Overview of the PhD research: the concept of level of detail in 3D city modelling

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1 Introduction

Level of detail (LoD) is a concept pioneered by Clark [1], and nowadays it is available in various disciplines from computer graphics and cartography to electrical circuit design. For GIS practitioners, the discipline where level of detail is most relevant and well known is 3D city modelling.

However, despite the widespread usage of LoDs, there is a number of shortcomings and the topic is not yet researched throughly.

For instance, the concept of level of detail vary in 3D city modelling and it is not officially standardised. There are standards such as CityGML (OGC), however, their concepts significantly differ from each other and there is no consensus on LoD: it is not unambiguous what an LoD is in 3D city modelling, and there is not a single and widely-accepted LoD paradigm in 3D city modelling. There are no guidelines, and it is not clear what drives the LoD, and technical specifications such as accuracy and precision requirements are not addressed for a certain level of detail. In short, the philosophy and the criteria that drive the level of detail in 3D city modelling are vague and undefined.

From a computer graphics perspective, continuous level of detail, and mixed scale (perspective-view) are not investigated in GIS for 3D City Modelling, and current implementations of 3D city models (e. g. CityGML) are limited to a certain number of discrete levels of detail.

Considering the applications, the number of LoDs in most standards is limited for a number of applications, and there is no LoD concept which adapts based on the application. Further, the acquisition, storage, manipulation and generation of multiple and different levels of detail is usually redundant, inconsistent, not linked, and it requires separate operations, which in practice yields high costs. There are obvious computational challenges with current LoD approaches, primarily redundancy.

Addressing and resolving these issues have both academic and business advantages.

This PhD research aims to improve the concept of level of detail in 3D city modelling through (1) its formalisation in a definition, (2) modelling it as a spatial dimension, i. e. in a space-scale hypercube, (3) definition of contexts with use-cases which take into account the environment in which level of detail are needed, and (4) generation of pseudo-continuous levels of detail which are customised for an application. The main research question that this research will answer:

> How should we treat, model and include the level of detail in 3D city models and what implementations are possible?

This research will be conducted over a period of 48 months with a dissertation as its principal deliverable. This short paper gives a short overview of the research goals.

2 Methodology

The aim of this research is to provide a theoretical foundation to overcome the shortcomings presented in the previous section. In order to achieve that, this research is divided in the following parts (themes), and the described will be investigated:

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1. Definition of LoD: what is level of detail in 3D city modelling.
2. Hyper-cube integration: how to integrate the scale in a single entity as the fourth spatial dimension.
3. Context awareness: how to create a level of detail suited up exclusively for an application or context.
4. Generate customised LoDs: how to generate a continuous or discrete number of levels of detail from the space-scale hypercube taking into account the context.

These themes and their tasks are further described in the following sections.

2.1 Formal definition of level of detail in 3D city modelling

The main deliverable of this part of the research is a broad literature review, and a new definition of LoD both in the GIS and mathematical term which will serve as a foundation for the next steps in the research. The key research tasks and topics are:

A. Investigate current industry standards and the general theory and application of 3D city models.

B. Investigate acquisition and modelling techniques in the industry.

C. Selection of use-cases (applications). Research the industry needs of LoDs through questionnaires.

D. Define the LoD in the frame of 3D city modelling and GIS. The key task of this part of the research, and one of the research questions, is to produce our own definition of what an LoD in the frame of 3D city modelling and GIS is. The definition will be composed of a theoretical, mathematical, and linguistic view.

E. Separation of a level of detail into sub-levels and components. This research will decompose 3D city models into components which are meaningful for a specific context, or in general.

F. Make a clear distinction between LoD, scale, and possibly granularity.

G. Quantification and possible metrification of the LoD. From a relative view, with current ordinal scaled LoD approaches, it is not possible to define to put the levels in an interval or ratio scale, e. g. that LoD2 has twice the amount of detail than LoD1. Analysing absolutely, it is also not possible to quantify the amount of details, e. g. what means when a level has 60% of the detail. This task will aim to solve the above issues, and further: define the range and units with which a level of detail can be expressed.

2.2 Integration of levels of detail as a spatial dimension

In line with the 5D project, of which this research is an integral part, the integration of LoD (or scale) as a spatial dimension will be investigated. The integration of LoDs in a separate and stand-alone spatial dimension is not unknown in GIS (variscale, see the work of Meijers [2]). Basically, the goal of this part of the research can also be seen as the extension of the variable scale approach to one dimension higher [3], i. e. as the 4th dimension. Its tasks are as follows:

A. Investigate the applicability of a 4D model, and development of a hyper-dimensional foundation. This task will consist of the research of hyper-dimensional theories and their applicability to this research.

