AUTOMATIC DERIVATION OF DIFFERENT LEVELS OF DETAIL FOR 3D BUILDINGS MODELED BY CITYGML

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Abstract

The new OGC standard CityGML defines a standard for ontology of buildings at four different Levels of Detail (LoDs). The building models at different LoDs differ in the complexity and granularity of the geometric representation and the thematic structuring of the models into components with a special semantic meaning. In line with the definition of LoDs this paper addresses the process of automatic derivation of building models at lower LoDs from a higher LoD. The approach has been implemented and tested on a number of 3D buildings modeled at LoD4 of CityGML. The experiments showed that the presented approach allows an automatic and efficient derivation of different LoDs from the most detailed model. Moreover, they proved the advantages of a standard modeling language.

Keywords: LoD, CityGML, Generalization, 3D building

Introduction

Three dimensional building models are getting increasingly popular and widely used nowadays. They are visualized mainly for applications in architecture, traffic planning and navigation systems as well as for various simulation purposes. However, different applications require different abstractions of 3D building models. This means, different representations or different Levels of Detail (LoDs) of the same reality have to be made available (Sester, 2007).

From a cost-efficient point of view, different LoDs should be automatically created by means of specific generalization procedures. This paper is dedicated to generalization algorithms for 3D buildings. Being aware of the fact that the capability of most existing approaches is largely constrained by the data format of input building models, we choose for the ongoing research project of “Integrating time-dependent features in 3D building models” at the Department of Cartography, Technische Universität München, Germany, the new OGC standard CityGML (City Geography Markup Language).

CityGML not only represents the shape and graphical appearance of 3D buildings but specifically addresses the object semantics and the representation of thematic properties, taxonomies and aggregations. Moreover, the CityGML defines a standard for ontology of buildings at different LoDs. This description comprises a categorization from LoD1 to LoD4, ranging from the coarsest block model to individual buildings with all their architectural details and interiors, stairs and furniture. However, CityGML does not indicate methods for the automatic derivation of the different LoDs. (Meng & Forberg, 2007 and Sester, 2007) give an overview of the state of the art of 3D generalization in academic community. Although most of the introduced works in their articles prove conceptually convincing and feasible on some contrived test datasets, they are still premature and cannot yet be implemented in mass datasets without substantial refinement and extension. This paper attempts to go a step further by introducing an automatic approach of deriving different LoDs of 3D buildings formatted in CityGML.

The approach starts from the most detailed 3D building models at LoD4. The neighboring LoD3 can be obtained by transferring the entire geometries and semantics from LoD4 while neglecting the interior structures defined at LoD4. The process from LoD3 to LoD2 is relatively complicated, since buildings at LoD2 should reveal more generalized geometry and semantic information than at LoD3. This process can be achieved in two steps: at first all the polygons belonging to doors and windows are removed, and the resulted holes are then filled; secondly, the detailed architectural representation of each building is generalized by simplifying its corresponding ground plan; at the same time, the detailed roof structure is replaced by a simplified version in which small components of the original roof at LoD3 are detected and eliminated. The model obtained in this way can be further simplified following the similar philosophy until the most abstract model defined as LoD1 is reached.

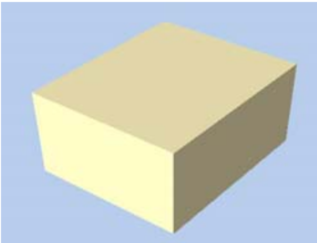
The paper is structured as follows: after a brief introduction of CityGML the methodology of automatic derivation of LoDs specified for CityGML will be explained and described; then we will show some results of our approach and conclude our work finally.

