New Concepts for Structuring 3D City Models – An Extended Level of Detail Concept for CityGML Buildings

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Abstract. We propose a new Level of Detail (LoD) concept for CityGML buildings that differentiates a Geometrical Level of Detail (GLoD) and a Semantical Level of Detail (SLoD). These two LoD concepts are separately defined for the interior characteristics and the outer shell of a building, respectively. The City Geography Markup Language (CityGML) is an open and application independent information model for the representation, storage, and exchange of virtual 3D city models. It covers geometric representations of 3D objects as well as their semantics and their interrelation. The CityGML Level of Detail concept in general offers the possibility to generalize CityGML features from very detailed to a less detailed description. The current LoD concept suffers from strictly coupling geometry and semantics. In addition it provides only one LoD (LoD4) for the description of the interior of a building. The benefits of our new LoD concept are first, a substantially higher informative value for the Level of Detail, second, a better description of the interior Level of Detail, third, a broadening of the opportunities for indoor modelling, and last, a better assignability to all other modules represented in CityGML. Due to more combinations of GLoD and SLoD, the Level of Detail definition for every module in CityGML can be defined according to the nature of modelled real world phenomenon.

Keywords: 3D City Models, CityGML, Level of Detail, Geometrical Level of Detail, Semantical Level of Detail.

1 Introduction

Semantically enriched virtual 3D city models support urban modelling in many ways. Possible applications are environmental and energy planning, disaster management, noise simulation, urban planning, and public participation in planning processes. In order to fully exploit virtual 3D city models, a commonly accepted data model for storage and exchange of geometry, semantics and relations of the modelled features is needed.

CityGML [1] is such an interoperable data model. It has been issued by the Open Geospatial Consortium (OGC), which is – besides the official International Organization for Standardization (ISO) – the most important standardization

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organization in the field of geospatial information technologies. CityGML is a common information model and encoding standard for the representation, storage, and exchange of virtual 3D city and landscape models. In addition to 3D geometric representations, it provides concepts to represent their semantics and their relations. CityGML is commonly accepted in the field of 3D city models; the number of available city models and their applications has increased significantly in the last ten years. Applications that rely on CityGML are e.g. the Energy Atlas of Berlin that supports investigations on energy consumption, energy demand, and energy saving potentials. Noise simulation and mapping has been performed for North Rhine-Westphalia in Germany using an extended CityGML data model [2], [3]. A fragmentary overview of CityGML applications in Germany is given in [4].

An advantage of CityGML is its scalability to the requirements of the user and the data available. The functionality of CityGML can be extended by applying the Application Domain Extension (ADE) mechanism. This mechanism extends CityGML classes by additional attributes and relations. Another way to extend CityGML is the definition of generic classes and attributes, which is more flexible, but hampers interoperability, since there is no common schema for the extension.

However, confining the functional range of CityGML is especially important in practice. On the one hand CityGML is organized in thematic modules that support a valid creation of tailored CityGML instance models without implementing the whole standard. On the other hand, almost every thematic class may be represented in different Levels of Detail (LoD). The LoD concept enables first, a gradual refinement of the geometrical characteristic, and second, the adjunction of semantic properties. Therefore it supports gradual data collection with respect to different application requirements and efficient data visualization and analysis.

Different LoDs first, serve different applications and, second, provide information about the quality of a modelled feature. The LoD concept has been developed first for the *Building* module and has been adapted to the other modules afterwards. Although the LoD concept of CityGML is used in practice and is subject to scientific research, from today's perspective it has considerable disadvantages as to informational content as well as to clearness of definition.

In this paper we propose a new approach to define the Levels of Detail for CityGML features. We start with a short description of CityGML to represent geometrically and semantically virtual 3D city models. In particular, we will focus on the *Building* module and will describe the current Level of Detail concept afterwards. In section 3 we will carve out the main deficits of this concept and develop a new approach that distinguishes between a geometrical and a semantical Level of Detail. We follow up with a discussion on the benefits of this new approach.

In this paper, names of classes and attributes used in CityGML and are written in *italics*.

2 CityGML – An International Standard for Virtual 3D City Models

The City Geography Markup Language (CityGML) is an open and application independent information model for the representation, storage, and exchange of virtual 3D city models. In addition to geometric representations of 3D objects it provides concepts to store their semantics and their interrelation. In addition, it covers the generalization and aggregation of semantically defined features. Therefore, it supports 3D content for visualization, but goes far beyond that point to support manifold analytical capacity. Unlike the Keyhole Markup Language (KML) used in the context of Google Earth, Collada or X3D, for instance, it distinguishes real world features providing 98 classes with 372 well defined attributes in total. These classes may have geometrical properties or not. Thus, in addition to visualisation application it supports the exchange of 3D city models for environmental simulations, energy estimations, disaster protection and others.

