<Geometry>> gml::MultiSurface
0..1

Fig. 34: UML diagram of the transportation model in CityGML.

The road itself is represented as a *TransportationComplex*, which is further subdivided into *TrafficAreas* and *AuxiliaryTrafficAreas*. The *TrafficAreas* are those elements, which are important in terms of traffic usage, like car driving lanes, pedestrian zones and cycle lanes. The *AuxiliaryTrafficAreas* are describing further elements of the road, like kerbstones, middle lanes, and green areas.

TransportationComplex objects can be thematically differentiated using the subclasses *Track, Road, Railway,* and *Square.* Every *TransportationComplex* has the attributes *function* and *usage*, referencing to external code lists (chapter 9.5.3 and 11.1). The attribute *function* describes the purpose of the object like, for example national motorway, country road, or airport, while the attribute *usage* can be used, if the way the object is actually used differs from the function. Both attributes can occur multiple times.

In addition every *TrafficArea* may have the attributes *function*, *usage*, and *surfaceMaterial*. The *function* describes, if the object may be a car driving lane, a pedestrian zones, or a cycle lane, while the *usage* attribute indicates which modes of transportation can use it (e.g. pedestrian, car, tram, roller skates). The attribute *surfaceMaterial* specifies the type of pavement and may also be used for *AuxiliaryTrafficAreas* (e.g. asphalt, concrete, gravel, soil, rail, grass etc.). The *function* attribute of the *AuxiliaryTrafficArea* defines, for example kerbstones, middle lanes, or green areas. The possible values are also specified in external code lists.

The shape of each traffic area is defined by an area geometry. Additional metadata may be defined by using attributes from pre-defined catalogues. This affects the function of the area, the usage and surface material definition for each area. The attribute catalogues may be customer- or country-specific. The following tables show examples for various kinds of *TrafficArea*:

Example:	Country road	Motorway entry
TransportationComplex – Function	road	road
TrafficArea – Usage	car, truck, bus, taxi, motorcycle	car, truck, bus, taxi, motorcycle
TrafficArea – Function	driving lane	motorway_entry
TrafficArea – SurfaceMaterial	asphalt	concrete

Example:	Runway of an airport	Apron of an airport
TransportationComplex – Function	road	apron
TrafficArea – Usage	aeroplane	aeroplane, car, truck, bus, pedestrian
TrafficArea – Function	airport – runway	airport – apron
TrafficArea – SurfaceMaterial	concrete	concrete

TransportationComplex is a subclass of *_TransportationObject* and of the root class *_CityObject*. The geometrical representation of the *TransportationComplex* varies through the different levels of detail. Since *TransportationComplex* is a subclass of *_CityObject* and hence a feature, it inherits the attribute *gml:name.* The street name is also stored within the *gml:name* property of the Road feature.

In the coarsest LOD0 the transportation complexes are modelled by line objects establishing a linear network. On this abstract level, path finding algorithms or similar analyses can be executed. It also can be used to generate schematic drawings and visualisations of the transport network. Since this abstract definition of transportation network does not contain explicit description of the transportation objects, it may be task of the viewer application to generate the graphical visualisation, for example by using a library with style-definitions (width, color resp. texture) for each transportation object.

Starting from LOD1 a *TransportationComplex* provides an explicit surface geometry, reflecting the actual shape of the object, not just its centerline. In LOD2 to LOD4, it is further subdivided thematically into *TrafficAreas*, which are used by transportation, such as cars, trains, public transport, airplanes, bicycles or pedestrians and in *AuxiliaryTrafficAreas*, which are of minor importance for transportation purposes, for example road markings, green spaces or flower tubs. The different representations of a *TransportationComplex* for each LOD are illustrated in Fig. 35.

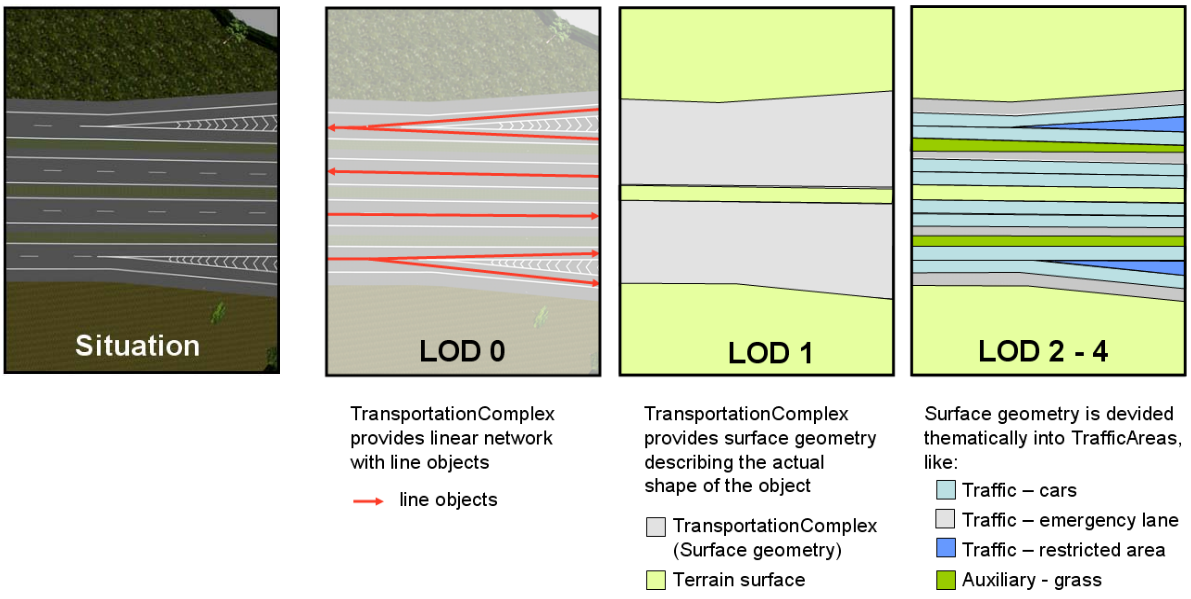

Situation
LOD 0
LOD 1
LOD 2 - 4
TransportationComplex provides linear network with line objects
line objects
TransportationComplex provides surface geometry describing the actual shape of the object
TransportationComplex (Surface geometry)
Terrain surface
Surface geometry is devided thematically into TrafficAreas, like:
Traffic – cars
Traffic – emergency lane
Traffic – restricted area
Auxiliary - grass

Fig. 35: *TransportationComplex* in LOD0, 1, and 2-4 (example shows part of a motorway) (source: Rheinmetall Defence Electronics).

In LOD0 areal transportation objects like squares should be modelled in the same way as in GDF, the ISO standard for transportation networks, which is used in most car navigation systems. In GDF a square is typically represented as a ring surrounding the place and to which the incident roads connect. CityGML does not cover further functional aspects of transportation network models (e.g. speed limits) as it is intended to complement and not replace existing standards like GDF. However, if specific functional aspects have to be associated with CityGML transportation objects, *GenericAttributes* can be used or further objects of interest can be added from other information systems by the use of *ExternalReferences* (see chapter 6.10 and 6.6). For example, GDF datasets, which provide additional information for car navigation, can be used for simulation and visualisation of traffic flows. The values of the object attributes can be augmented using the concept of dictionaries (see chapter 6.5). These directories may be country- or user-specific (especially for country-specific road signs and signals).

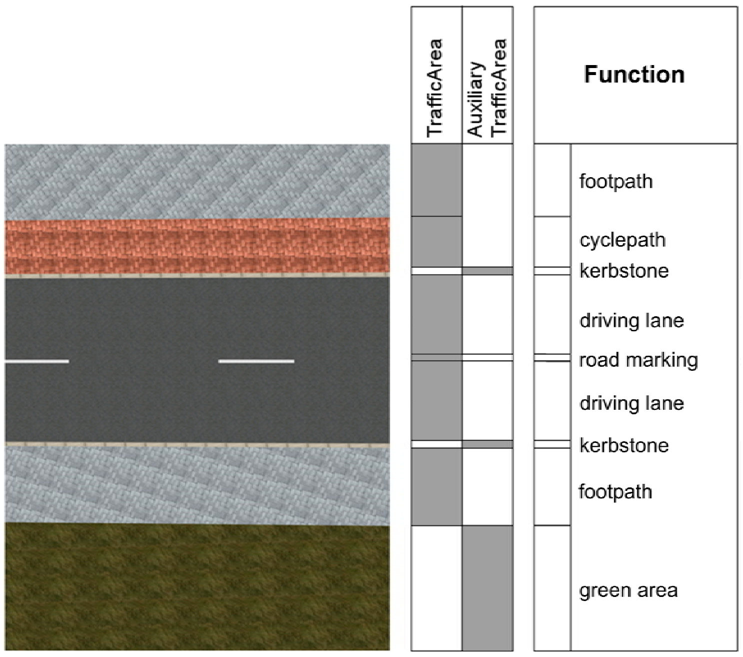


Fig. 36: *TransportationComplex* in LOD 2-4: representation of a road with a complex cross-section profile (example shows urban road) (source: Rheinmetall Defence Electronics).

The following example shows a complex urban crossing. The picture on the left is a screenshot of an editor application for a training simulator, which allows the definition of road networks consisting of transportation objects, external references, buildings and vegetation objects. On the right, the 3D representation of the defined crossing is shown including all referenced static and dynamic models.

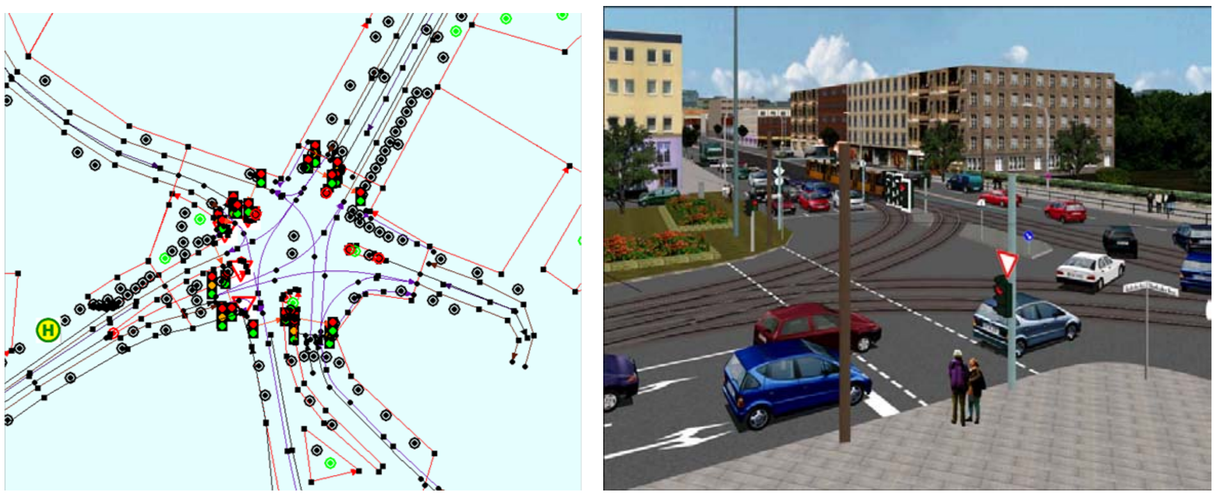


Fig. 37: Complex urban intersection (left: linear transportation network with surface descriptions and external references, right: generated scene) (source: Rheinmetall Defence Electronics).

9.5.1 Transportation complex

_TransportationObjectType, _TransportationObject

```
<xs:complexType name="_TransportationObjectType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfTransportationObject" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
```

```
<!-- ========================================================================================= -->
<xs:element name="_TransportationObject" type="_CityObjectType" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTransportationObject" type="xs:anyType" abstract="true"/>
```

_TransportationObject represents the abstract superclass for transportation objects. Future extensions of the CityGML transportation model shall be modelled as subclasses of this class.

TransportationComplexType, TransportationComplex

```
<xs:complexType name="TransportationComplexType">
  <xs:complexContent>
    <xs:extension base="_TransportationObjectType">
      <xs:sequence>
        <xs:element name="function" type="TransportationComplexFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="TransportationComplexUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="trafficArea" type="TrafficAreaPropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="auxiliaryTrafficArea" type="AuxiliaryTrafficAreaPropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod0Network" type="gml:GeometricComplexPropertyType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfTransportationComplex" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="TransportationComplex" type="TransportationComplexType" substitutionGroup="_TransportationObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTransportationComplex" type="xs:anyType" abstract="true"/>
```

This type and element describes transportation complexes like roads or railways which may be aggregated from different thematic components (traffic areas, e.g. pedestrian path, and auxiliary traffic areas). As a subclass of *_CityObject*, *TransportationComplex* inherits all attributes and relations, in particular an id, names, external references, generic attributes and generalisation relations. Furthermore, it represents the superclass for thematically distinct types of transportation complexes.

TrackType, Track

```
<xs:complexType name="TrackType">
  <xs:complexContent>
    <xs:extension base="TransportationComplexType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfTrack" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="Track" type="TrackType" substitutionGroup="TransportationComplex" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTrack" type="xs:anyType" abstract="true"/>
```

A *Track* is a small path mainly used by pedestrians. It is a subclass of *TransportationComplex* and thus inherits all its attributes and relations.

RoadType, Road

```
<xs:complexType name="RoadType">
  <xs:complexContent>
    <xs:extension base="TransportationComplexType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfRoad" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="Road" type="RoadType" substitutionGroup="TransportationComplex" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfRoad" type="xs:anyType" abstract="true"/>
```

Road is intended to be used to represent transportation features that are mainly used by vehicles like cars, for example streets, motorways, and country roads. It is a subclass of *TransportationComplex* and thus inherits all its attributes and relations.

RailwayType, Railway

```
<xs:complexType name="RailwayType">
  <xs:complexContent>
    <xs:extension base="TransportationComplexType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfRailway" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="Railway" type="RailwayType" substitutionGroup="TransportationComplex" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfRailway" type="xs:anyType" abstract="true"/>
```

Railway represents routes that are utilised by rail vehicles like trams or trains. It is a subclass of *Transportation-Complex* and thus inherits all its attributes and relations.

SquareType, Square

```
<xs:complexType name="SquareType">
  <xs:complexContent>
    <xs:extension base="TransportationComplexType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfSquare" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="Square" type="SquareType" substitutionGroup="TransportationComplex" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfSquare" type="xs:anyType" abstract="true"/>
```

A *Square* is an open area commonly found in cities (e.g. a plaza, market square). It is a subclass of *Transporta-tionComplex* and thus inherits all its attributes and relations.

9.5.2 Subclasses of transportation complexes

TrafficAreaType, TrafficArea

```
<xs:complexType name="TrafficAreaType">
  <xs:complexContent>
    <xs:extension base="_TransportationObjectType">
      <xs:sequence>
        <xs:element name="usage" type="TrafficAreaUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="function" type="TrafficAreaFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="surfaceMaterial" type="TrafficSurfaceMaterialType" minOccurs="0" />
        <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfTrafficArea" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="TrafficArea" type="TrafficAreaType" substitutionGroup="_TransportationObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTrafficArea" type="xs:anyType" abstract="true"/>
```

AuxiliaryTrafficAreaType, AuxiliaryTrafficArea

```
<xs:complexType name="AuxiliaryTrafficAreaType">
  <xs:complexContent>
    <xs:extension base="_TransportationObjectType">
      <xs:sequence>
        <xs:element name="function" type="AuxiliaryTrafficAreaFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="surfaceMaterial" type="TrafficSurfaceMaterialType" minOccurs="0" />
        <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfAuxiliaryTrafficArea" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="AuxiliaryTrafficArea" type="AuxiliaryTrafficAreaType" substitutionGroup="_TransportationObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAuxiliaryTrafficArea" type="xs:anyType" abstract="true"/>
```

9.5.3 External code lists

The transportation model introduces the following types, whose valid values are explicitly enumerated in an external code list (cf. chapter 6.5 and Annex A):

- TransportationComplexFunctionType
- TransportationComplexUsageType
- TrafficAreaFunctionType
- TrafficAreaUsageType
- AuxiliaryTrafficAreaFunctionType
- SurfaceMaterialType

9.6 Vegetation objects

Vegetation features are important components of a 3D city model, since they support the recognition of the surrounding environment. By the analysis and visualisation of vegetation objects, statements on their distribution, structure and diversification can be made. Habitats can be analysed and impacts on the fauna can be derived. The vegetation model may be used as a basis for simulations of, for example forest fire, urban aeration or micro climate. The model could be used, for example to examine forest damage, to detect obstacles (e.g. concerning air traffic) or to perform analysis tasks in the field of environmental protection.

The vegetation model of CityGML distinguishes between solitary vegetation objects like trees and vegetation areas, which represent biotopes like forests or other plant communities (Fig. 38). Single vegetation objects are modelled by the class *SolitaryVegetationObject*, while for areas filled with a specific vegetation the class *PlantCover* is used. The geometry representation of a *PlantCover* feature may be a MultiSurface or a MultiSolid, depending on the vertical extent of the vegetation. For example regarding forests, a MultiSolid representation might be more appropriate. The UML diagram of the vegetation model is depicted in Fig. 39, for XML schema definition see below or chapter 10.4.4.

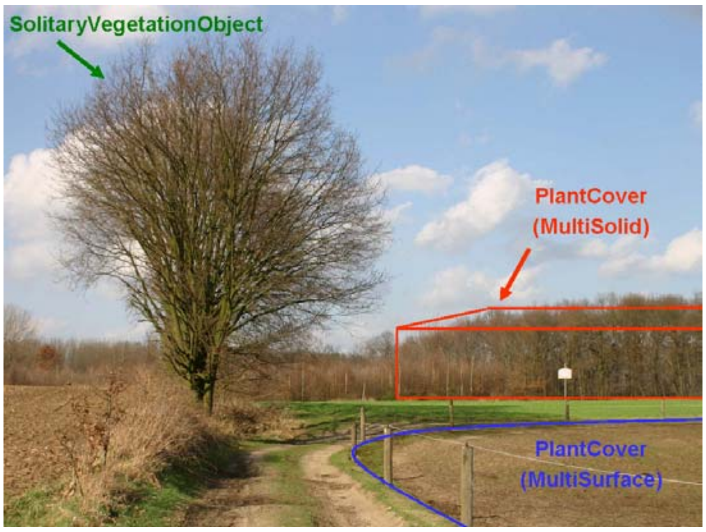
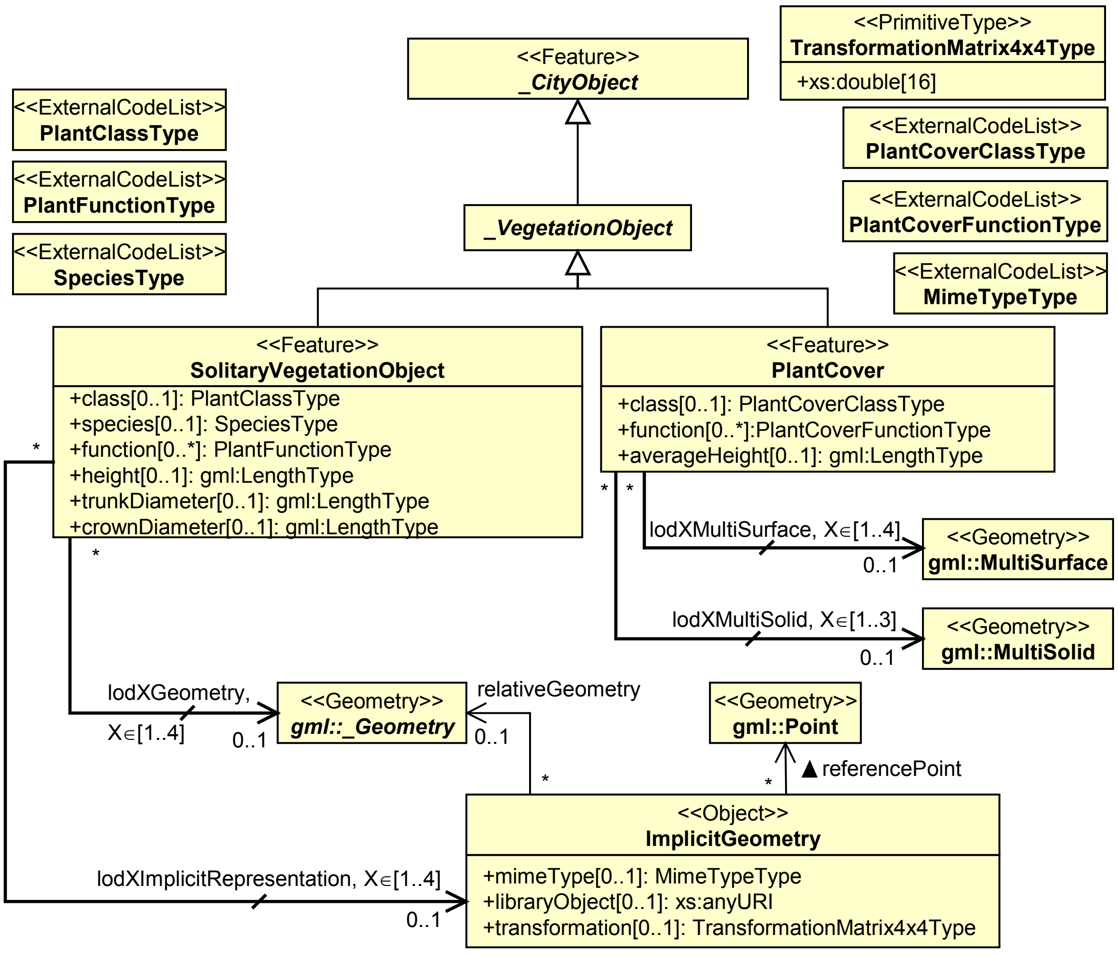


Fig. 38: Example for vegetation objects of the classes *SolitaryVegetationObject* and *PlantCover* (graphic: District of Recklinghausen).

A *SolitaryVegetationObject* may have the attributes *class*, *species, function, height*, *trunkDiameter* and *crownDiameter*. The attribute *class* contains the coarse classification of the object or plant habit, e.g. tree, bush, grass, and can occur only once (see external code list in chapter 9.6.4 and 11.1). The attribute *species* defines the species' name, for example "Abies alba", and can occur at most once (see external code list in chapter 9.6.4 and 11.1). The hierarchy between *class* and *species* is not reflected in the external code lists, thus inconsistencies have to be checked by application tools. The optional attribute *function* denotes the purpose of the object, for example botanical monument, and can occur multiple times. The attribute *height* contains the relative height of the object. The attributes *crownDiameter* and *trunkDiameter* represent the plant crown and trunk diameter respectively. The trunk diameter is often used in regulations of municipal cadastre (e.g. tree management rules).

A *PlantCover* feature may have the attributes *class, function* and *averageHeight*. The plant community of a *PlantCover* is represented by the attribute *class.* The values of this attribute are enumerated in an external code list (chapter 9.6.4 and 11.1), where each value describes not only one plant type or species, but denotes a typical mixture of plant types in a plant community. This information can be used in particular to generate realistic 3D visualisations, where the *PlantCover* region is automatically, perhaps randomly, filled with a corresponding mixture of 3D plant objects. The attribute *function* indicates the purpose of the object, for example national forest, and can occur multiple times. The attribute *averageHeight* denotes the average relative vegetation height.

Since both *SolitaryVegetationObject* and *PlantCover* are *CityObjects*, they inherit all attributes of a city object, in particular a name (*gml:name)* and an *ExternalReference* to a corresponding object in an external information system, which may contain botanical information from public environmental agencies (see chapter 6.6).



<<ExternalCodeList>> PlantClassType
<<ExternalCodeList>> PlantFunctionType
<<ExternalCodeList>> SpeciesType
<<Feature>> _CityObject
_VegetationObject
<<PrimitiveType>> TransformationMatrix4x4Type
+xs:double[16]
<<ExternalCodeList>> PlantCoverClassType
<<ExternalCodeList>> PlantCoverFunctionType
<<ExternalCodeList>> MimeTypeType
<<Feature>> SolitaryVegetationObject
+class[0..1]: PlantClassType
+species[0..1]: SpeciesType
+function[0..*]: PlantFunctionType
+height[0..1]: gml:LengthType
+trunkDiameter[0..1]: gml:LengthType
+crownDiameter[0..1]: gml:LengthType
<<Feature>> PlantCover
+class[0..1]: PlantCoverClassType
+function[0..*]:PlantCoverFunctionType
+averageHeight[0..1]: gml:LengthType
lodXMultiSurface, X∈[1..4]
0..1
<<Geometry>> gml::MultiSurface
lodXMultiSolid, X∈[1..3]
0..1
<<Geometry>> gml::MultiSolid
lodXGeometry, X∈[1..4]
0..1
<<Geometry>> gml::_Geometry
relativeGeometry
0..1
<<Geometry>> gml::Point
▲referencePoint
<<Object>> ImplicitGeometry
+mimeType[0..1]: MimeTypeType
+libraryObject[0..1]: xs:anyURI
+transformation[0..1]: TransformationMatrix4x4Type
lodXImplicitRepresentation, X∈[1..4]
0..1

Fig. 39: UML diagram of vegetation objects in CityGML.

The geometry of a *SolitaryVegetationObject* may be defined in LOD 1-4 explicitly by a GML geometry having absolute coordinates, or prototypically by an *ImplicitGeometry* (see chapter 7.2). Solitary vegetation objects probably are one of the most important features where implicit geometries are appropriate, since the shape of the most types of vegetation objects, such as trees of the same species, can be treated as identical in most cases. Furthermore, season dependent appearances may by mapped using *ImplicitGeometries.* For visualisation purposes, only the content of the library object defining the object's shape and appearance has to be swapped (cf. Fig. 40).

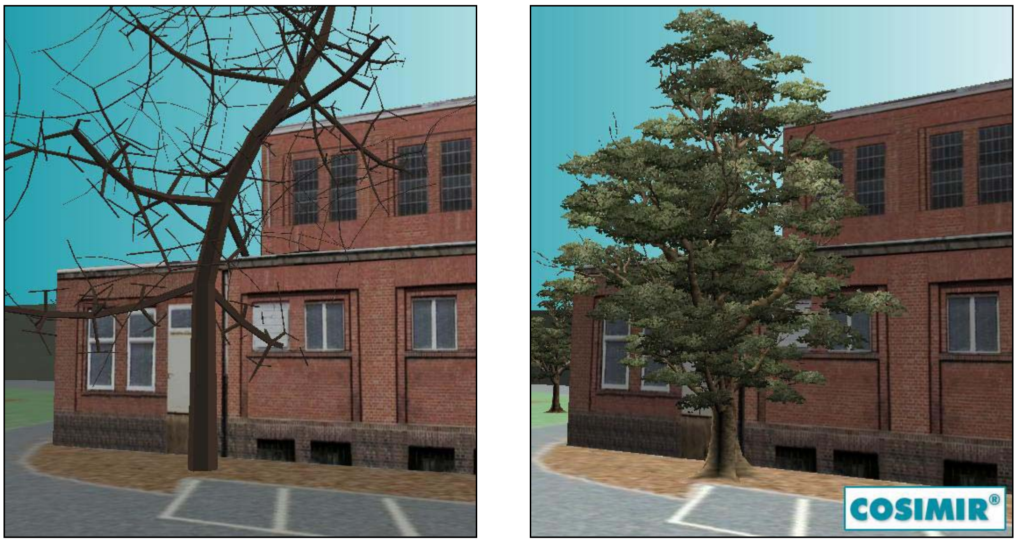


Fig. 40: Visualisation of a vegetation object in different seasons (source: District of Recklinghausen).

A *SolitaryVegetationObject* or a *PlantCover* may have a different geometry in each LOD, as indicated by the dashed lines in Fig. 39. Whereas a *SolitaryVegetationObject* is associated with the *_Geometry* class representing an arbitrary GML geometry (by the relation *lodXGeometry*), a *PlantCover* is restricted to be either a *MultiSolid* or a *MultiSurface.* An example of a *PlantCover* modelled as *MultiSolid* is a '*solid forest model'*, see Fig. 41.

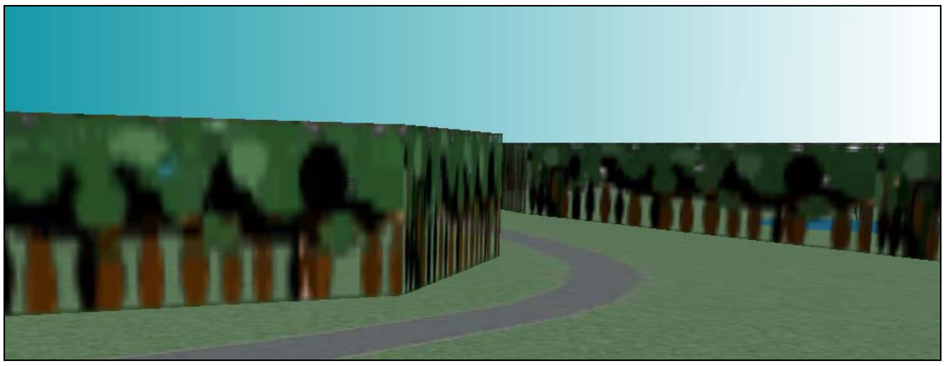


Fig. 41: Example for the visualisation/modelling of a solid forest (source: District of Recklinghausen).

9.6.1 Vegetation object

_VegetationObjectType, _VegetationObject

```
<xs:complexType name="_VegetationObjectType" abstract="true">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfVegetationObject" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ==========================================================================  -->
<xs:element name="_VegetationObject" type="_VegetationObjectType" substitutionGroup="_CityObject" />
<!-- ==========================================================================  -->
<xs:element name="_GenericApplicationPropertyOfVegetationObject" type="xs:anyType" abstract="true"/>
```

9.6.2 Solitary vegetation objects

SolitaryVegetationObjectType, SolitaryVegetationObject

```
<xs:complexType name="SolitaryVegetationObjectType">
  <xs:complexContent>
    <xs:extension base="_VegetationObjectType">
      <xs:sequence>
        <xs:element name="class" type="PlantClassType" minOccurs="0" />
        <xs:element name="function" type="PlantFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="species" type="SpeciesType" minOccurs="0" />
        <xs:element name="height" type="gml:LengthType" minOccurs="0" />
        <xs:element name="trunkDiameter" type="gml:LengthType" minOccurs="0" />
        <xs:element name="crownDiameter" type="gml:LengthType" minOccurs="0" />
        <xs:element name="lod1Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod1ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod2ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod3ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfSolitaryVegetationObject" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ==========================================================================  -->
<xs:element name="SolitaryVegetationObject" type="SolitaryVegetationObjectType" substitutionGroup="_VegetationObject" />
```

```
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfSolitaryVegetationObject" type="xs:anyType" abstract="true"/>
```

9.6.3 Plant cover objects

PlantCoverType, PlantCover

```
<xs:complexType name="PlantCoverType">
  <xs:complexContent>
    <xs:extension base="_VegetationObjectType">
      <xs:sequence>
        <xs:element name="class" type="PlantCoverClassType" minOccurs="0" />
        <xs:element name="function" type="PlantCoverFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="averageHeight" type="gml:LengthType" minOccurs="0" />
        <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod1MultiSolid" type="gml:MultiSolidPropertyType" minOccurs="0" />
        <xs:element name="lod2MultiSolid" type="gml:MultiSolidPropertyType" minOccurs="0" />
        <xs:element name="lod3MultiSolid" type="gml:MultiSolidPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfPlantCover" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="PlantCover" type="PlantCoverType" substitutionGroup="_VegetationObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfPlantCover" type="xs:anyType" abstract="true"/>
```

9.6.4 External code lists

The vegetation model introduces the following types, whose valid values are explicitly enumerated in an external code list (cf. chapter 6.5 and Annex A):

- PlantClassType
- PlantFunctionType
- SpeciesType
- PlantCoverClassType
- PlantCoverFunctionType

9.6.5 Example of a CityGML dataset

The following two excerpts of a CityGML dataset contain a solitary tree (*SolitaryVegetationObject)* and a plant community (*PlantCover*). The solitary tree has the attributes: *class* = 1070 (deciduous tree), *species* = 1040 (Fagus/beech), *height* = 8 m, *trunkDiameter* = 0.7 m, *crownDiameter* = 8.0 m. The plant community has the attributes: *class* =1180 (isoeto-nanojuncetea), *averageHeight* = 0.5 m.

```
<SolitaryVegetationObject>
  <class>1070</class>
  <species>1040</species>
  <height uom="#m">8</height>
  <trunkDiameter uom="#m">0.7</trunkDiameter>
  <crownDiameter uom="#m">8</crownDiameter>
  <lod1ImplicitRepresentation>
    <ImplicitGeometry>
      <mimeType>1010</mimeType>
      <LibraryObject>urn:sig3d:tree.wrl</LibraryObject>
      <referencePoint>
        <gml:Point srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
          <gml:pos srsDimension="3">5733690.578 2571129.123 60.0</gml:pos>
        </gml:Point>
      </referencePoint>
    </ImplicitGeometry>
```

```
   </lod1ImplicitRepresentation>
</SolitaryVegetationObject>
```

```
</PlantCover>
   <class>1180</class>
   <averageHeight uom="#m">0.5</averageHeight>
   <lod1Geometry>
      <gml:Polygon srsName=”urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783”>
         <gml:exterior>
            <gml:LinearRing>
               <gml:pos srsDimension="3">5733806.146 2571329.227 60.0</gml:pos>
               <gml:pos srsDimension="3">5733754.782 2571387.011 60.0</gml:pos>
               <gml:pos srsDimension="3">5733674.527 2571374.170 60.0</gml:pos>
               <gml:pos srsDimension="3">5733670.246 2571274.653 60.0</gml:pos>
               <gml:pos srsDimension="3">5733764.413 2571243.621 60.0</gml:pos>
               <gml:pos srsDimension="3">5733806.146 2571329.227 60.0</gml:pos>
            </gml:LinearRing>
         </gml:exterior>
      </gml:Polygon>
   </lod1Geometry>
</PlantCover>
```

9.7 City furniture

City furniture objects are immovable objects like lanterns, traffic lights, traffic signs, advertising columns, benches, delimitation stakes, or bus stops (Fig. 42, Fig. 43). City furniture objects can be found in traffic areas, residential areas, on squares or in built-up areas. The modelling of city furniture objects is used for visualisation of, for example city traffic, but also for analysing local structural conditions. The recognition of special locations in a city model is improved by the use of these detailed city furniture objects, and the city model itself becomes more alive and animated.

City furniture objects can have an important influence on simulations of, for example city traffic situations. Navigation systems can be realised, for example for visually handicapped people using a traffic light as routing target. Or city furniture objects are important to plan a heavy vehicle transportation, where the exact position and further conditions of obstacles must be known.

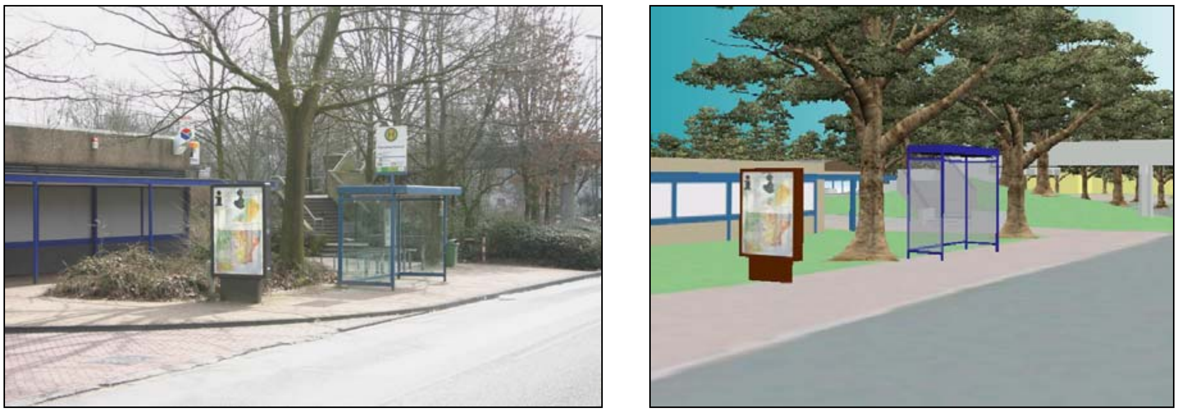


Fig. 42: Real situation showing a bus stop (left). The advertising billboard and the refuge are modelled as *CityFurniture* objects in the right image (source: 3D city model of Barkenberg).

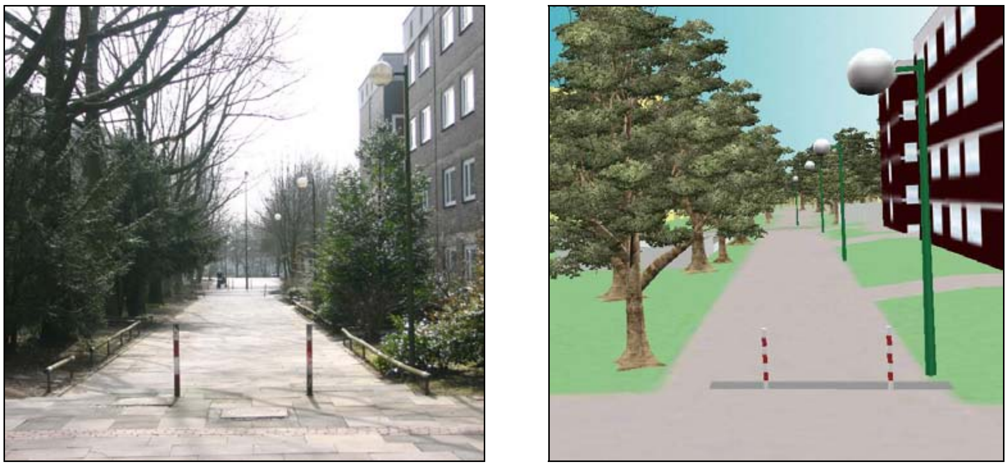


Fig. 43: Real situation showing lanterns and delimitation stakes (left). In the right image they are modelled as *CityFurniture* objects with *ImplicitGeometries* (source: 3D city model of Barkenberg).