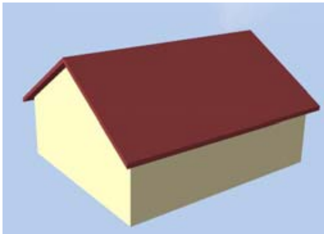
CityGML for 3D buildings

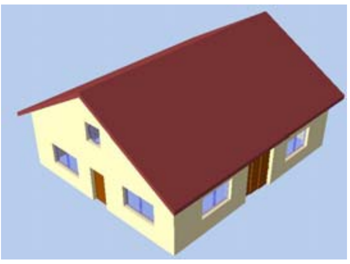
CityGML stands for the City Geography Markup Language. It is an open data model and XML-based format for the representation and exchange of virtual 3D city models. CityGML not only represents the shape and graphical appearance of city models but specifically addresses the object semantics and the representation of the thematic properties, taxonomies and aggregations (Kolbe, 2008). Since 20th, August, 2008 CityGML (City Geography Markup Language) version 1.0.0 has been adopted by the Open Geospatial Consortium, Inc. (OGC) for modeling 3D urban objects, especially 3D buildings.

The thematic information in CityGML goes beyond graphic exchange formats and allows users to employ virtual 3D city models for comprehensive analysis in different application domains such as simulation, urban data mining, facilities management, decision support and thematic inquiries.

The building model is the most detailed thematic concept of CityGML. It allows for the representation of thematic and spatial aspects of buildings, building parts and installations at four levels of detail LoD1 - LoD4 (Figure 1). At LoD1, 3D buildings are represented by block model with flat roofs. At LoD2, buildings have differentiated roof structures and thematically differentiated surfaces. LoD3 denotes architectural models with detailed wall and roof structures, balconies, bays and projections. LoD4 completes a LoD3 model by adding interior structures.


LoD1


LoD2


LoD3


LoD4

Fig. 1. The four levels of detail (LoD) defined by CityGML for building model (FZK-House modeled by Forschungszentrum Karlsruhe, Institute for Applied Computer Science), visualized in Autodesk LandXplorer CityGML Viewer

On the other hand, the LoDs in CityGML are also characterised by differing accuracies and minimal dimensions of objects. As shown in Table 1, the positional and height accuracy of points at LoD1 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 has to be 2m or better. And at this LoD all objects with a footprint of at least 4m by 4m must be considered. In the detailed model at LoD3, both types of accuracies are 0.5m, and the minimal footprint is 2m by 2m. Finally, the positional and height accuracy of LoD4 must be 0.2m or less.

Table 1: LoD1-4 for buildings in CityGML with its accuracy requirements (source: Albert et al. 2003)

	LoD1	LoD2	LoD3	LoD4
Model scale description	City, region	City districts	Architectural models (out-side), landmark	Architectural models (interior)
Class of accuracy	low	middle	high	very high
Accuracy of position and height	5m	2m	0.5m	0.2m
Generalization	Object blocks as generalized features; >6*6m	Objects as generalized features; >4*4m	Object as real features; >2*2m	Constructive elements and openings are represented
Building installations	-	-	Representative exterior effects	Real object form
Roof form/structure	flat	Roof type and orientation	Real object form	Real object form

Moreover, CityGML supports the aggregation/decomposition by providing an explicit generalization association between any CityObjects (Gröger et al. 2008). In this sense, buildings at a certain LoD could be generalized to be represented by an aggregate building at a lower LoD.

The methodology

In this section the algorithm of deriving 3D buildings at various corser LoDs from their neighboring finer LoDs will be explained and described.

- Transition from LoD4 to LoD3

Although LoD4 allows to describe the interior structure of a building with the classes *IntBuildingInstallation* and *Room* (Gröger et al. 2008). Thus the LoD3 model can be obtained by transferring the entire geometries and semantics from LoD4 model while neglecting the interior structures defined at LoD4. At the same time the referenced *SolidGeometry* or *MultiSurfaceGeometry* should be transcribed from LoD4 to LoD3. The whole process can be illustrated in Figure 2.