CityGML is an Open Geospatial Consortium (OGC) encoding standard and was released as version 1.0 in 2008 [5] and as version 2.0 in March 2012 [1]. Besides, the International Organization for Standardization (ISO), the OGC is seen to be the most important organization in the field of geospatial technologies.

CityGML is implemented as an application schema of the extensible Geography Markup Language (GML 3.1.1) [6] which is itself based on the Extensible Markup Language (XML). Hence, the exchange of CityGML benefits from all GML-intermateable techniques for data exchange, processing, and cataloguing, provided by the OGC. These include the Web Feature Service (WFS), the Web Processing Service (WPS), and the OGC Catalogue Service, for instance.

CityGML is organized in 13 thematic modules that enable a vertical scaling of a city model. This modularization is carried out by different XML-Schemas with different namespaces. The benefit of vertical modularization is the valid creation of thin CityGML instance models without implementing the whole standard. The most important of these thematic modules are the *Building* module containing semantic classes to represent buildings, i.e. houses or garages (cf. sec. 2.1) and the fundamental *Core* module. While the *Bridge* module and the *Tunnel* module are modelled as the *Building* module, the others are less detailed.

Besides offering an opportunity to confine CityGML by using only selective modules and the Level of Detail concept (rf. sec. 2.2) it is expandable, also. For this the Application Domain Extension (ADE) concept was developed. It allows the user, first, to add attributes or relations to CityGML classes and, second, to define new classes by generalization from CityGML classes. All attributes and classes then have to be defined in an own ADE namespace.

2.1 The CityGML *Building* Module

In CityGML the most important thematically module is the *Building* module. The central class is the abstract class *_AbstractBuilding* that is specialized to a *Building* or a *BuildingPart*, respectively. Both, *Building* and *BuildingPart* inherit the attributes *yearOfConstruction*, *yearOfDemolition*, *roofType*, *storeysAboveGround*, *storeysBelowGround*, *storeyHeightsAboveGround* und *storeyHeightsBelowGround* from *_AbstractBuilding* as well as *class*, *function*, and *usage*. As in all other thematic classes in CityGML the attribute *class* represents a classification of the *Building*, e.g. ‘habitation’ or ‘business’. The attributes *function* and *usage* contain information about planned and actual utilisation of the building, e.g. 'holiday house' or 'public building'. All values of the attributes may be defined in external code lists and therefore can be adapted to national standards or project oriented needs. The same accounts for the attribute *roofType*.

_AbstractBuilding is specialized either to *Building* or to *BuildingPart*, allowing the representation of an aggregation hierarchy of arbitrary depth of connected buildings and parts of buildings. Disconnected groups of buildings sharing the same semantics, e.g. industrial complexes may be modelled as *CityObjectGroups*.

The building's geometric representation as well as the improvement of semantical description may be gradually refined, applying the CityGML concept of Levels of Detail (LoD) that is outlined in the next section.

2.2 The CityGML Level of Detail Concept

The Level of Detail concept (LoD) is a characteristic quality of CityGML. Next to the horizontal modularization the LoD concept offers the possibility to generalize CityGML features from very detailed to a less detailed description. In CityGML the LoD concept enables first, a gradual refinement of the geometrical characteristic, and second, the adjunction of semantic properties. Therefore it supports gradual data collection with respect to different application requirements as well as efficient data visualization and analysis. The LoD concept is a prerequisite to model buildings in the context of cities or even regions as well as detailed buildings with interior structures. Thereby, CityGML is different to the Industry Foundation Classes (IFC) developed by buildingSMART for the representation of highly detailed building models [7].

The Level of Detail concept can be applied to all main thematic classes representing the most important types of objects within virtual 3D city models, i.e. *Bridge*, *Building*, *CityFurniture*, *CityObjectGroup*, *Generics*, *LandUse*, *Relief*, *Transportation*, *Tunnel*, *Vegetation*, and *WaterBody*. In a CityGML instance document the coexisting representation of one and the same object in different Levels of Detail is possible. The current LoD concept was developed primarily for the *Building* module and adopted for other modules, afterwards. That does not apply for the building's LoD0 representation that was added to the *Building* module in version 2.0 to handle 2D map representations for buildings. All in all there are 5 Levels of Detail in the *Building* module that are depicted in figure 1.