The UML diagram of the city furniture model is depicted in Fig. 44, for XML schema definition see below and chapter 10.4.6.

The class *CityFurniture* may have the attributes *class* and *function*. Their possible values are specified in the respective external code lists (chapter 9.7.2 and 11.1). The *class* attribute allows an object classification like traffic light, traffic sign, delimitation stake, or garbage can, and can occur only once. The *function* attribute describes, to which thematic area the city furniture object belongs (e.g. transportation, traffic regulation, architecture etc.), and can occur multiple times. The hierarchy between *class* and *function* is not reflected in the external code lists. Inconsistencies have to be checked by the application tools.

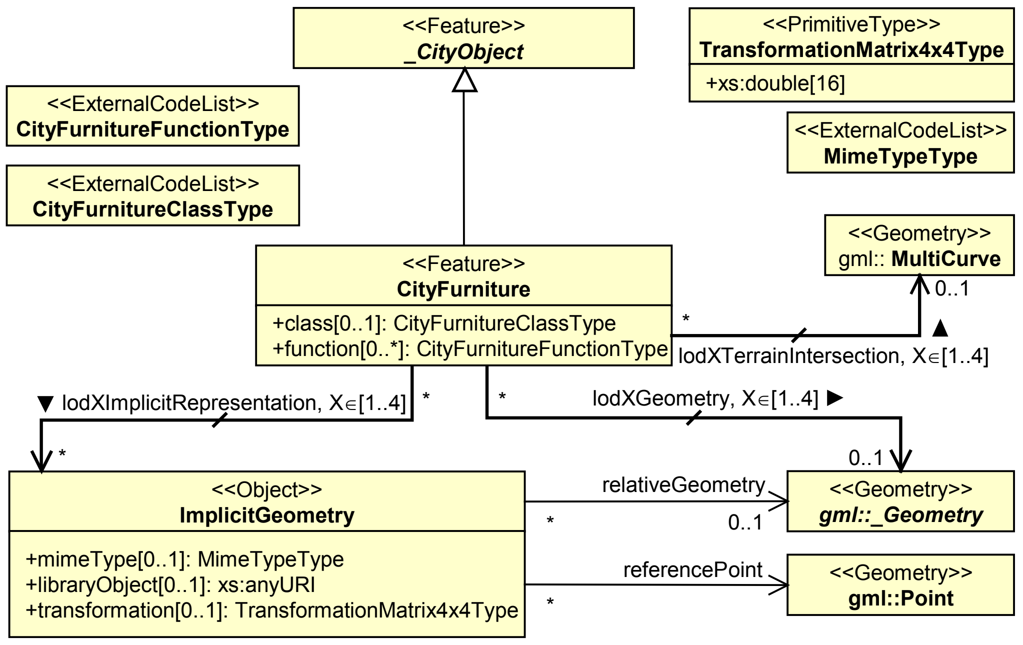


Fig. 44: UML diagram of city furniture objects in CityGML.

Since *CityFurniture* is a subclass of *_CityObject* and hence is a feature, it inherits the attribute *gml:name.* As with any *_CityObject*, *CityFurniture* objects may be assigned *ExternalReferences* and *GenericAttributes* (6.6, 6.10). For *ExternalReferences* city furniture objects can have links to external thematic databases. Thereby, semantical information of the objects, which can not be modelled in CityGML, can be transmitted and used in the 3D city model for further processing, for example information from systems of powerlines or pipelines, traffic sign cadaster, or water resources for disaster management.

City furniture objects can be represented in city models with its specific geometry, but in most cases the same kind of object has an identical geometry. The geometry of *CityFurniture* objects in LOD 1-4 may be represented by an explicit geometry (*lodXGeometry* where *X* is between 1 and 4) or an *ImplicitGeometry* object (*lodXImplicitRepresentation* with *X* between 1 and 4). In the concept of *ImplicitGeometry* the geometry of a prototype city furniture object is stored only once in a local coordinate system and referenced by a number of features (see chapter 7.2). Spatial information of city furniture objects can be taken from city maps (called "Stadtgrundkarte" in Germany) or from public and private external information systems.

In order to specify the exact intersection of the DTM with the 3D geometry of a city furniture object*,* the latter can have a *TerrainIntersectionCurve* (TIC) for each LOD (cf. chapter 6.4). This allows for ensuring a smooth transition between the DTM and the city furniture object.

9.7.1 City furniture object

CityFurnitureType, CityFurniture

```
<xs:complexType name="CityFurnitureType">
  <xs:annotation>
    <xs:documentaion>Type describing city furnitures, like traffic lights, benches, ... As subclass of _CityObject, a CityFurniture inherits all
attributes and relations, in particular an id, names, external references, generic attributes and generalization relations.</xs:documentation>
  </xs:annotation>
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="CityFurnitureClassType" minOccurs="0" />
        <xs:element name="function" type="CityFurnitureFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod1Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod1TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
        <xs:element name="lod2TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
        <xs:element name="lod3TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
        <xs:element name="lod4TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
        <xs:element name="lod1ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod2ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod3ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfCityFurniture" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="CityFurniture" type="CityFurnitureType" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfCityFurniture" type="xs:anyType" abstract="true"/>
```

9.7.2 External code lists

The city furniture model introduces the following types, whose valid values are explicitly enumerated in an external code list (cf. chapter 6.5 and Annex A):

- CityFurnitureFunctionType
- CityFurnitureClassType

9.7.3 Example of CityGML dataset

The following example of a CityGML dataset is an extract of the modelling of a delimitation stake in LOD3 and contains the attributes: *class* = 1000, *function* = 1520 (delimitation stake). The delimitation stake with the object ID *stake0815* is referencing by *urn:adv:oid:DEHE123400007001* to an cadastre object in the German ALKIS database (www.adv-online.de).

This example shows the geometry of *Cover Surface* (on the top of the stake) and of the left *Surface left* (Fig. 45). The *Cover Surface* has the material (color) white and the *Surface left* has the texture stake.gif with the relevant texture coordinates.

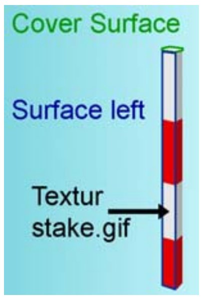


Fig. 45: Example of a simple city furniture object (source: District of Recklinghausen).

```
<!-- delimitation stake in LOD 3 -->
<CityFurniture gml:id="stake0815">
  <externalReference>
    <informationSystem>http://www.adv-online.de</informationSystem>
    <!-- Reference to ALKIS -->
    <externalObject>
      <uri>urn:adv:oid:DEHE123400007001</uri>
      <!-- ALKIS Object ID -->
    </externalObject>
  </externalReference>
  <appearanceMember>
    <Appearance>
      <surfaceDataMember>
        <X3DMaterial>
          <ambientIntensity>0.4</ambientIntensity>
          <diffuseColor>1.0  1.0  1.0</diffuseColor>
          <target>#cover</target>
        </X3DMaterial>
      </surfaceDataMember>
      <surfaceDataMember>
```

```
        <ParameterizedTexture>
          <imageURI>stake.gif</imageURI>
          <textureType>typical</textureType>
          <target uri="#surfLeft">
            <TexCoordList>
              <textureCoordinates ring="#surfLeft_ring1">
                0.000 0.000 1.000 0.000 1.000 1.000 0.000 1.000 0.000 0.000
              </textureCoordinates>
            </TexCoordList>
          </target>
        </ParameterizedTexture>
      </surfaceDataMember>
    </Appearance>
  </appearanceMember>
  <class>1000</class>
  <!-- 1000 = traffic  -->
  <function>1520</function>
  <!-- 1520 = delimitation stake  -->
  <lod3Geometry>
    <!--Stake 0.06x0.06x1.2-->
    <gml:Solid srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
      <gml:exterior>
        <gml:CompositeSurface>
          <gml:surfaceMember>
            <gml:Polygon gml:id="cover">
              <gml:exterior>
                <!-- Cover-Surface  -->
                <gml:LinearRing>
                  <gml:pos>2572400.060 5733500.060 61.200</gml:pos>
                  <gml:pos>2572400.000 5733500.060 61.200</gml:pos>
                  <gml:pos>2572400.000 5733500.000 61.200</gml:pos>
                  <gml:pos>2572400.060 5733500.000 61.200</gml:pos>
                  <gml:pos>2572400.060 5733500.060 61.200</gml:pos>
                </gml:LinearRing>
              </gml:exterior>
            </gml:Polygon>
          </gml:surfaceMember>
          <gml:surfaceMember>
            <gml:Polygon gml:id="surfLeft">
              <gml:exterior>
                <!-- Surface left  -->
                <gml:LinearRing gml:id="surfLeft_ring1">
                  <gml:pos>2572400.000 5733500.060 60.000</gml:pos>
                  <gml:pos>2572400.000 5733500.000 60.000</gml:pos>
                  <gml:pos>2572400.000 5733500.000 61.200</gml:pos>
                  <gml:pos>2572400.000 5733500.060 61.200</gml:pos>
                  <gml:pos>2572400.000 5733500.060 60.000</gml:pos>
                </gml:LinearRing>
              </gml:exterior>
            </gml:Polygon>
          </gml:surfaceMember>
          ....
        </gml:CompositeSurface>
      </gml:exterior>
    </gml:Solid>
  </lod3Geometry>
</CityFurniture>
```

9.8 Land use

LandUse objects describe areas of the earth's surface dedicated to a specific land use. They can be employed to represent parcels in 3D. Fig. 46 shows the UML diagram of land use objects, for the XML schema definition see chapters 9.8.1 and 10.4.7.

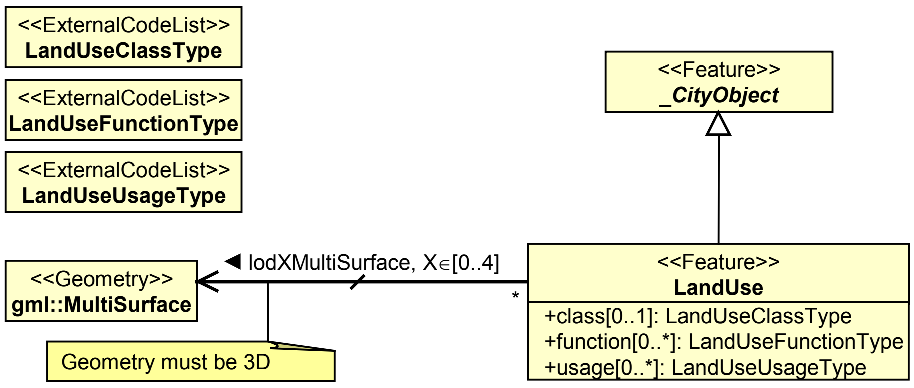


Fig. 46: UML diagram of land use objects in CityGML.

Every *LandUse* object may have the attributes *class*, *function*, and *usage*. The *class* attribute is used to represent the classification of land use objects, like settlement area, industrial area, farmland etc., and can occur only once. The possible values are specified in an external code list (see chapter 11.1). The attribute *function* defines the purpose of the object, like e.g. cornfield, while the attribute *usage* can be used, if the way the object is actually used differs from the function. Both attributes can occur multiple times.

The *LandUse* object is defined for all LOD 0-4 and may have different geometries in any LOD. The surface geometry of a *LandUse* object is required to have 3D coordinate values. It must be a GML3 *MultiSurface*, which might be assigned material properties like textures or colors (using CityGML's *TexturedSurface*).

LandUse objects can be employed to establish a coherent geometric/semantical tesselation of the earth's surface. In this case topological relations between neighbouring *LandUse* objects should be made explicit by defining the boundary *LineStrings* only once and by referencing them in the corresponding *Polygons* using XLinks (cf. chapter 7.1). Fig. 47 shows a land use tesselation, where the geometries of the land use objects are represented as triangulated surfaces. In fact, they are the result of a constrained triangulation of a DTM with consideration of breaklines defined by a 2D vector map of land use classifications.

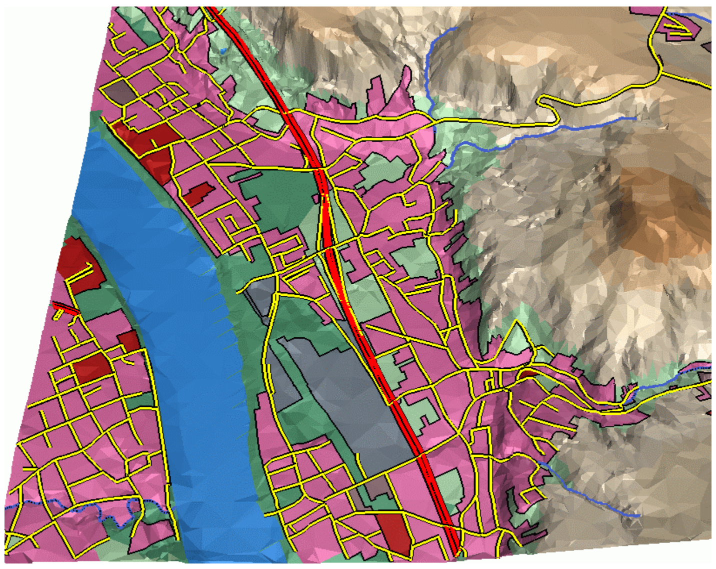


Fig. 47: LOD0 regional model consisting of land use objects in CityGML (source: IGG Uni Bonn).

9.8.1 Land use object

LandUseType, LandUse

```
<xs:complexType name="LandUseType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="LandUseClassType" minOccurs="0" />
        <xs:element name="function" type="LandUseFunctionType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="LandUseUsageType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod0MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfLandUse" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="LandUse" type="LandUseType" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfLandUse" type="xs:anyType" abstract="true"/>
```

9.8.2 External code lists

The land use model introduces the following types, whose valid values are explicitly enumerated in an external code list (cf. chapter 6.5 and Annex A):

- LandUseClassType
- LandUseFunctionType
- LandUseUsageType

9.9 *City object groups*

The grouping concept has already been introduced in chapter 6.7. *CityObjectGroups* are modelled using the Composite Design Pattern from software engineering (cf. Gamma et al. 1995): *CityObjectGroups* aggregate *CityObjects* and furthermore are defined as special *CityObjects*. This implies that a group may become a member of another group realizing a recursive aggregation schema. However, in a CityGML instance document it has to be ensured (by the generating application) that no cyclic groupings are included. Fig. 48 shows the UML diagram for the class *CityObjectGroup,* for the XML schema see chapter 9.9.1.

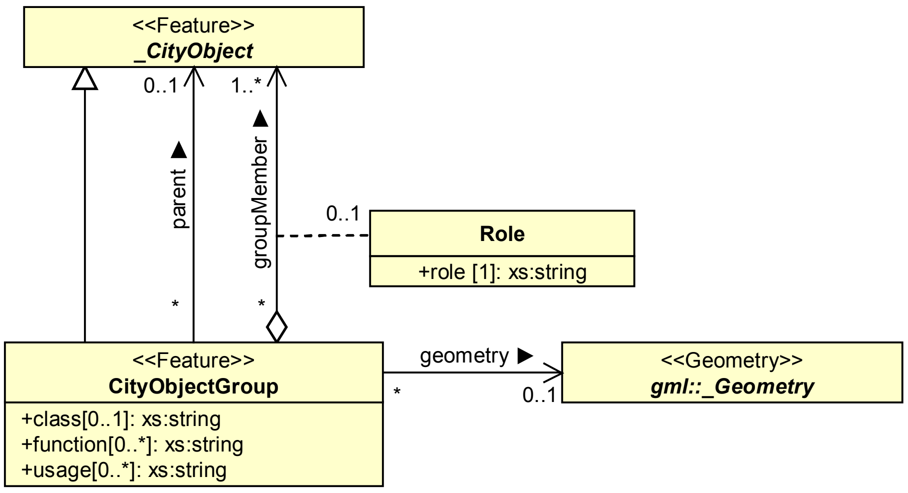


Fig. 48: UML diagram of city object groups in CityGML.

The class *CityObjectGroup* has the optional attributes *class, function* and *usage.* In contrast to the other thematic classes, no code lists are defined for these attributes, because the reasons for groupings can not completely be foreseen. The *class* attribute allows a group classification with respect to the stated function and may occur only once. The *function* attribute is intended to express the main purpose of a group, possibly to which thematic area it belongs (e.g. site, building, transportation, architecture, unknown etc.). The attribute *usage* can be used, if the way the object is actually used differs from the function. Both attributes can occur multiple times. Each member of a group may be qualified by a *role* name, reflecting the role each *CityObject* plays in the context of the group. Furthermore, a *CityObjectGroup* can optionally be assigned an arbitrary geometry object from the GML3 subset shown in Fig. 8 in chapter 7.1. This may be used to represent a generalised geometry generated from the members geometries.

The parent association linking a *CityObjectGroup* to a *CityObject* allows for the modelling of a generic hierarchical grouping concept. Named aggregations of components (CityObjects) can be added to specific CityObjects considered as the parent object. The parent association links to the aggregate, while the parts are given by the group members. This concept is used, for example, to represent storeys in buildings (see section 9.3.6.: Modelling building storeys using CityObjectGroups).

9.9.1 City object group

CityObjectGroupType, CityObjectGroup

```
<xs:complexType name="CityObjectGroupType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="xs:string" minOccurs="0" />
        <xs:element name="function" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="groupMember" type="CityObjectGroupMemberType" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="parent" type="CityObjectGroupMemberType " minOccurs="0"/>
        <xs:element name="geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element ref="_GenericApplicationPropertyOfCityObjectGroup" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="CityObjectGroup" type="CityObjectGroupType" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfCityObjectGroup" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:complexType name="CityObjectGroupMemberType">
  <xs:complexContent>
    <xs:extension base="gml:AssociationType">
      <xs:attribute name="role" type="xs:string" />
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
```

9.10 Generic objects and attributes

The concept of generic objects and attributes was introduced to ensure the storage and exchange of 3D objects, which are not covered by an explicitly modelled class within CityGML or which requires attributes not represented in CityGML. These generic extensions are realised by the classes *GenericCityObject* and *GenericAttribute*. Fig. 49 shows the UML diagram of generic objects and attributes, for XML schema definition see below and chapter 10.1.3.

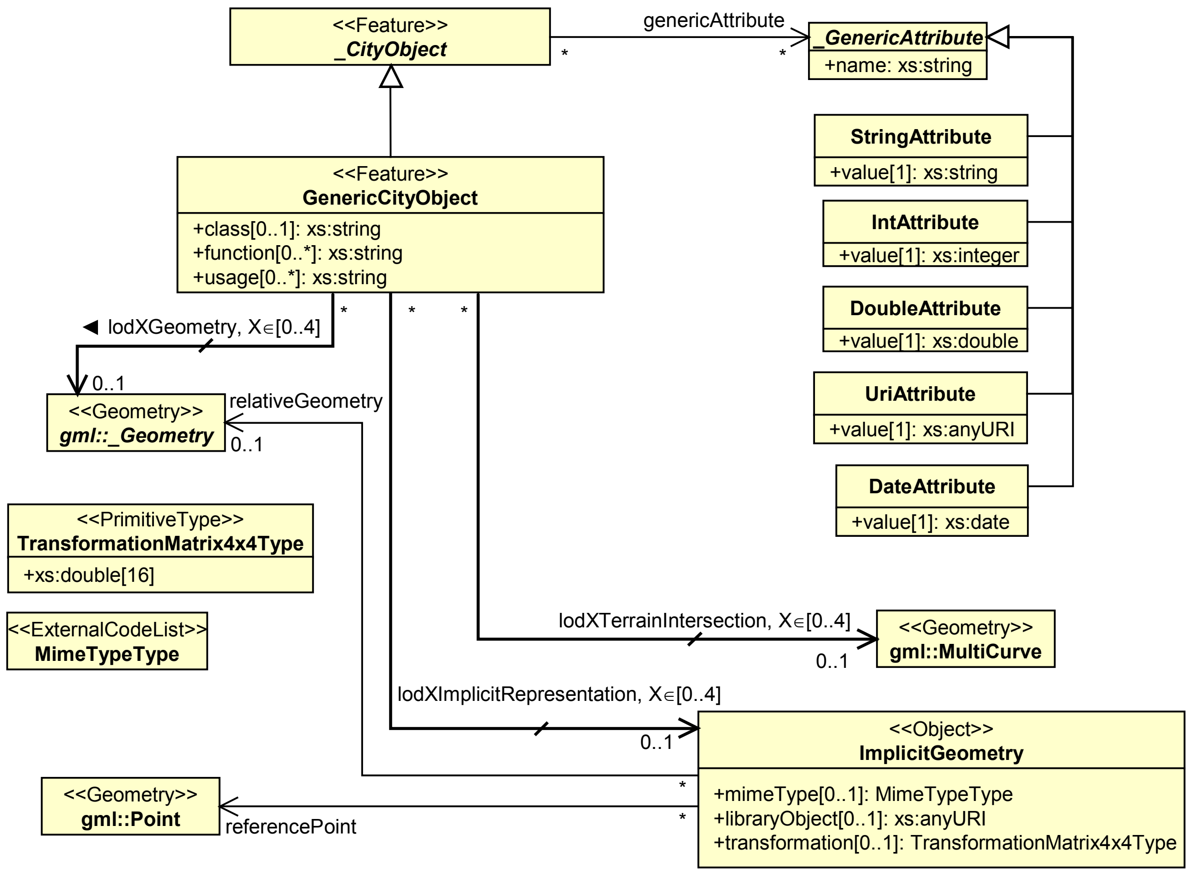


Fig. 49: UML diagram of generic objects and attributes in CityGML.

A *GenericCityObject* may have the attributes *class, function* and *usage* defined as *string*. The *class* attribute allows an object classification within the thematic area such as bridge, tunnel, pipe, power line, dam, or unknown. The *function* attribute describes to which thematic area the *GenericCityObject* belongs (e.g. site, transportation, architecture, energy supply, water supply, unknown etc.). The attribute *usage* can be used, if the way the object is actually used differs from the function. Both attributes can occur multiple times.

Every *_CityObject* can have an arbitrary number of *GenericAttributes*. Data types may be *String*, *Integer*, *Double* (floating point number), *URI* and *Date*. The attribute type is defined by the selection of the particular subclass (*StringAttribute*, *IntAttribute* etc.). *GenericAttributes* are inherited by all thematic sublasses of *CityObject*.

The geometry of a *GenericCityObject* can either be an explicit GML3 geometry or an *ImplicitGeometry* (see chapter 7.2). In the case of an explicit geometry the object can have only one geometry for each LOD, which may be an arbitrary 3D GML geometry object (class *_Geometry*, which is the base class of all GML geometries, *lodXGeometry, X in 0…4*). Absolute coordinates according to the reference system of the city model must be given for the explicit geometry. In the case of an *ImplicitGeometry*, a reference point (anchor point) of the object and optionally a transformation matrix must be given. In order to compute the actual location of the object, the transformation of the local coordinates into the reference system of the city model must be processed and the anchor point coordinates must be added. The shape of an *ImplicitGeometry* can be given as an external resource with a proprietary format, e.g. a VRML or DXF file from a local file system or an external web service. Alternatively the shape can be specified as a 3D GML3 geometry with local cartesian coordinates using the property *relativeGeometry* (further details are given in chapter 7.2).

In order to specify the exact intersection of the DTM with the 3D geometry of a *GenericCityObject,* the latter can have *TerrainIntersectionCurves* for every LOD (cf. chapter 6.4). This is important for 3D visualization but also for certain applications like driving simulators. For example, if a bridge should be represented as a *GenericCityObject,* a smooth transition between the DTM and the road on the bridge would have to be ensured (in order to avoid unrealistic bumps).

9.10.1 Generic city object

GenericCityObjectType, GenericCityObject

```
<xs:complexType name="GenericCityObjectType">
  <xs:complexContent>
    <xs:extension base="_CityObjectType">
      <xs:sequence>
        <xs:element name="class" type="xs:string" minOccurs="0" />
        <xs:element name="function" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="usage" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
        <xs:element name="lod0Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod1Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
        <xs:element name="lod0TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
        <xs:element name="lod1TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
        <xs:element name="lod2TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
        <xs:element name="lod3TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
        <xs:element name="lod4TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
        <xs:element name="lod0ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod1ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod2ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod3ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
        <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="GenericCityObject" type="GenericCityObjectType" substitutionGroup="_CityObject" />
```

9.10.2 Generic attributes

GenericAttributeType, _genericAttribute, StringAttributeType, stringAttribute, etc.

```
<xs:complexType name="_GenericAttributeType" abstract="true">
  <xs:sequence />
  <xs:attribute name="name" type="xs:string" use="required" />
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_genericAttribute" type="_GenericAttributeType" abstract="true" />
<!-- ========================================================================================= -->
<xs:complexType name="StringAttributeType">
  <xs:complexContent>
    <xs:extension base="_GenericAttributeType">
      <xs:sequence>
        <xs:element name="value" type="xs:string" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
 <xs:element name="stringAttribute" type="StringAttributeType" substitutionGroup="_genericAttribute" />
<!-- ========================================================================================= -->
<xs:complexType name="IntAttributeType">
  <xs:complexContent>
    <xs:extension base="_GenericAttributeType">
      <xs:sequence>
```

```
        <xs:element name="value" type="xs:integer" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================= -->
<xs:element name="intAttribute" type="IntAttributeType" substitutionGroup="_genericAttribute" />
<!-- ========================================================================= -->
<xs:complexType name="DoubleAttributeType">
  <xs:complexContent>
    <xs:extension base="_GenericAttributeType">
      <xs:sequence>
        <xs:element name="value" type="xs:double" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================= -->
<xs:element name="doubleAttribute" type="DoubleAttributeType" substitutionGroup="_genericAttribute" />
<!-- ========================================================================= -->
<xs:complexType name="DateAttributeType">
  <xs:complexContent>
    <xs:extension base="_GenericAttributeType">
      <xs:sequence>
        <xs:element name="value" type="xs:date" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================= -->
<xs:element name="dateAttribute" type="DateAttributeType" substitutionGroup="_genericAttribute" />
<!-- ========================================================================= -->
<xs:complexType name="UriAttributeType">
  <xs:complexContent>
    <xs:extension base="_GenericAttributeType">
      <xs:sequence>
        <xs:element name="value" type="xs:anyURI" />
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ========================================================================= -->
<xs:element name="uriAttribute" type="UriAttributeType" substitutionGroup="_genericAttribute" />
```

9.11 Application Domain Extensions (ADE)

CityGML has been designed as an application independent information model and exchange format for 3D city and landscape models. However, specific applications typically have additional information needs to be modeled and exchanged. In general, there are two different approaches to combine city model data and application data:

1. Embed the CityGML objects into a (larger) application framework and establish the connection between application data and CityGML data within the application framework. For example, CityGML data fragments may be embedded into the application's XML data files or stored as attributes of application objects according to the application's data model.
2. Incorporate application specific information into the CityGML instance documents. This approach is especially feasible, if the application specific information follows essentially the same structure as defined by the CityGML schema. This is the case, if the application data could be represented by additional attributes of CityGML objects and only some new feature types would have to be defined.

In the following, we will focus on the second option, as only this approach lies within the scope of this specification. Generic attributes and objects have been already introduced as a first possibility to support the exchange of application specific data (see section 9.10). Whereas they allow to extend CityGML without changing its XML schema definition, this flexibility has some disadvantages:

- Generic attributes and objects may occur arbitrarily in the CityGML instance documents, but there is no formal specification of the names, datatypes, and multiplicities. Thus, there is no guarantee for an application that a specific instance of a generic attribute is included a minimum or maximum number of times per CityGML feature. Unlike the predefined CityGML objects, the concrete layout and occurrence of generic objects and attributes cannot be validated by an XML parser. This may reduce semantic interoperability.
- Naming conflicts of generic attributes or objects can occur, if the CityGML instance documents should be augmented by specific information from different applications simultaneously.
- There is only a limited number of predefined data types that can be used for generic attributes. Also the structure of generic obects might not be appropriate to represent more complex objects.

If application specific information are well-structured, it is desirable to represent them in a systematic way, i. e. by the definition of an extra formal schema based on the CityGML schema. Such an XML schema is called a CityGML *Application Domain Extension* (ADE). It allows to validate instance documents both against the CityGML and the ADE schema and therefore helps to maintain semantic and syntactic interoperability between different systems working in the same application field. In order to prevent naming conflicts, every ADE has to be defined within its own namespace. The ADE concept defines a special way of extending existing CityGML feature types which allows to use different ADEs within the same instance document simultaneously (see below).

For example, the specification of ADEs can be useful in the following application fields: cultural heritage (extension of abstract class *_CityObject* e.g. by time period information and monument protection status); representation of subsurface objects (tunnel, underpass) or city lighting (light sources like street lamps and house lights); real estate management (economic parameters of the CityGML features; inclusion of attributes defined for real estate assets as defined by OSCRE); utility networks (as topographic features); additional building properties as defined by the U.S. national building information model standard (NBIMS).

9.11.1 Technical principle of ADEs

Each ADE is specified by its own XML schema file. The target namespace is provided by the information community who specifies the CityGML ADE. This is typically not the OGC or the SIG 3D. The namespace should be in the control of this information community and must be given as a previously unused and globally unique URI. This URI will be used in CityGML ADE instance documents to distinguish extensions from CityGML base elements. As the URI refers to the information community it also denotes the originator of the employed ADE.

The ADE's XML schema file must be available (or accessible on the Internet) to everybody creating and parsing CityGML instance documents including these ADE specific augmentations.

An ADE XML schema can define various extensions to CityGML. However, all extensions shall belong to one of the two following categories:

1. New feature types are defined within the ADE namespace and are based on CityGML abstract or concrete classes. In general, this mechanism follows the same principles as the definition of application schemas for GML. This means, that new feature types have to be derived from existing (here: CityGML) feature types. For example, new feature types could be defined by classes derived from the abstract classes like *_CityObject* or *_AbstractBuilding* or the concrete class *CityFurniture*. The new feature types then automatically inherit all properties (i.e. attributes) and associations (i.e. relations) from the respective CityGML superclasses.
2. Existing CityGML feature types are extended by application specific properties (in the ADE namespace). These properties may have simple or complex data types. Also geometries or embedded features (feature properties) are possible. The latter can also be used to model relations to other features.

   In this case, extension of the CityGML feature type is not being realised by the inheritance mechanism of XML schema. Instead, every CityGML feature type provides a "hook" in its XML schema definition, that allows to attach additional properties to it by ADEs. This "hook" is implemented as a GML property of the form "_GenericApplicationPropertyOf<*Featuretypename*>" where <*Featuretypename*> is equal to the name of the feature type definition in which it is included. The datatype for these kinds of properties is always "xsd:anyType" from the XSD namespace. The minimum occurrence of the "_GenericApplicationPropertyOf<*Featuretypename*>" is 0 and the maximum occurrence unbounded. This means, that the CityGML schema allows that every CityGML feature may have an arbitrary number of additional properties with arbitrary XML content with the name "_GenericApplicationPropertyOf<*Featuretypename*>". For example, the last property in the definition of the CityGML feature type *LandUse* is the element *_GenericApplicationPropertyOfLandUse* (see section 9.8.1).

   Such properties are called "hooks" to attach application specific properties, because they are used as the head of a substitution group by ADEs. Whenever an ADE wants to add an extra property to an existing CityGML feature type, it should declare the respective element with the appropriate dataype within the ADE namespace. In the element declaration this element shall be explicitly assigned to the substitution group defined by the corresponding "_GenericApplicationPropertyOf<*Featuretypename*>" in the CityGML namespace. An example is given in the following subsection.

   By following this concept, it is possible to specify different ADEs for different information communities. Every ADE may add their specific properties to the same CityGML feature type as they all can belong to the same substitution group. This allows to have CityGML instance documents where CityGML features contain additional information from different ADEs simultaneously.

Please note that usage of ADEs introduces an extra level of complexity as data files may contain mixed information (features, properties) from different namespaces, not only from the GML and CityGML namespace. However, extended CityGML instance documents are quite easy to handle by applications who are not "schema-aware", i.e. applications that do not parse and interpret GML application schemas in a generic way. These applications can simply overread anything from a CityGML instance document that is not from the CityGML or GML namespace. Thus, a building is still represented by the <*Building*> element with the standard CityGML properties, but with possibly some extra properties from different namespaces. Also features from a different namespace than CityGML or GML could be overread (e.g by a viewer application).

9.11.2 Example ADE

In this section, the ADE mechanism is illustrated by a short example, which deals with the application of virtual 3D city models to generate noise pollution maps. In our example, two extensions of CityGML are required for this task: buildings have to be extended to represent a "noise reflection correction" value and the number of inhabitants. As a new feature type noise barriers have to be defined which also have a "noise reflection correction" value.

The XSD schema which has to be defined to implement this model declares a new namespace for the noise extension (*http://www.citygml.org/ade/noise_de*) with a namespace prefix called *noise*. Another namespace is declared for the CityGML elements (referencing *http://www.citygml.org/citygml/1/0/0* as the official CityGML namespace) with the prefix *citygml*. The XML schema adds the elements *buildingReflectionCorrection* and *buildingHabitants*, both being members of the substitution group *_GenericApplicationPropertyOf-AbstractBuilding*. Now both may be used as child elements of CityGML building features. Noise barrier is defined as subtype of the CityGML abstract type *_SiteType*, applying the usual subtyping mechanism of XML and XSD.

The XSD file for this example CityGML Noise ADE is given by (the complete CityGML Noise ADE is given in Annex E, section 11.5):

```
<xsd:schema xmlns="http://www.citygml.org/ade/noise_de" xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:citygml="http://www.citygml.org/citygml/1/0/0" xmlns:noise="http://www.citygml.org/ade/noise_de"
xmlns:gml="http://www.opengis.net/gml" targetNamespace="http://www.citygml.org/ade/noise_de" elementFormDefault="qualified"
attributeFormDefault="unqualified">
   <xsd:import namespace="http://www.opengis.net/gml" schemaLocation="../3.1.1/base/gml.xsd"/>
   <xsd:import namespace="http://www.citygml.org/citygml/1/0/0" schemaLocation="../CityGML.xsd"/>

   <xsd:element name="buildingReflectionCorrection" type="gml:MeasureType"
     substitutionGroup="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="buildingHabitants" type="xsd:positiveInteger"
     substitutionGroup="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>

   <xsd:complexType name="NoiseBarrierType">
     <xsd:complexContent>
       <xsd:extension base="citygml:_SiteType">
         <xsd:sequence>
           <xsd:element name="barrierReflectionCorrection" type=" gml:MeasureType " minOccurs="0"/>
         </xsd:sequence>
       </xsd:extension>
     </xsd:complexContent>
   </xsd:complexType>
   <xsd:element name="NoiseBarrier" type="NoiseBarrierType" substitutionGroup="citygml:_CityObject"/>
</xsd:schema>
```

An example for a feature collection in a corresponding instance document is depicted below. Two CityGML buildings contain application specific properties distinguished from CityGML properties by the namespace *noise*. The other properties, function and geometry, are defined by CityGML. Please note, that the order of the child elements in the sequence is not arbitrary: the child elements defined by an ADE subschema have to occur after the child elements defined by CityGML. There is, however, no specific order of the ADE properties. In addition to the buildings, a noise barrier is included in the feature collection.

```
......................................
<citygml:cityObjectMember>
   <citygml:Building gml:id=”aa”>
     <citygml:function>1004</citygml:function>
     <citygml:lod1Solid>................</citygml:lod1Solid>
     <noise:buildingHabitants>14</noise: buildingHabitants>
     <noise:buildingReflectionCorrection uom="dB">4.123</noise:buildingReflectionCorrection>
   </citygml:Building>
   </citygml:cityObjectMember>
   <citygml:cityObjectMember>
   <citygml:Building gml:id=”aaa”>
     <citygml:function>1004</citygml:function>
     <citygml:lod1Solid>...........</citygml:lod1Solid>
     <noise:buildingReflectionCorrection uom="dB">3.123</noise:buildingReflectionCorrection>
     <noise:buildingHabitants>6</noise: buildingHabitants>
   </citygml:Building>
</citygml:cityObjectMember>
<citygml:cityObjectMember>
   <noise:NoiseBarrier>
     <barrierReflectionCorrection uom="dB">6.999</ barrierReflectionCorrection>
   </noise:NoiseBarrier>
</citygml:cityObjectMember>
..............................
```

9.12 Definition of code lists

For the representation of city object attributes having an enumerative range of values, the concept of dictionaries as provided by GML is used. The values of these attributes are defined in a file *CityGML_ExternalCode-Lists.xml*, which comes with the CityGML schema document, but is not a normative part of this schema, since it may be modified, augmented, or replaced by other communities. The actual values in the file *CityGML_ExternalCodeLists.xml* are a suggestion of the SIG 3D.

The external code list file defines attribute values and assigns an unique identifier to each value. In a CityGML instance document, an attribute value is denoted by an identifier of a value, not by the value itself. Thus typos are avoided and it is ensured that the same concept is denoted the same way, by the same identifier and not by two different terms with identical meaning. Thus the use of code lists facilitates semantic and syntactic interoperability, since they define common terms within an information community. Furthermore, the dictionary concept enables more than one term to be assigned to the same dictionary entry, thus the same concept may be explained in different languages. To differentiate between the languages, code spaces are used.