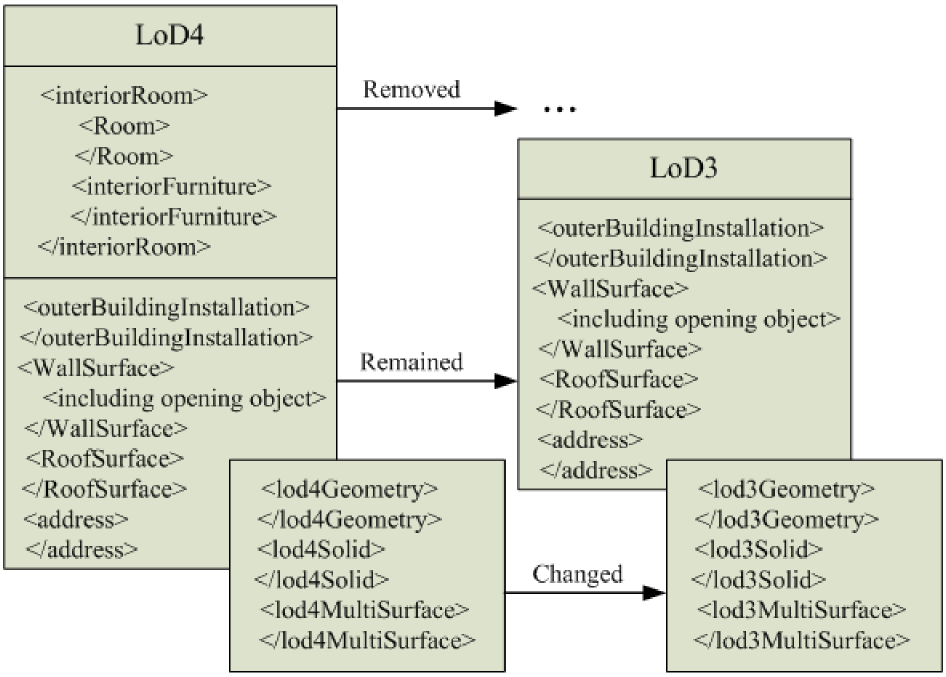


Fig. 2. Workflow for the derivation of LoD3 model from LoD4 model

- Transition from LoD3 to LoD2

Differences between LoD3 and LoD2 are twofold. Firstly, buildings at LoD2 reveal lower geometric precision than that for LoD3 (see Table 1). Secondly, the surface geometry at LoD2 must be simply connected, which means that the components of the MultiSurface (e.g. *gml:Polygon*) must not have inner holes (*gml:interior*). In contrast to LoD2, inner holes are required at LoD3 (and LoD4) to indicate the opening object like windows or doors. For these reasons, the process of deriving LoD2 model from LoD3 model will be divided into two steps (see Figure 3).

In the first step, the opening objects (windows, doors) will be separated from the LoD3 building model and then removed. The resulted holes in the wall will be filled by deleting the polygons modeled as <*gml:interior*>. So far the building model composed of the remaining entities might almost be a model at LoD2 except that it may contain features that are smaller than 4 x 4 meters, that is to say, below the smallest required size for LoD2 (see Table 1). Therefore, these small entities have to be generalized.

In the second step the generalization will be conducted for the walls and roof structure respectively. In order to reduce the complicated computation of 3D geometry during the process of the generalization, the elements of walls will be projected onto the ground. Then the ground plan can be obtained by connecting the footprint into a closed polygon. According to the algorithm for simplifying ground plan in (Sester & Brenner, 2004) the operations are going to be triggered by a building side S_n that is smaller than the threshold ($S_T = 4\text{m}$). In this way, intrusions and extrusions can be eliminated, the same principle holds for offsets and corners.

