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An improved LOD specification for 3D building models

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ABSTRACT

The level of detail (LOD) concept of the OGC standard CityGML 2.0 is intended to differentiate multi-scale representations of semantic 3D city models. The concept is in practice principally used to indicate the geometric detail of a model, primarily of buildings. Despite the popularity and the general acceptance of this categorisation, we argue in this paper that from a geometric point of view the five LODs are insufficient and that their specification is ambiguous.

We solve these shortcomings with a better definition of LODs and their refinement. Hereby we present a refined set of 16 LODs focused on the grade of the exterior geometry of buildings, which provide a stricter specification and allow less modelling freedom. This series is a result of an exhaustive research into currently available 3D city models, production workflows, and capabilities of acquisition techniques. Our specification also includes two hybrid models that reflect common acquisition practices. The new LODs are in line with the LODs of CityGML 2.0, and are intended to supplement, rather than replace the geometric part of the current specification. While in our paper we focus on the geometric aspect of the models, our specification is compatible with different levels of semantic granularity. Furthermore, the improved LODs can be considered format-agnostic.

Among other benefits, the refined specification could be useful for companies for a better definition of their product portfolios, and for researchers to specify data requirements when presenting use cases of 3D city models. We support our refined LODs with experiments, proving their uniqueness by showing that each yields a different result in a 3D spatial operation.

1. Introduction

The level of detail (LOD) of a 3D city model is one of its most important characteristics. It denotes the adherence of the model to its real-world counterpart, and it has implications on its usability (Biljecki, Ledoux, Stoter, & Zhao, 2014b).

The CityGML 2.0 standard from the Open Geospatial Consortium (2012) defines five LODs. The concept is intended for several thematic classes of objects but it is primarily focused on buildings, and the five described instances increase in their geometric and semantic complexity (Fig. 1). LOD0 is a representation of footprints and optionally roof edge polygons marking the transition from 2D to 3D GIS. LOD1 is a coarse prismatic model usually obtained by extruding an LOD0 model. LOD2 is a model with a simplified roof shape, and where the object's parts can be modelled in multiple semantic classes (e.g. roof, wall). LOD3 is an architecturally detailed model with windows and doors, being considerably more complex than its preceding counterpart. LOD4 completes an LOD3 by including indoor features (Kolbe, 2009). This taxonomy has been developed in the German Special Interest Group 3D (SIG 3D) initiative (Albert, Bachmann, & Hellmeier, 2003), and has been further described in Gröger and Plümer (2012). The five LODs have become widely adopted by the stakeholders in the 3D GIS industry and they now also describe the grade and the design quality of a 3D city model, especially its geometric aspect (i.e. "how much detail should be acquired?"). They have gained importance also in the computer graphics (Verdie, Lafarge, & Alliez, 2015; Musialski et al., 2013), and BIM (Tolmer, Castaing, Diab, & Morand, 2013) communities when dealing with 3D building models.

The LOD concept of CityGML is primarily intended to differentiate the grade of data resulting from different production workflows, and they are driven by semantics as much as geometry. In the industry and research community they were accepted from the outlook on geometric richness, which was partly caused by the lack of applications that require semantics. For instance, we have observed that while the LOD2 from the point of view of CityGML developers represents a model with differentiated semantic surfaces, practitioners primarily refer to models with roof shapes, even when not dealing with data that is semantically structured.

While the five LODs generally provide a categorisation of the overall level of abstraction, content, value, and usability of 3D city models, this classification has several drawbacks and shortcomings as we show in Section 2. Since the specification is crucial among practitioners and

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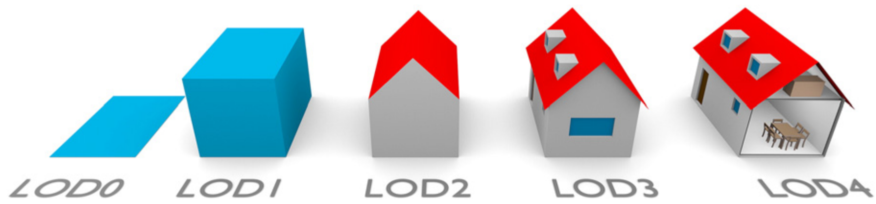

Fig. 1. The five LODs of CityGML 2.0. The geometric detail and the semantic complexity increase, ending with the LOD4 containing indoor features.

researchers for conveying the grade of a 3D city model and its adherence to the real-world, in this paper we present a refined specification to solve such problems. It should be noticed that the topic of refining and improving the current specification of the LODs is currently under consideration in the CityGML community for version 3.0 (Machl, 2013; Löwner & Gröger, 2016), and we hope that our proposal will help the discussions. However, our work is intended to be independent of any particular 3D format, and applicable to any format that can be used to store 3D building models, including ones such as COLLADA and OBJ.