Level of Detail 0 (LoD0): The building is represented by the building footprint or the roof outline. Both are horizontal surfaces with a constant height value. This representation corresponds to a city map representation and enables the integration of 2D data coming from cadastral map excerpts, for instance. A possible application for a LoD0 building representation might be density or distance calculations for fire precautions or just land tenure visualization.

Level of Detail 1 (LoD1): The building is represented by a block model, i.e. a vertical extrusion solid without any semantically structuring. The geometric representation is realized by a *gml:Solid* or a *gml:MultiSurface*.

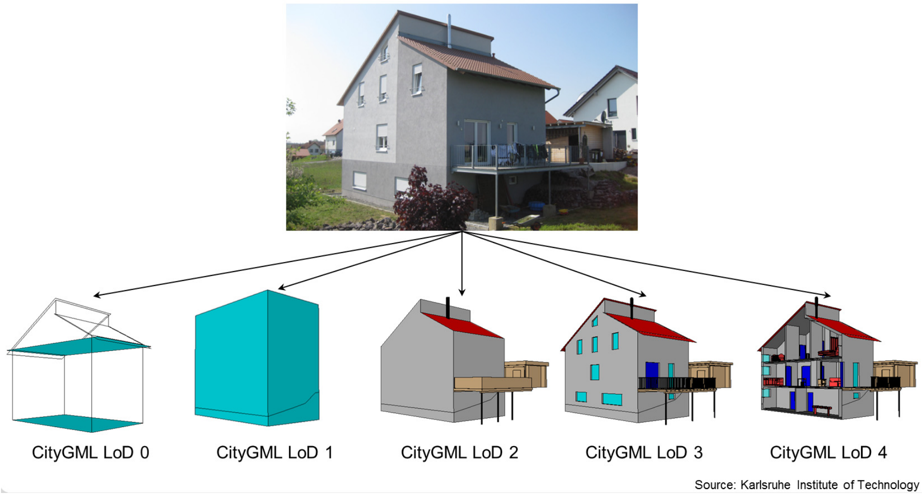

Fig. 1. Representation of a building using LoD0 - LoD4 [8]

Possible applications for LoD1 building models are noise mapping approaches [2], [3] or the estimation of real volume in flood planes for flood prevention. Even for modelling mobile communications networks, a LoD1 city model would be sufficient as long as no reflection properties are needed. Another application could be a multiple line of sight analysis to optimize the deployment of WLAN routers or checking blind spots for closed circuit television monitoring systems [9].

Level of Detail 2 (LoD2): The building is represented by a geometrically simplified exterior shell. The outer facade of a building may be differentiated semantically by the class *_BoundarySurface* as a part of the building's exterior shell apportioned a special function. This can be a wall (represented by the class *WallSurface*), roof (*RoofSurface*), ground plate (*GroundSurface*), outer floor (*OuterFloorSurface*), outer ceiling (*OuterCeilingSurface*) or a *ClosureSurface*. A *ClosureSurface* does not correspond to an object in the real world but is introduced to support the generation of closed volumes. Figure 2 depicts a LoD2 building representation using the boundary surfaces with the exception of a *ClosureSurface*. Further, additional building elements like chimneys, dormers, and balconies may be associated to a building in LoD2 using the class *BuildingInstallation*.

Compared to LoD1, the outer shell of a LoD2 building is differentiated both semantically and geometrically. Hence, more applications are possible in LoD2. Analysing the roof surfaces of a building leads to an estimation of solar energy potential [10]. Comprise building installations like dormers and chimneys can even improve this estimation if shadowing effects are considered [11]. Analysing the total surface of a building's wall surfaces could help to estimate thermal insulation effort.