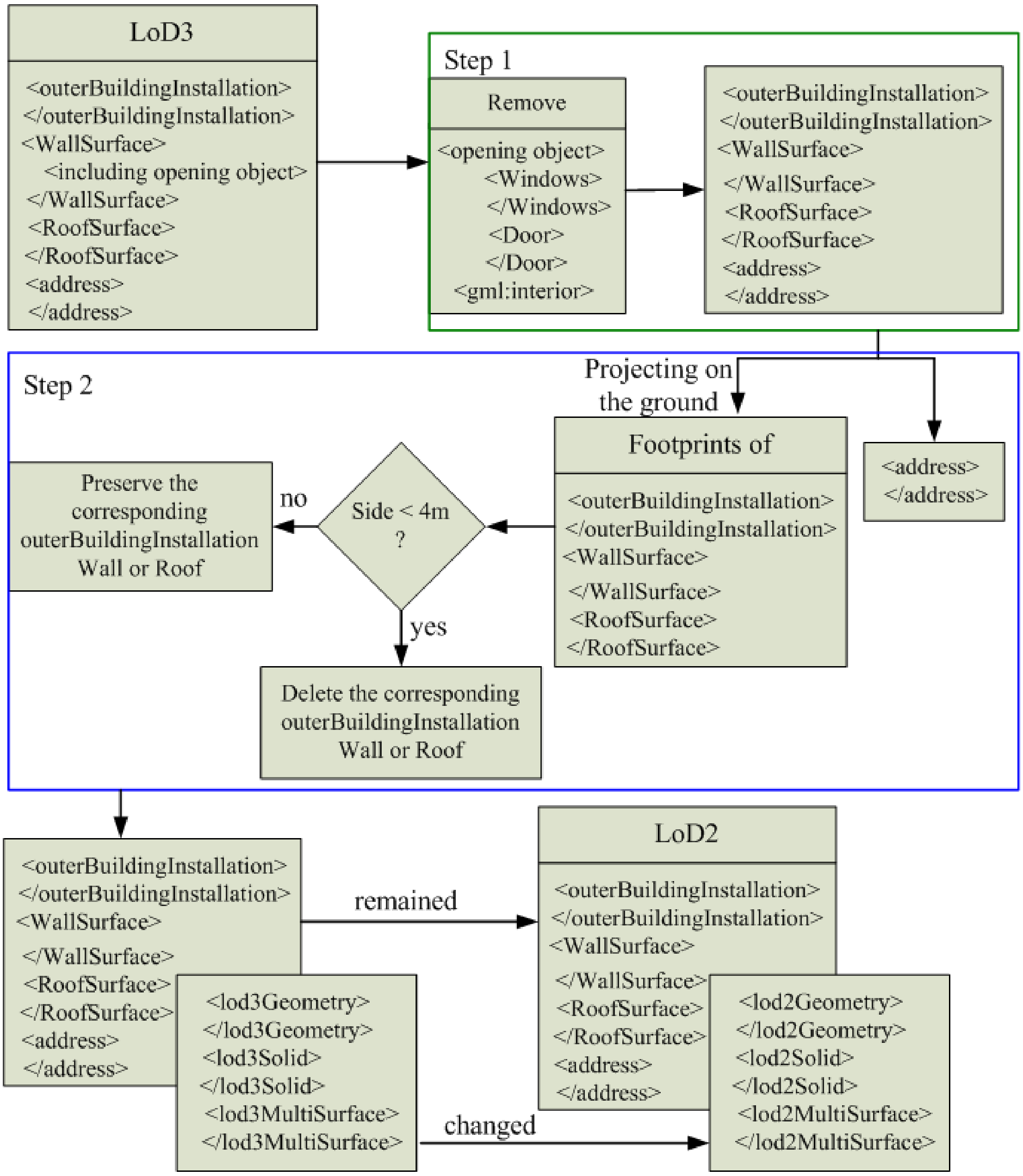


Fig. 3. Flow chart for derivation of LoD2 model from LoD3 model

After the ground plan is simplified the roof structure should be adjusted accordingly. If the roof is flat, it will be simplified in the same way as for the ground plan. Otherwise, the polygons of the roof should be projected onto the ground. Normally, the projection of roof outline and the ground plan are contained within each other. Therefore, they will be processed in the same way. For the new nodes created during the process their corresponding points on the roof can be easily computed:

$$\begin{pmatrix} X_{roof\_new} \\ Y_{roof\_new} \\ Z_{roof\_new} \end{pmatrix} = \begin{pmatrix} X_{new} \\ Y_{new} \\ \dfrac{-D_i - A_i X_{new} - B_i Y_{new}}{C_i} \end{pmatrix} \quad (1)$$

Where $(X_{new} \quad Y_{new} \quad Z_{new})^T$ stands for the new created point, the A_i, B_i, C_i and D_i are plane coefficients of the involved polygon, and $(X_{roof\_new} \quad Y_{roof\_new} \quad Z_{roof\_new})^T$ is the new created point on the roof.