In Fig. 2 we give an example of the shortcomings of the current concept, from the point of view of the geometric detail. The figure illustrates two LOD2 models: the model on the left has been acquired with two acquisition techniques, the walls are at their actual location and the roof overhangs are explicitly present. The representation in the middle has been acquired with one technique (aerial photogrammetry) where the walls are derived as projections from the roof outline (the third model will be introduced in another example in the following section). This example illustrates how the CityGML LOD concept is ambiguous and that it falls short in defining the complexity of the models: the two models are of the same LOD (LOD2) according to CityGML while the first one is more laborious to acquire and it may bring better results in a spatial analysis (e.g. more accurate volume; see Biljecki, Ledoux, Stoter, & Vosselman, 2016). Hence, practitioners would not consider them to be of equal value and usability. For these reasons we argue in this paper that they should be considered as different LODs, and our specification differentiates such cases.

This ambiguity is most evident in the production of the models. For instance, in 3D generalisation where researchers produce multiple geometric variants of LODs and discuss the ambiguity, among others see Guercke, Götzelmann, Brenner, and Sester (2011), Fan and Meng (2012), Stoter et al. (2011), Noskov and Doytsher (2014), and Deng et al. (2016).

Solving the ambiguity is also important considering: (1) the increasing number of acquisition techniques (e.g. the recently investigated being drones (Nex & Remondino, 2013), radar (Zhu & Shahzad, 2014), handheld devices (Rosser, Morley, & Smith, 2015; Sirmacek & Lindenbergh, 2014), procedural modelling (Wonka, Wimmer, Ribarsky, & Sillion, 2003; Müller, Wonka, Haegler, Ulmer, & van Gool, 2006; Kelly & Wonka, 2011; Müller Arisona, Zhong, Huang, & Qin, 2013; Tsiliakou, Labropoulos, & Dimopoulou, 2014; Smelik, Tutenel, Bidarra, & Benes, 2014), conversion from BIM and computer graphics models (Donkers, Ledoux, Zhao, & Stoter, in press; Kumar, Saran, & Kumar, in press), and generation from 2D drawings (Gimenez, Hippolyte, Robert, Suard, & Zreik, 2015)); (2) the number of data producers and national mapping agencies requesting 3D data is increasing (Stoter et al., 2015), and without a finer specification data producers and users may resort to creating their own specifications (e.g. see the series from Blom, 2011), which might increase the ambiguity; (3) the increase in quantity of data sets with non-homogenous LODs (Fan, Zipf, Fu, & Neis, 2014; Touya & Reimer, 2015; Arroyo Ohori, Ledoux, Biljecki, & Stoter, 2015a); and (4) use cases have different requirements when it comes to the complexity and quality of the data. Furthermore, the number of 3D use cases is rapidly increasing (Biljecki, Stoter, Ledoux, Zlatanova, & Çöltekin, 2015b), for instance — solar potential estimation (Freitas, Catita, Redweik, & Brito, 2015), studying the thermal characteristics of the outdoor space (Maragkogiannis, Kolokotsa, Maravelakis, & Konstantaras, 2014), firefighting simulations (Chen, Wu, Shen, & Chou, 2014), and advances in multi-scale navigation (Hildebrandt & Timm, 2014). Each of these use cases may have different requirements when it comes to the LOD of the models.

In this paper we improve the geometric aspect of the LOD specification of 3D building models. We provide an extended and more informative series of 16 LODs that are compatible with the existing CityGML LODs. The refined taxonomy is a result of a research into currently available 3D city models and an investigation of the acquisition workflows. We review related work on this topic (Section 3), and for each LOD we give requirements and show an example (Section 4).

We have generated a sample data set in 16 LODs and run them through a few GIS operations to show that each LOD is unique from a geometric point of view and may bring different results in a spatial analysis (Section 5).

In this paper we focus on the exterior of buildings (i.e. their exterior shell in LOD0–3). The refinement of the indoor and semantics aspect of the specification can be considered as orthogonal topics to this one. These topics are being tackled by other researchers who decompose it into different levels of abstraction and integrate them into expanded LOD1, LOD2 and LOD3 models (for examples see the work of Boeters, Arroyo Ohori, Biljecki, and Zlatanova (2015) and Löwner, Benner, Gröger, and Häfele (2013)). While the semantic LOD and indoor LOD are out of scope of our paper, present work on these topics is compatible with our work because such specification can be supplemented to ours. For instance, each of the newly refined

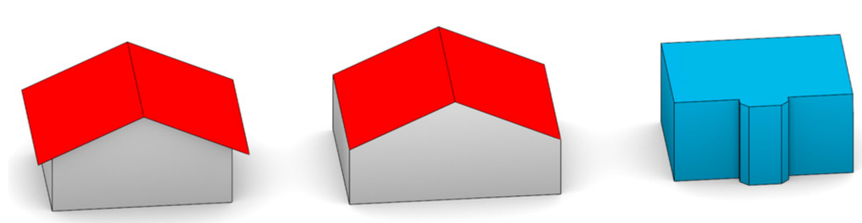

Fig. 2. Two variants of LOD2 and an LOD1 model exposing the shortcomings of the CityGML LOD concept, and why the computer graphics principles cannot be fully applied to GIS and 3D city modelling.