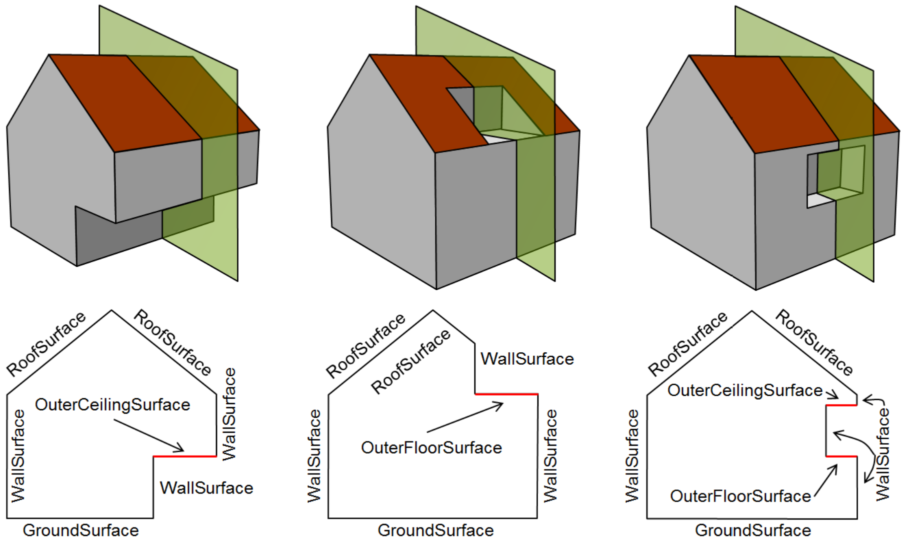

Fig. 2. Examples of boundary surfaces for a building in LoD2 ([8], according to [1] p. 70)

Level of Detail 3 (LoD3): The building is represented by a geometrically exact outer shell. Semantically this representation may be enriched by two features, *Door* and *Window*, as a specialization of the class *_Opening*. Since address information can be associated with both, a *Building* and a *Door*, the address information can be applied in much more spatial detail in LoD3, i.e. larger building complexes may get more than just one address.

With LoD3 city models, again the number of applications increases. Since doors and windows are represented, access ways to buildings can be analysed for evacuation scenarios or police operations. Windows may be sampled for coefficient of heat transmission and area to estimate restructuring requirements. In [12] an absolute vehicle positioning architecture in urban environments was proposed, realized by combining 3D city data and car side laser scanner. In particular, the geometries of window ledges could increase the number of observations for positioning calculations.

Level of Detail 4 (LoD4): In addition to the LoD3 representation of the building's outer shell, interior structures are represented in LoD4 by the class *Room* that again may be semantically enhanced by the attributes *class*, *function*, and *usage*. *Rooms* are bounded by one or many *InteriorWallSurface, FloorSurface,* and *CeilingSurface*. Installations within a room that are not movable, i.e. radiators or fireplaces, are represented using the *IntBuildingInstallation* class. Furniture, like tables and chairs, can be represented with the class *BuildingFurniture*. Since CityGML version 2.0 the geometry of *IntBuildingInstallation and BuildingFurniture* may be represented using an *ImplicitGeometry.* That is a prototypal geometry that is, on grounds of costs, used for more than one object. Even VRML-, DXF- or 3D Studio MAX files or a suitable web service may be imported to the city model. Next to memory requirements the use of implicit geometries enables a faster visualisation.

Since LoD4 city models hold interior structures of building available more applications are possible. Among these are the semiautomatic checking of digital building applications [13], or the calculation of air volume of a building for energy requirement reasons or the query for heating installations concerning their type and energy consumption. Additionally, CityGML LoD4 buildings are virtually assessable. That allows for build-up locations based services for visitors or simulate flight behaviour.

3 A New Separated Level of Detail Concept for CityGML

CityGML does not provide a consistent and superordinate Level of Detail concept for all available modules. There are separated concepts and descriptions, rather than definitions that may be suitable for the modules representing buildings, tunnel, bridges, land use, furniture and so on. To some extent these concepts appear to be transferable. However, this is complicated because the entities modelled are quite different in nature. Hence, a single view of all the entities modelled in CityGML must result in an erroneous interpretation and application of the Level of Detail concept. As a result, concepts for Levels of Detail must be discussed for each module separately.

3.1 Deficits of the CityGML 2.0 LoD Concept

The Level of Detail concept in CityGML was first developed for the *Building* module. Since buildings represent the most important entities of a city, a well-defined LoD concept for the corresponding CityGML module is important. It distinguishes between very rudimental block models (LoD1), a representation containing typical roof forms and a generalized shape of the building's facade (LoD2), a geometrically exact representation of the exterior shell (LoD3) and a representation of internal structures (LoD4). But this cannot be simply adapted to all other entities of an urban landscape. There is no clear reason to define an interior of a *SolitaryVegetationObject* that is used to model single vegetation objects like plants and trees. What exactly has to be modelled to represent the interior of a *WaterBody*. Further, taking into account the fact that the LoD concept accounts for both, geometry definition and semantically depth, what is the meaning of different LoDs for land use or relief?

Even for the *Building* module, the current Level of Detail concept seems to be insufficient. Take the interior structure of a building, e.g. rooms, interior boundary surfaces, installations etc., as an example. These features can only be modelled in one geometrical LoD, LoD4 that requires a geometrically exact representation. However, often this information is not available and is not needed for various use cases. An example is the Spanish cadastre, which often provides a coarse outer building shell (LoD1) and information on a story and interiors and its spatial structure. Currently, these models cannot be represented adequately in CityGML. Further, the interior structure of a building can only be modelled when, simultaneously, there is a geometrically exact model for the exterior shell of the building is available. This limits the application of indoor models.