To this end, the geometries and the entities' classes of the generalized building model have satisfied the requirement of LoD2. And the building model conforms entirely with LoD2, once the referenced *SolidGeometry* or *MultiSurfaceGeometry* are changed from LoD3 to LoD2.

- Transition from LoD2to LoD1

LoD1 is the coarsest level for building model in CityGML. At LoD1 the different structural entities of a building are aggregated to simple blocks and not differentiated in detail. Therefore, the entities modelled for *outerBuildingInstallation* like chimneys, stairs, antennas, balconies or attached roofs above stairs and paths will be eliminated at first. Then the derivation of LoD1 model from LoD2 model can actually be regarded as a process of aggregation and simplification for the building geometries at LoD2.

Similar to the second step of the transition from LoD3 to LoD2, the wall elements have to be projected onto ground prior to the aggregation and simplification. However, the threshold for triggering the simplification of ground plan should be bigger than that in the case of deriving LoD2 from LoD3, as the smallest object which can be distinguished becomes larger with the decrease of the LoDs (see Table 1).

Since LoD1 is the well-known block model without any roof structures, the remaining walls after the simplification of ground plan will be covered with a flat plane. In the simplest case all walls are equally high. The flat roof plane might be identical with the ground plan, however with the same height as the walls. Otherwise, the height of the highest wall (or the height of the boundary box) will be taken for the flat roof plane. The lower walls will be stretched to the height of the flat roof plane.

In the next step, the exterior shell will be extracted according to the algorithm in (Fan et al. 2009). The remaining polygons will be modelled as one solid (or *MultiSurface*) at LoD1, resulting a complete the block model.

Implementation and results

The above described algorithm has been implemented and tested on a number of 3D buildings modelled at LoD4 or LoD3 of CityGML. The experiments showed that the presented approach allows an automatic and efficient derivation of different LoDs from the higher LoD model.

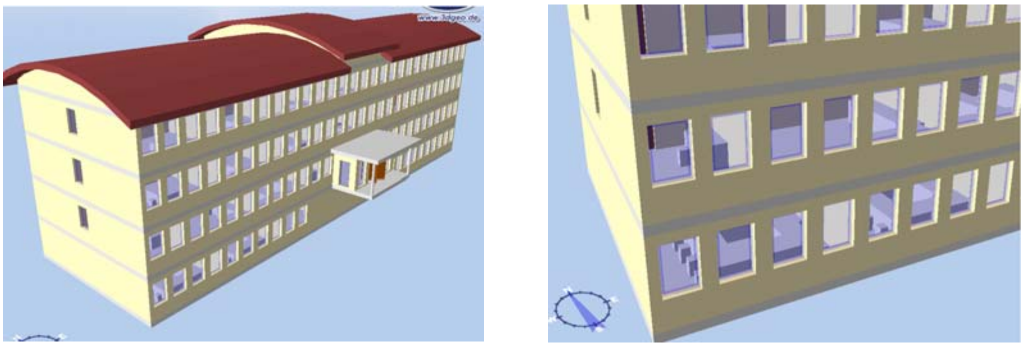


Fig. 4. Original building and the view of inside objects modeled at LoD4 visualized visualized in Autodesk LandXplorer CityGML Viewer

