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Formalisation of the level of detail in 3D city modelling

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ABSTRACT

The level of detail in 3D city modelling, despite its usefulness and importance, is still an ambiguous and undefined term. It is used for the communication of how thoroughly real-world features have been acquired and modelled, as we demonstrate in this paper. Its definitions vary greatly between practitioners, standards and institutions. We fundamentally discuss the concept, and we provide a formal and consistent framework to define discrete and continuous levels of detail (LODs), by determining six metrics that constitute it, and by discussing their quantification and their relations. The resulting LODs are discretisations of functions of metrics that can be specified in an acquisition–modelling specification form that we introduce. The advantages of this approach over existing paradigms are formalisation, consistency, continuity, and finer specification of LODs. As an example of the realisation of the framework, we derive a series of 10 discrete LODs. We give a proposal for the integration of the framework within the OGC standard CityGML (through the Application Domain Extension).

1. Introduction

The concept of level of detail (LOD) is essential in 3D city modelling. It is used to define a series of different representations of real world objects, and to suggest how thoroughly they have been acquired and modelled. Although the background and intention of the concept are intuitively recognised, in 3D city modelling the term LOD has been borrowed from 3D computer graphics and accepted without much discussion. In this paper we argue that the term of LOD in 3D city modelling is currently incoherent, and that it is different from the one in computer graphics. It does not have a significant overlap other than the goal of the selection of a model sufficient for accomplishing a required task while balancing computational, economical and cognitive limitations (Çöltekin & Reichenbacher, 2011; Luebke et al., 2003; Mao, 2011).

While the term is prevalent in several papers in the GIS research community, it is influenced by computer graphics and its meaning often differs. For instance, Meng and Forberg (2007) define LOD as a uniform number of milestones along the scale space when taking the scale space as a linear continuum. For Glander and Döllner (2008) it is a degree of generalisation. Forberg (2007) expresses that it as a common way to enhance the performance of interactive visualisation of polyhedral data. According to Sester (2007) and Goetz (2013) LODs are multi-scale models for different applications. Lemmens (2011) equals it to the term of resolution and states that it is related to how much detail is present in the data and may refer to space, time and semantics.

As explained in Section 2, the LOD in 3D city modelling serves as a specification-related instruction for the acquisition, modelling, generalisation and exchange of spatial data. This is in contrast with computer graphics where models are simplified to their coarser counterparts in a dynamic process. Moreover, LODs of 3D city models do not differ only by the amount of data, richness of *details* and visual properties, but may also define the semantics, and the complexity of buildings and other city objects required for different applications (Gröger & Plümer, 2012). While researchers recognise that there are no universally agreed LODs for 3D buildings and other objects comparably to the 2D topographic maps that have official scale series (Meng & Forberg, 2007), there is still not much work on the formalisation of LOD, i.e. a fundamental discussion that would standardise and unify the different approaches.

The CityGML 2.0 standard of the Open Geospatial Consortium (2012) contains the *de facto* LOD concept of 3D city modelling, developed by a Special Interest Group 3D (SIG3D) initiative (Albert, Bachmann, & Hellmeier, 2003; Gröger et al., 2004;

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Gröger et al., 2005). The specification of LOD for CityGML establishes quality classes for data acquisition, and the model's LOD roughly reflects the model's complexity and accuracy (Kolbe, Gröger, & Plümer, 2005; Kolbe, Nagel, & Stadler, 2009). However, as it is the case with other standards, the LOD concept of CityGML has deficiencies, and discussions for its improvement are undergoing (Benner, Geiger, Gröger, Häfele, & Löwner, 2013; Löwner, Benner, Gröger, & Häfele, 2013).

The goal of this paper is to formalise the concept of LOD in 3D city modelling, and to provide a framework for specifying LODs. Lacking a definition, specification, and a universal standard, the current LODs cannot be compared, translated, sorted, and evaluated. This leads to ambiguity in the communication of the acquisition–modelling properties of a 3D city model between users and producers.

We define the LOD of a 3D city model as the degree of its adherence to its corresponding subset of reality. In this paper we decompose the LOD into six metrics that may be defined by continuous functions (Section 3), yielding a continuous LOD approach. In this view, the LODs are discretisations from a series of functions of such metrics (Section 4). We argue that in such case the traditional term LOD might be misleading. However, we do not propose linguistic modifications because we are aware that the current term is deeply ingrained in the GIS community. We show the example of the implementation of the framework resulting in ten discrete LODs. Finally, a proposal for the integration within CityGML is made (Section 5).