An example for an enumerative attribute is *RoofType*, which is defined by the following excerpt of the external code list file:

```xml
<gml:DefinitionCollection gml:id="id356">
  <gml:description>Codelist derived from German authoritative standards  ALKIS/ATKIS (www.adv-online.de) by S. Schlueter and U. 
Gruber</gml:description>
  <gml:name>RoofTypeType</gml:name>
     <gml:definitionMember>
        <gml:Definition gml:id="id357">
           <gml:description></gml:description>
           <gml:name codeSpace="urn:d_nrw_sig3d">1000</gml:name>
           <gml:name>flat roof</gml:name>
        </gml:Definition>
     </gml:definitionMember>
     <gml:definitionMember>
        <gml:Definition gml:id="id358">
           <gml:description></gml:description>
           <gml:name codeSpace="urn:d_nrw_sig3d">1010</gml:name>
           <gml:name>monopitch roof</gml:name>
        </gml:Definition>
     </gml:definitionMember>
   ….
</gml:DefinitionCollection>
```

In the dictionary concept the values of an attribute are represented by a *DefinitionCollection* element, where each value is given by a *Definition* entry. In CityGML a definition entry is identified by the *name* element, which is qualified by the SIG 3D code space. The unqualified *name* element represents the value of the attribute. An optional description explains the value. CityGML does not use GML identifiers (*gml:id*) to link to attribute values, since IDs are restricted syntactically, and must be globally unique, which is not feasible for code lists.

10 XML schema definition (Normative)

10.1 *Base Classes*

10.1.1 Root element CityModel

```
<?xml version="1.0" encoding="UTF-8" ?>
<xs:schema xmlns="http://www.citygml.org/citygml/1/0/0" xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0"
        xmlns:xs="http://www.w3.org/2001/XMLSchema" xmlns:gml="http://www.opengis.net/gml"
        xmlns:xlink="http://www.w3.org/1999/xlink" targetNamespace="http://www.citygml.org/citygml/1/0/0" elementFormDe-
        fault="qualified" attributeFormDefault="unqualified">
    <xs:import namespace="http://www.opengis.net/gml" schemaLocation="3.1.1/base/gml.xsd" />
    <xs:import namespace="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0" schemaLocation="xAL/xAL.xsd" />
    <!-- ================================================================================== -->
    <xs:complexType name="CityModelType">
        <xs:annotation>
            <xs:documentation>Type describing the "root" element of any city model file. It is a collection whose members are restricted to be
                    features of a city model. All features are included as cityObjectMember.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="gml:AbstractFeatureCollectionType">
                <xs:sequence>
                     <xs:element ref="_GenericApplicationPropertyOfCityModel" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ================================================================================== -->
    <xs:element name="CityModel" type="CityModelType" substitutionGroup="gml:_FeatureCollection" />
    <!-- ================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfCityModel" type="xs:anyType" abstract="true"/>
    <!-- ================================================================================== -->
    <xs:element name="cityObjectMember" type="gml:FeaturePropertyType" substitutionGroup="gml:featureMember" />
    …
    …
</xs:schema>
```

10.1.2 Base class _CityObject

```
    <xs:complexType name="_CityObjectType" abstract="true">
        <xs:annotation>
            <xs:documentation>Type describing the abstract superclass of most CityGML features. Its purpose is to provide a creation and a
                    termination date as well as a reference to corresponding objects in other information systems and gerneric attributes. A
                    generalization relation may be used to relate features, which represent the same real-world object in different Levels-of-
                    Detail, i.e. a feature and its generalized counterpart(s). The direction of this relation is from the feature to the correspond-
                    ing generalized feature.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="gml:AbstractFeatureType">
                <xs:sequence>
                    <xs:element name="creationDate" type="xs:date" minOccurs="0" />
                    <xs:element name="terminationDate" type="xs:date" minOccurs="0" />
                    <xs:element name="externalReference" type="ExternalReferenceType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element ref="_genericAttribute" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="generalizesTo" type="GeneralizationRelationType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element ref="appearanceMember" minOccurs="0" maxOccurs="unbounded"/>
                    <xs:element ref="_GenericApplicationPropertyOfCityObject" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ================================================================================== -->
    <xs:element name="_CityObject" type="_CityObjectType" abstract="true" substitutionGroup="gml:_Feature" />
    <!-- ================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfCityObject" type="xs:anyType" abstract="true"/>
```

10.1.3 Generic objects and attributes / generalisation relation

```
    <xs:complexType name="_GenericAttributeType" abstract="true">
        <xs:annotation>
            <xs:documentation>Generic (user defined) attributes may be used to represent attributes which are not covered explicitly by the
                    CityGML schema. Generic attributes should be used with care;  they should only be used if there is no appropiate attribute
                    available in the schema. Oherwise, problems concerning semantic interoperability may arise. A generic attribute has a
                    name and a value, which has further subclasses (IntAttrribute, StringAttribute, ...).</xs:documentation>
        </xs:annotation>
        <xs:sequence />
        <xs:attribute name="name" type="xs:string" use="required" />
    </xs:complexType>
    <!-- ========================================================================================= -->
    <xs:element name="_genericAttribute" type="_GenericAttributeType" abstract="true" />
    <!-- ========================================================================================= -->
    <xs:complexType name="StringAttributeType">
        <xs:annotation>
            <xs:documentation />
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_GenericAttributeType">
                <xs:sequence>
                    <xs:element name="value" type="xs:string" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================= -->
     <xs:element name="stringAttribute" type="StringAttributeType" substitutionGroup="_genericAttribute" />
    <!-- ========================================================================================= -->
    <xs:complexType name="IntAttributeType">
        <xs:annotation>
            <xs:documentation />
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_GenericAttributeType">
                <xs:sequence>
                    <xs:element name="value" type="xs:integer" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================= -->
    <xs:element name="intAttribute" type="IntAttributeType" substitutionGroup="_genericAttribute" />
    <!-- ========================================================================================= -->
    <xs:complexType name="DoubleAttributeType">
        <xs:annotation>
            <xs:documentation />
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_GenericAttributeType">
                <xs:sequence>
                    <xs:element name="value" type="xs:double" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================= -->
    <xs:element name="doubleAttribute" type="DoubleAttributeType" substitutionGroup="_genericAttribute" />
    <!-- ========================================================================================= -->
    <xs:complexType name="DateAttributeType">
        <xs:annotation>
            <xs:documentation />
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_GenericAttributeType">
                <xs:sequence>
                    <xs:element name="value" type="xs:date" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================= -->
    <xs:element name="dateAttribute" type="DateAttributeType" substitutionGroup="_genericAttribute" />
    <!-- ========================================================================================= -->
    <xs:complexType name="UriAttributeType">
        <xs:annotation>
            <xs:documentation />
        </xs:annotation>
        <xs:complexContent>
```

```
            <xs:extension base="_GenericAttributeType">
                <xs:sequence>
                    <xs:element name="value" type="xs:anyURI" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ===================================================================================== -->
    <xs:element name="uriAttribute" type="UriAttributeType" substitutionGroup="_genericAttribute" />
    <!-- ===================================================================================== -->
    <xs:complexType name="GenericCityObjectType">
        <xs:annotation>
            <xs:documentation />
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_CityObjectType">
                <xs:sequence>
                    <xs:element name="class" type="xs:string" minOccurs="0" />
                    <xs:element name="function" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="usage" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="lod0Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                    <xs:element name="lod1Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                    <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                    <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                    <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                    <xs:element name="lod0TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                    <xs:element name="lod1TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                    <xs:element name="lod2TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                    <xs:element name="lod3TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                    <xs:element name="lod4TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                    <xs:element name="lod0ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                    <xs:element name="lod1ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                    <xs:element name="lod2ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                    <xs:element name="lod3ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                    <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ===================================================================================== -->
    <xs:element name="GenericCityObject" type="GenericCityObjectType" substitutionGroup="_CityObject" />
    <!-- ===================================================================================== -->
    <xs:complexType name="GeneralizationRelationType">
        <xs:annotation>
            <xs:documentation>Denotes the relation of an CityObject to its corresponding CityObject in higher LoD, i.e. to the CityObjects repre-
                    senting the same real world object in higher LoD.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:restriction base="gml:AssociationType">
                <xs:sequence minOccurs="0">
                    <xs:element ref="gml:_Feature" />
                </xs:sequence>
                <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
            </xs:restriction>
        </xs:complexContent>
    </xs:complexType>
```

10.1.4 City object groups

```
    <xs:complexType name="CityObjectGroupType">
        <xs:annotation>
            <xs:documentation>A group may be used to aggregate arbitrary CityObjects according to some user-defined criteria. Examples for
                    groups are the buildings in a specific region, the result of a query, or objects put together for visualization purposes. Each
                    group has a name (inherited from AbstractGMLType), functions (e.g., building group), a class and zero or more usages. A ge-
                    ometry may optionally be attached to a group, if the geometry of the whole group differs from the geometry of the parts. Each
                    member of a group may be qualified by a role name, reflecting the role each cityObject plays in the context of the group. As
                    subclass of _CityObject, a CityObjectGroup inherits all attributes and relations, in particular an id, names, external references,
                    generic attributes and generalization relations. As CityObjectGroup itself is a CityObject, it may also contain
                    groups.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_CityObjectType">
                <xs:sequence>
                    <xs:element name="class" type="xs:string" minOccurs="0" />
                    <xs:element name="function" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="usage" type="xs:string" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="groupMember" type="CityObjectGroupMemberType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="parent" type=" CityObjectGroupMemberType " minOccurs="0"/>
                    <xs:element name="geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                    <xs:element ref="_GenericApplicationPropertyOfCityObjectGroup" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================== -->
    <xs:element name="CityObjectGroup" type="CityObjectGroupType" substitutionGroup="_CityObject" />
    <!-- ========================================================================================== -->
    <xs:complexType name="CityObjectGroupMemberType">
        <xs:annotation>
            <xs:documentation>Denotes the relation of a group to its members, which are CityObjects. Since an association attribute group for
                    enabling the use of references is provided, the relation may either be given by a reference to a city object defined alsewhere, or
                    by inlining of the complete city object.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="gml:AssociationType">
                <xs:attribute name="role" type="xs:string" />
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfCityObjectGroup" type="xs:anyType" abstract="true"/>
```

10.1.5 External references

```
<xs:complexType name="ExternalReferenceType">
    <xs:annotation>
        <xs:documentation>Type describing the reference to an corresponding object in an other information system, for example in the ger-
                man cadastre ALKIS, the german topographic information system or ATKIS, or the Ordnance Survey Mastermap. The refer-
                ence consists of the name of the external information system, represented by an URI, and the reference of the external object,
                given either by a string or by an URI. If the informationSystem element is missing in the ExternalReference, the Exter-
                nalObjectReference must be an URI, which contains an indication of the informationSystem.</xs:documentation>
    </xs:annotation>
    <xs:sequence>
        <xs:element name="informationSystem" type="xs:anyURI" minOccurs="0" />
        <xs:element name="externalObject" type="ExternalObjectReferenceType" />
    </xs:sequence>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:complexType name="ExternalObjectReferenceType">
    <xs:choice>
        <xs:element name="name" type="xs:string" />
        <xs:element name="uri" type="xs:anyURI" />
    </xs:choice>
</xs:complexType>
```

10.2 *Extensions to the GML geometry model*

10.2.1 Special surfaces with material [deprecated]

```
<xs:complexType name="TexturedSurfaceType">
    <xs:annotation>
        <xs:appinfo>deprecated</xs:appinfo>
        <xs:documentation>Deprecated in CityGML version 0.4.0. Use the concepts of the new appearance model instead. The concept of po-
                sitioning textures on surfaces complies with the standard X3D. Because there has been no appropriate texturing concept in
                GML3, CityGML adds the class TexturedSurface to the geometry model of GML 3. A texture is specified as a raster image
                referenced by an URI, and can be an arbitrary resource, even in the internet. Textures are positioned by employing the concept
                of texture coordinates, i.e. each texture coordinate matches with exactly one 3D coordinate of the TexturedSurface. The use of
                texture coordinates allows an exact positioning and trimming of the texture on the surface geometry. Each surface may be as-
                signed one or more appearances, each refering to one side of the surface.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="gml:OrientableSurfaceType">
            <xs:sequence>
                <xs:element ref="appearance" maxOccurs="unbounded" />
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ==================================================================================== -->
<xs:element name="TexturedSurface" type="TexturedSurfaceType" substitutionGroup="gml:OrientableSurface" />
<!-- ==================================================================================== -->
<xs:element name="appearance" type="_AppearancePropertyType" />
<!-- ==================================================================================== -->
<xs:complexType name="_AppearancePropertyType">
    <xs:annotation>
        <xs:appinfo>deprecated</xs:appinfo>
        <xs:documentation>Deprecated in CityGML version 0.4.0. Use the concepts of the new appearance model instead. A property that has
                an _Appearance as its value domain, which can either be a Material (Color,...) or a Texture. The _Appearance Element can ei-
                ther be encapsulated in an element of this type or an XLink reference to a remote _Appearance element (where remote includes
                geometry elements located elsewhere in the same document). Either the reference or the contained element must be given, but
                neither both nor none. The side of the surface the _Appearance refers to is given by the orientation attribute, which refers to the
                corresponding sign attribute of the orientable surface: + means the side with positive orientation, and - the side with negative
                orientation.</xs:documentation>
    </xs:annotation>
    <xs:sequence>
        <xs:element ref="_Appearance" minOccurs="0" />
    </xs:sequence>
    <xs:attribute name="orientation" type="gml:SignType" default="+" />
    <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
</xs:complexType>
<!-- ==================================================================================== -->
<xs:complexType name="_AppearanceType" abstract="true">
    <xs:annotation>
        <xs:appinfo>deprecated</xs:appinfo>
        <xs:documentation>Deprecated in CityGML version 0.4.0. Use the concepts of the new appearance model instead. This abstract type
                is the parent type of MaterialType and SimpleTextureType. It is derived from gml:AbstractGMLType, thus it inherits the at-
                tribute gml:id and may be referenced by an appearanceProperty, although it is defined elsewhere in another appearanceProp-
                erty.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="gml:AbstractGMLType" />
    </xs:complexContent>
</xs:complexType>
<!-- ==================================================================================== -->
<xs:element name="_Appearance" type="_AppearanceType" abstract="true" substitutionGroup="gml:_GML" />
<!-- ==================================================================================== -->
<xs:complexType name="MaterialType">
    <xs:annotation>
        <xs:appinfo>deprecated</xs:appinfo>
        <xs:documentation>Deprecated in CityGML version 0.4.0. Use the concepts of the new appearance model instead. Adopted from
                X3D standard (http://www.web3d.org/x3d/)</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_AppearanceType">
            <xs:sequence>
                <xs:element name="shininess" type="doubleBetween0and1" minOccurs="0" />
                <xs:element name="transparency" type="doubleBetween0and1" minOccurs="0" />
                <xs:element name="ambientIntensity" type="doubleBetween0and1" minOccurs="0" />
```

```
                    <xs:element name="specularColor" type="Color" minOccurs="0" />
                    <xs:element name="diffuseColor" type="Color" minOccurs="0" />
                    <xs:element name="emissiveColor" type="Color" minOccurs="0" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================== -->
    <xs:element name="Material" type="MaterialType" substitutionGroup="_Appearance" />
    <!-- ========================================================================================== -->
    <xs:complexType name="SimpleTextureType">
        <xs:annotation>
            <xs:appinfo>deprecated</xs:appinfo>
            <xs:documentation>Deprecated in CityGML version 0.4.0. Use the concepts of the new appearance model instead. Adopted from
                    X3D standard (http://www.web3d.org/x3d/). ToDo: repeat</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_AppearanceType">
                <xs:sequence>
                    <xs:element name="textureMap" type="xs:anyURI" />
                    <xs:element name="textureCoordinates" type="gml:doubleList" />
                    <xs:element name="textureType" type="TextureTypeType" minOccurs="0" />
                    <xs:element name="repeat" type="xs:boolean" minOccurs="0" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================== -->
    <xs:element name="SimpleTexture" type="SimpleTextureType" substitutionGroup="_Appearance" />
    <!-- ========================================================================================== -->
    <xs:simpleType name="Color">
        <xs:annotation>
            <xs:documentation>List of three values (red, green, blue), separated by spaces. The values must be in the range between zero and
                    one.</xs:documentation>
        </xs:annotation>
        <xs:restriction base="doubleBetween0and1List">
            <xs:minLength value="3" />
            <xs:maxLength value="3" />
        </xs:restriction>
    </xs:simpleType>
    <!-- ========================================================================================== -->
    <xs:simpleType name="TextureTypeType">
        <xs:annotation>
            <xs:appinfo>deprecated</xs:appinfo>
            <xs:documentation>Deprecated in CityGML version 0.4.0. Use the concepts of the new appearance model instead. Textures can be
                    qualified by the attribute textureType. The textureType differentiates between textures, which are specific for a certain object
                    and are only used for that object (specific), and prototypic textures being typical for that kind of object and are used many
                    times for all objects of that kind (typical). A typical texture may be replaced by a specific, if available. Textures may also be
                    classified as unknown.</xs:documentation>
        </xs:annotation>
        <xs:restriction base="xs:string">
            <xs:enumeration value="specific" />
            <xs:enumeration value="typical" />
            <xs:enumeration value="unknown" />
        </xs:restriction>
    </xs:simpleType>
```

10.2.2 Implicit geometries

```
    <xs:complexType name="ImplicitRepresentationPropertyType">
        <xs:annotation>
            <xs:documentation>A property that has a Implicit Representation as its value domain, which is a representation of a geometry by ref-
                    erencing a prototype and transforming it to its real position in space.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:restriction base="gml:AssociationType">
                <xs:sequence minOccurs="0">
                    <xs:element ref="ImplicitGeometry" />
                </xs:sequence>
                <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
            </xs:restriction>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================== -->
    <xs:complexType name="ImplicitGeometryType">
```

```
        <xs:annotation>
            <xs:documentation>Type for the implicit representation of a geometry. An implicit geometry is a geometric object, where the shape is
                    stored only once as a prototypical geometry, e.g. a tree or other vegetation object, a traffic light or a traffic sign. This proto-
                    typic geometry object is re-used or referenced many times, wherever the corresponding feature occurs in the 3D city model.
                    Each occurrence is represented by a link to the prototypic shape geometry (in a local cartesian coordinate system), by a trans-
                    forma-tion matrix that is multiplied with each 3D coordinate tuple of the prototype, and by an anchor point denoting the base
                    point of the object in the world coordinate reference system. In order to determine the absolute coordinates of an implicit ge-
                    ometry, the anchor point coordinates have to be added to the matrix multiplication results. The transformation matrix accounts
                    for the intended rotation, scaling, and local translation of the prototype. It is a 4x4 matrix that is multiplied with the prototype
                    coordinates using homogeneous coordinates, i.e. (x,y,z,1). This way even a projection might be modelled by the transformation
                    matrix. The concept of implicit geometries is an enhancement of the geometry model of GML3.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="gml:AbstractGMLType">
                <xs:sequence>
                    <xs:element name="mimeType" type="MimeTypeType" minOccurs="0" />
                    <xs:element name="transformationMatrix" type="TransformationMatrix4x4Type" minOccurs="0" />
                    <xs:element name="libraryObject" type="xs:anyURI" minOccurs="0" />
                    <xs:element name="relativeGMLGeometry" type="gml:GeometryPropertyType" minOccurs="0" />
                    <xs:element name="referencePoint" type="gml:PointPropertyType" />
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================= -->
    <xs:element name="ImplicitGeometry" type="ImplicitGeometryType" substitutionGroup="gml:_GML" />
    <!-- ========================================================================================= -->
    <xs:simpleType name="MimeTypeType">
        <xs:annotation>
            <xs:documentation>MIME type of a geometry in an external library file. MIME types are defined by the IETF (Internet Engineering
                    Task Force). The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, according to the dictionary
                    concept of GML3.</xs:documentation>
        </xs:annotation>
        <xs:restriction base="xs:string" />
    </xs:simpleType>
```

10.3 Appearance model

```
<xs:complexType name="AppearanceType">
    <xs:annotation>
        <xs:documentation> Named container for all surface data (texture/material). All appearances of the same name ("theme") within a
                CityGML file are considered a group.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="gml:AbstractFeatureType">
            <xs:sequence>
                <xs:element name="theme" type="xs:string" minOccurs="0"/>
                <xs:element name="surfaceDataMember" type="SurfaceDataPropertyType" minOccurs="0" maxOccurs="unbounded"/>
                <xs:element ref="_GenericApplicationPropertyOfAppearance" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="appearanceMember" type="AppearancePropertyType" substitutionGroup="gml:featureMember"/>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAppearance" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:complexType name="AppearancePropertyType">
    <xs:complexContent>
        <xs:extension base="gml:FeaturePropertyType">
            <xs:sequence minOccurs="0">
                <xs:element name="Appearance" type="AppearanceType"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:complexType name="AbstractSurfaceDataType">
    <xs:annotation>
        <xs:documentation>Base class for textures and material. Contains only isFront-flag.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="gml:AbstractFeatureType">
            <xs:sequence>
                <xs:element name="isFront" type="xs:boolean" default="true" minOccurs="0"/>
                <xs:element ref="_GenericApplicationPropertyOfAbstractSurfaceData" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_SurfaceData" type="AbstractSurfaceDataType" abstract="true" substitutionGroup="gml:_Feature"/>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAbstractSurfaceData" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:complexType name="SurfaceDataPropertyType">
    <xs:sequence minOccurs="0">
        <xs:element ref="_SurfaceData" minOccurs="0"/>
    </xs:sequence>
    <xs:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:complexType name="AbstractTextureType">
    <xs:annotation>
        <xs:documentation>Base class for textures. "imageURI" can contain any valid URI from references to a local file to preformatted
                web service requests. The linking to geometry and texture parameterization is provided by derived
                classes.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="AbstractSurfaceDataType">
            <xs:sequence>
                <xs:element name="imageURI" type="xs:anyURI"/>
                <xs:element name="mimeType" type="MimeTypeType" minOccurs="0"/>
                <xs:element name="textureType" type="TextureTypeType" minOccurs="0"/>
                <xs:element name="wrapMode" type="WrapModeType" minOccurs="0"/>
                <xs:element name="borderColor" type="ColorPlusOpacity" minOccurs="0"/>
                <xs:element ref="_GenericApplicationPropertyOfAbstractTexture" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ====================================================================== -->
<xs:element name="_Texture" type="AbstractTextureType" abstract="true" substitutionGroup="_SurfaceData"/>
<!-- ====================================================================== -->
<xs:element name="_GenericApplicationPropertyOfAbstractTexture" type="xs:anyType" abstract="true"/>
<!-- ====================================================================== -->
<xs:simpleType name="WrapModeType">
    <xs:annotation>
        <xs:documentation>Fill mode for a texture. "wrap" repeats the texture, "clamp" extends the edges of the texture, and "border"
                fills all undefined areas with "borderColor"</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string">
        <xs:enumeration value="none"/>
        <xs:enumeration value="wrap"/>
        <xs:enumeration value="mirror"/>
        <xs:enumeration value="clamp"/>
        <xs:enumeration value="border"/>
    </xs:restriction>
</xs:simpleType>
<!-- ====================================================================== -->
<xs:complexType name="ParameterizedTextureType">
    <xs:annotation>
        <xs:documentation>Specialization for standard 2D textures. "target" provides the linking to surface geometry. Only
                gml:MultiSurface and decendants of gml:AbstractSurfaceType are valid targets. As property of the link, a texture parame-
                terization either as set of texture coordinates or transformation matrix is given. </xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="AbstractTextureType">
            <xs:sequence>
                <xs:element name="target" type="TextureAssociationType" minOccurs="0" maxOccurs="unbounded"/>
                <xs:element ref="_GenericApplicationPropertyOfParameterizedTexture" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ====================================================================== -->
<xs:element name="ParameterizedTexture" type="ParameterizedTextureType" substitutionGroup="_Texture"/>
<!-- ====================================================================== -->
<xs:element name="_GenericApplicationPropertyOfParameterizedTexture" type="xs:anyType" abstract="true"/>
<!-- ====================================================================== -->
<xs:complexType name="GeoreferencedTextureType">
    <xs:annotation>
        <xs:documentation>Specialization for georeferenced textures, i.e. textures using a planimetric projection. Such textures contain
                an implicit parameterization (either stored within the image file, in an acompanying world file, or using the "reference-
                Point" and "orientation"-elements). A georeference provided by "referencePoint" and "orientation" always takes prece-
                dence. Precedence between a world file and image data is ruled by "lowerWorldFilePriority". If it is set to false (the de-
                fault value), the world file, if available, should be used. Otherwise, the world file is ignored. The "boundedBy"-property
                should contain the bounding box of the projected image data. Since a georeferenced texture has a unique parameterization,
                "target" only provides links to surface geometry without any additional texture parameterization. Only gml:MultiSurface
                or decendants of gml:AbstractSurfaceType are valid targets.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="AbstractTextureType">
            <xs:sequence>
                <xs:element name="preferWorldFile" type="xs:boolean" default="true" minOccurs="0"/>
                <xs:element name="referencePoint" type="gml:PointPropertyType" minOccurs="0"/>
                <xs:element name="orientation" type="TransformationMatrix2x2Type" minOccurs="0"/>
                <xs:element name="target" type="xs:anyURI" minOccurs="0" maxOccurs="unbounded"/>
                <xs:element ref="_GenericApplicationPropertyOfGeoreferencedTexture" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ====================================================================== -->
<xs:element name="GeoreferencedTexture" type="GeoreferencedTextureType" substitutionGroup="_Texture"/>
<!-- ====================================================================== -->
<xs:element name="_GenericApplicationPropertyOfGeoreferencedTexture" type="xs:anyType" abstract="true"/>
<!-- ====================================================================== -->
<xs:complexType name="TextureAssociationType">
    <xs:annotation>
        <xs:documentation>Link of a texture to a surface, that is augmented by a TextureParameterization object. This object can be a
                remote property.</xs:documentation>
    </xs:annotation>
    <xs:sequence minOccurs="0">
        <xs:element ref="_TextureParameterization"/>
    </xs:sequence>
    <xs:attribute name="uri" type="xs:anyURI" use="required"/>
    <xs:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:complexType name="TextureParameterizationType" abstract="true">
    <xs:annotation>
        <xs:documentation>Base class for augmenting a link "texture->surface" with texture parameterization. Subclasses of this class
                define concrete parameterizations. Currently, texture coordinates and texture coordinate generation using a transformation
                matrix are available.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="gml:AbstractGMLType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfTextureParameterization" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_TextureParameterization" type="TextureParameterizationType" abstract="true" substitutionGroup="gml:_GML"/>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTextureParameterization" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:complexType name="TexCoordListType">
    <xs:annotation>
        <xs:documentation>Texture parameterization using texture coordinates: Each gml:LinearRing that is part of the surface requires a
                separate "textureCoordinates"-entry with 2 doubles per ring vertex. The "ring"- attribute provides the gml:id of the target
                LinearRing. It is prohibited to link texture coordinates to any other object type than LinearRing. Thus, surfaces not con-
                sisting of LinearRings cannot be textured this way. Use transformation matrices (see below) or georeferenced textures in-
                stead.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="TextureParameterizationType">
            <xs:sequence>
                <xs:element name="textureCoordinates" maxOccurs="unbounded">
                    <xs:complexType>
                        <xs:simpleContent>
                            <xs:extension base="gml:doubleList">
                                <xs:attribute name="ring" type="xs:anyURI" use="required"/>
                            </xs:extension>
                        </xs:simpleContent>
                    </xs:complexType>
                </xs:element>
                <xs:element ref="_GenericApplicationPropertyOfTexCoordList" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="TexCoordList" type="TexCoordListType" substitutionGroup="_TextureParameterization"/>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTexCoordList" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:complexType name="TexCoordGenType">
    <xs:annotation>
        <xs:documentation>Texture parameterization using a transformation matrix. The transformation matrix "worldToTexture" can be
                used to derive texture coordinates from an object's location. This 3x4 matrix T computes the coordinates (s,t) from a ho-
                mogeneous world position p as (s,t) = (s'/q', t'/q') with (s', t', q') = T*p. Thus, perspective projections can be specified. The
                SRS can be specified using standard attributes. If an object is given in a different reference system, it is transformed to the
                SRS before applying the transformation. A transformation matrix can be used for whole surfaces. It is not required to
                specify it per LinearRing.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="TextureParameterizationType">
            <xs:sequence>
                <xs:element name="worldToTexture">
                    <xs:complexType>
                        <xs:simpleContent>
                            <xs:extension base="TransformationMatrix3x4Type">
                                <xs:attributeGroup ref="gml:SRSReferenceGroup"/>
                            </xs:extension>
                        </xs:simpleContent>
                    </xs:complexType>
                </xs:element>
                <xs:element ref="_GenericApplicationPropertyOfTexCoordGen" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="TexCoordGen" type="TexCoordGenType" substitutionGroup="_TextureParameterization"/>
<!-- ====================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfTexCoordGen" type="xs:anyType" abstract="true"/>
<!-- ====================================================================================== -->
<xs:complexType name="X3DMaterialType">
    <xs:annotation>
        <xs:documentation>Class for defining constant surface properties. It is based on X3D's material definition. In addition, "isS-
                mooth" provides a hint for value interpolation. The link to surface geometry is established via the "target"-property. Only
                decendants of gml:AbstractSurfaceType ar valid targets. </xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="AbstractSurfaceDataType">
            <xs:sequence>
                <xs:element name="ambientIntensity" type="doubleBetween0and1" default="0.2" minOccurs="0"/>
                <xs:element name="diffuseColor" type="Color" default="0.8 0.8 0.8" minOccurs="0"/>
                <xs:element name="emissiveColor" type="Color" default="0.0 0.0 0.0" minOccurs="0"/>
                <xs:element name="specularColor" type="Color" default="1.0 1.0 1.0" minOccurs="0"/>
                <xs:element name="shininess" type="doubleBetween0and1" default="0.2" minOccurs="0"/>
                <xs:element name="transparency" type="doubleBetween0and1" default="0.0" minOccurs="0"/>
                <xs:element name="isSmooth" type="xs:boolean" default="false" minOccurs="0"/>
                <xs:element name="target" type="xs:anyURI" minOccurs="0" maxOccurs="unbounded"/>
                <xs:element ref="_GenericApplicationPropertyOfX3DMaterial" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ====================================================================================== -->
<xs:element name="X3DMaterial" type="X3DMaterialType" substitutionGroup="_SurfaceData"/>
<!-- ====================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfX3DMaterial" type="xs:anyType" abstract="true"/>
<!-- ====================================================================================== -->
<xs:simpleType name="ColorPlusOpacity">
    <xs:annotation>
        <xs:documentation>List of three or four values (red, green, blue, opacity), separated by spaces. The values must be in the range
                between zero and one. If no opacity is given, it is assumed as 1.0.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="doubleBetween0and1List">
        <xs:minLength value="3"/>
        <xs:maxLength value="4"/>
    </xs:restriction>
</xs:simpleType>
```

10.4 Thematic model

10.4.1 Sites

```
<xs:complexType name="_SiteType" abstract="true">
    <xs:annotation>
        <xs:documentation>Type describing the abstract superclass for buildings, facilities, etc. Future extensions of CityGML like bridges
                and tunnels would be modelled as subclasses of _Site. The german translation of site is 'Anlage'. As subclass of _CityObject, a
                _Site inherits all attributes and relations, in particular an id, names, external references, generic attributes and generalization
                relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfSite" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================  -->
<xs:element name="_Site" type="_SiteType" abstract="true" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfSite" type="xs:anyType" abstract="true"/>
```