For Level of Detail representations higher than 2, this attribute does not provide much information on the actual semantically content of a building model. For a LoD3 building, the range of valid representations goes from a pure *gml:MultiSurface* geometry for the exterior shell to semantically structured representation with wall surfaces, roof surfaces, outer installations, doors and windows (rf. [14]).

3.2 General Consideration for a New Level of Detail Concept for CityGML

General considerations must be addressed to overcome the aforementioned problems in defining, assigning and applying the Level of Detail concept to CityGML classes and instances. This involves also a readiness to reassess the building as the constructional drawing for LoD concepts for other city objects and modules. Below we suggest some of these general considerations.

The Level of Detail attribute is a sign of quality for every single *CityObject*, i.e. a feature of the urban environment that is represented in CityGML. In other words, the LoD is a measure of the consistency between real world feature and modelled feature, both geometrically and semantically. Geometrically a LoD declaration should be a sign of maximum geometrical deviation of points in the real world and the model. This maximal deviation is required to be more precise the smaller the modelled features are. Semantically the value of a LoD attribute should indicate how many of important subcomponents are modelled from real world features. That should also include the question whether values are assigned to relevant attributes of a thematic class. Since almost all of the attributes in CityGML are optional, this is important information. Finally, the LoD attribute could contain information on the degree of conformity of the feature's appearance both in the real world and the model representation.

As a consequence, for almost all semantic classes in CityGML, the LoD cannot be expressed by simply one number between 0 and 4 but rather as an explicit attribute expressing all supported Levels of Detail. Since at least geometry and semantical depth have to be considered, this attribute needs to be one of a complex type.

We propose the differentiation of a Geometrical Level of Detail (GLoD) and a Semantical Level of Detail (SLoD). These two LoDs are separately defined for the interior characteristics and the outer shell of a building, respectively. For the sake of completeness, however, an additionally Level of Detail on the appearance (ALoD) of a model has to be considered. It should allow statements whether there is colour or texture information either are available, partly available or not available. However, this ALoD is not discussed here.

3.3 Geometrical Level of Detail (GLoD)

The Geometrically Level of Detail (GLoD) denotes the geometrical resolution and the deviation of the modelled feature from the real world phenomenon. Since more information on Level of Detail for interior building structures is embedded, the GLoD is divided into an outer shell GLoD and an interior GLoD.

The highest number of our new GLoD concept is 3 resulting in 4 GLoDs. The former concept comprises 5 Levels of Detail, where the LoD4 just indicates that interior structures of a building are modelled. Since the new concept distinguishes between outer shell and interior structures of a building, the fifth LoD, i.e. LoD4, can be omitted. Even more detailed characteristics of the model's quality can be expressed when exterior GLoD and interior GLoD are combined. For the outer shell of a building the GLoD has the following encoding (rf. fig. 3):

Geometrical Level of Detail 0 (GLoD0): 2D / 2.5D geometry. The outer building is represented by a two-dimensional surface, a planar surface embedded into the 3D space, or a non-vertical surface. The latter means that within the extent of the surface the vertical height z of a surface point is a unique function $z=f(x,y)$ of the horizontal point position. Attributes specify the meaning of the surface, i.e. whether it represents the building outline or the roof outline.

Geometrical Level of Detail 1 (GLoD1): Vertical extrusion body. The building is represented by a block model. An attribute specifies the meaning of the surface used for the extrusion, i.e. whether it represents the building footprint or the roof outline.

Geometrical Level of Detail 2 (GLoD2): Generalized geometry. The building is represented by a geometrically simplified outline contour with a well-defined maximum geometrically deviation between model and real world feature.

Geometrical Level of Detail 3 (GLoD3): Exact geometry. The building is represented by a geometrically exact outer shell. Again, there is a well-defined maximum geometrically deviation between model and real world feature much smaller than in GLoD2.

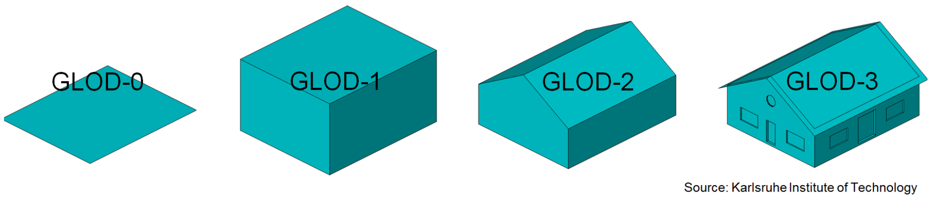

Fig. 3. Representation of the outer shell with the new GLoD concept. Here, no additional semantics are represented, i.e. the Semantically LoD (SLoD) is 0 (see section 3.4)

The interior GLoD solely characterises the Level of Detail for inner structures of a modelled building. A priory, it is not bound to a specific GLoD for exterior feature granularity. Therefore, this new concept allows modelling highly detailed interior structures of a building without providing exact outer building shell at the same time. Since the current LoD4 concept needs to have exact outer shell geometry, this representation is not possible that concept. The numbering of the interior GLoD follows that of the outer shell GLoD (rf. fig. 4).