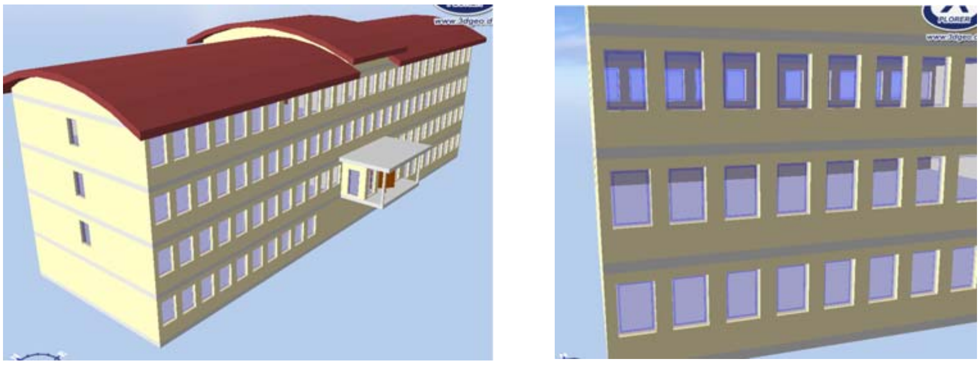


Fig. 5. The derived building model at LoD3

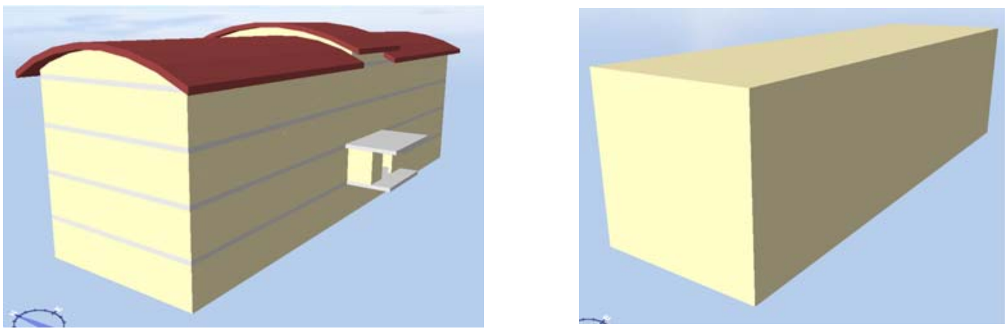


Fig. 6. The derived building model at LoD2 and LoD1

Figure 4 shows the original building (left Figure) and the interior furniture (right Figure) of an artificial office building modeled by Institute for Applied Computer Science Karlsruhe, Germany. The building model at LoD3 was obtained after eliminating interior objects (Figure 5). From the LoD3 model the opening object like windows and doors were separated and removed at first. Then the resulted holes were filled by deleting the corresponding <*gml:interior*> polygons. After this step the facades and the building installation were generalized using $S_T = 4\text{m}$ as threshold. In our case the two pillars in front of the main door was removed, because their diameters are smaller than four meters. As the result a building model at LoD2 was obtained (left image in Figure 6). The right image of Figure 6 shows the LoD1 building model derived from the LoD2 model according to the algorithm described in the former section.

Conclusion and outlook

The paper presented an approach for deriving 3D building models at different levels of detail modeled by CityGML. The approach starts from the most detailed 3D building models at LoD4 which is progressively transferred to LoD3, LoD2 and LoD1. The algorithms were developed on the basis of a precise study on the definitions of the four levels of detail (LoDs) for building modeling and the inside structure of the CityGML.

As the title of this paper is already implicated, the developed algorithm is specified for building models modeled by CityGML. CityGML not only represents the shape and graphical appearance of 3D buildings but specifically addresses the object semantics and the representation of thematic properties, taxonomies and aggregations. The presented approach takes this advantage into account. In other words, the process of the generalization and simplification deals with the 3D geometries of buildings while considering the corresponding semantic information.

The developed algorithm has been implemented under the Matlab environment. The input data should be buildings modeled at least higher than LoD1. The output could be at different LoDs that are lower than the input model. The experiments showed that the presented approach allows an automatic and efficient derivation of different LoDs from the most detailed model. Moreover, the program can not only handle single buildings, but also groups of buildings.

Originally, in CityGML the four levels of detail (LoDs) of building models are defined for different applications respectively. However, there is a substantial information change and reduction when LoD2 models are derived from LoD3 models. In the nearest future, a certain number of subLoDs will be defined between LoD2 and LoD3. And the algorithms developed in the previous work (Fan et al. 2009) of 3D generalization for 3D buildings modeled by CityGML will be integrated in the current approach.

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