10.4.2 Buildings

```
<xs:complexType name="_AbstractBuildingType" abstract="true">
    <xs:annotation>
        <xs:documentation>Type describing the thematic and geometric attributes and the associations of buildings. It is an abstract type, only
                its subclasses Building and BuildingPart can be instantiated. An _AbstractBuilding may consist of BuildingParts, which are
                again _AbstractBuildings by inheritance. Thus an aggregation hierarchy between _AbstractBuildings of arbitrary depth may be
                specified. In such an hierarchy, top elements are Buildings, while all other elements are BuildingParts. Each element of such a
                hierarchy may have all attributes and geometries of _AbstractBuildings. It must, however, be assured than no inconsistencies
                occur (for example, if the geometry of a Building does not correspond to the geometries of its parts, of if the roof type of a
                Building is saddle roof, while its parts have an hip roof).</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_SiteType">
            <xs:sequence>
                <xs:annotation>
                    <xs:documentation>The name will be represented by gml:name (inherited from _GML) . list order for storeyHeight-
                            sAboveground: first floor, second floor,... list order for storeyHeightsBelowground: first floor below ground, sec-
                            ond floor below ground,... The lodXMultiSurface must be used, if the geometry of a building is just a collection of
                            surfaces bounding a solid, but not a topologically clean solid boundary necessary for GML3 solid bounda-
                            ries.</xs:documentation>
                </xs:annotation>
                <xs:element name="class" type="BuildingClassType" minOccurs="0" />
                <xs:element name="function" type="BuildingFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="usage" type="BuildingUsageType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="yearOfConstruction" type="xs:gYear" minOccurs="0" />
                <xs:element name="yearOfDemolition" type="xs:gYear" minOccurs="0" />
                <xs:element name="roofType" type="RoofTypeType" minOccurs="0" />
                <xs:element name="measuredHeight" type="gml:LengthType" minOccurs="0" />
                <xs:element name="storeysAboveGround" type="xs:nonNegativeInteger" minOccurs="0" />
                <xs:element name="storeysBelowGround" type="xs:nonNegativeInteger" minOccurs="0" />
                <xs:element name="storeyHeightsAboveGround" type="gml:MeasureOrNullListType" minOccurs="0" />
                <xs:element name="storeyHeightsBelowGround" type="gml:MeasureOrNullListType" minOccurs="0" />
                <xs:element name="lod1Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod1TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="lod2Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod2MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="lod2TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="outerBuildingInstallation" type="BuildingInstallationPropertyType" minOccurs="0"
                        maxOccurs="unbounded" />
                <xs:element name="interiorBuildingInstallation" type="IntBuildingInstallationPropertyType" minOccurs="0"
                        maxOccurs="unbounded" />
                <xs:element name="boundedBy" type="BoundarySurfacePropertyType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="lod3Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod3MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="lod3TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="lod4Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod4MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="lod4TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="interiorRoom" type="InteriorRoomPropertyType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="consistsOfBuildingPart" type="BuildingPartPropertyType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="address" type="AddressPropertyType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element ref="_GenericApplicationPropertyOfAbstractBuilding" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_AbstractBuilding" type="_AbstractBuildingType" abstract="true" substitutionGroup="_Site" />
<!-- ========================================================================================== -->
<xs:simpleType name="BuildingClassType">
    <xs:annotation>
        <xs:documentation>Class of a building. The values of this type are defined in a the XML file "CityGML_ExternalCodeLists.xml", ac-
                cording to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="BuildingFunctionType">
    <xs:annotation>
        <xs:documentation>Intended function of a building. The values of this type are defined in the XML file
                "CityGML_ExternalCodeLists.xml", according to the dictionary concept of GML3. The values may be adopted from ALKIS,
                the german standard for cadastre modelling. If the cadastre models from other countries differ in the building functions, these
                values may be compiled in another codelist to be used with CityGML.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="BuildingUsageType">
    <xs:annotation>
        <xs:documentation>Actual usage of a building. The values of this type are defined in a the XML file
                "CityGML_ExternalCodeLists.xml", according to the dictionary concept of GML3..</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="RoofTypeType">
    <xs:annotation>
        <xs:documentation>Roof Types. The values of this type are defined in a XML file, according to the dictionary concept of
                GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:complexType name="BuildingPartType">
    <xs:complexContent>
        <xs:extension base="_AbstractBuildingType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfBuildingPart" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="BuildingPart" type="BuildingPartType" substitutionGroup="_AbstractBuilding" />
<!-- ========================================================================================== -->
<xs:complexType name="BuildingType">
    <xs:complexContent>
        <xs:extension base="_AbstractBuildingType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfBuilding" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="Building" type="BuildingType" substitutionGroup="_AbstractBuilding" />
<!-- ========================================================================================== -->
<xs:complexType name="BuildingPartPropertyType">
    <xs:annotation>
```

```
        <xs:documentation>Denotes the relation of an _AbstractBuilding to its building parts. The gml:AssociationType attribute group for
                enabling the use of refs is not repeated in the restriction and thus omitted. The building part has to be given inline, i.e. explic-
                itely in this property. The reason for this inline definition is that no BuildingPart is used by more than one building, thus the
                use or references to building parts defined elsewhere is prohibited.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence>
                <xs:element ref="BuildingPart" />
            </xs:sequence>
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ==================================================================================== -->
<xs:complexType name="BuildingInstallationType">
    <xs:annotation>
        <xs:documentation>A BuildingInstallation (German translation is 'Gebäudecharakteristik') is a part of a Building which has not the
                significance of a BuildingPart. Examples are stairs, antennas, balconies or small roofs. As subclass of _CityObject, a Building-
                Installation inherits all attributes and relations, in particular an id, names, external references, generic attributes and generaliza-
                tion relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element name="class" type="BuildingInstallationClassType" minOccurs="0" />
                <xs:element name="function" type="BuildingInstallationFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="usage" type="BuildingInstallationUsageType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfBuildingInstallation" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ==================================================================================== -->
<xs:element name="BuildingInstallation" type="BuildingInstallationType" substitutionGroup="_CityObject" />
<!-- ==================================================================================== -->
<xs:simpleType name="BuildingInstallationClassType">
    <xs:annotation>
        <xs:documentation>Class of a building installation. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ==================================================================================== -->
<xs:simpleType name="BuildingInstallationFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a building installation. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ==================================================================================== -->
<xs:simpleType name="BuildingInstallationUsageType">
    <xs:annotation>
        <xs:documentation>Actual Usage of a building installation. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ==================================================================================== -->
<xs:complexType name="BuildingInstallationPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an AbstractBuilding to its building installations. The gml:AssociationType attribute group
                for enabling the use of refs is not repeated in the restriction and thus omitted. The building installation has to be given inline,
                i.e. explicitely in this property. The reason for this inline definition is that no installation of a building is used by more than one
                building, thus the use or references to building installations defined elsewhere is prohibited.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence>
                <xs:element ref="BuildingInstallation" />
            </xs:sequence>
        </xs:restriction>
    </xs:complexContent>
```

```
</xs:complexType>
<!-- ========================================================================================= -->
<xs:complexType name="IntBuildingInstallationType">
    <xs:annotation>
        <xs:documentation>An IntBuildingInstallation (German translation is 'Gebäudeinstallation') is an interior part of a Building which has
                a specific function or semantical meaning. Examples are interior stairs, railings, radiators or pipes. As subclass of _CityObject,
                an IntBuildingInstallation inherits all attributes and relations, in particular an id, names, external references, generic attributes
                and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element name="class" type="IntBuildingInstallationClassType" minOccurs="0" />
                <xs:element name="function" type="IntBuildingInstallationFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="usage" type="IntBuildingInstallationUsageType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfIntBuildingInstallation" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="IntBuildingInstallation" type="IntBuildingInstallationType" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:simpleType name="IntBuildingInstallationClassType">
    <xs:annotation>
        <xs:documentation>Class of an interior building installation. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:simpleType name="IntBuildingInstallationFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a interior building installation. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:simpleType name="IntBuildingInstallationUsageType">
    <xs:annotation>
        <xs:documentation>Actual Usage of a interior building installation. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:complexType name="IntBuildingInstallationPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an AbstractBuilding to its interior building installations. The gml:AssociationType attrib-
                ute group for enabling the use of refs is not repeated in the restriction and thus omitted. The building installation has to be
                given inline, i.e. explicitely in this property. The reason for this inline definition is that no installation of a building is used by
                more than one building, thus the use or references to building installations defined elsewhere is prohib-
                ited.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence>
                <xs:element ref="IntBuildingInstallation" />
            </xs:sequence>
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfAbstractBuilding" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
 <xs:element name="_GenericApplicationPropertyOfBuildingPart" type="xs:anyType" abstract="true"/>
 <!-- ========================================================================================= -->
 <xs:element name="_GenericApplicationPropertyOfBuilding" type="xs:anyType" abstract="true"/>
 <!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfBuildingInstallation" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfIntBuildingInstallation" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<!-- =====================SURFACES OF BUILDINGS AND ROOMS( LoD2 to LOD4)==================== -->
```

```
<xs:complexType name="_BoundarySurfaceType" abstract="true">
    <xs:annotation>
        <xs:documentation>A BoundarySurface (German translation is 'Begrenzungsfläche') is a thematic object which classifies surfaces
                bounding a building or a room. The geometry of a BoundarySurface is given by MultiSurfaces. As it is a subclass of
                _CityObject, it inherits all atributes and relations, in particular the external references, the generic attributes, and the generali-
                zation relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="opening" type="OpeningPropertyType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element ref="_GenericApplicationPropertyOfBoundarySurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_BoundarySurface" type="_BoundarySurfaceType" abstract="true" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:complexType name="RoofSurfaceType">
    <xs:complexContent>
        <xs:extension base="_BoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfRoofSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="RoofSurface" type="RoofSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:complexType name="WallSurfaceType">
    <xs:complexContent>
        <xs:extension base="_BoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfWallSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="WallSurface" type="WallSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:complexType name="GroundSurfaceType">
    <xs:complexContent>
        <xs:extension base="_BoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfGroundSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="GroundSurface" type="GroundSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:complexType name="ClosureSurfaceType">
    <xs:complexContent>
        <xs:extension base="_BoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfClosureSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="ClosureSurface" type="ClosureSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ===================================LoD4 only Surfaces============================================= -->
<xs:complexType name="FloorSurfaceType">
    <xs:complexContent>
        <xs:extension base="_BoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfFloorSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="FloorSurface" type="FloorSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:complexType name="InteriorWallSurfaceType">
    <xs:complexContent>
        <xs:extension base="_BoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfInteriorWallSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="InteriorWallSurface" type="InteriorWallSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:complexType name="CeilingSurfaceType">
    <xs:complexContent>
        <xs:extension base="_BoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfCeilingSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="CeilingSurface" type="CeilingSurfaceType" substitutionGroup="_BoundarySurface" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfBoundarySurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfWallSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfRoofSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfGroundSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfClosureSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfFloorSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfInteriorWallSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfCeilingSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfOpening" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfWindow" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfDoor" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<!-- ============================Relation of Buildings/Rooms to its bounding Surfaces====================== -->
<xs:complexType name="BoundarySurfacePropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an Building or Room to its bounding thematic surfaces (walls, roofs, ..). There is no dif-
                ferentiation between interior surfaces bounding rooms and outer ones bounding buildings (one reason is, that ClosureSurfaces
                belong to both types). It has to be made sure by additional integrity constraints that, e.g. a building is not related to CeilingSur-
                faces or a room not to RoofSurfaces.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence minOccurs="0">
                <xs:element ref="_BoundarySurface" />
            </xs:sequence>
            <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ================================Openings (LoD3 and LoD4 only)================================ -->
<xs:complexType name="OpeningPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an BondarySurface to its openings (doors, windows).</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence minOccurs="0">
                <xs:element ref="_Opening" />
            </xs:sequence>
            <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:complexType name="_OpeningType" abstract="true">
    <xs:annotation>
```

```
      <xs:documentation>Type for openings (doors, windows) in walls. Used in LoD3 and LoD4 only. As subclass of _CityObject, an
            _Opening inherits all attributes and relations, in particular an id, names, external references, generic attributes and generaliza-
            tion relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
      <xs:extension base="_CityObjectType">
        <xs:sequence>
          <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
          <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
          <xs:element ref="_GenericApplicationPropertyOfOpening" minOccurs="0" maxOccurs="unbounded"/>
        </xs:sequence>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>
  <!-- ========================================================================================= -->
  <xs:element name="_Opening" type="_OpeningType" abstract="true" substitutionGroup="_CityObject" />
  <!-- ========================================================================================= -->
  <xs:complexType name="WindowType">
    <xs:annotation>
      <xs:documentation>Type for windows in walls. Used in LoD3 and LoD4 only . As subclass of _CityObject, a window inherits all at-
            tributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
            tions.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
      <xs:extension base="_OpeningType">
        <xs:sequence>
           <xs:element ref="_GenericApplicationPropertyOfWindow" minOccurs="0" maxOccurs="unbounded"/>
        </xs:sequence>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>
  <!-- ========================================================================================= -->
  <xs:element name="Window" type="WindowType" substitutionGroup="_Opening" />
  <!-- ========================================================================================= -->
  <xs:complexType name="DoorType">
    <xs:annotation>
      <xs:documentation>Type for doors in walls. Used in LoD3 and LoD4 only . As subclass of _CityObject, a Door inherits all attributes
            and relations, in particular an id, names, external references, generic attributes and generalization rela-
            tions.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
      <xs:extension base="_OpeningType">
        <xs:sequence>
          <xs:element name="address" type="AddressPropertyType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element ref="_GenericApplicationPropertyOfDoor" minOccurs="0" maxOccurs="unbounded"/>
        </xs:sequence>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>
  <!-- ========================================================================================= -->
  <xs:element name="Door" type="DoorType" substitutionGroup="_Opening" />
  <!-- ========================================================================================= -->
  <xs:element name="_GenericApplicationPropertyOfWindow" type="xs:anyType" abstract="true"/>
  <xs:element name="_GenericApplicationPropertyOfDoor" type="xs:anyType" abstract="true"/>
  <!-- ========================================================================================= -->
  <!-- ===================================ROOMS (LoD4 only)==================================== -->
  <xs:complexType name="RoomType">
    <xs:annotation>
      <xs:documentation>A Room is a thematic object for modelling the closed parts inside a building. It has to be closed, if necessary by
            using closure surfaces. The geometry may be either a solid, or a MultiSurface if the boundary is not topologically clean. The
            room connectivity may be derived by detecting shared thematic openings or closure surfaces: two rooms are connected if both
            use the same opening object or the same closure surface. The thematic surfaces bounding a room are referenced by the bound-
            edBy property. As subclass of _CityObject, a Room inherits all attributes and relations, in particular an id, names, external ref-
            erences, generic attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
      <xs:extension base="_CityObjectType">
        <xs:sequence>
          <xs:element name="class" type="RoomClassType" minOccurs="0" />
          <xs:element name="function" type="RoomFunctionType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="usage" type="RoomUsageType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="lod4Solid" type="gml:SolidPropertyType" minOccurs="0" />
          <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
          <xs:element name="boundedBy" type="BoundarySurfacePropertyType" minOccurs="0" maxOccurs="unbounded" />
          <xs:element name="interiorFurniture" type="InteriorFurniturePropertyType" minOccurs="0" maxOccurs="unbounded" />
```

```
                <xs:element name="roomInstallation" type="IntBuildingInstallationPropertyType" minOccurs="0"
                        maxOccurs="unbounded"/>
                <xs:element ref="_GenericApplicationPropertyOfRoom" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="Room" type="RoomType" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:simpleType name="RoomClassType">
    <xs:annotation>
        <xs:documentation>Class of a room . The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, accord-
                ing to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="RoomFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a room. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, ac-
                cording to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="RoomUsageType">
    <xs:annotation>
        <xs:documentation>Actual Usage of a room. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml,
                according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- =========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfRoom" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:complexType name="BuildingFurnitureType">
    <xs:annotation>
        <xs:documentation>Type for building furnitures. As subclass of _CityObject, a BuildingFurniture inherits all attributes and relations,
                in particular an id, names, external references, generic attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element name="class" type="BuildingFurnitureClassType" minOccurs="0" />
                <xs:element name="function" type="BuildingFurnitureFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="usage" type="BuildingFurnitureUsageType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfBuildingFurniture" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="BuildingFurniture" type="BuildingFurnitureType" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:simpleType name="BuildingFurnitureClassType">
    <xs:annotation>
        <xs:documentation>Class of a building furniture. The values of this type are defined in a XML file, according to the dictionary con-
                cept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="BuildingFurnitureFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a building furniture. The values of this type are defined in a XML file, according to the dictionary
                concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="BuildingFurnitureUsageType">
    <xs:annotation>
```

```
        <xs:documentation>Actual Usage of a building Furniture. The values of this type are defined in a XML file, according to the diction-
                ary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ============================================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfBuildingFurniture" type="xs:anyType" abstract="true"/>
<!-- ============================Relation of Building to Rooms (LoD4 only)============================  -->
<xs:complexType name="InteriorRoomPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an AbstractBuilding to its rooms. The gml:AssociationType attribute group for enabling
                the use of refs is not repeated in the restriction and thus omitted. The room has to be given inline within this property, not by
                reference.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence>
                <xs:element ref="Room" />
            </xs:sequence>
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================================  -->
<xs:complexType name="InteriorFurniturePropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of a room to its interior furnitures (movable). The gml:AssociationType attribute group for
                enabling the use of refs is not repeated in the restriction and thus omitted. The BuildingFurniture has to be given inline within
                this property, not by reference.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence>
                <xs:element ref="BuildingFurniture" />
            </xs:sequence>
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ====================================== Address (all LoD) ======================================  -->
<!-- =======================================uses xAL Standard=======================================  -->
<xs:complexType name="AddressPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an AbstractBuilding or a Door to its Addresses.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence minOccurs="0">
                <xs:element ref="Address" />
            </xs:sequence>
            <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================================  -->
<xs:complexType name="AddressType">
    <xs:annotation>
        <xs:documentation>Type for addresses. It references the xAL address standard issued by the OASIS consortium. Please note, that ad-
                dresses are modelled as GML features. Every address can be assigned zero or more 2D or 3D point geometries (one
                gml:MultiPoint geometry) locating the entrance(s). </xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="gml:AbstractFeatureType">
            <xs:sequence>
                <xs:element name="xalAddress" type="xalAddressPropertyType" />
                <xs:element name="multiPoint" type="gml:MultiPointPropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfAddress" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================================  -->
<xs:element name="Address" type="AddressType" substitutionGroup="gml:_Feature" />
<!-- ============================================================================================================  -->
<xs:complexType name="xalAddressPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an Address feature to the xAL address element.</xs:documentation>
    </xs:annotation>
```

```
        <xs:sequence>
            <xs:element ref="xAL:AddressDetails" />
        </xs:sequence>
    </xs:complexType>
    <!-- ========================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfAddress" type="xs:anyType" abstract="true"/>
```

10.4.3 Transportation objects

```
    <xs:complexType name="_TransportationObjectType" abstract="true">
        <xs:annotation>
            <xs:documentation>Type describing the abstract superclass for transportation objects.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_CityObjectType">
                <xs:sequence>
                    <xs:element ref="_GenericApplicationPropertyOfTransportationObject" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================= -->
    <xs:element name="_TransportationObject" type="_CityObjectType" substitutionGroup="_CityObject" />
    <!-- ========================================================================================= -->
    <xs:element name="_GenericApplicationPropertyOfTransportationObject" type="xs:anyType" abstract="true"/>
    <!-- ========================================================================================= -->
    <xs:complexType name="TransportationComplexType">
        <xs:annotation>
            <xs:documentation>Type describing transportation complexes, which are aggregated features, e.g. roads, which consist of parts (traf-
                    fic areas, e.g. pedestrian path, and auxiliary traffic areas). As subclass of _CityObject, a TransportationComplex inherits all at-
                    tributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
                    tions.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_TransportationObjectType">
                <xs:sequence>
                    <xs:element name="function" type="TransportationComplexFunctionType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="usage" type="TransportationComplexUsageType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="trafficArea" type="TrafficAreaPropertyType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="auxiliaryTrafficArea" type="AuxiliaryTrafficAreaPropertyType" minOccurs="0"
                        maxOccurs="unbounded" />
                    <xs:element name="lod0Network" type="gml:GeometricComplexPropertyType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                    <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                    <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                    <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                    <xs:element ref="_GenericApplicationPropertyOfTransportationComplex" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ========================================================================================= -->
    <xs:element name="TransportationComplex" type="TransportationComplexType" substitutionGroup="_TransportationObject" />
    <!-- ========================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfTransportationComplex" type="xs:anyType" abstract="true"/>
    <!-- ========================================================================================= -->
    <xs:complexType name="TrafficAreaType">
        <xs:annotation>
            <xs:documentation>Type describing the class for traffic Areas. Traffic areas are the surfaces where traffic actually takes place. As
                    subclass of _CityObject, a TrafficArea inherits all attributes and relations, in particular an id, names, external references, ge-
                    neric attributes and generalization relations.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_TransportationObjectType">
                <xs:sequence>
                    <xs:element name="usage" type="TrafficAreaUsageType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="function" type="TrafficAreaFunctionType" minOccurs="0" maxOccurs="unbounded" />
                    <xs:element name="surfaceMaterial" type="TrafficSurfaceMaterialType" minOccurs="0" />
                    <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                    <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                    <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                    <xs:element ref="_GenericApplicationPropertyOfTrafficArea" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
```

```
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="TrafficArea" type="TrafficAreaType" substitutionGroup="_TransportationObject" />
<!-- =========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfTrafficArea" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:complexType name="AuxiliaryTrafficAreaType">
    <xs:annotation>
        <xs:documentation>Type describing the class for auxiliary traffic Areas. These are the surfaces where no traffic actually takes place,
                but which belong to a transportation object. Examples are kerbstones, road markings and grass stripes. As subclass of
                _CityObject, an AuxiliaryTrafficArea inherits all attributes and relations, in particular an id, names, external references, ge-
                neric attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_TransportationObjectType">
            <xs:sequence>
                <xs:element name="function" type="AuxiliaryTrafficAreaFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="surfaceMaterial" type="TrafficSurfaceMaterialType" minOccurs="0" />
                <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfAuxiliaryTrafficArea" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="AuxiliaryTrafficArea" type="AuxiliaryTrafficAreaType" substitutionGroup="_TransportationObject" />
<!-- ========================================================================================== -->
<xs:complexType name="TrafficAreaPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of a transportation complex to its parts, which are traffic areas in this case. Since an attribute
                group for enabling the use of references is provided, the relation may be given by a reference to an an element defined else-
                where or by the complete TrafficArea inline.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence minOccurs="0">
                <xs:element ref="TrafficArea" />
            </xs:sequence>
            <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:complexType name="AuxiliaryTrafficAreaPropertyType">
    <xs:annotation>
        <xs:documentation>Denotes the relation of an Transportation Complex to its parts, which are AuxiliaryTrafficAreas in this case .
                Since an attribute group for enabling the use of references is provided, the relation may be given by a reference to a Auxiliary-
                TrafficArea defined elsewhere or by the inline definition of an AuxiliaryTrafficArea.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence minOccurs="0">
                <xs:element ref="AuxiliaryTrafficArea" />
            </xs:sequence>
            <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfAuxiliaryTrafficArea" type="xs:anyType" abstract="true"/>
<!-- ===========================Subtypes of Transportation Complex=================================== -->
<xs:complexType name="TrackType">
    <xs:annotation>
        <xs:documentation>Type describing the class for tracks. A track is a small path mainly used by pedestrians. As subclass of
                _CityObject, a Track inherits all attributes and relations, in particular an id, names, external references, generic attributes and
                generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="TransportationComplexType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfTrack" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
```

```
</xs:complexType>
<!-- ============================================================================================ -->
<xs:element name="Track" type="TrackType" substitutionGroup="TransportationComplex" />
<!-- ============================================================================================ -->
<xs:complexType name="RoadType">
    <xs:annotation>
        <xs:documentation>Type describing the class for roads. As subclass of _CityObject, a Road inherits all attributes and relations, in par-
                ticular an id, names, external references, generic attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="TransportationComplexType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfRoad" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================ -->
<xs:element name="Road" type="RoadType" substitutionGroup="TransportationComplex" />
<!-- ============================================================================================ -->
<xs:complexType name="RailwayType">
    <xs:annotation>
        <xs:documentation>Type describing the class for railways. As subclass of _CityObject, a Railway inherits all attributes and relations,
                in particular an id, names, external references, generic attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="TransportationComplexType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfRailway" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================ -->
<xs:element name="Railway" type="RailwayType" substitutionGroup="TransportationComplex" />
<!-- ============================================================================================ -->
<xs:complexType name="SquareType">
    <xs:annotation>
        <xs:documentation>Type describing the class for squares. A square is an open area commonly found in cities (like a plaza). As sub-
                class of _CityObject, a Square inherits all attributes and relations, in particular an id, names, external references, generic at-
                tributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="TransportationComplexType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfSquare" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ============================================================================================ -->
<xs:element name="Square" type="SquareType" substitutionGroup="TransportationComplex" />
<!-- ============================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfTrack" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfRoad" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfRailway" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfSquare" type="xs:anyType" abstract="true"/>
<!-- ============================================================================================ -->
<xs:simpleType name="TransportationComplexFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a transportation complex. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ============================================================================================ -->
<xs:simpleType name="TransportationComplexUsageType">
    <xs:annotation>
        <xs:documentation>Actual Usage of a transportation complex. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ============================================================================================ -->
<xs:simpleType name="TrafficAreaFunctionType">
    <xs:annotation>
```

```
        <xs:documentation>Function of a traffic area. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml,
                according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="AuxiliaryTrafficAreaFunctionType">
    <xs:annotation>
        <xs:documentation>Function of an auxiliary traffic area. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="TrafficAreaUsageType">
    <xs:annotation>
        <xs:documentation>Usage of a traffic area. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, ac-
                cording to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="TrafficSurfaceMaterialType">
    <xs:annotation>
        <xs:documentation>Type for surface materials of transportation objects. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
```

10.4.4 Vegetation objects

```
<xs:complexType name="_VegetationObjectType" abstract="true">
    <xs:annotation>
        <xs:documentation>Type describing the abstract superclass for vegetation objects. A subclass is either a SolitaryVegetationObject or
                a PlantCover.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfVegetationObject" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_VegetationObject" type="_VegetationObjectType" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfVegetationObject" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:complexType name="PlantCoverType">
    <xs:annotation>
        <xs:documentation>Type describing Plant Covers resp. Biotopes (German translation: Vegetation). As subclass of _CityObject, a
                VegetationObject inherits all attributes and relations, in particular an id, names, external references, generic attributes and gen-
                eralization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_VegetationObjectType">
            <xs:sequence>
                <xs:element name="class" type="PlantCoverClassType" minOccurs="0" />
                <xs:element name="function" type="PlantCoverFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="averageHeight" type="gml:LengthType" minOccurs="0" />
                <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod1MultiSolid" type="gml:MultiSolidPropertyType" minOccurs="0" />
                <xs:element name="lod2MultiSolid" type="gml:MultiSolidPropertyType" minOccurs="0" />
                <xs:element name="lod3MultiSolid" type="gml:MultiSolidPropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfPlantCover" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
```

```
<xs:element name="PlantCover" type="PlantCoverType" substitutionGroup="_VegetationObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfPlantCover" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:simpleType name="PlantCoverClassType">
   <xs:annotation>
      <xs:documentation>Class of a PlantCover. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, ac-
            cording to the dictionary concept of GML3.</xs:documentation>
   </xs:annotation>
   <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:simpleType name="PlantCoverFunctionType">
   <xs:annotation>
      <xs:documentation>Function of a PlantCover. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml,
            according to the dictionary concept of GML3.</xs:documentation>
   </xs:annotation>
   <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfVegetationObject" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:complexType name="SolitaryVegetationObjectType">
   <xs:annotation>
      <xs:documentation>Type describing solitary vegetation objects, e.g., trees. Its geometry is either defined explicitly by a GML 3 ge-
            ometry with absolute coordinates, or in the case of multiple occurences of the same vegetation object, implicitly by a reference
            to a shape definition and a transformation. The shape definition may be given in an external file. As subclass of _CityObject, a
            SolitaryVegetationObject inherits all attributes and relations, in particular an id, names, external references, generic attributes
            and generalization relations.</xs:documentation>
   </xs:annotation>
   <xs:complexContent>
      <xs:extension base="_VegetationObjectType">
         <xs:sequence>
            <xs:element name="class" type="PlantClassType" minOccurs="0" />
            <xs:element name="function" type="PlantFunctionType" minOccurs="0" maxOccurs="unbounded" />
            <xs:element name="species" type="SpeciesType" minOccurs="0" />
            <xs:element name="height" type="gml:LengthType" minOccurs="0" />
            <xs:element name="trunkDiameter" type="gml:LengthType" minOccurs="0" />
            <xs:element name="crownDiameter" type="gml:LengthType" minOccurs="0" />
            <xs:element name="lod1Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
            <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
            <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
            <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
            <xs:element name="lod1ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
            <xs:element name="lod2ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
            <xs:element name="lod3ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
            <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
            <xs:element ref="_GenericApplicationPropertyOfSolitaryVegetationObject" minOccurs="0" maxOccurs="unbounded"/>
         </xs:sequence>
      </xs:extension>
   </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="SolitaryVegetationObject" type="SolitaryVegetationObjectType" substitutionGroup="_VegetationObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfSolitaryVegetationObject" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:simpleType name="PlantClassType">
   <xs:annotation>
      <xs:documentation>Class of a PlantType. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, ac-
            cording to the dictionary concept of GML3.</xs:documentation>
   </xs:annotation>
   <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:simpleType name="PlantFunctionType">
   <xs:annotation>
      <xs:documentation>Function of a PlantType. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml,
            according to the dictionary concept of GML3.</xs:documentation>
   </xs:annotation>
   <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:simpleType name="SpeciesType">
   <xs:annotation>
```

```
        <xs:documentation>Type of a Species. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, accord-
                ing to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
```

10.4.5 Water bodies

```
<xs:complexType name="_WaterObjectType" abstract="true">
    <xs:annotation>
        <xs:documentation>Type describing the abstract superclass for water objects. As subclass of _CityObject, a _WaterObject inherits all
                attributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
                tions.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfWaterObject" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="_WaterObject" type="_WaterObjectType" substitutionGroup="_CityObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterObject" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:complexType name="WaterBodyType">
    <xs:annotation>
        <xs:documentation>Type describing Water Bodies, e.g., lakes, rivers. As subclass of _CityObject, a WaterBody inherits all attributes
                and relations, in particular an id, names, external references, generic attributes and generalization rela-
                tions.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_WaterObjectType">
            <xs:sequence>
                <xs:element name="class" type="WaterBodyClassType" minOccurs="0" />
                <xs:element name="function" type="WaterBodyFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="usage" type="WaterBodyUsageType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="lod0MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="lod0MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod1MultiCurve" type="gml:MultiCurvePropertyType" minOccurs="0" />
                <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod1Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="lod2Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="lod3Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="lod4Solid" type="gml:SolidPropertyType" minOccurs="0" />
                <xs:element name="boundedBy" type="BoundedByWaterSurfacePropertyType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element ref="_GenericApplicationPropertyOfWaterBody" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================== -->
<xs:element name="WaterBody" type="WaterBodyType" substitutionGroup="_WaterObject" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterBody" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================== -->
<xs:simpleType name="WaterBodyClassType">
    <xs:annotation>
        <xs:documentation>Class of a Water Body. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, ac-
                cording to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="WaterBodyFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a Water Body. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml,
                according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================== -->
<xs:simpleType name="WaterBodyUsageType">
```

```
    <xs:annotation>
        <xs:documentation>Actual usage of a water body. The values of this type are defined in the XML file
                CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:complexType name="BoundedByWaterSurfacePropertyType">
    <xs:annotation>
        <xs:documentation>A type for a property of a Water Body denoting its boundary, which is a water surface. Since an attribute group
                for enabling the use of references is provided, the relation may be given by a reference to a WaterBoundarySurface defined
                elsewhere or by the inline definition of a WaterBoundarySurface.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:restriction base="gml:AssociationType">
            <xs:sequence minOccurs="0">
                <xs:element ref="_WaterBoundarySurface" />
            </xs:sequence>
            <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:complexType name="_WaterBoundarySurfaceType" abstract="true">
    <xs:annotation>
        <xs:documentation>A WaterBoundarySurface is a thematic object which classifies surfaces bounding a water
                body.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element name="lod2Surface" type="gml:SurfacePropertyType" minOccurs="0" />
                <xs:element name="lod3Surface" type="gml:SurfacePropertyType" minOccurs="0" />
                <xs:element name="lod4Surface" type="gml:SurfacePropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfWaterBoundarySurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="_WaterBoundarySurface" type="_WaterBoundarySurfaceType" abstract="true" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfWaterBoundarySurface" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:simpleType name="WaterLevelType">
    <xs:annotation>
        <xs:documentation>Type for the specification of the level of a water surface. The optional attribute waterLevel of a WaterSurface can
                be used to describe the water level, for which the given 3D surface geometry was acquired. This is especially important, when
                the water body is influenced by the tide. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml,
                according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- ========================================================================================= -->
<xs:complexType name="WaterSurfaceType">
    <xs:annotation>
        <xs:documentation>Type describing the surface of a water body, which separates the water from the air. As subclass of _CityObject, a
                WaterSurface inherits all attributes and relations, in particular an id, names, external references, generic attributes and gener-
                alization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_WaterBoundarySurfaceType">
            <xs:sequence>
                <xs:element name="waterLevel" type="WaterLevelType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfWaterSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="WaterSurface" type="WaterSurfaceType" substitutionGroup="_WaterBoundarySurface" />
<!-- ========================================================================================= -->
<xs:element name="_GenericApplicationPropertyOfWaterSurface" type="xs:anyType" abstract="true"/>
<!-- ========================================================================================= -->
<xs:complexType name="WaterGroundSurfaceType">
    <xs:annotation>
```

```
        <xs:documentation>Type describing the ground surface of a water body, i.e. the boundary to the digital terrain model. As subclass of
                _CityObject, a WaterGroundSurface inherits all attributes and relations, in particular an id, names, external references, generic
                attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_WaterBoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfWaterGroundSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="WaterGroundSurface" type="WaterGroundSurfaceType" substitutionGroup="_WaterBoundarySurface" />
<!-- ========================================================================================= -->
<xs:complexType name="WaterClosureSurfaceType">
    <xs:annotation>
        <xs:documentation>Type describing the closure surface between water bodys. As subclass of _CityObject, a WaterClosureSurface in-
                herits all attributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
                tions.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_WaterBoundarySurfaceType">
            <xs:sequence>
                <xs:element ref="_GenericApplicationPropertyOfWaterClosureSurface" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="WaterClosureSurface" type="WaterClosureSurfaceType" substitutionGroup="_WaterBoundarySurface" />
<!-- ========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfWaterGroundSurface" type="xs:anyType" abstract="true"/>
<xs:element name="_GenericApplicationPropertyOfWaterClosureSurface" type="xs:anyType" abstract="true"/>
```

10.4.6 City furniture

```
<xs:complexType name="CityFurnitureType">
    <xs:annotation>
        <xs:documentation>Type describing city furnitures, like traffic lights, benches, ... As subclass of _CityObject, a CityFurniture inherits
                all attributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
                tions.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element name="class" type="CityFurnitureClassType" minOccurs="0" />
                <xs:element name="function" type="CityFurnitureFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="lod1Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element name="lod2Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0" />
                <xs:element name="lod1TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
                <xs:element name="lod2TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
                <xs:element name="lod3TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
                <xs:element name="lod4TerrainIntersection" type="gml:MultiCurvePropertyType" minOccurs="0"/>
                <xs:element name="lod1ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                <xs:element name="lod2ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                <xs:element name="lod3ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                <xs:element name="lod4ImplicitRepresentation" type="ImplicitRepresentationPropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfCityFurniture" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ========================================================================================= -->
<xs:element name="CityFurniture" type="CityFurnitureType" substitutionGroup="_CityObject" />
<!-- ========================================================================================= -->
<xs:simpleType name="CityFurnitureFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a Furniture. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml,
                according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
```

```
<!-- =========================================================================================== -->
<xs:simpleType name="CityFurnitureClassType">
    <xs:annotation>
        <xs:documentation>Class of a Furniture. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- =========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfCityFurniture" type="xs:anyType" abstract="true"/>
```

10.4.7 Land use

```
<xs:complexType name="LandUseType">
    <xs:annotation>
        <xs:documentation>Type describing the class for Land Use in all LoD. LandUse objects describe areas of the earth's surface dedicated to a specific land use. The geometry must consist of 3-D surfaces. As subclass of _CityObject, a LandUse inherits all attributes and relations, in particular an id, names, external references, generic attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
        <xs:extension base="_CityObjectType">
            <xs:sequence>
                <xs:element name="class" type="LandUseClassType" minOccurs="0" />
                <xs:element name="function" type="LandUseFunctionType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="usage" type="LandUseUsageType" minOccurs="0" maxOccurs="unbounded" />
                <xs:element name="lod0MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod1MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod2MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod3MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element name="lod4MultiSurface" type="gml:MultiSurfacePropertyType" minOccurs="0" />
                <xs:element ref="_GenericApplicationPropertyOfLandUse" minOccurs="0" maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- =========================================================================================== -->
<xs:element name="LandUse" type="LandUseType" substitutionGroup="_CityObject" />
<!-- =========================================================================================== -->
<xs:simpleType name="LandUseClassType">
    <xs:annotation>
        <xs:documentation>Class of a Landuse. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- =========================================================================================== -->
<xs:simpleType name="LandUseFunctionType">
    <xs:annotation>
        <xs:documentation>Function of a Landuse. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- =========================================================================================== -->
<xs:simpleType name="LandUseUsageType">
    <xs:annotation>
        <xs:documentation>Usage of a Landuse. The values of this type are defined in the XML file CityGML_ExternalCodeLists.xml, according to the dictionary concept of GML3.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:string" />
</xs:simpleType>
<!-- =========================================================================================== -->
<xs:element name="_GenericApplicationPropertyOfLandUse" type="xs:anyType" abstract="true"/>
```

10.4.8 Digital Terrain Model

```
<xs:complexType name="ReliefFeatureType">
    <xs:annotation>
        <xs:documentation>Type describing the features of the Digital Terrain Model. As subclass of _CityObject, a ReliefFeature inherits all attributes and relations, in particular an id, names, external references, generic attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
```

```
      <xs:extension base="_CityObjectType">
        <xs:sequence>
          <xs:element name="lod" type="integerBetween0and4" />
          <xs:element name="reliefComponent" type="ReliefComponentPropertyType" maxOccurs="unbounded" />
          <xs:element ref="_GenericApplicationPropertyOfReliefFeature" minOccurs="0" maxOccurs="unbounded"/>
        </xs:sequence>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>
  <!-- ==================================================================================== -->
  <xs:element name="ReliefFeature" type="ReliefFeatureType" substitutionGroup="_CityObject" />
  <!-- ==================================================================================== -->
  <xs:element name="_GenericApplicationPropertyOfReliefFeature" type="xs:anyType" abstract="true"/>
  <!-- ==================================================================================== -->
  <xs:complexType name="_ReliefComponentType" abstract="true">
    <xs:annotation>
      <xs:documentation>Type describing the vomponents of a relief feature - either a TIN, a Grid, mass points or break lines. As subclass
          of _CityObject, a ReliefComponent inherits all attributes and relations, in particular an id, names, external references, generic
          attributes and generalization relations.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
      <xs:extension base="_CityObjectType">
        <xs:sequence>
          <xs:element name="lod" type="integerBetween0and4" />
          <xs:element name="extent" type="gml:PolygonPropertyType" minOccurs="0" />
          <xs:element ref="_GenericApplicationPropertyOfReliefComponent" minOccurs="0" maxOccurs="unbounded"/>
        </xs:sequence>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>
  <!-- ==================================================================================== -->
  <xs:element name="_ReliefComponent" type="_ReliefComponentType" abstract="true" substitutionGroup="_CityObject" />
  <!-- ==================================================================================== -->
  <xs:element name="_GenericApplicationPropertyOfReliefComponent" type="xs:anyType" abstract="true"/>
  <!-- ==================================================================================== -->
  <xs:complexType name="ReliefComponentPropertyType">
    <xs:annotation>
      <xs:documentation>Denotes the relation of a relief feature to its components. The relation may be given by a reference to a compo-
          nent definede elsewhere or by the complete inline definition of a component.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
      <xs:restriction base="gml:AssociationType">
        <xs:sequence minOccurs="0">
          <xs:element ref="_ReliefComponent" />
        </xs:sequence>
        <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
      </xs:restriction>
    </xs:complexContent>
  </xs:complexType>
  <!-- ==================================================================================== -->
  <xs:complexType name="TINReliefType">
    <xs:annotation>
      <xs:documentation>Type describing the TIN component of a relief feature. As subclass of _CityObject, a TINRelief inherits all at-
          tributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
          tions.</xs:documentation>
    </xs:annotation>
    <xs:complexContent>
      <xs:extension base="_ReliefComponentType">
        <xs:sequence>
          <xs:element name="tin" type="tinPropertyType" />
          <xs:element ref="_GenericApplicationPropertyOfTinRelief" minOccurs="0" maxOccurs="unbounded"/>
        </xs:sequence>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>
  <!-- ==================================================================================== -->
  <xs:element name="TINRelief" type="TINReliefType" substitutionGroup="_ReliefComponent" />
  <!-- ==================================================================================== -->
  <xs:element name="_GenericApplicationPropertyOfTinRelief" type="xs:anyType" abstract="true"/>
  <!-- ==================================================================================== -->
  <xs:complexType name="RasterReliefType">
    <xs:annotation>
      <xs:documentation>Type describing the raster component of a relief feature. As subclass of _CityObject, a RasterRelief inherits all at-
          tributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
          tions.</xs:documentation>
    </xs:annotation>
```

```
        <xs:complexContent>
            <xs:extension base="_ReliefComponentType">
                <xs:sequence>
                    <xs:element name="grid" type="gridPropertyType" />
                    <xs:element ref="_GenericApplicationPropertyOfRasterRelief" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ====================================================================================  -->
    <xs:element name="RasterRelief" type="RasterReliefType" substitutionGroup="_ReliefComponent" />
    <!-- ===================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfRasterRelief" type="xs:anyType" abstract="true"/>
    <!-- ====================================================================================  -->
    <xs:complexType name="MassPointReliefType">
        <xs:annotation>
            <xs:documentation>Type describing the mass point component of a relief feature. As subclass of _CityObject, a MassPoint Relief in-
                    herits all attributes and relations, in particular an id, names, external references, generic attributes and generalization rela-
                    tions.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_ReliefComponentType">
                <xs:sequence>
                    <xs:element name="reliefPoints" type="gml:MultiPointPropertyType" />
                    <xs:element ref="_GenericApplicationPropertyOfMassPointRelief" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ====================================================================================  -->
    <xs:element name="MassPointRelief" type="MassPointReliefType" substitutionGroup="_ReliefComponent" />
    <!-- ===================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfMassPointRelief" type="xs:anyType" abstract="true"/>
    <!-- ====================================================================================  -->
    <xs:complexType name="BreaklineReliefType">
        <xs:annotation>
            <xs:documentation>Type describing the break line Component of a relief feature. A break line relief consists of break lines or rid-
                    geOrValleyLines (German Translation: Geripplinie) As subclass of _CityObject, a BreaklineRelief inherits all attributes and
                    relations, in particular an id, names, external references, generic attributes and generalization relations.</xs:documentation>
        </xs:annotation>
        <xs:complexContent>
            <xs:extension base="_ReliefComponentType">
                <xs:sequence>
                    <xs:choice>
                        <xs:element name="ridgeOrValleyLines" type="gml:MultiCurvePropertyType" minOccurs="0" />
                        <xs:element name="breaklines" type="gml:MultiCurvePropertyType" minOccurs="0" />
                    </xs:choice>
                    <xs:element ref="_GenericApplicationPropertyOfBreaklineRelief" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:extension>
        </xs:complexContent>
    </xs:complexType>
    <!-- ====================================================================================  -->
    <xs:element name="BreaklineRelief" type="BreaklineReliefType" substitutionGroup="_ReliefComponent" />
    <!-- ===================================================================================== -->
    <xs:element name="_GenericApplicationPropertyOfBreaklineRelief" type="xs:anyType" abstract="true"/>
    <!-- ====================================================================================  -->
    <xs:complexType name="tinPropertyType">
        <xs:complexContent>
            <xs:restriction base="gml:AssociationType">
                <xs:sequence minOccurs="0">
                    <xs:element ref="gml:TriangulatedSurface" />
                </xs:sequence>
                <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
            </xs:restriction>
        </xs:complexContent>
    </xs:complexType>
    <!-- ====================================================================================  -->
    <xs:complexType name="gridPropertyType">
        <xs:complexContent>
            <xs:restriction base="gml:AssociationType">
                <xs:sequence minOccurs="0">
                    <xs:element ref="gml:RectifiedGridCoverage" />
                </xs:sequence>
                <xs:attributeGroup ref="gml:AssociationAttributeGroup" />
            </xs:restriction>
        </xs:complexContent>
    </xs:complexType>
    <!-- ====================================================================================== -->
    <xs:element name="Elevation" type="gml:LengthType" substitutionGroup="gml:_Object" />
```

10.5 Definition of restricted types

```
<xs:simpleType name="doubleBetween0and1">
    <xs:annotation>
        <xs:documentation>Type for values, which are greater or equal than 0 and less or equal than 1. Used for color encoding, for exam-
                ple.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:double">
        <xs:minInclusive value="0" />
        <xs:maxInclusive value="1" />
    </xs:restriction>
</xs:simpleType>
<!-- ================================================================================== -->
<xs:simpleType name="doubleBetween0and1List">
    <xs:annotation>
        <xs:documentation>List for double values, which are greater or equal than 0 and less or equal than 1. Used for color encoding, for ex-
                ample.</xs:documentation>
    </xs:annotation>
    <xs:list itemType="doubleBetween0and1" />
</xs:simpleType>
<!-- ================================================================================== -->
<xs:simpleType name="TransformationMatrix4x4Type">
    <xs:annotation>
        <xs:documentation>Used for implicit geometries. The Transformation matrix is a 4 by 4 matrix, thus it must be a list with 16 items.
                The order the matrix element are represented is row-major, i. e. the first 4 elements represent the first row, the fifth to the eight
                element the second row,...</xs:documentation>
    </xs:annotation>
    <xs:restriction base="gml:doubleList">
        <xs:minLength value="16" />
        <xs:maxLength value="16" />
    </xs:restriction>
</xs:simpleType>
<!-- ================================================================================== -->
<xs:simpleType name="TransformationMatrix2x2Type">
    <xs:annotation>
        <xs:documentation>Used for georeferencing. The Transformation matrix is a 2 by 2 matrix, thus it must be a list with 4 items.
                The order the matrix element are represented is row-major, i. e. the first 2 elements represent the first row, the fifth to the
                eight element the second row,...
       </xs:documentation>
    </xs:annotation>
    <xs:restriction base="gml:doubleList">
       <xs:minLength value="4"/>
       <xs:maxLength value="4"/>
    </xs:restriction>
</xs:simpleType>
<!-- ================================================================================== -->
<xs:simpleType name="TransformationMatrix3x4Type">
    <xs:annotation>
        <xs:documentation>Used for texture parameterization. The Transformation matrix is a 3 by 4 matrix, thus it must be a list with 12
                items. The order the matrix element are represented is row-major, i. e. the first 4 elements represent the first row, the
                fifth to the eight element the second row,...
        </xs:documentation>
    </xs:annotation>
    <xs:restriction base="gml:doubleList">
        <xs:minLength value="12"/>
        <xs:maxLength value="12"/>
    </xs:restriction>
 </xs:simpleType>
<!-- ================================================================================== -->
<xs:simpleType name="integerBetween0and4">
    <xs:annotation>
        <xs:documentation>Type for integer values, which are greater or equal than 0 and less or equal than 4. Used for encoding of the LoD
                number.</xs:documentation>
    </xs:annotation>
    <xs:restriction base="xs:integer">
        <xs:minInclusive value="0" />
        <xs:maxInclusive value="4" />
    </xs:restriction>
</xs:simpleType>
</xs:schema>
```

11 Annex

11.1 Annex A: External code lists

In this chapter the corresponding values of the external code lists of CityGML are given. The following values are a proposal of the SIG 3D and may be extended or replaced by other communities to fit their needs. The external code list for roof types is given in XML format below, while the others are depicted in tabular form for space reasons.