2. Analysis of existing concepts and the need for an LOD definition

We have evaluated different 3D city model representations and LOD concepts found in academia, standards, products and guidelines (Section 2.1), and we have made an analysis and summarised their shortcomings in Section 2.2. We have found that these standards are essentially different not only by their specification, but also by their driving metrics, targeted usage, and arrangement of thematic classes and elements. In total, 26 level of detail paradigms comprising 79 mutually exclusive LODs have been evaluated.

2.1. Analysis of the concepts of LODs

CityGML defines five discrete LODs (LOD0–4), which are differentiated mostly by the complexity of the geometries. The LOD0 is a digital terrain model with building footprints, and no volumes are present. Subsequent LODs are improving in terms of the complexity of objects in the geometric and semantic sense. The LOD4 adds interior geometry, but otherwise it retains the same properties as LOD3. The textures can be added to any LOD (i.e. the texture is not part of the LOD specification), and generalisation of the geometry is vaguely described and seldom implemented. The standard includes different thematic classes, e.g. buildings, roads, and vegetation.

The progress of the LODs is not consistent: the first LOD is 2.5D only, while LOD1–3 improve the exterior geometry, and LOD4 adds one level of detail of the interior, that is indeterminate. Therefore, instead of five LODs, with respect the 3D city models and exterior geometry, there are three distinguished LODs with different flavours.

CityGML partly owes its popularity to this simple and straightforward LOD concept. However, we argue that this concept has shortcomings and drawbacks, making it unsustainable as the number of producers, applications, and users grow. Researchers are aware of the deficiencies, and as of the production of this paper, discussions about the improvements of the LOD concept for the next version of CityGML (v. 3.0) are undergoing (Machl, 2013).

National mapping agencies recently started adopting 3D city modelling standards. Examples include the Netherlands (Stoter et al., 2013), whose standard is tied to CityGML, and China (Chinese Ministry of Housing & Urban-Rural Development, 2010) developed from scratch not basing their model on any international standard. The Dutch standard extends CityGML classes and attributes, being more precise in the specifications. It also gives recommendations for the textures. The Chinese standard contains four LODs, and defines which topographic objects should be modelled, and their thresholds (minimum size). The building LODs are defined by accuracy and basic description of the geometry. Also, different models have different requirements for the texture resolution.

In academia, especially in the field of 3D generalisation, there are different specifications of the discrete LODs (Meng & Forberg, 2007). For instance, Thiemann (2003) defines three LODs for settlements and buildings: LOD1 contains aggregated settlement blocks with a uniform height, LOD2 blocks of the individual buildings without roof form, and LOD3 is LOD2 enhanced with a simplified roof form. Schilcher, Roschlaub, and Guo (1998) describes three LODs for individual buildings: LOD1 is a model popping up of the ground plan to a uniform height, LOD2 is LOD1 enhanced with a standard roof form, and LOD3 is an LOD2 enhanced with photorealistic textures and small surface features.

A few companies offer product portfolios of off-the-shelf 3D city models or for integration in a product (e.g. navigation software). Examples include Blom ASA (2011), Vertex Modelling (2013), NAVTEQ (2011), CyberCity 3D (2013), Sanborn (2013), and TeleAtlas (Vande Velde, 2005). The companies offer a few LODs (in all cases five or less), which are distinguished by the wealth of details and/or textures, and where landmarks have a special status. The semantics and the required accuracy are seldom specified. Further, some companies offer additional adaptation and customisation of their models to fit the needs of their clients, making these LODs rather generic guidelines and frames of a final product later to be agreed by the two parties. However, most of the producers of 3D city models do not advertise their models in form of a series of LODs with a description and usage recommendation for each. Their internal standards serve rather as a general frame, and may differ for each client or project. By direct inquiry, we have obtained the modelling specifications of a few companies. They are essentially different but commonly contain a few LODs where the texture is not a part of an LOD specification.

The popular applications on smartphones for personal navigation, such as Google Maps and Apple Maps, recently started including 3D city models for their 3D visualisation mode. They contain up to two LODs distinguished by the complexity of the geometry and appearance.

We have studied a few tenders for the procurement of 3D city models, and publicly available models maintained by local authorities, such as the ones from the Glasgow City Council (2009), Lusail in Qatar (Hochtief ViCon, 2011), and Australian cities: City of Wollongong (2010), City of Perth (2013), and Adelaide City Council (2009). The tender specifications of 3D city models define one LOD, and are often not detailed: they rather specify the minimum requirements for the deliverables, e.g. minimum accuracy, which features of a building should be included, and a set of library roofs to be used.

For this paper, we have also studied specific cases which cannot be accomplished and fit in a multi-purpose LOD specification as are most of the above paradigms. These include the integration of the interior in a CityGML LOD2 model (Boeters, 2013), mixing LOD for buildings of different types (Glander & Döllner, 2009), and further, mixing CityGML LODs in the same object (different LODs for the