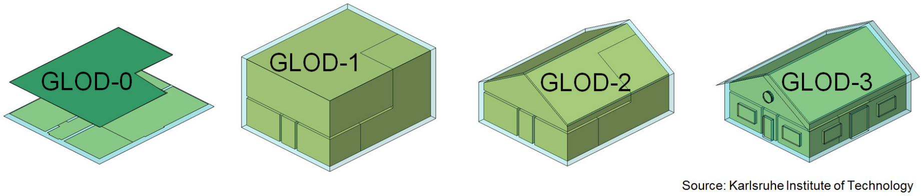

Fig. 4. Representation of the interior of a building, i.e. rooms, using the new GLoD concept. Here, no additional semantics are represented, i.e. the Semantical LoD (SLoD) is 0 (see section 3.4)

3.4 Semantical Level of Detail (SLoD)

The new Level of Detail concept proposed here separates clearly between geometrical and semantical accurateness of a modelled feature. Besides, since the separation of geometry and semantic is a basic principle of the OGC Abstract Specification [15], our approach is more compliant to OGC policies than the current one. The Semantical Level of Detail (SLoD) denotes the degree to which the semantical structure of a real world phenomenon is reflected in the modelled feature. Next to geometrical integrity it describes the semantical depth that is expressed in a model, i.e. whether the boundary surfaces have a type and additionally attributes or are just surfaces without any meaning. The SLoD is represented using the following graduations:

Semantical Level of Detail 0 (SLoD0): There is no semantical structuring of the building's outer shell or a room, only the building is represented semantically. Hence, no differentiation of the boundary surface is available.

Semantical Level of Detail 1 (SLoD1): The geometry representing the outer shell is completely structured by boundary surfaces. As mentioned in sec. 2.2 a *BoundarySurface* is specialized in several classes representing semantics of these surfaces, e.g. an *OuterCeilingSurface*.

Semantical Level of Detail 2 (SLoD2): In addition to the boundary surfaces in SLoD2, particular parts of the outer shell are modelled by *BuildingInstallation*. Building installations themselves are represented by boundary surfaces as well.

Semantical Level of Detail 3 (SLoD3): *Openings*, i.e. *Doors* and *Windows* are represented.

Like the GLoD, the SLoD can be applied for the outer representation of a building as well as for the interior. Due to the combination of different SLoDs with GLoDs, there are substantially more ways to describe a *CityObject's* model correctness than applying the current LoD concept.

3.5 Possible Combinations of GLoDs and SLoDs and Their Relationship to the Current Concept

The main advantage of the new LoD concept, i.e. first, separating information about geometry and semantics, and second, separating the outer shell from the interior of a building, is an enhanced description of the deviation between the real world feature and the modelled object. It enables more information depth on the modelled feature by combining different geometrical and semantical Levels of Detail. However, not every combination of GLoD and SLoD is valid. In GLoD0, where the building's outer shell geometrically is represented by an (almost) planar surface, it does not make sense to identify *_BoundarySurface* or *BuildingInstallation*, which would have to be modelled as lines. For the extrusion volume used in GLoD1, it is implicitly obvious that the lower horizontal plane corresponds to a *GroundSurface*, the upper plane corresponds to a *RoofSurface*, and the vertical planes correspond to *WallSurface*. An additional modelling of these structures as *BoundarySurface* therefore would not generate any additional information and is prohibited. Table 1 shows valid combinations of GLoDs and SLoDs for the exterior shell of a building. It can also be seen, that this combinations are capable to represent the current Level of Detail concept.

Table 1. Possible combinations of GLoD and SLoD representing the exterior shell of a Building. Every LoD of the former model can be represented.