External code list for roof types:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<gml:Dictionary gml:id="ExternalCodeLists"
  xmlns="http://www.opengis.net/gml"
  xmlns:gml="http://www.opengis.net/gml"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.opengis.net/gml ../3.1.1/base/gml.xsd">
<gml:description>External Code Lists for CityGML</gml:description>
<gml:name>CityGML</gml:name>
 <gml:dictionaryEntry>
  <gml:DefinitionCollection gml:id="id356">
   <gml:description>Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)</gml:description>
   <gml:name>RoofTypeType</gml:name>
     <gml:definitionMember>
       <gml:Definition gml:id="id357">
         <gml:description></gml:description>
         <gml:name codeSpace="urn:d_nrw_sig3d">1000</gml:name>
         <gml:name>flat roof</gml:name>
       </gml:Definition>
     </gml:definitionMember>
     <gml:definitionMember>
       <gml:Definition gml:id="id358">
         <gml:description></gml:description>
         <gml:name codeSpace="urn:d_nrw_sig3d">1010</gml:name>
         <gml:name>monopitch roof</gml:name>
       </gml:Definition>
     </gml:definitionMember>
     <gml:definitionMember>
       <gml:Definition gml:id="id359">
         <gml:description></gml:description>
         <gml:name codeSpace="urn:d_nrw_sig3d">1020</gml:name>
         <gml:name>skip pent roof</gml:name>
       </gml:Definition>
     </gml:definitionMember>
     <gml:definitionMember>
       <gml:Definition gml:id="id360">
         <gml:description></gml:description>
         <gml:name codeSpace="urn:d_nrw_sig3d">1030</gml:name>
         <gml:name>gabled roof</gml:name>
       </gml:Definition>
     </gml:definitionMember>
     <gml:definitionMember>
       <gml:Definition gml:id="id361">
         <gml:description></gml:description>
         <gml:name codeSpace="urn:d_nrw_sig3d">1040</gml:name>
         <gml:name>hipped roof</gml:name>
       </gml:Definition>
     </gml:definitionMember>
     <gml:definitionMember>
       <gml:Definition gml:id="id362">
         <gml:description></gml:description>
         <gml:name codeSpace="urn:d_nrw_sig3d">1050</gml:name>
         <gml:name>half-hipped roof</gml:name>
       </gml:Definition>
     </gml:definitionMember>
     <gml:definitionMember>
       <gml:Definition gml:id="id363">
         <gml:description></gml:description>
         <gml:name codeSpace="urn:d_nrw_sig3d">1060</gml:name>
         <gml:name>mansard roof</gml:name>
       </gml:Definition>
```

```
      </gml:definitionMember>
      <gml:definitionMember>
        <gml:Definition gml:id="id364">
          <gml:description></gml:description>
          <gml:name codeSpace="urn:d_nrw_sig3d">1070</gml:name>
          <gml:name>pavilion roof</gml:name>
        </gml:Definition>
      </gml:definitionMember>
      <gml:definitionMember>
        <gml:Definition gml:id="id365">
          <gml:description></gml:description>
          <gml:name codeSpace="urn:d_nrw_sig3d">1080</gml:name>
          <gml:name>cone roof</gml:name>
        </gml:Definition>
      </gml:definitionMember>
      <gml:definitionMember>
        <gml:Definition gml:id="id366">
          <gml:description></gml:description>
          <gml:name codeSpace="urn:d_nrw_sig3d">1090</gml:name>
          <gml:name>copula roof</gml:name>
        </gml:Definition>
      </gml:definitionMember>
      <gml:definitionMember>
        <gml:Definition gml:id="id367">
          <gml:description></gml:description>
          <gml:name codeSpace="urn:d_nrw_sig3d">1100</gml:name>
          <gml:name>shed roof</gml:name>
        </gml:Definition>
      </gml:definitionMember>
      <gml:definitionMember>
        <gml:Definition gml:id="id368">
          <gml:description></gml:description>
          <gml:name codeSpace="urn:d_nrw_sig3d">1110</gml:name>
          <gml:name>arch roof</gml:name>
        </gml:Definition>
      </gml:definitionMember>
      <gml:definitionMember>
        <gml:Definition gml:id="id369">
          <gml:description></gml:description>
          <gml:name codeSpace="urn:d_nrw_sig3d">1120</gml:name>
          <gml:name>pyramidal broach roof</gml:name>
        </gml:Definition>
      </gml:definitionMember>
      <gml:definitionMember>
        <gml:Definition gml:id="id370">
          <gml:description></gml:description>
          <gml:name codeSpace="urn:d_nrw_sig3d">1130</gml:name>
          <gml:name>combination of roof forms</gml:name>
        </gml:Definition>
      </gml:definitionMember>
    </gml:DefinitionCollection>
  </gml:dictionaryEntry>
  <gml:dictionaryEntry>
</gml:Dictionary>
```

BuildingClassType			
Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)			
1000	habitation	1100	schools, education, research
1010	sanitation	1110	maintainence and waste management
1020	administration	1120	healthcare
1030	business, trade	1130	communicating
1040	catering	1140	security
1050	recreation	1150	storage
1060	sport	1160	industry
1070	culture	1170	traffic
1080	church institution	1180	function
1090	agriculture, forestry		

BuildingFunctionType			
Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)			
1000	residential building	1840	rubbish bunker
1010	tenement	1850	building for rubbish incineration
1020	hostel	1860	building for rubbish disposal
1030	residential- and administration building	1870	building for agrarian and forestry
1040	residential- and office building	1880	barn
1050	residential- and business building	1890	stall
1060	residential- and plant builiding	1900	equestrian hall
1070	agrarian- and forestry builiding	1910	alpine cabin
1080	residential- and commercial building	1920	hunting lodge
1090	forester's lodge	1930	arboretum
1100	holiday house	1940	glass house
1110	summer house	1950	moveable glass house
1120	office building	1960	public building
1130	credit institution	1970	administration building
1140	insurance	1980	parliament
1150	business building	1990	guildhall
1160	department store	2000	post office
1170	shopping centre	2010	customs office
1180	kiosk	2020	court
1190	pharmacy	2030	embassy or consulate
1200	pavilion	2040	district administration
1210	hotel	2050	district government
1220	youth hostel	2060	tax office
1230	campsite building	2070	building for education and research
1240	restaurant	2080	comprehensive school
1250	cantine	2090	vocational school
1260	recreational site	2100	college or university
1270	function room	2110	research establishment
1280	cinema	2120	building for cultural purposes
1290	bowling alley	2130	castle
1300	casino	2140	theatre or opera
1310	industrial building	2150	concert building
1320	factory	2160	museum
1330	workshop	2170	broadcasting building
1340	petrol / gas station	2180	activity building
1350	washing plant	2190	library
1360	cold store	2200	fort
1370	depot	2210	religious building
1380	building for research purposes	2220	church
1390	quarry	2230	synagogue
1400	salt works	2240	chapel
1410	miscellaneous industrial building	2250	community center
1420	mill	2260	place of worship
1430	windmill	2270	mosque
1440	water mill	2280	temple
1450	bucket elevator	2290	convent
1460	weather station	2300	building for health care
1470	traffic assets office	2310	hospital
1480	street maintenance	2320	healing centre or care home
1490	waiting hall	2330	health centre or outpatients clinic
1500	signal control box	2340	building for social purposes

1510	engine shed	2350	youth centre
1520	signal box or stop signal	2360	seniors centre
1530	plant building for air traffic	2370	homeless shelter
1540	hangar	2380	kindergarten or nursery
1550	plant building for shipping	2390	asylum seekers home
1560	shipyard	2400	police station
1570	dock	2410	fire station
1580	plant building for canal lock	2420	barracks
1590	boathouse	2430	bunker
1600	plant building for cablecar	2440	penitentiary or prison
1610	multi-storey car park	2450	cemetery building
1620	parking level	2460	funeral parlor
1630	garage	2470	crematorium
1640	vehicle hall	2480	train station
1650	underground garage	2490	airport building
1660	building for supply	2500	building for underground station
1670	waterworks	2510	building for tramway
1680	pump station	2520	building for bus station
1690	water basin	2530	shipping terminal
1700	electric power station	2540	building for recuperation purposes
1710	transformer station	2550	building for sport purposes
1720	converter	2560	sports hall
1730	reactor	2570	building for sports field
1740	turbine house	2580	swimming baths
1750	boiler house	2590	indoor swimming pool
1760	building for telecommunications	2600	sanatorium
1770	gas works	2610	zoo building
1780	heat plant	2620	green house
1790	pumping station	2630	botanical show house
1800	building for disposal	2640	bothy
1810	building for effluent disposal	2650	tourist information centre
1820	building for filter plant	2700	others
1830	toilet		

BuildingUsageType
Code list identically specified as *BuildingFunctionType*

RoofTypeType			
Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)			
1000	flat roof	1070	pavilion roof
1010	monopitch roof	1080	cone roof
1020	skip pent roof	1090	copula roof
1030	gabled roof	1100	shed roof
1040	hipped roof	1110	arch roof
1050	half-hipped roof	1120	pyramidal broach roof
1060	mansard roof	1130	combination of roof forms

BuildingInstallationClassType			
Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)			
1000	outer characteristics	1040	communicating
1010	inner characteristics	1050	security

1020	waste management	1060	others
1030	maintenance		

BuildingInstallationFunctionType			
Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)			
1000	balcony	1040	tower (part of a building)
1010	winter garden	1050	column
1020	arcade	1060	stairs
1030	chimney (part of a building)	1070	others

IntBuildingInstallationClassType			
Code list proposed by the SIG 3D			
1000	Heating, Ventilation, Climate	6000	Statics
2000	Safety	7000	Entertainmant
3000	Illumination	8000	Miscellaneous
4000	Communication	9999	Unknown
5000	Supply and Disposal		

IntBuildingInstallationFunctionType			
Code list proposed by the SIG 3D			
1010	Radiator	3020	Light switch
1020	Oven	5030	Power point
1030	Fireside	5020	Cable
1040	Ventilator	7010	Rafter
1050	Air Conditioning	7020	Column
5010	Pipe	8010	Railing
3010	Lamp	8020	Stair

IntBuildingInstallationUsageType
Code list identically specified as *IntBuildingInstallationFunctionType*

BuildingFurnitureClassType			
Code list proposed by the SIG 3D			
1000	habitation	1100	schools, education, research
1010	sanitation	1110	maintenance, waste management
1020	administration	1120	healthcare
1030	business, trade	1130	communicating
1040	catering	1140	security
1050	recreation	1150	storage
1060	sport	1160	industry
1070	culture	1170	traffic
1080	church institution	1180	function
1090	agriculture, forestry		

BuildingFurnitureFunctionType			
Code list proposed by the SIG 3D			
1000	cupboard	2010	sink, hand-basin
1010	wardrobe	2020	water tap
1020	cabinet	2030	toilet bowl

1030	sideboard	2040	bathtub
1040	locker	2050	shower
1050	tool cabinet	2060	bidet
1100	shelf	2100	animal park
1110	rack	2110	aquarium
1120	coat stand	2120	cage
1200	table	2130	birdcage
1210	dining table	2200	religious equipment
1220	coffee table	2300	shop fittings
1230	desk	2310	sales counter
1240	bedside cabinet	2320	glass cabinet
1250	baby changing table	2330	changing cubicle
1260	bar	2340	refrigerated counter
1270	pool table	2350	cash desk or till or counter
1280	snooker table	2360	box-office
1290	roulette table	2400	machines
1270	work bench	2410	ticket machine
1300	chair	2420	cigarette machine
1310	bench	2430	cash machine or ATM
1320	office chair	2440	vending machine
1330	sofa	2450	gambling machine
1340	rocking chair	2500	technical furniture
1350	bar stool	2510	heating installation
1360	armchair	2520	tank
1400	bed	2521	oil tank
1410	crib	2522	water tank
1420	bunk bed	2523	gas tank
1430	cradle	2524	fuel tank
1440	cot	2525	milk tank
1450	stretcher	2526	steel tank
1500	lighting	2530	fire protection appliance
1510	standard lamp	2531	fire extinguishing system
1520	ceiling light	2532	fire alarm
1530	spotlight	2533	fire extinguisher
1600	electric appliances	2540	switch board
1610	television set	2550	lifting platform
1620	video recorder	2560	compressed air system
1630	stereo unit	2570	loud-speaker
1700	kitchen appliances	2580	microphone
1710	cooker	2600	sports equipment
1720	oven	2610	goal posts
1730	refrigerator	2620	basketball basket
1740	coffee machine	2630	volleyball net
1750	toaster	2640	gymnastic apparatus
1760	kettle	2650	diving platform
1770	microwave	2660	swimming pool
1780	dish washer	2700	sales promotion furniture
1800	laundry equipment	2710	display panel
1810	washing machine	2720	billboard
1820	ironing machine	2730	display cabinet
1830	rotary iron (mangle)	2800	functional furniture
1840	laundry tumble drier	2805	ashtray
1850	spin drier	2810	lectern

1900	technical office equipment	2815	stage
1910	copy machine	2820	blackboard
1920	scanner	2825	screen
1930	plotter	2830	mapstand
1940	printer	2835	rubbish bin
1950	screen	2840	sauna
1960	computer	2845	carpet
1970	overhead projector	2850	wall clock
1980	video projector	2855	curtain
2000	sanitation equipment	2860	mirror

BuildingFurnitureUsageType
Code list identically specified as *BuildingFurnitureFunctionType*

RoomClassType			
Code list proposed by the SIG 3D			
1000	habitation	1080	accommodation, waste management
1010	administration	1090	healthcare
1020	business, trade	1100	communicating
1030	catering	1110	security
1040	recreation	1120	store
1050	church institution	1130	industry
1060	agriculture, forestry	1140	traffic
1070	schools, education, research	1150	function

RoomFunctionType			
Code list proposed by the SIG 3D			
1000	living room	2170	showers
1010	bedroom	2200	tribune
1020	kitchen	2210	seating / standing capacity
1030	hall	2220	cash point
1040	bath, washroom	2230	vivarium
1050	toilet	2240	enclosure
1060	stairs	2250	aquarium
1070	home office	2260	terrarium
1080	utility room	2270	aviary
1090	dining room	2280	menagerie
1100	common room	2290	stables
1110	party room	2300	greenhouse
1120	nursery	2310	food silo
1130	store room	2320	hayloft
1140	canteen, common kitchen	2330	motor pool
1150	storeroom	2340	barn
1160	balcony, gallery	2350	riding hall
1170	terrace	2360	horse box
1180	drying room	2370	hunting lodge
1190	heatingroom	2400	waste container
1200	fuel depot	2410	motor pool
1210	hobby room	2420	washing-bay
1220	stable, hovel	2430	installations room
1300	cash office	2440	monitoring room

1310	ticket office	2450	heating system
1320	conference room	2460	public utility use
1330	reception	2470	pump room
1340	sales room	2480	effluent treatment
1350	store room	2490	treatment installation
1360	delivery	2500	recycling installation
1370	lounge, common room	2600	chancel
1380	escalator	2610	sacristy
1390	guest toilet	2620	bell tower
1400	strong room	2630	baptism room
1500	office	2640	confessional
1510	entrance hall	2650	benches
1520	elevator	2660	pulpit
1530	canteen	2670	lobby
1540	tea kitchen / Coffee kitchen	2680	parish
1550	archive	2690	chapel
1560	citizen office	2700	police station
1570	conference hall	2710	headquarters
1580	copier room / blueprint room	2720	prison cell
1590	information	2730	motor pool hall
1600	computer room	2740	fire brigade, emergency vehicle
1610	printer / plotter room	2750	relaxation room
1700	reception	2760	tool / pipe store
1710	guest room	2770	emergency call center
1720	bar	2780	arms depot
1730	breakfast room	2790	ammunition dump
1740	dining room	2800	vehicle hall
1750	celebration room	2810	panic room
1760	pub	2900	satellite receiver
1770	beer garden	2910	communication room
1780	restaurant	3000	industrial building
1790	cool store	3010	production building
1800	bowling alley, shoot alley	3020	factory building
1810	lounge	3030	workshop
1820	canteen kitchen	3040	storage depot
1900	stage	3050	cold storage
1910	auditorium	3060	store
1920	VIP box	3100	station concourse
1930	projection room	3110	track
1940	dressing room	3120	ticket office
1950	cabin	3130	waiting hall
1960	showroom	3140	engine shed
1970	equipment or props	3150	signal box
1980	make-up room	3160	departure terminal
1990	recording studio	3170	check-out counter
2000	sound studio	3180	check-in counter
2010	music archive	3190	check
2020	administration	3200	baggage carousel
2030	ticket office	3210	security check
2040	library	3300	classroom
2050	media room	3310	staff room
2060	dressing room	3320	break or recess hall
2070	sport room	3330	laboratory

2080	equipment room	3340	utility room
2090	platform	3350	media room
2100	swimming-pool	3360	science laboratory
2110	slide	3370	sports hall
2120	relaxation room	3380	school library
2130	sauna	3390	office
2140	fitness room	3400	lecture theatre
2150	solarium	3410	refectory
2160	catering	3420	function room

RoomUsageType
Code list identically specified as *RoomFunctionType*

CityFurnitureClassType			
Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)			
1000	traffic	1020	others
1010	communication		

CityFurnitureFunctionType			
Code list derived from German authoritative standards ALKIS/ATKIS (www.adv-online.de)			
1000	communication fixture	1270	pole
1010	telephone box	1280	radio mast
1020	postbox	1290	aerial
1030	emergency call fixture	1300	radio telescope
1040	fire detector	1310	chimney
1050	police call post	1320	marker
1060	switching unit	1330	hydrant
1070	road sign	1340	upper corridor fire-hydrant
1080	traffic light	1350	lower floor panel fire-hydrant
1090	free-standing sign	1360	slidegate valve cap
1100	free-standing warning sign	1370	entrance shaft
1110	bus stop	1380	converter
1120	milestone	1390	stair
1130	rail level crossing	1400	outside staircase
1140	gate	1410	escalator
1150	streetlamp, latern or candelabra	1420	ramp
1160	column	1430	patio
1170	lamp post	1440	fence
1180	flagpole	1450	memorial/monument
1190	street sink box	1470	wayside shrine
1200	rubbish bin	1480	crossroads
1210	clock	1490	cross on the summit of a mountain
1220	directional spot light	1500	fountain
1230	floodlight mast	1510	block mark
1240	windmill	1520	boundary post
1250	solar cell	1530	bench
1260	water wheel	1540	others

TransportationComplexClass			
Code list proposed by the SIG 3D			
1000	private	1050	air traffic
1010	common	1060	rail traffic
1020	civil	1070	waterway
1030	military	1080	subway
1040	road traffic	1090	others

TransportationComplexFunction			
Code list proposed by the SIG 3D			
1000	road	1855	railway track
1010	freeway/motorway	1860	magnetic levitation train
1020	highway/national primary road	1900	railway station
1030	land road	1910	stop
1040	district road	1920	station
1050	main through-road	2000	power-wheel
1060	main through-road	2100	airport
1100	freeway interchange/ highway junction	2110	international airport
1110	junction	2120	regional airport
1200	road	2130	landing place
1210	driveway	2140	heliport
1220	footpath/footway	2150	landing place
1230	hiking trail	2160	gliding airfield
1240	bikeway/cycle-path	2170	taxiway
1250	bridleway/bridlepath	2180	apron
1260	main agricultural road	2190	runway
1270	agricultural road	2200	canal
1280	bikeway/footway	2300	harbor
1290	dead-end road	2310	pleasure craft harbour
1300	dead-end road	2400	ferry
1400	lane	2410	car ferry
1410	lane, one direction	2420	train ferry
1420	lane, both direction	2430	ferry
1500	pedestrian zone	2500	landing stage
1600	place	2600	waterway I order
1610	parking area	2610	navigable river
1620	marketplace	2620	inland navigation waterway 0
1700	service area	2621	inland navigation waterway 0
1800	rail transport	2622	inland navigation waterway I
1805	rail	2623	inland navigation waterway II
1810	urban/city train	2624	inland navigation waterway III
1815	city railway	2625	inland navigation waterway IV
1820	tram	2626	inland navigation waterway V
1825	subway	2627	inland navigation waterway VI
1830	funicular/mountain railway	2628	inland navigation waterway VII
1835	mountain railway	2630	maritime navigation
1840	chairlift	2640	navigable lake
1845	ski-lift/ski tow lift	2700	others
1850	suspension railway		

TransportationComplexUsage
Code list identically specified as *TransportationComplexFunction*

AuxiliaryTrafficAreaFunctionType			
Code list proposed by the SIG 3D			
1000	soft shoulder	1300	traffic island
1010	hard shoulder	1400	bank
1020	green area	1410	embankment, dike
1030	middle lane	1420	railroad embankment
1040	lay by	1430	noise protection
1100	parking bay	1440	noise protection wall
1200	ditch	1500	noise guard bar
1210	drainage	1600	towpath
1220	kerbstone	1700	others
1230	flower tub		

TrafficSurfaceMaterialType			
Code list proposed by the SIG 3D			
1	asphalt	8	soil
2	concrete	9	sand
3	pavement	10	grass
4	cobblestone	11	wood
5	gravel	12	steel
6	rail_with_bed	13	marble
7	rail_without_bed	9999	unknown

TrafficAreaUsageType			
Code list proposed by the SIG 3D			
1	pedestrian	9	boat, ferry, ship
2	car	10	teleferic
3	truck	11	aeroplane
4	bus, taxi	12	helicopter
5	train	13	taxi
6	bicycle	14	horse
7	motorcycle	9999	unknown
8	tram, streetcar		

TrafficAreaFunctionType			
Code list proposed by the SIG 3D			
1	driving_lane	20	crosswalk
2	footpath	21	barrier
3	cyclepath	22	stairs
4	combined foot-/cyclepath	23	escalator
5	square	24	filtering lane
6	car_park	25	airport_runway
7	parking_lay_by	26	airport_taxiway
8	rail	27	airport_apron
9	rail_road_combined	28	airport_heliport
10	drainage	29	airport_runway_marking
11	road marking	30	green spaces

12	road_marking_direction	31	recreation
13	road_marking_lane	32	bus_lay_by
14	road_marking_restricted	33	motorway
15	road_marking_crosswalk	34	motorway_entry
16	road_marking_stop	35	motorway_exit
17	road_marking_other	36	motorway_emergency lane
18	overhead wire (trolley)	37	private_area
19	train platform	9999	unknown

PlantCoverClassType			
Code list proposed by the SIG 3D. It is based on information extracted from http://www.biologie.uni-hamburg.de/b-online/e57/57.htm (Tab.3).			
1010	Lemnetea	1280	Arrhenatheretea
1020	Asplenietea rupestris	1290	Molinio-Juncetea
1030	Adiantetea	1300	Scheuchzerio-Caricetea fuscae azi-dophile
1040	Thlaspietea rotundifolii	1310	Festuco-Brometea
1050	Crithmo-Limonietea	1320	Elyno-Seslerietea
1060	Ammophietea	1330	Caricetea curvulae azidophile
1070	Cakiletea maritimae halophile	1340	Calluno-Ulicetea
1080	Secalinetea	1350	Oxycocco-Sphagnetea
1090	Chenopodietea	1360	Salicetea purpureae
1100	Onopordetea	1370	Betulo-Adenostyletea
1110	Epilobietea angustifolii	1380	Alnetea glutinosae
1120	Bidentetea tripartiti	1390	Erico-Pinetea
1130	Zoosteretea marinae halophile	1400	Vaccinio-Piceetea
1140	Ruppietea maritimae	1410	Quercetea robori-petraeae
1150	Potametea haftende	1420	Querco-Fagetea
1160	Litorelletea	1430	Crithmo-Staticetea
1170	Plantaginetea majoris	1440	Tuberarietea guttati
1180	Isoeto-Nanojuncetea	1450	Juncetea maritimae
1190	Montino-Cardaminetea	1460	Thero-Brachypodietea
1200	Corynephoretea	1470	Ononido-Rosmarinetea
1210	Asteretea tripolium	1480	Nerio-Tamaricetea
1220	Salicornietea	1490	Pegano-Salsoletea
1230	Juncetea maritimi	1500	Cisto-Lavanduletea
1240	Phragmitetea	1510	Quercetea ilicis
1250	Spartinetea	1520	Populetea albae
1260	Sedo-Scleranthetea	9999	unknown
1270	Salicetea herbaceae		

PlantClassType			
Code list proposed by the SIG 3D. It is based on information extracted from http://www.bundessortenamt.de and http://www.forst-hamburg.de/baumarten.htm.			
1000	shrub	1060	coniferous tree
1010	low plants	1070	decidous tree
1020	medium high plants	1080	bushes
1030	high plants	1090	aquatic plants
1040	grasses	1100	climber
1050	ferns	9999	unknown

SpeciesType (excerpt)			
Code list proposed by the SIG 3D. It is based on information extracted from http://www.bundessortenamt.de and http://www.forst-hamburg.de/baumarten.htm.			
1640	Abies alba	1790	Acer circinatum
1650	Abies cephalonica	1800	Acer Davidii
1660	Abies concolor	1810	Acer ginnala Maxim
1670	Abies grandis	1820	Acer grosserii
1680	Abies homolepsis	1830	Acer monspessulanum
1690	Abies koreana	1840	Acer negundo
1700	Abies lasiocarpa	1850	Acer palmatum
1710	Abies nordmanniana	1860	Acer platanoides
1720	Abies pinsapo	1870	Acer platanoides 'Crimson King'
1730	Abies procera	1880	Acer pseudoplatanus
1740	Abies procera 'Glauca'	1890	Acer rubrum
1750	Abies veitchii	1900	Acer saccharinum
1760	Acer campéstre	1910	Acer saccharum Marsch
1770	Acer capillipes	1920	Acer tartaricum
1780	Acer cappadocicum		

WaterLevelType			
Code list proposed by the SIG 3D			
1000	MSL - Mean Sea Level	1090	Hundred Year Flood
1010	LAT - Lowest Astronomical Tide	1100	highest known water level
1020	National Water Level	1110	critical low-water level
1030	Mean High Tide (related to National Waterlevel)	1120	lowest known water level
1040	Extreme High Tide (related to National Waterlevel)	1130	Established Line of Navigability
1050	Mean Low Tide (related to National Waterlevel)	1140	Minimum Limit of Navigability
1060	Extreme Low Tide (related to National Waterlevel)	1150	Maximum Limit of Navigability
1070	Mean Water Level (watercourse)	9999	unknown
1080	critical high-water level		

WaterBodyClassType			
Code list proposed by the SIG 3D			
1000	sea	1140	flooded land
1010	tidal waterbody	1150	artificial waterbody
1020	watercourse	1160	aqueduct
1030	river / stream	1170	canal
1040	ditch	1180	port basin
1050	spring / water hole	1190	reservior
1060	lake / pont	1200	excavation pont
1070	bayou	1210	moat
1080	body of standing water	1220	pool
1090	waterfall	1230	fountain
1100	rapids	1240	well
1110	swamp	1250	cistern
1120	sinkhole (karst)	1260	fish ladder
1130	ephemeral watercourse	9999	unknown

WaterBodyFunctionType			
Code list proposed by the SIG 3D			
1000	nature-sanctuary	1090	public swimming
1010	protected waterbody	1100	public fountain
1020	reservoir	1110	private waterbody
1030	retention waterbody	1120	irrigation waterbody
1040	flood plain waterbody	1130	watering place
1050	waterway	1140	industrial waterbody
1060	habor waterbody	1150	waterbody for fire-fighting
1070	sluice waterbody	9999	unknown
1080	sewage system		

WaterBodyUsageType			
Codelist derived from Ruediger Drees und Andreas Kohlhaas			
1000	sanctuary	1110	industrial / craft water supply
1010	recreation / sports	1120	military use
1020	drinking water supply	1130	mining / excavation
1030	hydroelectric water supply	1140	irrigation water supply
1040	ocean shipping	1150	fishing water
1050	inland shipping	1160	fish farm
1060	sewer	1170	archaeological site
1070	port	1180	water protection area
1080	anchorage	1190	abandoned
1090	public use	9999	unknown
1100	private use		

LandUseClassType			
Code list derived from German authoritative Standard ATKIS (www.adv-online.de)			
1000	Settlement Area	3000	Vegetation
1100	Undeveloped Area	4000	Water
2000	Traffic		

LandUseFunctionType			
Code list proposed by the SIG 3D			
1010	Residential	2050	Track
1020	Industry and Business	2060	Square
1030	MIxed use	3010	Grassland
1040	Special Function Area	3020	Agriculture
1050	Monument	3030	Forest
1060	Dump	3040	Grove
1070	Mining	3050	Heath
1110	Park	3060	Moor
1120	Cemetary	3070	Marsh
1130	Sports, leisure and recreation	3080	Untilled land
1140	Open pit, quarry	4010	River
2010	Road	4020	Standing Waterbody
2020	Railway	4030	Harbour
2030	Airfield	4040	Sea
2040	Shipping		

LandUseUsageType			
Code list proposed by the SIG 3D			
1000	Civil	1300	Religious
1100	Private	1400	Military
1200	Public		

MimeTypeType			
The MIME types given in this table are defined by the Internet Assigned Numbers Authority (IANA), see http://www.iana.org/. Generally, the MIME format is standardized by the Internet Engineering Task Force (IETF), see http://www.ietf.org/. Unlike the other code lists the MIME types are not represented by numbers, but instead use their given identifier. This code list is not exhaustive. It contains a selection of frequently used MIME types.			
model/vrml	VRML97	model/x3d+xml	X3D
application/x-3ds	3ds max	model/x3d+binary	X3D
application/dxf	AutoCad DXF	image/gif	*.gif images
application/x-autocad	AutoCad DXF	image/jpeg	*.jpeg, *.jpg images
application/x-dxf	AutoCad DXF	image/png	*.png images
application/acad	AutoCad DWG	image/tiff	*.tiff, *.tif images
application/x-shockwave-flash	Shockwave 3D	image/bmp	*.bmp images
model/x3d+vrml	X3D		

11.2 Annex B: Overview of employed GML3 geometry classes

Abstract GML classes referenced in CityGML	**GML subclass actually used in CityGML**
_Geometry	
_Solid	Solid (boundary is restricted to OrientableSurfaces, TexturedSurfaces, Polygons or CompositeSurfaces)
	CompositeSolid
_Surface	Polygon (with holes, modelled by Rings. The boundary is restricted to LineStrings or CompositeCurves)
	OrientableSurface (base surface is restricted to a Poly-gon)
	TexturedSurface (defined in CityGML, not in GML. For restrictions see OrientableSurface)
	CompositeSurface (members are restricted to Ori-entableSurfaces, TexturedSurfaces, Polygons or Compo-siteSurfaces)
	TriangulatedSurface
	Tin
_Curve	LineString
	CompositeCurve (members are restricted to LineStrings or CompositeCurves)
	Point
_Coverage	RectifiedGridCoverage
	MultiSolid
	MultiSurface (members are restricted to OrientableSurfaces, TexturedSurfaces, Polygons or CompositeSurfaces)
	MultiCurve(members are restricted to LineStrings or CompositeCurves)
	MultiPoint
	GeometricComplex (restricted to connected, linear networks)

11.3 *Annex C: Overview of the assignment of features to LODs*

The following table lists all feature types of CityGML. For each type, all non-spatial and spatial properties are given, including its type. Each feature is assigned a range of LOD in which it may occur, and for each spatial property the LOD in which it represents the feature is stated.

Feature Class	Property	Type	LOD
CityModelType			0 – 4
	cityObjectMember	gml:FeaturePropertyType	0 – 4
CityObjectType			0 – 4
	creationDate	xs:date	0 – 4
	terminationDate	xs:date	0 – 4
	externalReference	ExternalReferenceType	0 – 4
	_genericAttribute	_GenericAttributType	0 – 4
	generalizesTo	GeneralizationRelationType	0 – 4
	appearanceMember	AppearancePropertyType	0 – 4
GenericCityObjectType			0 – 4
	function	xs:string	0 – 4
	class	xs:string	0 – 4
	usage	xs:string	0 – 4
	lod0Geometry	gml:GeometryPropertyType	0
	lod1Geometry	gml:GeometryPropertyType	1
	lod2Geometry	gml:GeometryPropertyType	2
	lod3Geometry	gml:GeometryPropertyType	3
	lod4Geometry	gml:GeometryPropertyType	4
	lod0TerrainIntersection	gml:MultiCurvePropertyType	0
	lod1TerrainIntersection	gml:MultiCurvePropertyType	1
	lod2TerrainIntersection	gml:MultiCurvePropertyType	2
	lod3TerrainIntersection	gml:MultiCurvePropertyType	3
	lod4TerrainIntersection	gml:MultiCurvePropertyType	4
	lod0ImplicitRepresentation	ImplicitRepresentationPropertyType	0
	lod1ImplicitRepresentation	ImplicitRepresentationPropertyType	1
	lod2ImplicitRepresentation	ImplicitRepresentationPropertyType	2
	lod3ImplicitRepresentation	ImplicitRepresentationPropertyType	3
	lod4ImplicitRepresentation	ImplicitRepresentationPropertyType	4
CityObjectGroupType			0 – 4
	function	xs:string	0 – 4
	class	xs:string	0 – 4
	usage	xs:string	0 – 4
	groupMember	CityObjectGroupMemberType	0 – 4
	parent	CityObjectGroupMemberType	0 – 4
	geometry	gml:GeometryPropertyType	0 – 4
_SiteType			1 – 4
_AbstractBuildingType			1 – 4
	class	BuildingClassType	1 – 4
	function	BuildingFunctionType	1 – 4
	usage	BuildingUsageType	1 – 4
	yearOfConstruction	xs:gYear	1 – 4
	yearOfDemolition	xs:gYear	1 – 4
	roofType	RoofTypeType	1 – 4
	measuredHeight	gml:LengthType	1 – 4
	storeysAboveGround	xs:nonNegativeInteger	1 – 4
	storeysBelowGround	xs:nonNegativeInteger	1 – 4
	storeyHeightsAboveGround	gml:MeasureOrNullListType	1 – 4
	storeyHeightsBelowGround	gml:MeasureOrNullListType	1 – 4
	lod1Solid	gml:SolidPropertyType	1
	lod1MultiSurface	gml:MultiSurfacePropertyType	1
	lod1TerrainIntersection	gml:MultiCurvePropertyType	1
	lod2Solid	gml:SolidPropertyType	2
	lod2MultiSurface	gml:MultiSurfacePropertyType	2
	lod2MultiCurve	gml:MultiCurvePropertyType	2
	lod2TerrainIntersection	gml:MultiCurvePropertyType	2
	outerBuildingInstallation	BuildingInstallationPropertyType	1 – 4

	interiorBuildingInstallation	IntBuildingInstallationPropertyType	4
	boundedBy	BoundarySurfacePropertyType	2 – 4
	lod3Solid	gml:SolidPropertyType	3
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod3MultiCurve	gml:MultiCurvePropertyType	3
	lod3TerrainIntersection	gml:MultiCurvePropertyType	3
	lod4Solid	gml:SolidPropertyType	4
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
	lod4MultiCurve	gml:MultiSurfacePropertyType	4
	lod4TerrainIntersection	gml:MultiCurvePropertyType	4
	interiorRoom	InteriorRoomPropertyType	4
	consistsOfBuildingPart	BuildingPartPropertyType	1 – 4
	address	AddressPropertyType	1 – 4
BuildingPartType			1 – 4
BuildingInstallationType			2 – 4
	class	BuildingInstallationClassType	2 – 4
	function	BuildingInstallationFunctionType	2 – 4
	usage	BuildingInstallationUsageType	2 – 4
	lod2Geometry	gml:GeometryPropertyType	2
	lod3Geometry	gml:GeometryPropertyType	3
	lod4Geometry	gml:GeometryPropertyType	4
IntBuildingInstallationType			4
	class	IntBuildingInstallationClassType	4
	function	IntBuildingInstallationFunctionType	4
	usage	IntBuildingInstallationUsageType	4
	lod4Geometry	gml:GeometryPropertyType	4
_BoundarySurfaceType			2 – 4
	lod2MultiSurface	gml:MultiSurfacePropertyType	2
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
	opening	OpeningPropertyType	3 – 4
RoofSurfaceType			2 – 4
WallSurfaceType			2 – 4
GroundSurfaceType			2 – 4
ClosureSurfaceType			2 – 4
FloorSurfaceType			4
InteriorWallSurfaceType			4
CeilingSurfaceType			4
_OpeningType			3 – 4
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
WindowType			3 – 4
DoorType			3 – 4
	address	AddressPropertyType	3 – 4
RoomType			4
	class	RoomClassType	4
	function	RoomFunctionType	4
	usage	RoomUsageType	4
	lod4Solid	gml:SolidPropertyType	4
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
	boundedBy	BoundarySurfacePropertyType	4
	interiorFurniture	InteriorFurniturePropertyType	4
	roomInstallation	IntBuildingInstallationPropertyType	4
BuildingFurnitureType			4
	class	BuildingFurnitureClassType	4
	function	BuildingFurnitureFunctionType	4
	usage	BuildingFurnitureUsageType	4
	lod4Geometry	gml:GeometryPropertyType	4
	lod4ImplicitRepresentation	ImplicitRepresentationPropertyType	4
_TransportationObjectType			0 – 4
TransportationComplexType			0 – 4
	function	TransportationComplexFunctionType	0 – 4
	usage	TransportationComplexUsageType	0 – 4
	trafficArea	TrafficAreaPropertyType	0 – 4
	auxilaryTrafficArea	AuxilaryTrafficAreaPropertyType	0 – 4

	lod0Network	gml:GeometricComplexPropertyType	0
	lod1MultiSurface	gml:MultiSurfacePropertyType	1
	lod2MultiSurface	gml:MultiSurfacePropertyType	2
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
TrafficAreaType			1 – 4
	usage	TrafficAreaUsageType	1 – 4
	function	TrafficAreaFunctionType	1 – 4
	surfaceMaterial	TrafficSurfaceMaterialType	1 – 4
	lod1MultiSurface	gml:MultiSurfacePropertyType	1
	lod2MultiSurface	gml:MultiSurfacePropertyType	2
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
AuxillaryTrafficAreaType			1 – 4
	function	AuxiliaryTrafficAreaFunctionType	1 – 4
	surfaceMaterial	TrafficSurfaceMaterialType	1 – 4
	lod1MultiSurface	gml:MultiSurfacePropertyType	1
	lod2MultiSurface	gml:MultiSurfacePropertyType	2
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
TrackType			1 – 4
RoadType			1 – 4
RailwayType			1 – 4
SquareType			1 – 4
_VegetationObjectType			1 – 4
PlantCoverType			1 – 4
	class	PlantCoverClassType	1 – 4
	function	PlantCoverFunctionType	1 – 4
	averageHeight	gml:LengthType	1 – 4
	lod1MultiSurface	gml:MultiSurfacePropertyType	1
	lod2MultiSurface	gml:MultiSurfacePropertyType	2
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
	lod1MultiSolid	gml:MultiSolidPropertyType	1
	lod2MultiSolid	gml:MultiSolidPropertyType	2
	lod3MultiSolid	gml:MultiSolidPropertyType	3
SolitaryVegetationObjectType			1 – 4
	class	PlantClassType	1 – 4
	function	PlantFunctionType	1 – 4
	species	SpeciesType	1 – 4
	height	gml:LengthType	1 – 4
	trunkDiameter	gml:LengthType	1 – 4
	crownDiameter	gml:LengthType	1 – 4
	lod1Geometry	gml:GeometryPropertyType	1
	lod2Geometry	gml:GeometryPropertyType	2
	lod3Geometry	gml:GeometryPropertyType	3
	lod4Geometry	gml:GeometryPropertyType	4
	lod1ImplicitRepresentation	ImplicitRepresentationPropertyType	1
	lod2ImplicitRepresentation	ImplicitRepresentationPropertyType	2
	lod3ImplicitRepresentation	ImplicitRepresentationPropertyType	3
	lod4ImplicitRepresentation	ImplicitRepresentationPropertyType	4
_WaterObjectType			0 – 4
ImplicitGeometryType			0 – 4
	mimeType	MimeTypeType	0 – 4
	transformationMatrix	TransformationMatrix4x4Type	0 – 4
	libraryObject	xs:anyURI	0 – 4
	relativeGMLGeometry	gml:GeometryPropertyType	0 – 4
	referencePoint	gml:PointPropertyType	0 – 4
WaterBodyType			0 – 4
	class	WaterBodyClassType	0 – 4
	function	WaterBodyFunctionType	0 – 4
	usage	WaterBodyUsageType	0 – 4
	lod0MultiCurve	gml:MultiCurvePropertyType	0
	lod1MultiCurve	gml:MultiCurvePropertyType	1
	lod0MultiSurface	gml:MultiSurfacePropertyType	0

	lod1MultiSurface	gml:MultiSurfacePropertyType	1
	lod1Solid	gml:SolidPropertyType	1
	lod2Solid	gml:SolidPropertyType	2
	lod3Solid	gml:SolidPropertyType	3
	lod4Solid	gml:SolidPropertyType	4
	boundedBy	BoundedByWaterSurfacePropertyType	2 – 4
_WaterBoundarySurfaceType			2 – 4
	lod2Surface	gml:SurfacePropertyType	2
	lod3Surface	gml:SurfacePropertyType	3
	lod4Surface	gml:SurfacePropertyType	4
WaterSurfaceType			2 – 4
	waterLevel	WaterLevelType	2 – 4
WaterGroundSurfaceType			2 – 4
WaterClosureSurfaceType			2 – 4
LandUseType			0 – 4
	class	LandUseClassType	0 – 4
	function	LandUseFunctionType	0 – 4
	usage	LandUseUsageType	0 – 4
	lod0MultiSurface	gml:MultiSurfacePropertyType	0
	lod1MultiSurface	gml:MultiSurfacePropertyType	1
	lod2MultiSurface	gml:MultiSurfacePropertyType	2
	lod3MultiSurface	gml:MultiSurfacePropertyType	3
	lod4MultiSurface	gml:MultiSurfacePropertyType	4
CityFurnitureType			1 – 4
	function	FurnitureFunctionType	1 – 4
	class	FurnitureClassType	1 – 4
	lod1Geometry	gml:GeometryPropertyType	1
	lod2Geometry	gml:GeometryPropertyType	2
	lod3Geometry	gml:GeometryPropertyType	3
	lod4Geometry	gml:GeometryPropertyType	4
	lod1TerrainIntersection	gml:MultiCurvePropertyType	1
	lod2TerrainIntersection	gml:MultiCurvePropertyType	2
	lod3TerrainIntersection	gml:MultiCurvePropertyType	3
	lod4TerrainIntersection	gml:MultiCurvePropertyType	4
	lod1ImplicitRepresentation	ImplicitRepresentationPropertyType	1
	lod2ImplicitRepresentation	ImplicitRepresentationPropertyType	2
	lod3ImplicitRepresentation	ImplicitRepresentationPropertyType	3
	lod4ImplicitRepresentation	ImplicitRepresentationPropertyType	4
ReliefFeatureType			0 – 4
	lod	integerBetween0and4	0 – 4
	reliefComponent	ReliefComponentPropertyType	0 – 4
_ReliefComponentType			0 – 4
	lod	integerBetween0and4	0 – 4
	extent	gml:PolygonPropertyType	0 – 4
TINReliefType			0 – 4
	tin	tinPropertyType	0 – 4
RasterReliefType			0 – 4
	grid	gridPropertyType	0 – 4
MassPointReliefType			0 – 4
	reliefPoints	gml:MultiPointPropertyType	0 – 4
MassPointRelief			0 – 4
BreakLineReliefType			0 – 4
	ridgeOrValleyLines	gml:MultiCurvePropertyType	0 – 4
	breaklines	gml:MultiCurvePropertyType	0 – 4

11.4 *Annex D: Examples*

11.4.1 Example of a CityGML dataset for a building in LOD1 and LOD2

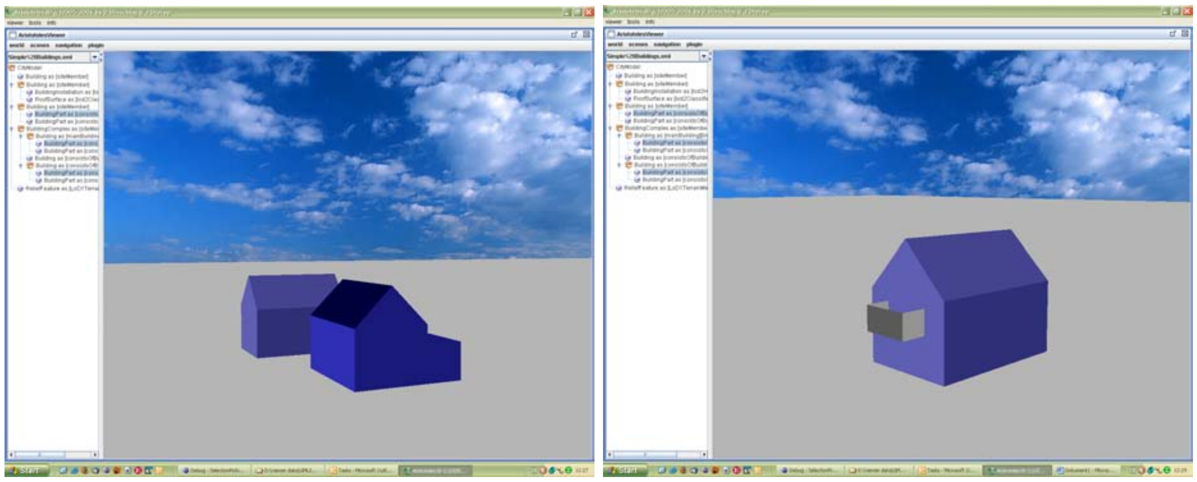


Fig. 50: Visualisation of the following CityGML dataset containing buildings in LOD1 and LOD2 (source: IGG Uni Bonn).

```
<?xml version="1.0" encoding="UTF-8"?>
<CityModel xmlns="http://www.citygml.org/citygml/1/0/0" xmlns:gml="http://www.opengis.net/gml"
            xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0" xmlns:xlink="http://www.w3.org/1999/xlink"
            xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
            xsi:schemaLocation="http://www.citygml.org/citygml/1/0/0 ../CityGML.xsd">
    <gml:description> Simple example for an XML dataset according to CityGML, the GML application
        schema of the SIG 3D. This dataset contains four parts with different complexities, which have been truncated here
        (the full version can be obtained from www.citygml.org):
        1.) Simple building in LOD2 with one textured and one colored surface
        2.) Simple building in LOD1 as blocks model without balcony, and the same building with gabled roof and balcony in LOD2.
        3.) House with gabled roof and garage, represented by two BuildingParts. The common wall surface of the building and the garage
        is defined only once and is in the boundary of one solid, and re-used by the second solid.
        4.) Building group consisting of two buildings that have been defined previously.
        The coordinate reference system is given in DHDN / Gauss-Krueger 3 degree (2nd zone) +
        normal heights above sea level (DHHN92).
        This system is referred to by srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783".
        Please note that the coordinates actually used in this dataset have been trimmed for clarity reasons
        and thus do not match this CRS.
    </gml:description>
    <gml:name>3D city model of Samplecity</gml:name>
    <gml:boundedBy>
        <gml:Envelope srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
            <gml:pos srsDimension="3">0.0 0.0 0.0 </gml:pos>
            <gml:pos srsDimension="3">33.0 34.0 2.5</gml:pos>
        </gml:Envelope>
    </gml:boundedBy>
    <cityObjectMember>
    <!--Simple building with gabled roof with two storeys and an address. It is a LOD 2 model, because it contains a roof shape.-->
        <Building gml:id="Build0815">
            <externalReference>
                <informationSystem>http://www.adv-online.de</informationSystem>
                <!-- Reference to the german cadastral database -->
                <externalObject>
                    <uri>urn:adv:oid:DEHE123400007001</uri>
                    <!-- ID of the object, being unique country-wide -->
                </externalObject>
            </externalReference>
            <function>1000</function>
            <yearOfConstruction>1985</yearOfConstruction>
            <roofType>1030</roofType>
            <measuredHeight uom="#m">8.0</measuredHeight>
            <storeysAboveGround>2</storeysAboveGround>
            <storeyHeightsAboveGround uom="#m">2.5 2.5</storeyHeightsAboveGround>
            <lod2Solid>
                <!--simple building with gabled roof-->
                <gml:Solid srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
                    <gml:exterior>
                    <gml:CompositeSurface>
                        <gml:surfaceMember>
                            <TexturedSurface orientation="+">
                                <!--front surface-->
                                <gml:baseSurface>
                                    <gml:Polygon>
                                        <gml:exterior>
                                            <gml:LinearRing>
                                                <gml:posList srsDimension="3">
                                                    1.0 1.0 0.0
                                                    3.0 1.0 1.5
                                                    2.0 1.0 2.5
                                                    1.0 1.0 1.5
                                                    1.0 1.0 0.0
                                                </gml:posList>
                                            </gml:LinearRing>
                                        </gml:exterior>
                                    </gml:Polygon>
                                </gml:baseSurface>
                                <appearance>
                                    <SimpleTexture>
                                        <textureMap>FrontTexture096454.jpg</textureMap>
                                        <textureCoordinates> 0.05 0.07 0.95 0.07 0.95 0.5 0.5 1
                                            0.05 0.5 0.05 0.07 </textureCoordinates>
                                        <textureType>specific</textureType>
                                    </SimpleTexture>
                                </appearance>
                            </TexturedSurface>
                        </gml:surfaceMember>
                        <gml:surfaceMember>
                            <TexturedSurface orientation="+">
                                <!--back surface-->
                                <gml:baseSurface>
                                    <gml:Polygon>
                                        <gml:exterior>
                                            <gml:LinearRing>
                                                <gml:pos srsDimension="3">1.0 4.0 0.0</gml:pos>
                                                <gml:pos srsDimension="3">1.0 4.0 1.5</gml:pos>
                                                <gml:pos srsDimension="3">2.0 4.0 2.5</gml:pos>
                                                <gml:pos srsDimension="3">3.0 4.0 1.5</gml:pos>
                                                <gml:pos srsDimension="3">3.0 4.0 0.0</gml:pos>
                                                <gml:pos srsDimension="3">1.0 4.0 0.0</gml:pos>
                                            </gml:LinearRing>
                                        </gml:exterior>
                                    </gml:Polygon>
                                </gml:baseSurface>
                                <appearance>
                                    <Material>
                                        <ambientIntensity>0.4</ambientIntensity>
                                        <diffuseColor> 0 0 1 </diffuseColor>     <!-- defines blue color -->
                                    </Material>
                                </appearance>
                            </TexturedSurface>
                        </gml:surfaceMember>
                        ..........................
                    </gml:CompositeSurface>
                </gml:exterior>
            </gml:Solid>
        </lod2Solid>
    </Building>
</cityObjectMember>
<cityObjectMember>
    <!--  Simple building represented in LOD1 (as blocks model without balcony) and in LOD2
        with roof shape and balcony. One of the roof surfaces is represented explicitly as a thematic surface object (RoofSurface).
        The function is residential building (1000) and the roof type is 'gabled roof' (1030).
        Both values are defined in external code lists.-->
    <Building gml:id="Build0816">
        <gml:name>Villa Kunterbunt</gml:name>
        <function>1000</function>
        <yearOfConstruction>1952</yearOfConstruction>
        <roofType>1030</roofType>
        <lod1Solid>
            <gml:Solid srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
                <!--simple blocks model -->
                <gml:exterior>
                    <gml:CompositeSurface>
                        <gml:surfaceMember>
                            <!--front surface-->
                            <gml:Polygon>
                                <gml:exterior>
                                    <gml:LinearRing>
                                        <gml:pos srsDimension="3">31.0 31.0 0.0</gml:pos>
                                        <gml:pos srsDimension="3">33.0 31.0 0.0</gml:pos>
                                        <gml:pos srsDimension="3">33.0 31.0 1.5</gml:pos>
                                        <gml:pos srsDimension="3">31.0 31.0 1.5</gml:pos>
                                        <gml:pos srsDimension="3">31.0 31.0 0.0</gml:pos>
                                    </gml:LinearRing>
                                </gml:exterior>
                            </gml:Polygon>
                        </gml:surfaceMember>
                    ..................................
                    </gml:CompositeSurface>
                </gml:exterior>
        </lod1Solid>
        <lod2Solid>
            <gml:Solid srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
                <!-- simple building with gabled roof-->
                <gml:exterior>
                    <gml:CompositeSurface>
                        <gml:surfaceMember>
                            <!--front surface-->
                            <gml:Polygon>
                                <gml:exterior>
                                    <gml:LinearRing>
                                        <gml:pos srsDimension="3">31.0 31.0 0.0</gml:pos>
                                        <gml:pos srsDimension="3">33.0 31.0 0.0</gml:pos>
                                        <gml:pos srsDimension="3">33.0 31.0 1.5</gml:pos>
                                        <gml:pos srsDimension="3">32.0 31.0 2.5</gml:pos>
                                        <gml:pos srsDimension="3">31.0 31.0 1.5</gml:pos>
                                        <gml:pos srsDimension="3">31.0 31.0 0.0</gml:pos>
                                    </gml:LinearRing>
                                </gml:exterior>
                            </gml:Polygon>
                        </gml:surfaceMember>
                        <gml:surfaceMember>
                                <!--1st roof surface. This polygon will be referenced below.-->
                                <gml:Polygon gml:id="roofsurface4711">
                                    <gml:exterior>
                                        <gml:LinearRing>
                                            <gml:posList srsDimension="3">
                                                32.0 31.0 2.5
                                                33.0 31.0 1.5
                                                33.0 34.0 1.5
                                                32.0 34.0 2.5
                                                32.0 31.0 2.5
                                            </gml:posList>
                                        </gml:LinearRing>
                                    </gml:exterior>
                                </gml:Polygon>
                        </gml:surfaceMember>
                    ..........................................
                    </gml:CompositeSurface>
                </gml:exterior>
            </gml:Solid>
        </lod2Solid>
        <outerBuildingInstallation>
            <BuildingInstallation>
                <gml:name>The nice balcony to the south</gml:name>
                <function>1000</function>
                <!--function 1000 of a BuildingInstallation means 'balcony'-->
                <lod2Geometry>
                    <!-- The balcony is situated at the 1st  front surface -->
                    <!-- The geometry of the balcony is defined by an aggregation of 3D surfaces. -->
                    <gml:CompositeSurface srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
                        <gml:surfaceMember>
                            <!-- ground surface of the balcony -->
                            <gml:Polygon>
                                <gml:exterior>
                                    <gml:LinearRing>
                                        <gml:pos srsDimension="3">31.5 30.5 0.8</gml:pos>
                                        <gml:pos srsDimension="3">31.5 31.0 0.8</gml:pos>
                                        <gml:pos srsDimension="3">32.5 31.0 0.8</gml:pos>
                            <gml:pos srsDimension="3">32.5 30.5 0.8</gml:pos>
                            <gml:pos srsDimension="3">31.5 30.5 0.8</gml:pos>
                        </gml:LinearRing>
                    </gml:exterior>
                </gml:Polygon>
            </gml:surfaceMember>
            ...............................
            </gml:CompositeSurface>
        </lod2Geometry>
      </BuildingInstallation>
</outerBuildingInstallation>
<boundedBy>
    <RoofSurface>
        <externalReference>
            <informationSystem>http://www.solar-panel.com/database/samplecity</informationSystem>
            <!--  This may be a database, which contains all roof surfaces of a city covered with solar panels -->
            <externalObject>
                <name>roof_10786</name>
                <!-- roof_10786 is the id of the roof surface in the external solar panel database  -->
            </externalObject>
        </externalReference>
        <lod2MultiSurface>
            <gml:MultiSurface>
            <!-- Reference to a surface which has already been defined in the solid boundary of the outer building shell.-->
                <gml:surfaceMember xlink:href="#roofsurface4711"/>
            </gml:MultiSurface>
        </lod2MultiSurface>
    </RoofSurface>
</boundedBy>
</Building>
</cityObjectMember>
<cityObjectMember>
    <!-- House with gabled roof and a garage, represented by two BuildingParts. The common wall surface of the building and the
        garage is shared by both solids realizing a topological connection between both parts.-->
    <Building gml:id="Build0817">
        <consistsOfBuildingPart>
            <BuildingPart gml:id="Build0817a">
                <function>1000</function>
                <yearOfConstruction>1964</yearOfConstruction>
                <roofType>1030</roofType>
                <storeysAboveGround>2</storeysAboveGround>
                <lod2Solid>
                    <gml:Solid srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
                        <!--Building with gabled roof-->
                        <gml:exterior>
                            <gml:CompositeSurface>
                                <gml:surfaceMember>
                                    <!--front surface-->
                                    <gml:Polygon>
                                        <gml:exterior>
                                            <gml:LinearRing>
                                                <gml:posList srsDimension="3">
                                                    8.0 2.0 0.0
                                                    8.0 4.0 0.0
                                                    8.0 4.0 1.5
                                                    8.0 3.0 2.5
                                                    8.0 2.0 1.5
                                                    8.0 2.0 0.0
                                                </gml:posList>
                                            </gml:LinearRing>
                                        </gml:exterior>
                                    </gml:Polygon>
                                </gml:surfaceMember>
                                .....................................
                                <gml:surfaceMember>
                                    <!--2nd side surface, shares surface with garage geometry-->
                                    <gml:Polygon gml:id="polygon007">
                                        <gml:exterior>
                                            <gml:LinearRing>
                                                <gml:pos srsDimension="3">8.0 4.0 1.0</gml:pos>
                                                <gml:pos srsDimension="3">8.0 4.0 0.0</gml:pos>
                                                <gml:pos srsDimension="3">6.5 4.0 0.0</gml:pos>
                                                <gml:pos srsDimension="3">6.5 4.0 1.0</gml:pos>
                                                <gml:pos srsDimension="3">8.0 4.0 1.0</gml:pos>
                                            </gml:LinearRing>
                                        </gml:exterior>
                                    </gml:Polygon>
                                </gml:surfaceMember>
                    ..............................................
            </BuildingPart>
        </consistsOfBuildingPart>
        <consistsOfBuildingPart>
            <BuildingPart gml:id="Build817b">
                <function>1630</function>
                    <!-- Function 1630 means 'garage' -->
                <yearOfConstruction>1996</yearOfConstruction>
                <roofType>1000</roofType>
                <storeysAboveGround>1</storeysAboveGround>
                <lod2Solid>
                    <gml:Solid srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
                        <!--garage-->
                        <gml:exterior>
                            <gml:CompositeSurface>
                                <gml:surfaceMember>
                                    <!--front surface-->
                                    <gml:Polygon>
                                        <gml:exterior>
                                            <gml:LinearRing>
                                                <gml:pos srsDimension="3">8.0 4.0 0.0</gml:pos>
                                                <gml:pos srsDimension="3">8.0 5.0 0.0</gml:pos>
                                                <gml:pos srsDimension="3">8.0 5.0 1.0</gml:pos>
                                                <gml:pos srsDimension="3">8.0 4.0 1.0</gml:pos>
                                                <gml:pos srsDimension="3">8.0 4.0 0.0</gml:pos>
                                            </gml:LinearRing>
                                        </gml:exterior>
                                    </gml:Polygon>
                                </gml:surfaceMember>
                                ...................................
                                <gml:surfaceMember>
                                    <!--2nd side surface, shares surface with building geometry-->
                                    <gml:OrientableSurface orientation="-">    <!-- Surface orientation has to be reversed! -->
                                        <baseSurface xlink:href="#polygon007"/>
                                    </gml:OrientableSurface>
                                </gml:surfaceMember>
                            </gml:CompositeSurface>

                    </gml:Solid>
                </lod2Solid>
            </BuildingPart>
        </consistsOfBuildingPart>

            <Address>

                    <xAL:AddressDetails>
                        <xAL:Country>
                            <xAL:CountryName>Germany</xAL:CountryName>
                                <xAL:Locality Type="Town">

                                <xAL:Thoroughfare Type="Street">
                                    <xAL:ThoroughfareNumber>172</xAL:ThoroughfareNumber>
                                    <xAL:ThoroughfareName>Meckenheimer Allee</xAL:ThoroughfareName>
                                </xAL:Thoroughfare>

                                    <xAL:PostalCodeNumber>53115</xAL:PostalCodeNumber>
                                </xAL:PostalCode>
                            </xAL:Locality>
                        </xAL:Country>

                </xalAddress>
                <multiPoint>
                    <gml:MultiPoint>
                        <gml:pointMember>

                                <gml:pos srsDimension="3">6.5 4.0 1.0</gml:pos>
                            </gml:Point>
                        </gml:pointMember>
                    </gml:MultiPoint>

            </Address>
        </address>
    </Building>
</cityObjectMember>
```

```
    <cityObjectMember>
        <!--Building group with name 'Scenic view', consisting of the two buildings Build0815 and Build0817.
            Both buildings are included by reference.-->
        <CityObjectGroup gml:id="Complex113">
            <gml:name>Hotel Complex ‘Scenic View’</gml:name>

            <groupMember role="main building" xlink:href="#Build0817"/>
            <groupMember xlink:href="#Build0815"/>
        </CityObjectGroup>
    </cityObjectMember>
</CityModel>
```

Listing 3:Excerpt from the CityGML dataset for buildings in LOD1 and 2 visualised in Fig. 50.

11.4.2 Example of a CityGML dataset for a building in LOD 3

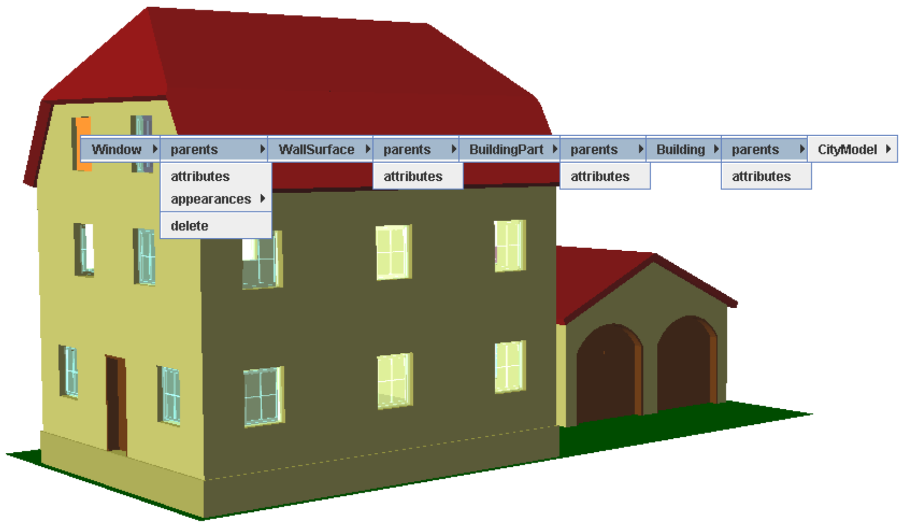


Fig. 51: Visualisation of buildings in LOD 3, automatically generated from IFC building objects. Please note the coherent semantic and geometric decomposition (source: Research Center Karlsruhe).

```
<?xml version="1.0" encoding="ISO-8859-1" ?>
<CityModel xmlns="http://www.citygml.org/citygml/1/0/0" xmlns:gml="http://www.opengis.net/gml"
      xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:schemaLocation="http://www.citygml.org/citygml/1/0/0 ../CityGML.xsd">
   <gml:description>This file contains four buildings which are automatically converted from IFC models. This listing only shows an excerpt. The
         full dataset can be downloaded from http://www.citygml.org  (example dataset for “four buildings in LOD3”)</gml:description>
   <gml:name>IFC_Building_Variant</gml:name>
   <gml:boundedBy>
      <gml:Envelope srsName="urn:ogc:def:crs,crs:EPSG:6.12:31467,crs:EPSG:6.12:5783">
         <gml:pos srsDimension="3">5429999.751795 3449999.751795 0.0</gml:pos>
         <gml:pos srsDimension="3">5430023.2 3450021.2 20.0</gml:pos>
      </gml:Envelope>
   </gml:boundedBy>
   …
   <cityObjectMember>
      <Building gml:id="GEB_TH_IFC_Building_Variant_GEB_75">
         <gml:description>Building in LOD 3</gml:description>
         <gml:name>Building-ADT-2006</gml:name>
         <externalReference>
            <informationSystem>http://www.iai.fzk.de/raw/pages/german/projekte/VR-Systeme/html/Download/</informationSystem>
            <externalObject>
               <uri>urn:ifc:oid:0deJpNQ05BvwV03c405oVp</uri>
            </externalObject>
         </externalReference>
         <boundedBy>
            <RoofSurface gml:id="GEB_TH_IFC_Building_Variant_DACH_136">
               <externalReference>
                  <informationSystem>http://www.iai.fzk.de/raw/pages/german/projekte/VR-Systeme/html/Download/</informationSystem>
                  <externalObject>
                     <uri>urn:ifc:oid:3CPSkwS7f9QRfhfr5gf7dq</uri>
                  </externalObject>
               </externalReference>
               <lod3MultiSurface>
                  <gml:MultiSurface>
                     <gml:surfaceMember>
                        <gml:Polygon>
                           <gml:exterior>
                              <gml:LinearRing>
                                 <gml:posList srsDimension="3">5430006.994499969 3449999.850802998 9.141580054626465
                                       5430007.093499946 3449999.7517950004 8.970100114212036 5430000.906494903
                                       3449999.7517950004 8.970100114212036 5430001.005499649 3449999.850802998
                                       9.141580054626465 5430003.999999809 3450000.9735459564 11.086200187072754
                                       5430006.994499969 3449999.850802998 9.141580054626465</gml:posList>
                              </gml:LinearRing>
                           </gml:exterior>
                        </gml:Polygon>
                     </gml:surfaceMember>
                     <gml:surfaceMember>
                        <gml:Polygon>
                           <gml:exterior>
                              <gml:LinearRing>
                                 <gml:posList srsDimension="3">5430006.920299816 3449999.925 8.870099971160888
                                       5430006.845300007 3450000.000000003 8.999999949798584 5430003.999999809
                                       3450001.066800046 10.847800204620361 5430001.154700088 3450000.000000003
                                       8.999999949798584 5430001.079700279 3449999.925 8.870099971160888 5430006.920299816
                                       3449999.925 8.870099971160888</gml:posList>
                              </gml:LinearRing>
                           </gml:exterior>
                        </gml:Polygon>
                     </gml:surfaceMember>
                     …
                  </gml:MultiSurface>
               </lod3MultiSurface>
            </RoofSurface>
         </boundedBy>
         <boundedBy>
            <WallSurface gml:id="GEB_TH_IFC_Building_Variant_WAND_78">
               <externalReference>
                  <informationSystem>http://www.iai.fzk.de/raw/pages/german/projekte/VR-Systeme/html/Download/</informationSystem>
                  <externalObject>
                     <uri>urn:ifc:oid:2es$8LnAD9UxRIGzY8UaVK</uri>
                  </externalObject>
               </externalReference>
               <lod3MultiSurface>
                  <gml:MultiSurface>
                     <gml:surfaceMember>
                        <gml:Polygon>
                           <gml:exterior>
                              <gml:LinearRing>
                                 <gml:posList srsDimension="3">5429999.999999809 3450004.4950001715 6.059999996886253
                                       5429999.999999809 3450004.4950001715 4.800000021324157 5430000.119999695
                                       3450004.4950001715 4.800000021324157 5430000.180000114 3450004.4950001715
                                       4.800000021324157 5430000.3 3450004.4950001715 4.800000021324157 5430000.3
                                       3450004.4950001715 6.059999996886253 5430000.180000114 3450004.4950001715
                                       6.059999996886253 5430000.119999695 3450004.4950001715 6.059999996886253
                                       5429999.999999809 3450004.4950001715 6.059999996886253</gml:posList>
                              </gml:LinearRing>
                           </gml:exterior>
                        </gml:Polygon>
                     </gml:surfaceMember>
                     …
                  </gml:MultiSurface>
               </lod3MultiSurface>
               <opening>
                  <Window gml:id="GEB_TH_IFC_Building_Variant_OEFF_OBJ_80">
                     <externalReference>
                        <informationSystem>http://www.iai.fzk.de/raw/pages/german/projekte/VR-
                              Systeme/html/Download/</informationSystem>
                        <externalObject>
                           <uri>urn:ifc:oid:3VkZRUoa97GgMdD342zHck</uri>
                        </externalObject>
                     </externalReference>
                     <lod3MultiSurface>
                        <gml:MultiSurface>
                           <gml:surfaceMember>
                              <gml:Polygon>
                                 <gml:exterior>
                                    <gml:LinearRing>
                                       <gml:posList srsDimension="3">5430000.119999695 3450008.940000343 2.9999999497985836
                                             5430000.180000114 3450008.940000343 2.9999999497985836 5430000.180000114
                                             3450008.940000343 1.920000026092529 5430000.180000114 3450008.940000343
                                             1.860000083312988 5430000.119999695 3450008.940000343 1.860000083312988
                                             5430000.119999695 3450008.940000343 2.9999999497985836</gml:posList>
                                    </gml:LinearRing>
                                 </gml:exterior>
                              </gml:Polygon>
                           </gml:surfaceMember>
                           …
                        </gml:MultiSurface>
                     </lod3MultiSurface>
                  </Window>
               </opening>
               …
```

```
                </WallSurface>
            </boundedBy>
        </Building>
    </cityObjectMember>
</CityModel>
```

Listing 4:Excerpt from the CityGML dataset for the buildings in LOD3 visualised in Fig. 51.

11.4.3 Example of a CityGML dataset illustrating the appearance model

The following CityGML dataset contains a simple building given in geometric representations for LOD1 and LOD2. Furthermore two separate appearance themes are defined – a summer theme and a winter theme – describing different visual appearances for the building and the surrounding terrain. Each LOD has an individual appearance for these specific themes.

Several concepts of CityGML's appearance model are used in this dataset. Regarding LOD1, an *X3DMaterial* object defines the material of the whole building which is applied to all of its surfaces. In addition, a *GeoreferencedTexture* is assigned both to the terrain and the roof surface of the building. In LOD2 the vertical surfaces of the building are texturized individually using *ParameterizedTexture* objects whereas the roof surfaces and the terrain again are described by a *GeoreferencedTexture*. The modelling approach results in four possible visualizations of the dataset that are represented in Fig. 52 and Fig. 53.

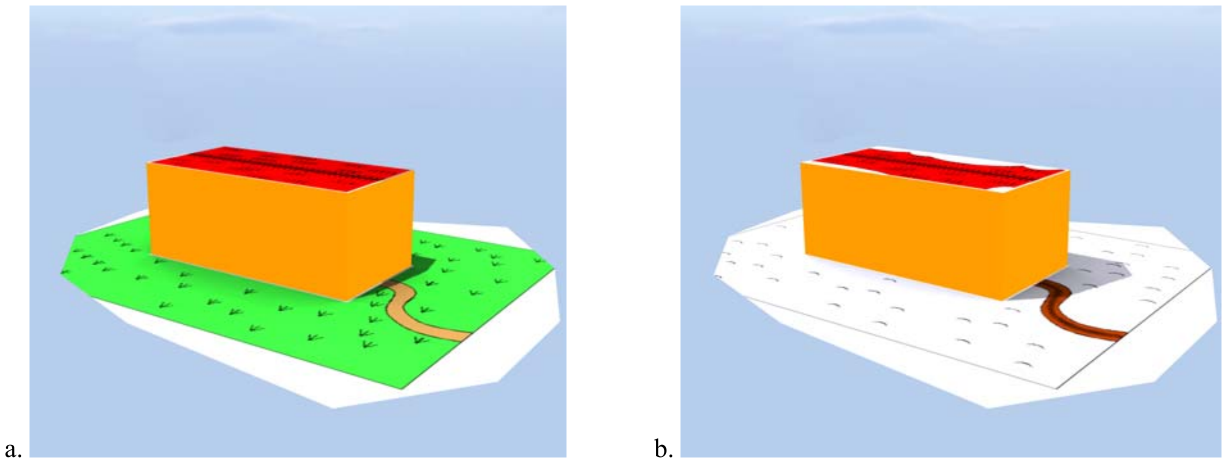


Fig. 52: Visualisation of a simple building in LOD1 using CityGML's appearance model. Two themes are defined for the building and the surrounding terrain: (a) theme showing the building in summer time and (b) showing the building in winter time (image: Hasso-Plattner-Institute).

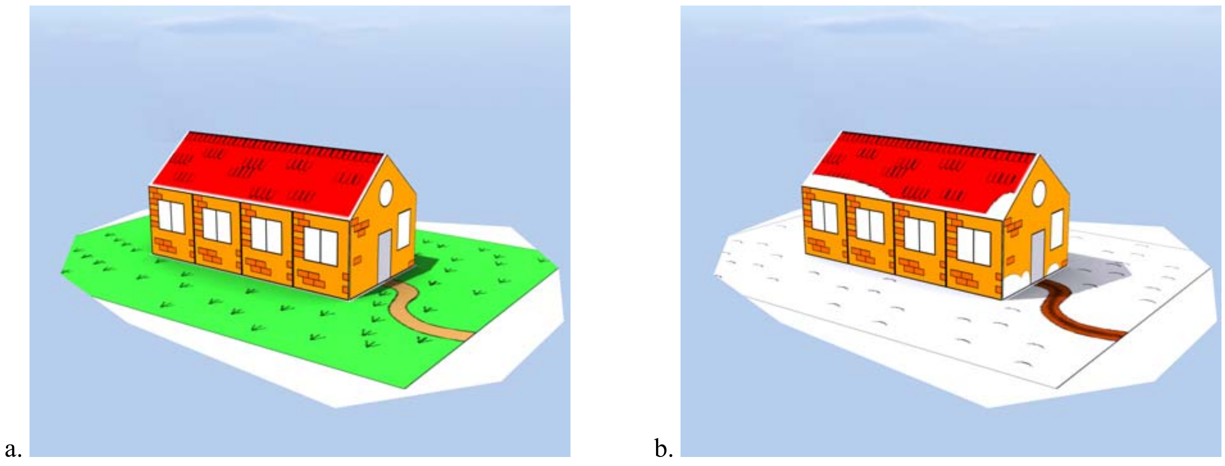


Fig. 53: Visualisation of a simple building in LOD2 using CityGML's appearance model. Two themes are defined for the building and the surrounding terrain: (a) theme showing the building in summer time and (b) showing the building in winter time (image: Hasso-Plattner-Institute).