	SLoD0	SLoD1	SLoD2	SLoD3
GLoD0	LoD0	prohibited	prohibited	prohibited
GLoD1	LoD1	prohibited	prohibited	prohibited
GLoD2	LoD2	LoD2	LoD2	new
GLoD3	LoD3	LoD3	LoD3	LoD3

Since the current LoD concept offers only one LoD for the interior of buildings, i.e. the LoD4, the new concept gives more information. Further, the combination of different GLoDs and SLoDs allows the representation of more semantical information, even if geometry is not available in the best resolution, e.g. GLoD3. Table 2 shows possible combinations of GLoD and SLoD for the interior of a building as well as the relationship between the current LoD concept and the new one.

Table 2. Possible combinations of GLoD and SLoD representing the interior of a building. Every LoD of the former model can be represented.

	SLoD0	SLoD1	SLoD2	SLoD3
GLoD0	new	prohibited	prohibited	prohibited
GLoD1	new	prohibited	prohibited	prohibited
GLoD2	new	new	new	new
GLoD3	LoD4	LoD4	LoD4	LoD4

Since GLoD and SLoD can be combined once for the outer shell of a building and the interior of a building, the overall Level of Detail is given by a combination of interior and outside. While allowance of valid combinations is ambiguous, possible combinations need to be discussed. Here, we present a more restrictive set of combinations that is expected to fit the requirements of users quite well (rf. fig. 5).

		outer shell										
		not modelled	GLoD0 / SLoD0	GLoD1 / SLoD0	GLoD2 / SLoD0	GLoD2 / SLoD1	GLoD2 / SLoD2	GLoD2 / SLoD3	GLoD3 / SLoD0	GLoD3 / SLoD1	GLoD3 / SLoD2	GLoD3 / SLoD3
building interior	not modelled	X	LoD0	LoD1	LoD2	LoD2	LoD2	new	LoD3	LoD3	LoD3	LoD3
	GLoD0 / SLoD0	X	new	X	X	X	X	X	X	X	X	X
	GLoD1 / SLoD0	X	X	new	X	X	X	X	X	X	X	X
	GLoD2 / SLoD0	X	X	X	new	new	new	new	X	X	X	X
	GLoD2 / SLoD1	X	X	X	new	new	new	new	X	X	X	X
	GLoD2 / SLoD2	X	X	X	new	new	new	new	X	X	X	X
	GLoD2 / SLoD3	X	X	X	new	new	new	new	X	X	X	X
	GLoD3 / SLoD0	X	X	X	X	X	X	X	LoD4	LoD4	LoD4	LoD4
	GLoD3 / SLoD1	X	X	X	X	X	X	X	LoD4	LoD4	LoD4	LoD4
	GLoD3 / SLoD2	X	X	X	X	X	X	X	LoD4	LoD4	LoD4	LoD4
	GLoD3 / SLoD3	X	X	X	X	X	X	X	LoD4	LoD4	LoD4	LoD4

Fig. 5. Possible combinations of GLoD and SLoD representations for the outer shell and the interior of a building characterising its total Level of Detail. A 'X' indicates an invalid combination and LoDx the correspondent to the current LoD concept.

The above proposed combinations fit well for the *Building* module. One of the major sources of criticism on the current LoD concept is that it was simply transferred from a building LoD definition to all other modules in CityGML. In general, this accounts for this approach, also. But the main improvement is the intricacy of design that enables a balanced design of the table given in fig. 5 for every single module. As a result, for some modules the interior GLoD and SLoD will be omitted, e.g. for the *Vegetation* module or the *LandUse* module.

An example of improved application using the new LoD concept is given in fig. 6. Here, the exterior shell of a building is represented only in GLoD1 and SLod0. That is a block model with no semantical differentiation of boundary surfaces. It can be generated by extruding municipal maps. Nevertheless, the interior of the building, i.e. the rooms and interior building installations, are modelled in the highest GLoD and SLoD, i.e. GLoD3 and SLoD3, respectively. This option is important for interior designers that are not interested in the outer shape of a building.

Fig. 7 depicts a reverse situation. Here, the outer shell of a building is represented using a combination of the most precise GLoD3 and SLoD3. This reflects the current LoD3 or LoD4 representation, depending on whether the interior of a building is modelled or not. Because the interior of a building was only representable in LoD4 in the current concept, maximum precision and semantic information were required. Here, a less detailed interior Level of Detail may be applied, i.e. a GLoD0 and SLoD0 representing just floor plans. This building representation might be useful for sales conversations.

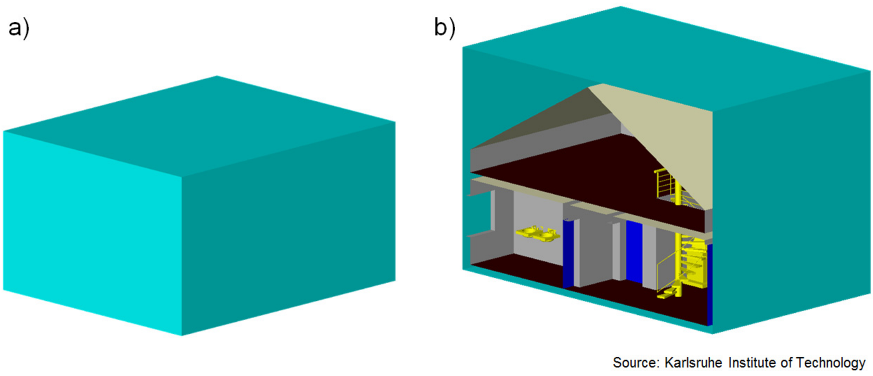

Fig. 6. Representation of the buildings a) outer shell in GLoD1 and SLoD0 and b) the interior of the same building in GLoD3 and SLoD3

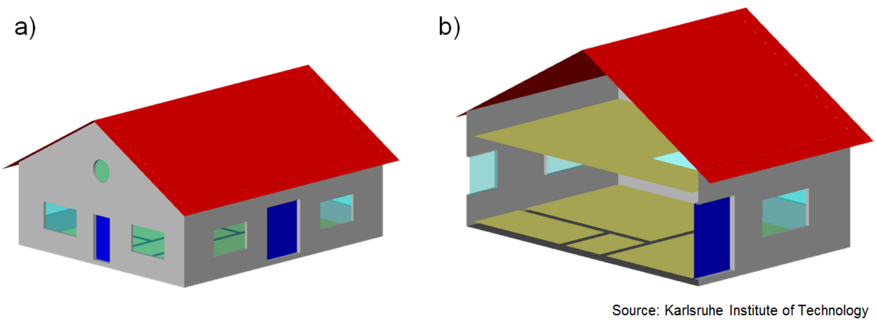

Fig. 7. Representation of the buildings a) outer shell in GLoD3 and SLoD3 and b) the interior of the same building in GLoD0 and SLoD0

4 Conclusions and Discussion

We proposed a new Level of Detail concept for the international Open Geospatial Consortium encoding standard CityGML, a common information model for representing, storing, and exchanging virtual 3D city models. The concept involves the separation of a Geometrical LoD (GLoD) from that of a Semantical LoD (SLoD) as well as the separation of exterior and interior properties of a *CityObject.*

Since August 2008, CityGML 1.0 is an Open Geospatial Consortium encoding standard. It was republished in March 2012 in the version 2.0. Next to the quality of model concepts and certain flexibility, continuity is a major reason for a standard to be accepted. The version change from 1.0 to 2.0 was characterized by only small changes. A new major release was necessary only because of OGC policies, disallowing additions on existing classes (rf. [16]). Since a new release offers just extensions to the old one, i.e. additional features and attributes, instance models based on the former encoding standard are still valid or can easily be converted. Here, we state that our new LoD concept is an extension that first, enables more information depth on the modelled feature and, second, is easily be applied to instance models of CityGML version 2.0. Compared to the current concept, the new approach offers the following advantages:

- A substantially higher informative value for the Level of Detail of *CityObjects* due to manifold combination of GLoD and SLoD for both, the interior and exterior of a *CityObject*.
- A better description of the interior Level of Detail. Since the current concept offers only one LoD (LoD4), ten different quality classes are available now.
- A broadening of the opportunities for indoor modelling. Since the current LoD concept demands on high resolution geometry, the new approach allows for the representation even of 2.5D data for interior objects. That enables novel applications, for example the representation of room or floor plans for indoor navigation.
- A better assignability to all other modules represented in CityGML. Due to more combinations of GLoD and SLoD, the Level of Detail definition for every module in CityGML can be defined according to the nature of modelled real world phenomenon.

Further work needs to be done to develop this approach of GLoD and SLoD to a comprehensive metadata model. This metadata model should allow the testing and evaluating of instance documents for certain applications. This metadata model has to provide answers to the following questions:

- Does the model represent an explicit building volume, directly or indirectly?
- Is there explicit information about the appearance available, i.e. colour or textures?
- If so, is this information related to visual nature or to special information, e.g. to a thermographic image of the surface?
- For which subset of the set of (mostly optional) attributes are values provided?

The work on the new Level of Detail concept is still in progress and under discussion in the modelling working group of the Special Interest Group 3D (SIG 3D, see www.sig3d.org) of the initiative Spatial Data Infrastructure Germany (GDI-DE). After the group has agreed upon the new concept, it will be forwarded as an official change request to the OCG, particularly to the CityGML Standards Working Group (CityGML SWG) of the OGC.

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