```
<?xml version="1.0" encoding="UTF-8"?>
<CityModel xmlns:gml="http://www.opengis.net/gml" xsi:schemaLocation="http://www.citygml.org/citygml/1/0/0
http://www.citygml.org/citygml/1/0/0/CityGML.xsd" xmlns="http://www.citygml.org/citygml/1/0/0"
xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <gml:description> Simple example for an XML dataset according to CityGML, the GML application
        schema of the SIG 3D. This dataset contains one simple building in LOD1 and LOD2 and the surrounding terrain as well as two
        separate appearance themes:
        1.) Simple building in LOD1
        2.) Simple building in LOD2
        3.) Digital terrain given by a TIN.
        4.) Appearance theme “summer”.
        5.) Appearance theme “winter”.
        Please note, that appearances are explicitly linked to GML geometry objects using URIs. Since Texture objects are modelled as
        features (with a unique id) they can be (and in fact are) reused. This is realized using XLinks.
        The coordinate reference system is given in DHDN / Gauss-Krueger 3 degree (2nd zone) +
        normal heights above sea level (DHHN92).
        This system is referred to by srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783".
        Please note, that the coordinates actually used in this dataset have been trimmed for clarity reasons
        and thus do not match this CRS.
    </gml:description>
  <gml:boundedBy>
    <gml:Envelope srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
      <gml:lowerCorner>-6.0 -7.0 0.0</gml:lowerCorner>
      <gml:upperCorner>17.0 13.0 5.0</gml:upperCorner>
    </gml:Envelope>
  </gml:boundedBy>
  <cityObjectMember>
    <Building gml:id="Build0815">
      <yearOfConstruction>2007</yearOfConstruction>
      <measuredHeight uom="#m">5.0</measuredHeight>
      <lod1Solid>
        <gml:Solid>
          <gml:exterior>
            <gml:CompositeSurface gml:id="lod1Surface">
              <gml:surfaceMember>
                <gml:Polygon>
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:posList srsDimension="3">
                        0.0 0.0 0.0
                        10.0 0.0 0.0
                        10.0 0.0 4.0
                        0.0 0.0 4.0
                        0.0 0.0 0.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
              ...
              <gml:surfaceMember>
                <gml:Polygon gml:id="lod1RoofPoly1">
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:posList srsDimension="3">
                        0.0 0.0 4.0
                        10.0 0.0 4.0
                        10.0 5.0 4.0
                        0.0 5.0 4.0
                        0.0 0.0 4.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
            </gml:CompositeSurface>
          </gml:exterior>
        </gml:Solid>
      </lod1Solid>
      <lod2Solid>
        <gml:Solid>
          <gml:exterior>
            <gml:CompositeSurface>
              <gml:surfaceMember>
                <gml:CompositeSurface gml:id="fLeft">
                  <gml:surfaceMember>
                    <gml:Polygon>
                      <gml:exterior>
                        <gml:LinearRing gml:id="fLeftExt1">
                          <gml:posList srsDimension="3">
                            0.0 0.0 0.0
                            5.0 0.0 0.0
                            5.0 0.0 3.0
                            0.0 0.0 3.0
                            0.0 0.0 0.0
                          </gml:posList>
                        </gml:LinearRing>
                      </gml:exterior>
                    </gml:Polygon>
                  </gml:surfaceMember>
                  <gml:surfaceMember>
                    <gml:Polygon>
                      <gml:exterior>
                        <gml:LinearRing gml:id="fLeftExt2">
                          <gml:posList srsDimension="3">
                            5.0 0.0 0.0
                            10.0 0.0 0.0
                            10.0 0.0 3.0
                            5.0 0.0 3.0
                            5.0 0.0 0.0
                          </gml:posList>
                        </gml:LinearRing>
                      </gml:exterior>
                    </gml:Polygon>
                  </gml:surfaceMember>
                </gml:CompositeSurface>
              </gml:surfaceMember>
              <gml:surfaceMember>
                <gml:Polygon gml:id="fFront">
                  <gml:exterior>
                    <gml:LinearRing gml:id="fFrontExt">
                      <gml:posList srsDimension="3">
                        10.0 0.0 0.0
                        10.0 5.0 0.0
                        10.0 5.0 3.0
                        10.0 2.5 5.0
                        10.0 0.0 3.0
                        10.0 0.0 0.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
              <gml:surfaceMember>
                <gml:Polygon gml:id="fRight">
                  <gml:exterior>
                    <gml:LinearRing gml:id="fRightExt">
                      <gml:posList srsDimension="3">
                        10.0 5.0 0.0
                        0.0 5.0 0.0
                        0.0 5.0 3.0
                        10.0 5.0 3.0
                        10.0 5.0 0.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
              <gml:surfaceMember>
                <gml:Polygon gml:id="fBack">
                  <gml:exterior>
                    <gml:LinearRing gml:id="fBackExt">
                      <gml:posList srsDimension="3">
                        0.0 5.0 0.0
                        0.0 0.0 0.0
                        0.0 0.0 3.0
                        0.0 2.5 5.0
                        0.0 5.0 3.0
                        0.0 5.0 0.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
              <gml:surfaceMember>
                <gml:Polygon gml:id="lod2RoofPoly1">
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:posList srsDimension="3">
                        0.0 0.0 3.0
                        10.0 0.0 3.0
```

```
                        10.0 2.5 5.0
                        0.0 2.5 5.0
                        0.0 0.0 3.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
              <gml:surfaceMember>
                <gml:Polygon gml:id="lod2RoofPoly2">
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:posList srsDimension="3">
                        10.0 5.0 3.0
                        0.0 5.0 3.0
                        0.0 2.5 5.0
                        10.0 2.5 5.0
                        10.0 5.0 3.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
            </gml:CompositeSurface>
          </gml:exterior>
        </gml:Solid>
      </lod2Solid>
    </Building>
  </cityObjectMember>
  <cityObjectMember>
    <ReliefFeature gml:id="DTM_1">
      <lod>1</lod>
      <reliefComponent>
        <TINRelief gml:id="GUID_04D4DsNGv1MfvYu5O3lkcW">
          <gml:name>Ground</gml:name>
          <lod>1</lod>
          <tin>
            <gml:TriangulatedSurface gml:id="ground">
              <gml:trianglePatches>
                <gml:Triangle>
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:posList>
                        -6.0 5.0 0.0
                        0.0 5.0 0.0
                        -6.0 9.0 0.0
                        -6.0 5.0 0.0
                      </gml:posList>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Triangle>
                …
              </gml:trianglePatches>
            </gml:TriangulatedSurface>
          </tin>
        </TINRelief>
      </reliefComponent>
    </ReliefFeature>
  </cityObjectMember>
  <appearanceMember>
    <Appearance>
      <theme>Summer</theme>
      <surfaceDataMember>
        <X3DMaterial gml:id="lod1Material">
          <diffuseColor>1.0 0.6 0.0</diffuseColor>
          <target>#lod1Surface</target>
        </X3DMaterial>
      </surfaceDataMember>
      <surfaceDataMember>
        <GeoreferencedTexture>
          <imageURI>ground_summer.png</imageURI>
          <wrapMode>none</wrapMode>
          <referencePoint>
            <gml:Point>
              <gml:pos> -5.0 -5.0 </gml:pos>
            </gml:Point>
          </referencePoint>
          <orientation>
            0.05 0.0
            0.0 0.066667
          </orientation>
          <target>#ground</target>
          <target>#lod1RoofPoly1</target>
          <target>#lod2RoofPoly1</target>
          <target>#lod2RoofPoly2</target>
        </GeoreferencedTexture>
      </surfaceDataMember>
      <surfaceDataMember>
        <ParameterizedTexture gml:id="sideTexture">
          <imageURI>facade.png</imageURI>
          <wrapMode>wrap</wrapMode>
          <target uri="#fLeft">
            <TexCoordList>
              <textureCoordinates ring="#fLeftExt1">0.0 0.0 2.0 0.0 2.0 1.0 0.0 1.0 0.0 0.0</textureCoordinates>
              <textureCoordinates ring="#fLeftExt2">2.0 0.0 4.0 0.0 4.0 1.0 2.0 1.0 2.0 0.0</textureCoordinates>
            </TexCoordList>
          </target>
          <target uri="#fRight">
            <TexCoordGen>
              <worldToTexture>
                -0.4  0.0     0.0  1.0
                 0.0  0.0  0.3333  0.0
                 0.0  0.0     0.0  1.0
              </worldToTexture>
            </TexCoordGen>
          </target>
        </ParameterizedTexture>
      </surfaceDataMember>
      <surfaceDataMember>
        <ParameterizedTexture>
          <imageURI>front_back_summer.png</imageURI>
          <wrapMode>none</wrapMode>
          <target uri="#fFront">
            <TexCoordList gml:id="frontTexCoord">
              <textureCoordinates ring="#fFrontExt">0.0 0.0 0.5 0.0 0.5 0.6 0.25 1.0 0.0 0.6 0.0 0.0</textureCoordinates>
            </TexCoordList>
          </target>
          <target uri="#fBack">
            <TexCoordList gml:id="backTexCoord">
              <textureCoordinates ring="#fBackExt">0.5 0.0 1.0 0.0 1.0 0.6 0.75 1.0 0.5 0.6 0.5 0.0</textureCoordinates>
            </TexCoordList>
          </target>
        </ParameterizedTexture>
      </surfaceDataMember>
    </Appearance>
  </appearanceMember>
  <appearanceMember>
    <Appearance>
      <theme>Winter</theme>
      <surfaceDataMember>
        <GeoreferencedTexture>
          <imageURI>ground_winter.png</imageURI>
          <wrapMode>none</wrapMode>
          <referencePoint>
            <gml:Point>
              <gml:pos> -5.0 -5.0 </gml:pos>
            </gml:Point>
          </referencePoint>
          <orientation>
            0.05 0.0
            0.0 0.066667
          </orientation>
          <target>#ground</target>
          <target>#lod1RoofPoly1</target>
          <target>#lod2RoofPoly1</target>
          <target>#lod2RoofPoly2</target>
        </GeoreferencedTexture>
      </surfaceDataMember>
      <surfaceDataMember xlink:href="#lod1Material"/>
      <surfaceDataMember xlink:href="#sideTexture"/>
      <surfaceDataMember>
        <ParameterizedTexture>
```

```
          <imageURI>front_back_winter.png</imageURI>
          <wrapMode>none</wrapMode>
          <target uri="#fFront" xlink:href="#frontTexCoord"/>
          <target uri="#fBack" xlink:href="#backTexCoord"/>
        </ParameterizedTexture>
      </surfaceDataMember>
    </Appearance>
  </appearanceMember>
</CityModel>
```

Listing 5: Excerpt from the CityGML dataset illustrating CityGML's appearance model. The dataset is visualised in Fig. 52 and Fig. 53.

The following three raster images (Fig. 54 - Fig. 56) are referenced in the dataset by *ParameterizedTexture* objects to texturize the vertical boundary surfaces of the building in LOD2. The image *facade.png* (cf. Fig. 54) is assigned to the side surfaces using the texture wrapping mode *wrap* and is applied both within the summer and the winter theme.

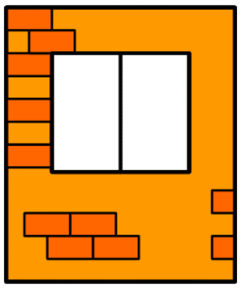


Fig. 54: Image *facade.png* used in the dataset to texturize the side surfaces of the building in LOD2 (cf. Fig. 53 a. and b.) (image: Hasso-Plattner-Institute).

Fig. 55 shows the texture atlas *front_back_summer.png* combining the textures for the front surface and the back surface of the building in LOD2 within the summer theme. Only a portion of this image is assigned to the specific surfaces. The relevant parts are defined using a *TextCoordList* object.

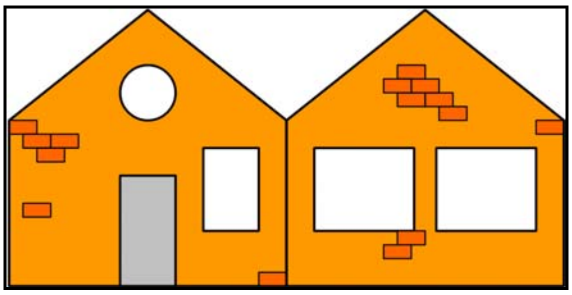


Fig. 55: Texture atlas *front_back_summer.png* containing the textures for the front surface and the back surface of the building in LOD2 within the summer theme (cf. Fig. 53 a.) (image: Hasso-Plattner-Institute).

Identically to *front_back_summer.png* the texture atlas *front_back_winter.png* contains the textures for the front surface and the back surface of the building in LOD2 within the winter theme.

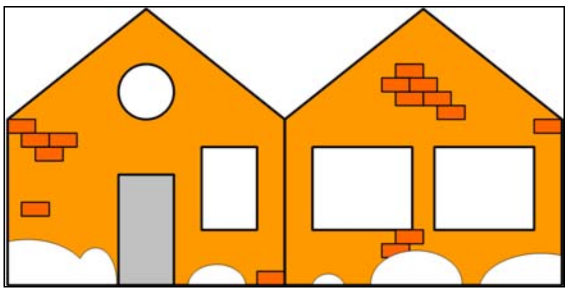


Fig. 56: Texture atlas *front_back_winter.png* containing the textures for the front surface and the back surface of the building in LOD2 within the winter theme (cf. Fig. 53 b.) (image: Hasso-Plattner-Institute).

The raster images shown in Fig. 57 and Fig. 58 are assigned to the terrain and the roof surfaces of the building in LOD1 as well as in LOD2. In the dataset this is implemented by a *GeoreferencedTexture* object linking to the according GML geometry objects. Whereas the image *ground_summer.png* (cf. Fig. 57) represents the texture for the summer theme, *ground_winter.png* (cf. Fig. 58) is used within the winter theme.

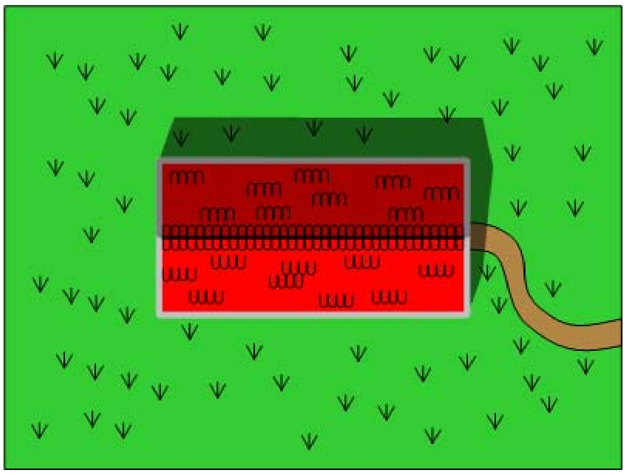


Fig. 57: The image *ground_summer.png* is assigned to the terrain and the roof surfaces of the building both in LOD1 and LOD2 (cf. Fig. 52 a. and Fig. 53 a.) within the summer theme (image: Hasso-Plattner-Institute).

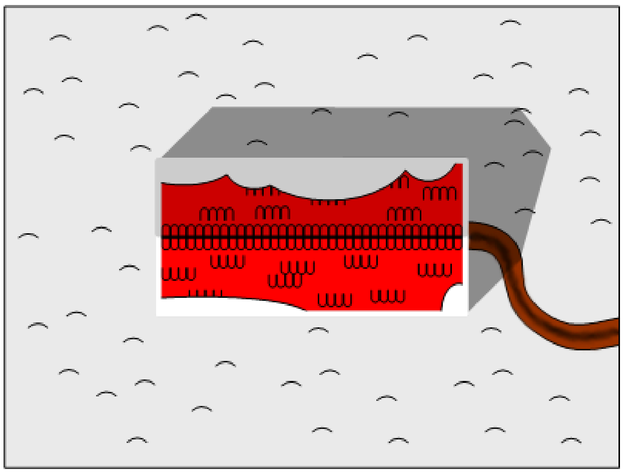


Fig. 58: The image *ground_winter.png* is assigned to the terrain and the roof surfaces of the building both in LOD1 and LOD2 (cf. Fig. 52 b. and Fig. 53 b.) within the winter theme (image: Hasso-Plattner-Institute).

11.5 Annex E: Example ADE for Noise Immission Simulation

This section illustrates the usage of CityGML within an environmental simulation application. The definition of the corresponding Application Domain Extension (ADE) is included as an example.

The Environmental Noise Directive of the European Union 2002/49/EG obligates the EU member states to calculate every 5 years the noise levels at a height of 4m on buildings and to document the results in noise maps. The noise maps serve as information for the European Union and the citizens affected by noise (Fig. 59). These noise maps are generated on the basis of acoustic models and noise propagation calculations, not on the basis of measurements (Fig. 60). For the noise propagation calculations, a great number of thematic data and 3D geodata is necessary for each EU member state. Because of the large spatial extent of the noise calculation, the provision of statewide and ubiquitous 3D geodata on buildings, roads, railways and terrain for a multitude of users is necessary, in part with high requirements on resolution.

The calculation of noise levels from a road requires information about the traffic flow, the heavy vehicle percentage, the speed limits, the road surface types and the road gradient. Furthermore, the noise level depends on the distance between point of emission and reception (immission) as well as on reflection (e.g. on building facades) or shielding effects (e.g. noise barriers). The noise level is calculated separately for the day (06.00-18.00), the evening (18.00-22.00) and the night (22.00-06.00). As the noise level is calculated at a height of 4m and as the influence of vertical reflecting surfaces is considered (e.g. noise barriers and buildings), a multitude of geodata in the third dimension is necessary. In addition to all 3D geodata specific thematic data are required. For example the following data are necessary for the noise calculation of roads: Digital Terrain Model with 10m grid, 3D building models with their thematic attributes (e.g. reflection, inhabitants), 3D road data with their thematic attributes (e.g. traffic flow, heavy vehicle percentage, speed limit, type of road surface, road gradient, width of a road), 3D noise barriers and their thematic attributes (e.g. reflection).

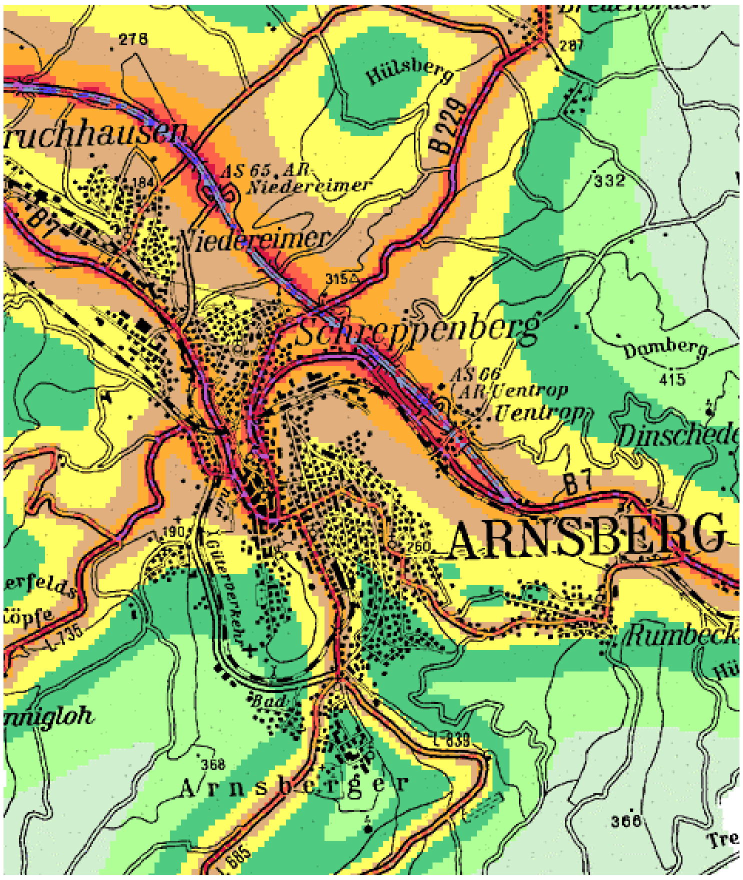


Fig. 59: Noise map generated from the 3D CityGML geodata and used for the reporting demanded of the EU Environmental Noise Directive (dark colours show higher noise immission) (source: State Agency for nature, environment and consumer protection NRW).

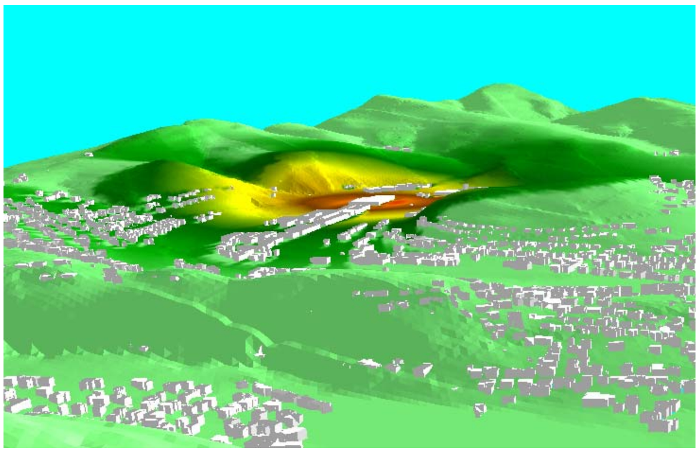


Fig. 60: Modelling a noise emission source using the 3D CityGML geodata in a special noise calculation software as first step before generating the noise map in Fig. 59 (source: Surveying and Mapping Agency NRW, Stapelfeldt GmbH, Institute of Geodesy and Geoinformation Uni Bonn).

In the state of North Rhine-Westphalia, special conditions have to be considered: high population and transportation route density and therefore the highest amount of noise calculation areas and objects in Germany. The aim is to provide a sustainable, efficient and variable access to the required 3D geodata for the 5 years iteration period and the different noise calculation authorities.

In order to provide this considerable amount of statewide 3D geodata, the responsible partners, in particular the State Ministry of Environment, Nature Conservation, Agriculture and Consumer Protection of North Rhine-Westphalia, the State Agency for nature, environment and consumer protection of North Rhine-Westphalia and the Surveying and Mapping Agency of North Rhine-Westphalia, have decided to use the Spatial Data Infrastructure in North Rhine-Westphalia (GDI NRW) and to extend it with statewide Web Services for 2.5D and 3D geoinformation. Therefore, new OGC Web Services for building models, terrain, road and railway data were implemented (e.g. Web Feature Service for 3D block models in LOD1 and for 3D road and railway data, Web Coverage Service for DTM).

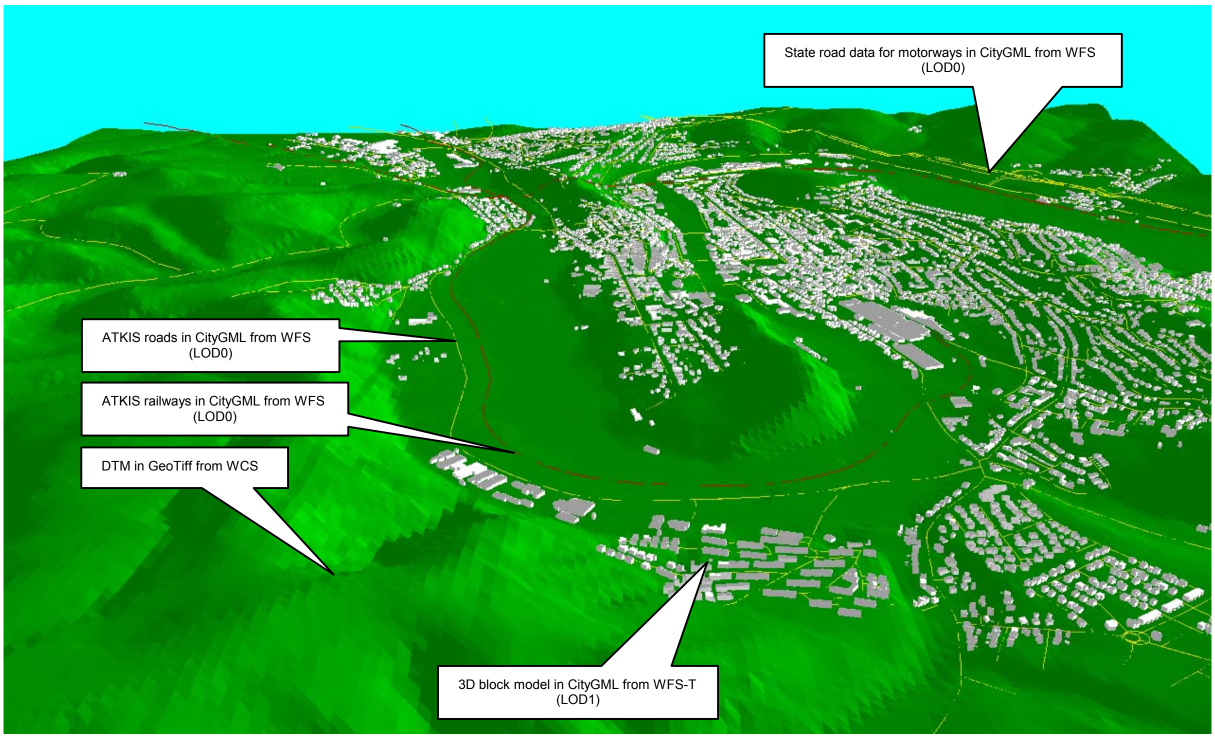

State road data for motorways in CityGML from WFS (LOD0)
ATKIS roads in CityGML from WFS (LOD0)
ATKIS railways in CityGML from WFS (LOD0)
DTM in GeoTiff from WCS
3D block model in CityGML from WFS-T (LOD1)

Fig. 61: 3D geodata in CityGML for the calculation of the noise map in Fig. 59: DTM in GeoTiff, 3D block model in CityGML, 3D road and railway data in CityGML, state road data for higher-level roads in CityGML (source: Surveying and Mapping Agency NRW, State Road Enterprice NRW, Stapelfeldt GmbH, Institute of Geodesy and Geoinformation Uni Bonn).

CityGML is used together with GeoTIFF as the only exchange formats between web services and noise calculation software (Fig. 61 -Fig. 63). For the special requirements of the noise directive, a CityGML noise application schema has been developed by the Institute of Geodesy and Geoinformation University of Bonn and the Special Interest Group SIG 3D of GDI NRW. It is based on the ADE mechanism (see chapter 6.11 and 9.11). This mechanism allows the supplementation of existing classes and objects in CityGML (e.g. buildings) by thematic attributes. The quantity as well as the type of these attributes is selectable. The CityGML schema can also be complemented by new classes. Hence, the noise application schema contains new objects (e.g. segmentation of roads according to noise requirements - *NoiseRoadSegment*, Fig. 64) as well as noise attributes attached to existing objects (e.g. reflection of buildings, Fig. 65). These additional noise attributes are derived from regulations issued by the Federal Government of Germany realising the obligations of the Environmental Noise Directive of the European Union (cf. BImSchV 2006, VBUS 2006, VBUSch 2006).

The interoperability techniques of this project demonstrate a remarkable innovation, as for the first time statewide 3D geodata are provided via common standards and web services. Therefore, the Spatial Data Infrastructure for noise calculation in North Rhine-Westphalia provides an application example for the INSPIRE directive of the European Union 2007/2/EC (Infrastructure for Spatial Information in Europe).

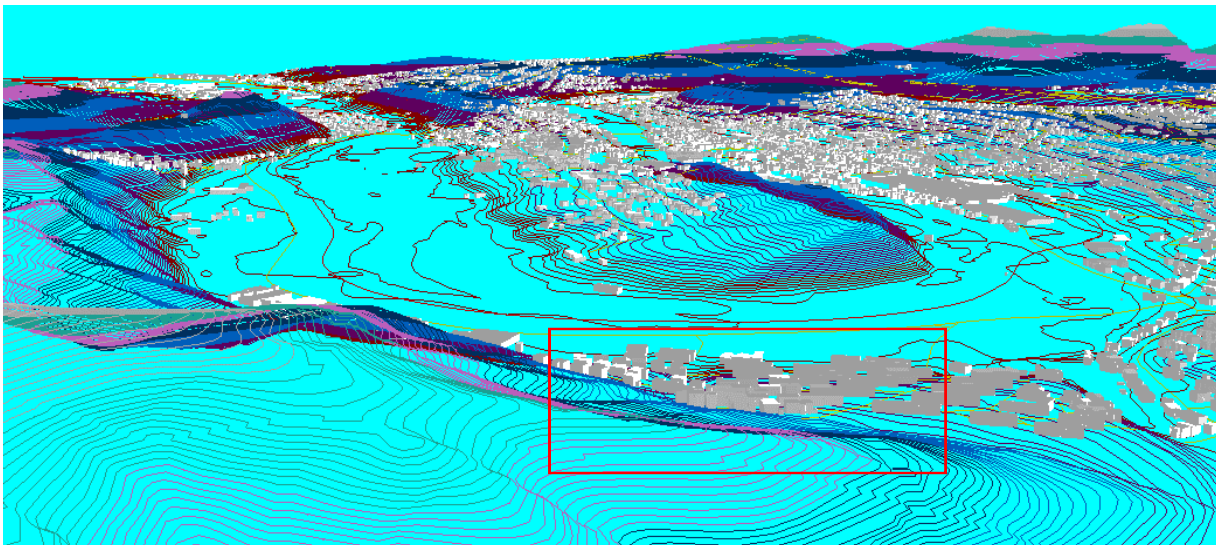


Fig. 62: 3D geodata in CityGML for the calculation of the noise map in Fig. 59: Derived contour lines for the generation of CityGML breaklines, 3D block model in CityGML, 3D road and railway data in CityGML, state road data for higher-level roads in CityGML (source: Surveying and Mapping Agency NRW, State Road Enterprise NRW, Stapelfeldt GmbH, Institute of Geodesy and Geoinformation Uni Bonn).

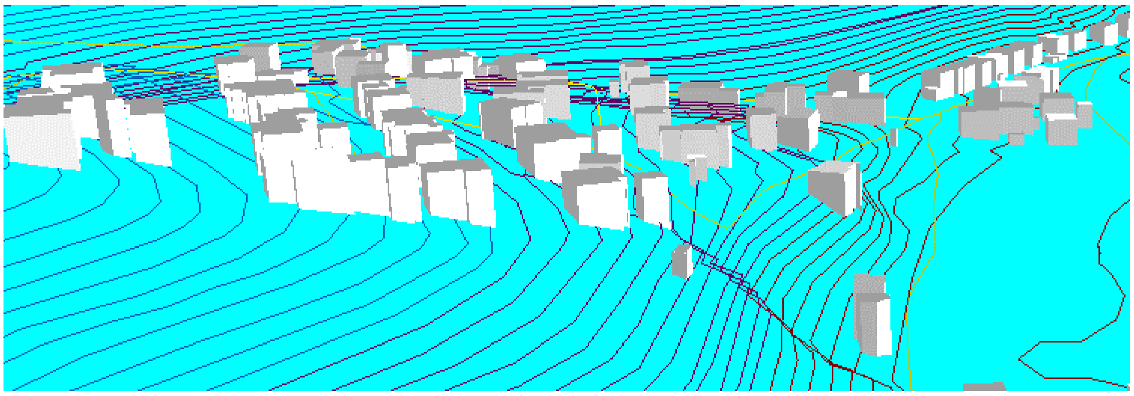
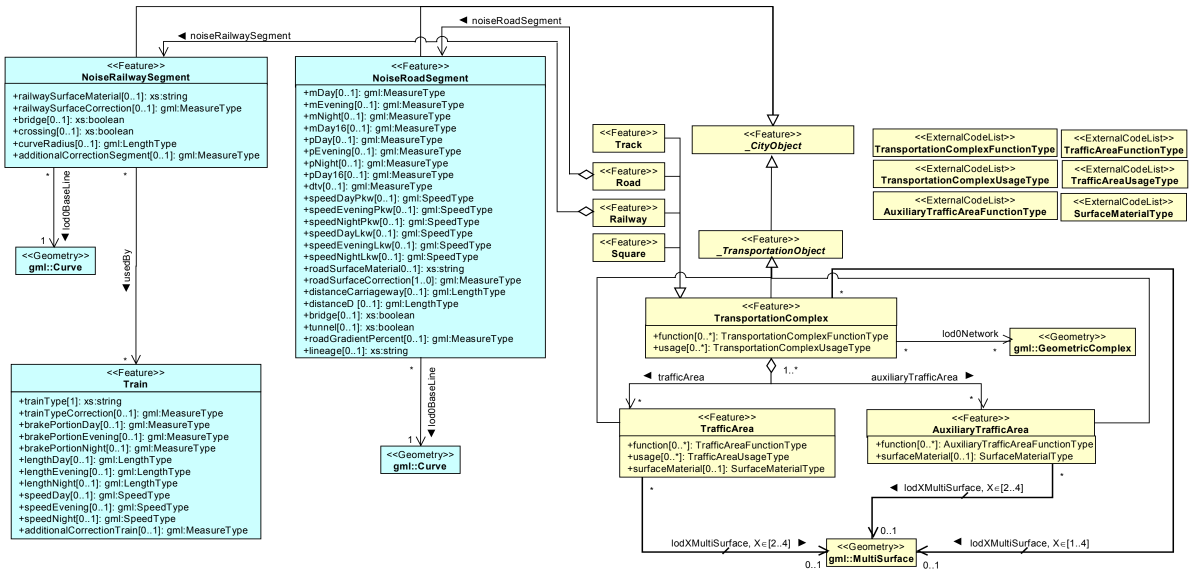


Fig. 63: Extract from Fig. 62 shows the integration of 3D block models in the DTM by appropriate CityGML modelling (lowest point of ALK building polygon is taken as measure to generate the building bottom side) (source: Surveying and Mapping Agency NRW, Stapelfeldt GmbH, Institute of Geodesy and Geoinformation Uni Bonn).

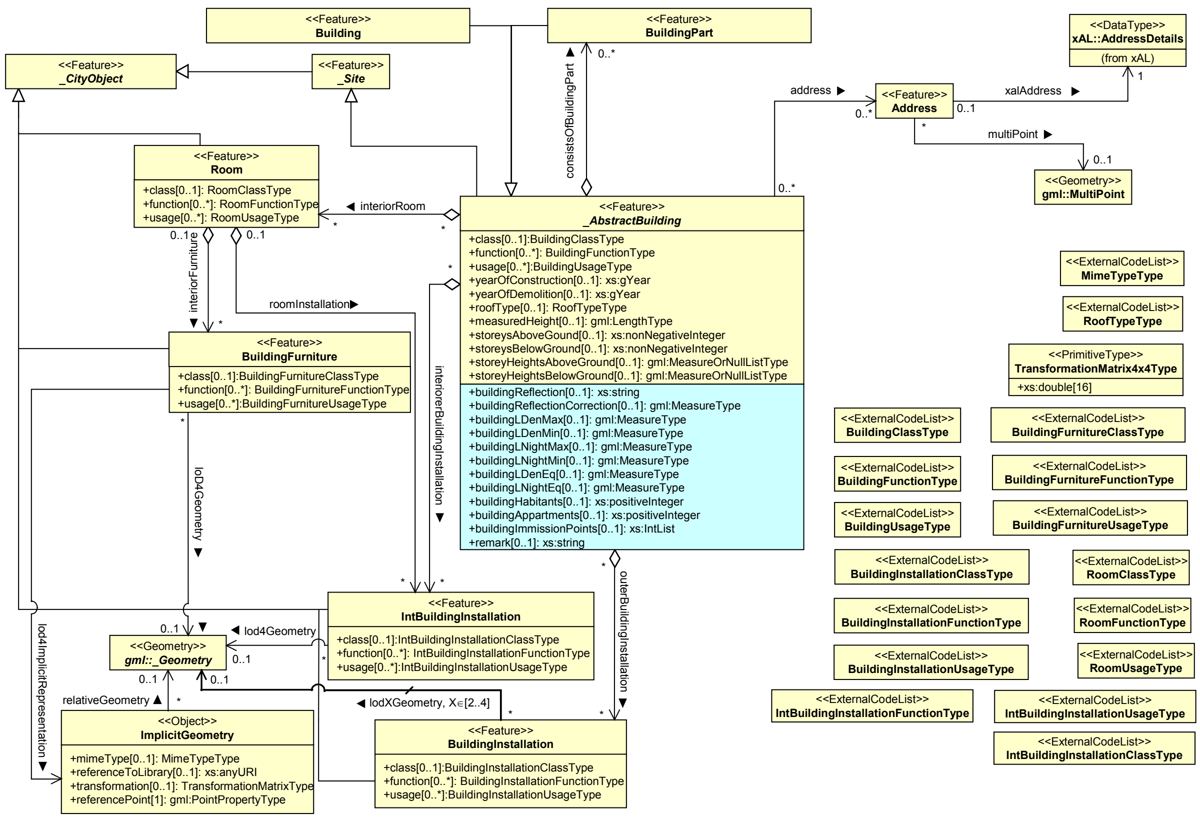
11.5.1 CityGML Noise ADE

In this section the data models for the CityGML Noise ADE are given as UML diagrams and XML schema. As the semantics of the specific attributes and object types result from the German regulations for noise immision computations, we do not explain them in detail here (see BimSchV 2006, VBUS 2006, VBUSch 2006). The purpose of this section is to provide an example how CityGML can be extended using the ADE mechanism.



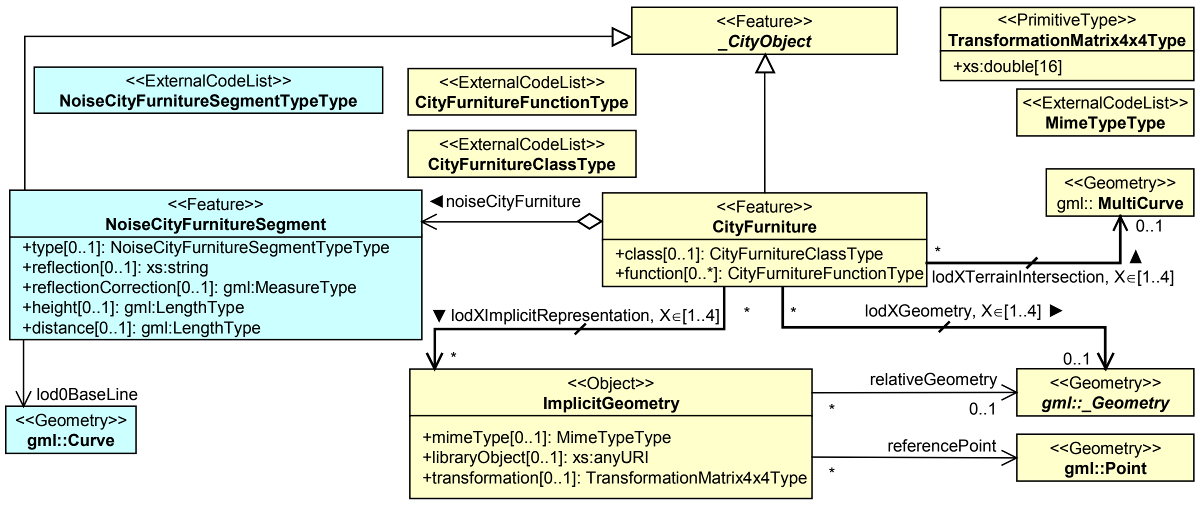
<<Feature>> NoiseRailwaySegment
+railwaySurfaceMaterial[0..1]: xs:string
+railwaySurfaceCorrection[0..1]: gml:MeasureType
+bridge[0..1]: xs:boolean
+crossing[0..1]: xs:boolean
+curveRadius[0..1]: gml:LengthType
+additionalCorrectionSegment[0..1]: gml:MeasureType
<<Feature>> NoiseRoadSegment
+mDay[0..1]: gml:MeasureType
+mEvening[0..1]: gml:MeasureType
+mNight[0..1]: gml:MeasureType
+mDay16[0..1]: gml:MeasureType
+pDay[0..1]: gml:MeasureType
+pEvening[0..1]: gml:MeasureType
+pNight[0..1]: gml:MeasureType
+pDay16[0..1]: gml:MeasureType
+dtv[0..1]: gml:MeasureType
+speedDayPkw[0..1]: gml:SpeedType
+speedEveningPkw[0..1]: gml:SpeedType
+speedNightPkw[0..1]: gml:SpeedType
+speedDayLkw[0..1]: gml:SpeedType
+speedEveningLkw[0..1]: gml:SpeedType
+speedNightLkw[0..1]: gml:SpeedType
+roadSurfaceMaterial0..1]: xs:string
+roadSurfaceCorrection[1..0]: gml:MeasureType
+distanceCarriageway[0..1]: gml:LengthType
+distanceD [0..1]: gml:LengthType
+bridge[0..1]: xs:boolean
+tunnel[0..1]: xs:boolean
+roadGradientPercent[0..1]: gml:MeasureType
+lineage[0..1]: xs:string
◄ noiseRailwaySegment
◄ noiseRoadSegment
lod0BaseLine
usedBy
<<Geometry>> gml::Curve
<<Feature>> Train
+trainType[1]: xs:string
+trainTypeCorrection[0..1]: gml:MeasureType
+brakePortionDay[0..1]: gml:MeasureType
+brakePortionEvening[0..1]: gml:MeasureType
+brakePortionNight[0..1]: gml:MeasureType
+lengthDay[0..1]: gml:LengthType
+lengthEvening[0..1]: gml:LengthType
+lengthNight[0..1]: gml:LengthType
+speedDay[0..1]: gml:SpeedType
+speedEvening[0..1]: gml:SpeedType
+speedNight[0..1]: gml:SpeedType
+additionalCorrectionTrain[0..1]: gml:MeasureType
<<Feature>> Track
<<Feature>> Road
<<Feature>> Railway
<<Feature>> Square
<<Feature>> _CityObject
<<Feature>> _TransportationObject
<<Feature>> TransportationComplex
+function[0..*]: TransportationComplexFunctionType
+usage[0..*]: TransportationComplexUsageType
lod0Network
<<Geometry>> gml::GeometricComplex
◄ trafficArea
auxiliaryTrafficArea ►
<<Feature>> TrafficArea
+function[0..*]: TrafficAreaFunctionType
+usage[0..*]: TrafficAreaUsageType
+surfaceMaterial[0..1]: SurfaceMaterialType
<<Feature>> AuxiliaryTrafficArea
+function[0..*]: AuxiliaryTrafficAreaFunctionType
+surfaceMaterial[0..1]: SurfaceMaterialType
◄ lodXMultiSurface, X∈[2..4]
lodXMultiSurface, X∈[2..4] ►
◄ lodXMultiSurface, X∈[1..4]
<<Geometry>> gml::MultiSurface
<<ExternalCodeList>> TransportationComplexFunctionType
<<ExternalCodeList>> TrafficAreaFunctionType
<<ExternalCodeList>> TransportationComplexUsageType
<<ExternalCodeList>> TrafficAreaUsageType
<<ExternalCodeList>> AuxiliaryTrafficAreaFunctionType
<<ExternalCodeList>> SurfaceMaterialType

Fig. 64: CityGML noise application schema – transportation model (light yellow=CityGML standard, light blue=CityGML Noise ADE) (source: Institute of Geodesy and Geoinformation Uni Bonn).



<<Feature>> Building
<<Feature>> BuildingPart
<<Feature>> _CityObject
<<Feature>> _Site
consistsOfBuildingPart
address ►
<<Feature>> Address
xalAddress ►
<<DataType>> xAL::AddressDetails
(from xAL)
multiPoint ►
<<Geometry>> gml::MultiPoint
<<Feature>> Room
+class[0..1]: RoomClassType
+function[0..*]: RoomFunctionType
+usage[0..*]: RoomUsageType
◄ interiorRoom
<<Feature>> _AbstractBuilding
+class[0..1]:BuildingClassType
+function[0..*]: BuildingFunctionType
+usage[0..*]:BuildingUsageType
+yearOfConstruction[0..1]: xs:gYear
+yearOfDemolition[0..1]: xs:gYear
+roofType[0..1]: RoofTypeType
+measuredHeight[0..1]: gml:LengthType
+storeysAboveGound[0..1]: xs:nonNegativeInteger
+storeysBelowGround[0..1]: xs:nonNegativeInteger
+storeyHeightsAboveGround[0..1]: gml:MeasureOrNullListType
+storeyHeightsBelowGround[0..1]: gml:MeasureOrNullListType
+buildingReflection[0..1]: xs:string
+buildingReflectionCorrection[0..1]: gml:MeasureType
+buildingLDenMax[0..1]: gml:MeasureType
+buildingLDenMin[0..1]: gml:MeasureType
+buildingLNightMax[0..1]: gml:MeasureType
+buildingLNightMin[0..1]: gml:MeasureType
+buildingLDenEq[0..1]: gml:MeasureType
+buildingLNightEq[0..1]: gml:MeasureType
+buildingHabitants[0..1]: xs:positiveInteger
+buildingAppartments[0..1]: xs:positiveInteger
+buildingImmissionPoints[0..1]: xs:IntList
+remark[0..1]: xs:string
interiorFurniture
roomInstallation►
interiorBuildingInstallation
<<Feature>> BuildingFurniture
+class[0..1]:BuildingFurnitureClassType
+function[0..*]: BuildingFurnitureFunctionType
+usage[0..*]:BuildingFurnitureUsageType
lod4Geometry
lod4ImplicitRepresentation
<<Geometry>> gml::_Geometry
◄ lod4Geometry
<<Feature>> IntBuildingInstallation
+class[0..1]:IntBuildingInstallationClassType
+function[0..*]: IntBuildingInstallationFunctionType
+usage[0..*]:IntBuildingInstallationUsageType
relativeGeometry ▲
◄ lodXGeometry, X∈[2..4]
outerBuildingInstallation
<<Object>> ImplicitGeometry
+mimeType[0..1]: MimeTypeType
+referenceToLibrary[0..1]: xs:anyURI
+transformation[0..1]: TransformationMatrixType
+referencePoint[1]: gml:PointPropertyType
<<Feature>> BuildingInstallation
+class[0..1]:BuildingInstallationClassType
+function[0..*]: BuildingInstallationFunctionType
+usage[0..*]:BuildingInstallationUsageType
<<ExternalCodeList>> MimeTypeType
<<ExternalCodeList>> RoofTypeType
<<PrimitiveType>> TransformationMatrix4x4Type
+xs:double[16]
<<ExternalCodeList>> BuildingClassType
<<ExternalCodeList>> BuildingFurnitureClassType
<<ExternalCodeList>> BuildingFunctionType
<<ExternalCodeList>> BuildingFurnitureFunctionType
<<ExternalCodeList>> BuildingUsageType
<<ExternalCodeList>> BuildingFurnitureUsageType
<<ExternalCodeList>> BuildingInstallationClassType
<<ExternalCodeList>> RoomClassType
<<ExternalCodeList>> BuildingInstallationFunctionType
<<ExternalCodeList>> RoomFunctionType
<<ExternalCodeList>> BuildingInstallationUsageType
<<ExternalCodeList>> RoomUsageType
<<ExternalCodeList>> IntBuildingInstallationFunctionType
<<ExternalCodeList>> IntBuildingInstallationUsageType
<<ExternalCodeList>> IntBuildingInstallationClassType

Fig. 65: CityGML noise application schema – building model (light yellow=CityGML standard, light blue=CityGML Noise ADE) (source: Institute of Geodesy and Geoinformation Uni Bonn).



<<Feature>> _CityObject
<<PrimitiveType>> TransformationMatrix4x4Type
+xs:double[16]
<<ExternalCodeList>> NoiseCityFurnitureSegmentTypeType
<<ExternalCodeList>> CityFurnitureFunctionType
<<ExternalCodeList>> CityFurnitureClassType
<<ExternalCodeList>> MimeTypeType
<<Geometry>> gml:: MultiCurve
<<Feature>> NoiseCityFurnitureSegment
+type[0..1]: NoiseCityFurnitureSegmentTypeType
+reflection[0..1]: xs:string
+reflectionCorrection[0..1]: gml:MeasureType
+height[0..1]: gml:LengthType
+distance[0..1]: gml:LengthType
◀ noiseCityFurniture
<<Feature>> CityFurniture
+class[0..1]: CityFurnitureClassType
+function[0..*]: CityFurnitureFunctionType
lodXTerrainIntersection, X∈[1..4]
0..1
▼ lodXImplicitRepresentation, X∈[1..4]
lodXGeometry, X∈[1..4] ▶
lod0BaseLine
<<Geometry>> gml::Curve
<<Object>> ImplicitGeometry
+mimeType[0..1]: MimeTypeType
+libraryObject[0..1]: xs:anyURI
+transformation[0..1]: TransformationMatrix4x4Type
relativeGeometry
referencePoint
<<Geometry>> gml::_Geometry
<<Geometry>> gml::Point

Fig. 66: CityGML noise application schema – city furniture model (light yellow=CityGML standard, light blue=CityGML Noise ADE) (source: Institute of Geodesy and Geoinformation Uni Bonn).

Header of the Noise ADE Schema File

```
<xsd:schema xmlns="http://www.citygml.org/ade/noise_de" xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:citygml="http://www.citygml.org/citygml/1/0/0" xmlns:noise="http://www.citygml.org/ade/noise_de"
xmlns:gml="http://www.opengis.net/gml" targetNamespace="http://www.citygml.org/ade/noise_de" elementFormDefault="qualified"
attributeFormDefault="unqualified">
  <xsd:import namespace="http://www.opengis.net/gml" schemaLocation="../3.1.1/base/gml.xsd"/>
  <xsd:import namespace="http://www.citygml.org/citygml/1/0/0" schemaLocation="../CityGML.xsd"/>
  …
</xsd:schema>
```

NoiseCityFurnitureSegmentTypeType, NoiseCityFurnitureSegment

```
<xsd:element name="noiseCityFurnitureSegmentProperty" type="noise:NoiseCityFurnitureSegmentPropertyType" substitution-
Group="citygml:_GenericApplicationPropertyOfCityFurniture"/>
<xsd:complexType name="NoiseCityFurnitureSegmentPropertyType">
  <xsd:sequence minOccurs="0">
    <xsd:element ref="NoiseCityFurnitureSegment" minOccurs="0"/>
  </xsd:sequence>
  <xsd:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xsd:complexType>
<!-- ========================================================================================== -->
<xsd:complexType name="NoiseCityFurnitureSegmentType">
  <xsd:complexContent>
    <xsd:extension base="citygml:_CityObjectType">
      <xsd:sequence>
        <xsd:element name="type" type="noise:NoiseCityFurnitureSegmentTypeType" minOccurs="0"/>
        <xsd:element name="reflection" type="xsd:string" minOccurs="0"/>
        <xsd:element name="reflectionCorrection" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="height" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="distance" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="lod0BaseLine" type="gml:CurvePropertyType"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<!-- ========================================================================================== -->
<xsd:simpleType name="NoiseCityFurnitureSegmentTypeType">
  <xsd:restriction base="xsd:string"/>
</xsd:simpleType>
<!-- ========================================================================================== -->
<xsd:element name="NoiseCityFurnitureSegment" type="NoiseCityFurnitureSegmentType" substitutionGroup="citygml:_CityObject"/>
```

NoiseRoadSegmentType, NoiseRoadSegment

```
<xsd:element name="noiseRoadSegmentProperty" type="noise:NoiseRoadSegmentPropertyType" substitution-
Group="citygml:_GenericApplicationPropertyOfRoad"/>
<!-- ============================================================================================ -->
<xsd:complexType name="NoiseRoadSegmentPropertyType">
  <xsd:sequence minOccurs="0">
    <xsd:element ref="NoiseRoadSegment"/>
  </xsd:sequence>
  <xsd:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xsd:complexType>
<xsd:complexType name="NoiseRoadSegmentType">
  <xsd:complexContent>
    <xsd:extension base="citygml:_TransportationObjectType">
      <xsd:sequence>
        <xsd:element name="mDay" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="mEvening" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="mNight" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="mDay16" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="pDay" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="pEvening" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="pNight" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="pDay16" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="dtv" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="speedDayPkw" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="speedEveningPkw" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="speedNightPkw" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="speedDayLkw" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="speedEveningLkw" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="speedNightLkw" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="roadSurfaceMaterial" type="xsd:string" minOccurs="0"/>
        <xsd:element name="roadSurfaceCorrection" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="distanceCarriageway" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="distanceD" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="bridge" type="xsd:boolean" minOccurs="0"/>
        <xsd:element name="tunnel" type="xsd:boolean" minOccurs="0"/>
        <xsd:element name="roadGradientPercent" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="lod0BaseLine" type="gml:CurvePropertyType"/>
        <xsd:element name="lineage" type="xsd:string" minOccurs="0"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<!-- ============================================================================================ -->
<xsd:element name="NoiseRoadSegment" type="NoiseRoadSegmentType" substitutionGroup="citygml:_CityObject"/>
```

NoiseRailwaySegmentType, NoiseRailwaySegment

```
<xsd:element name="noiseRailwaySegmentProperty" type="noise:NoiseRailwaySegmentPropertyType" substitution-
Group="citygml:_GenericApplicationPropertyOfRailway"/>
<!-- ============================================================================================ -->
<xsd:complexType name="NoiseRailwaySegmentPropertyType">
    <xsd:sequence minOccurs="0">
      <xsd:element ref="NoiseRailwaySegment"/>
    </xsd:sequence>
    <xsd:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xsd:complexType>
<xsd:complexType name="NoiseRailwaySegmentType">
  <xsd:complexContent>
    <xsd:extension base="citygml:_TransportationObjectType">
      <xsd:sequence>
        <xsd:element name="railwaySurfaceMaterial" type="xsd:string" minOccurs="0"/>
        <xsd:element name="railwaySurfaceCorrection" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="bridge" type="xsd:boolean" minOccurs="0"/>
        <xsd:element name="crossing" type="xsd:boolean" minOccurs="0"/>
        <xsd:element name="curveRadius" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="additionalCorrectionSegment" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="lod0BaseLine" type="gml:CurvePropertyType"/>
        <xsd:element name="usedBy" type="noise:TrainPropertyType" minOccurs="0" maxOccurs="unbounded"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
```

```
<!-- ====================================================================================== -->
<xsd:element name="NoiseRailwaySegment" type="NoiseRailwaySegmentType" substitutionGroup="citygml:_CityObject"/>
```

TrainType, Train

```
<xsd:complexType name="TrainPropertyType">
  <xsd:sequence>
    <xsd:element name="Train" type="noise:TrainType"/>
  </xsd:sequence>
  <xsd:attributeGroup ref="gml:AssociationAttributeGroup"/>
</xsd:complexType>
<!-- ====================================================================================== -->
<xsd:complexType name="TrainType">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="trainType" type="xsd:string"/>
        <xsd:element name="trainTypeCorrection" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="brakePortionDay" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="brakePortionEvening" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="brakePortionNight" type="gml:MeasureType" minOccurs="0"/>
        <xsd:element name="lengthDay" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="lengthEvening" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="lengthNight" type="gml:LengthType" minOccurs="0"/>
        <xsd:element name="speedDay" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="speedEvening" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="speedNight" type="gml:SpeedType" minOccurs="0"/>
        <xsd:element name="additionalCorrectionTrain" type="gml:MeasureType" minOccurs="0"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
```

Application specific attributes for _AbstractBuilding

```
<xsd:element name="buildingReflection" type="xsd:string" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingReflectionCorrection" type="gml:MeasureType" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingLDenMax" type="gml:MeasureType" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingLDenMin" type="gml:MeasureType" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingLDenEq" type="gml:MeasureType" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingLNightMax" type="gml:MeasureType" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingLNightMin" type="gml:MeasureType" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingLNightEq" type="gml:MeasureType" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingHabitants" type="xsd:positiveInteger" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingAppartments" type="xsd:positiveInteger" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="buildingImmissionPoints" type="gml:integerList" substitution-
       Group="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
<xsd:element name="remark" type="xsd:string" substitutionGroup="citygml:_GenericApplicationPropertyOfAbstractBuilding"/>
```

11.5.2 Example dataset

The following dataset illustrates a CityGML instance document which uses the application noise schema. It contains two CityObject features: a road object and a building object. The dataset references the XML schema definition file of the CityGML Noise ADE which explicitly imports the CityGML standard schema. Thus, all classes of the standard CityGML data model can be used in the instance document. Furthermore, the application specific additions such as new object types (e.g. *NoiseRoadSegment*) and additional thematic attributes (e.g. the attributes defined for *_AbstractBuilding*) are available. These additional elements are distinguished from standard CityGML elements by the namespace prefix *noise* which refers to the noise schema definition.

```xml
<?xml version="1.0" encoding="ISO-8859-1"?>
<CityModel xmlns="http://www.citygml.org/citygml/1/0/0" xmlns:gml="http://www.opengis.net/gml"
xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0"
xmlns:noise="http://www.citygml.org/ade/noise_de" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.citygml.org/citygml/1/0/0 ../CityGML.xsd http://www.citygml.org/ade/noise_de ./CityGML-NoiseADE-0-
5-0.xsd">
  <gml:boundedBy>
    <gml:Envelope srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
      <gml:pos srsDimension="3">5616000.0 2540097.5 54.5</gml:pos>
      <gml:pos srsDimension="3">5673522.3 2576495.6 172.9</gml:pos>
    </gml:Envelope>
  </gml:boundedBy>
  <cityObjectMember>
    <Road gml:id="CR_0815">
      <gml:name>B1</gml:name>
      <gml:boundedBy>
        <gml:Envelope srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
          <gml:pos srsDimension="3">5618686.0 2573988.4 158.0</gml:pos>
          <gml:pos srsDimension="3">5618705.5 2574049.8 158.2</gml:pos>
        </gml:Envelope>
      </gml:boundedBy>
      <function>B1303</function>
      <noise:noiseRoadSegmentProperty>
        <noise:NoiseRoadSegment gml:id="CNRS_0815">
          <gml:boundedBy>
            <gml:Envelope srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
              <gml:pos srsDimension="3">5618686.0 2573988.4 158.0</gml:pos>
              <gml:pos srsDimension="3">5618705.5 2574049.8 158.2</gml:pos>
            </gml:Envelope>
          </gml:boundedBy>
          <noise:mDay uom="kfzph">2564.123</noise:mDay>
          <noise:mEvening uom="kfzph">145.123</noise:mEvening>
          <noise:mNight uom="kfzph">1231.123</noise:mNight>
          <noise:mDay16 uom="kfzph">2010.123</noise:mDay16>
          <noise:pDay uom="percent">25.123</noise:pDay>
          <noise:pEvening uom="percent">35.123</noise:pEvening>
          <noise:pNight uom="percent">45.123</noise:pNight>
          <noise:pDay16 uom="percent">30.123</noise:pDay16>
          <noise:dtv uom="kfzp24h">20564.123</noise:dtv>
          <noise:speedDayPkw uom="kmph">130.123</noise:speedDayPkw>
          <noise:speedEveningPkw uom="kmph">100.123</noise:speedEveningPkw>
          <noise:speedNightPkw uom="kmph">50.123</noise:speedNightPkw>
          <noise:speedDayLkw uom="kmph">80.123</noise:speedDayLkw>
          <noise:speedEveningLkw uom="kmph">80.123</noise:speedEveningLkw>
          <noise:speedNightLkw uom="kmph">50.123</noise:speedNightLkw>
          <noise:roadSurfaceMaterial>Pflaster mit ebener Oberfläche</noise:roadSurfaceMaterial>
          <noise:roadSurfaceCorrection uom="dB">2.123</noise:roadSurfaceCorrection>
          <noise:distanceCarriageway uom="m">15.123</noise:distanceCarriageway>
          <noise:distanceD uom="m">10.123</noise:distanceD>
          <noise:bridge>true</noise:bridge>
          <noise:tunnel>false</noise:tunnel>
          <noise:roadGradientPercent uom="percent">5.245</noise:roadGradientPercent>
          <noise:lod0BaseLine>
            <gml:LineString srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783" srsDimension="3">
              <gml:coordinates decimal="." cs="," ts=" ">5618686.0, 2573988.4,158.200000 5618692.5,2574008.8,158.000000
5618705.5,2574049.8,158.100000</gml:coordinates>
            </gml:LineString>
          </noise:lod0BaseLine>
          <noise:lineage>ATKIS-LVermA</noise:lineage>
        </noise:NoiseRoadSegment>
      </noise:noiseRoadSegmentProperty>
      …
    </Road>
  </cityObjectMember>
  <cityObjectMember>
    <Building gml:id="UUID_ef6e19e3-c412-440b-8ba9-24900aa173b5">
      <gml:name>small building</gml:name>
      <creationDate>2007-01-04T00:00:00</creationDate>
      <function>1060</function>
      <measuredHeight uom="m">2.38</measuredHeight>
      <lod1Solid>
        <gml:Solid>
          <gml:exterior>
            <gml:CompositeSurface>
              <gml:surfaceMember>
```

```
                    <gml:Polygon srsName="urn:ogc:def:crs,crs:EPSG:6.12:31466,crs:EPSG:6.12:5783">
                      <gml:outerBoundaryIs>
                        <gml:LinearRing>
                          <gml:coordinates cs="," decimal="." ts=" ">5662497.03,2559357.47,38.2357750703488
5662489.23,2559355.51,38.2357750703488 5662488.178,2559355.247,38.2357750703488 5662489.022,2559351.872,38.2357750703488
5662497.877,2559354.097,38.2357750703488 5662501.43,2559354.99,38.2357750703488 5662500.584,2559358.357,38.2357750703488
5662497.03,2559357.47,38.2357750703488</gml:coordinates>
                        </gml:LinearRing>
                      </gml:outerBoundaryIs>
                    </gml:Polygon>
                  </gml:surfaceMember>
                  …
                </gml:CompositeSurface>
              </gml:exterior>
            </gml:Solid>
          </lod1Solid>
          <address>
            <Address>
              <xalAddress>
                <xAL:AddressDetails>
                  <xAL:Country>
                    <xAL:CountryName>Germany</xAL:CountryName>
                    <xAL:Locality Type="Town">
                      <xAL:LocalityName>Musterstadt</xAL:LocalityName>
                      <xAL:Thoroughfare Type="Street">
                        <xAL:ThoroughfareNumber>1</xAL:ThoroughfareNumber>
                        <xAL:ThoroughfareName>Musterstrasse</xAL:ThoroughfareName>
                      </xAL:Thoroughfare>
                      <xAL:PostalCode>
                        <xAL:PostalCodeNumber>10000</xAL:PostalCodeNumber>
                      </xAL:PostalCode>
                    </xAL:Locality>
                  </xAL:Country>
                </xAL:AddressDetails>
              </xalAddress>
            </Address>
          </address>
          <noise:buildingReflection>Fassade</noise:buildingReflection>
          <noise:buildingReflectionCorrection  uom="dB">3.23</noise:buildingReflectionCorrection>
          <noise:buildingLDenMax uom="dB">10</noise:buildingLDenMax>
          <noise:buildingLDenMin uom="dB">30</noise:buildingLDenMin>
          <noise:buildingLDenEq uom="dB">20</noise:buildingLDenEq>
          <noise:buildingLNightMax uom="dB">40</noise:buildingLNightMax>
          <noise:buildingLNightMin uom="dB">60</noise:buildingLNightMin>
          <noise:buildingLNightEq uom="dB">50</noise:buildingLNightEq>
          <noise:buildingHabitants>32</noise:buildingHabitants>
          <noise:buildingAppartments>8</noise:buildingAppartments>
          <noise:buildingImmissionPoints>45 1 1 1 50 2 2 2</noise:buildingImmissionPoints>
        </Building>
      </cityObjectMember>
    </CityModel>
```

Listing 6: Excerpt from a CityGML dataset implementing the illustrated CityGML noise application schema.

12 Bibliography

Albert, J., Bachmann, M., Hellmeier, A (2003): Zielgruppen und Anwendungen für Digitale Stadtmodelle und Digitale Geländemodelle. Erhebungen im Rahmen der SIG 3D der GDI NRW (in German only). Available at http://www.ikg.uni-bonn.de/fileadmin/sig3d/pdf/Tabelle_Anwendungen_Zielgruppen.pdf.

Benner, J., Geiger, A., Leinemann, K. (2005): Flexible generation of semantic 3D building models. In: Gröger, G., Kolbe, T. H. (eds.): First International ISPRS/EuroSDR/DGPF-Workshop on Next Generation 3D City Models. Bonn, Germany, EuroSDR Publication No. 49. pp.17-22.

BImSchV (2006): Federal Government of Germany (eds.): 34. Verordnung zur Durchführung des Bundesimmissionsschutzgesetzes - Verordnung über die Lärmkartierung [34. BImSchV], in der Fassung vom 6.3.06, in Kraft seit 16.3.06, In: BGBl. I 06, Nr. 12, S. 516 (in German only).

Booch, G., Rumbaugh, J., Jacobson, I. (1997): Unified Modeling Language User Guide. Addison-Wesley.

CityGML 2007. Homepage of CityGML. http://www.citygml.org.

Cox, S., Daisy, P., Lake, R., Portele, C., Whiteside, A. (2004): OpenGIS Geography Markup Language (GML 3.1), Implementation Specification Version 3.1.0, Recommendation Paper, OGC Doc. No. 03-105r1.

Czerwinski, A., Kolbe, T. H., Plümer, L., Stöcker-Meier, E. (2006): Interoperability and accuracy requirements for EU environmental noise mapping, In: Kremers, Horst (Hg.): Proceedings, InterCarto – InterGIS 12. Berlin 2006.

Czerwinski, A., Kolbe, T. H., Plümer, L., Stöcker-Meier, E. (2006): Spatial data infrastructure techniques for flexible noise mapping strategies, In: Tochtermann, K. / Scharl, A. (Hg.): Proceedings of the 20th International Conference on Environmental Informatics - Managing Environmental Knowledge. Graz 2006.

Döllner, J., Kolbe, T. H., Liecke, F., Sgouros, T., Teichmann, K. (2006): The Virtual 3D City Model of Berlin - Managing, Integrating and Communicating Complex Urban Information. In: Proc. of the 25th Intern. Symposium on Urban Data Management UDMS 2006 in Aal-borg, Denmark, 15-17 May 2006.

European Union (eds.): Directive 2002/49/EG of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, in: Official Journal of the European Communities from 18.7.02.

Federal Government of Germany (eds.): Gesetz zur Umsetzung der EG-Richtlinie über die Bewertung und Bekämpfung von Umgebungslärm vom 24. Juni 2005, in: Bundesgesetzblatt Jg. 2005, Teil 1, Nr. 38, Bonn 29.6.05 (in German only). Available at http://217.160.60.235/BGBL/bgbl1f/bgbl105s1794.pdf.

Foley, J., van Dam, A,. Feiner, S., Hughes, J. (1995): Computer Graphics: Principles and Practice. Addison Wesley, 2nd Ed.

Gamma, E., Helm, R., Johnson, R., Vlissides, J. (1995). Design Patterns: Elements of Reusable Object-Oriented Software, Addison-Wesley.

Gröger, G., Plümer, L. (2005): How to get 3-D for the Price of 2-D – Topology and Consistency of 3-D Urban GIS. *Geoinformatica*, 9(2).

Gröger, G., Benner, J., Dörschlag, D., Drees, R., Gruber U., Leinemann K., Löwner, M.-O.(2005): Das interoperable 3D-Stadtmodell der SIG 3D, in: Zeitschrift für Vermessungswesen (in German only).

Herring, J. (2001): The OpenGIS Abstract Specification, Topic 1: Feature Geometry (ISO 19107 Spatial Schema), Version 5. OGC Document Number 01-101.

IAI (2006): International Alliance for Interoperability: IFC 2x3 – Industry Foundation Classes. http://www.iai-international.org/Model/IFC(ifcXML)Specs.html, 2006.

Khronos Group Inc., Sony Computer Inc. (June 2006): COLLADA – Digital Asset Schema Release 1.4.1 – Specification. http://www.khronos.org/files/collada_spec_1_4.pdf.

Kohlhaas, A., Mitchell, J. (2007): Modelling cities. In: Constructing the future: nD modelling, p. 372-392, Taylor & Francis

Kolbe, T. H., Gröger, G. (2003): Towards unified 3D city models. In: Schiewe, J., Hahn, M., Madden, M., Sester, M. (eds): Challenges in Geospatial Analysis, Integration and Visualization II. Proc. of Joint ISPRS Workshop, Stuttgart.

Kolbe, T. H., Gröger, G., Plümer, L. (2007): CityGML - 3D City Models for Emergency Response, to appear in: Geoinformation-Technology for Emergency Response, ISPRS book series, Taylor & Francis.

Kolbe, T. H., Gröger, G., Plümer, L. (2005): CityGML – Interoperable Access to 3D City Models, In: van Oosterom, Peter, Zlatanova, Sisi, Fendel, E.M. (Hrsg.): Geo-information for Disaster Management. Proc. of the 1st International Symposium on Geo-information for Disaster Management, Delft, The Netherlands, March 21-23. Delft.

OASIS 2003: xNAL Name and Address Standard. Organization for the Advancement of Structured Information Standards. http://xml.coverpages.org/xnal.html

Okabe, A., Boots, B., Sugihara, K. (1992): Spatial Tessellations: Concepts and Applications of Voronoi Diagrams. John Wiley & Sons.

Stadler, A., Kolbe, T. H. (2007): Spatio-Semantic Coherence in the Integration of 3D City Models. In: Proceedings of 5th International ISPRS Symposium on Spatial Data Quality ISSDQ 2007 in Enschede, The Netherlands, 13-15 June 2007

VBUS (2006): Federal Government of Germany (eds.): Vorläufige Berechnungsmethode für den Umgebungslärm an Straßen vom 15.5.2006 (in German only).

VBUSch (2006): Federal Government of Germany (eds.): Vorläufige Berechnungsmethode für den Umgebungslärm an Schienenwegen vom 10.5.2006 (in German only).

VRML97, Information technology - Computer graphics and image processing - The Virtual Reality Modeling Language (VRML) – Part 1: Functional specification and UTF-8 encoding. Part 1 of ISO/IEC Standard 14772-1:1997.

Web 3D, Information technology - Computer graphics and image processing - Extensible 3D (X3D). ISO/IEC 19775:2004. http://www.web3d.org/x3d/specifications/, 2004.