B. Creating the 3D+Scale hypercube. In order to understand the integration of scale as the fourth spatial dimension, the Figure 1 shows an example: a simple cube-like house with a door in a pseudo-4D view. Two levels of detail are stored: a finer one (blue), and a coarser (black), where the door in both levels (green) has a different level of detail. The two levels are *linked* through a fourth spatial dimension (red).

C. Implementation of the quantification (and metrification) of LoDs. The Figure 1 does not address the metrification of the fourth axis.

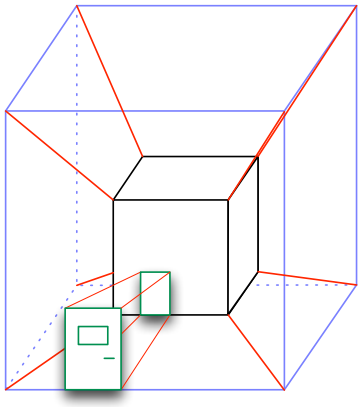

Figure 1: Storing two levels of detail in a 4D tesseract-like object.

Since the LoDs are integrated as a spatial dimension, they should be placed on a spatial axis, hence the dimensions should be discussed as well. Each LoD should be placed in its *place* on the *scale axis*. This mostly depends on the last step of the previous theme *Quantification and possible metrification of the LoD*.

D. Maintaining the relationships between features through a hierarchy of rules. Another key task is to link the relationships between features. The discussed example shows two LoDs in hyperspace, however, they could also be seen as *floating* in hyper-space, as they are not fully linked.

E. Automatic generation of supplementary levels of detail. The above relationships will require the generation of supplementary levels of detail, i. e. auxiliary projections in hyperspace.

F. Integration of texture and interior. The last part will investigate how to integrate the texture and the interior in the developed methodology.

2.3 Context awareness

The current LoD paradigms do not take into account several factors on which the LoD depend. We call this context, and it can be considered as one of the pillars of this research.

The view of this research is that each application requires different features in different detail, and having a uniform LoD paradigm in that sense leads to redundancy (some of the features are not needed) and on the other hand also loss of the information (some of the features should be detailed even in the coarsest LoDs).

For instance, in estimating the solar potential, features as windows and doors are not relevant and can be omitted in all levels.

This theme has the following tasks:

A. Constitution of a context and the factors: this task will investigate the prominent factors which constitute the context in the frame of this research (e. g. field of view, distance to the observer, computational aspects, application needs).

B. Investigation of use cases and quantification. Taking into account application needs and developing rules based on use-cases.

C. Investigating the effects of the usage of different LoDs

Computation-wise, different LoDs yield different results in most of the applications. For example, using a CityGML LoD1 in calculating the shadow effect will in many cases have different results than using LoD2 due to the presence of the roof structure.

2.4 Generation of customised levels of detail

The final theme will deal with the generation of levels of detail from a 4D hypercube taking into account the context in order to generate customised levels of detail suited for an application:

A. General slicing (scale-stamping). This task will deal with the construction of a foundation for hyper-slicing in order to generate new levels of detail. As an example, Figure 2 shows a pseudo-4D view where scale is integrated as a 4th dimension, and the generation of a new level of detail is done through slicing the hyperspace with a hyper-plane.

B. Integration of rules in slicing. Beside general slicing, in order to generate the customised LoD, the context should be taken into

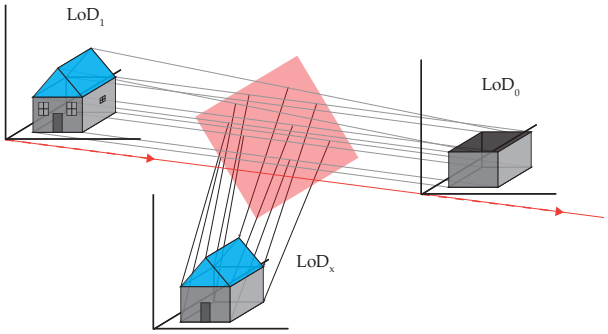

Figure 2: *Slicing* an new intermediary level of detail between a finer and coarser level in 4D.

account. The context awareness can be expressed through weights, where each feature is given importance.

C. Context-aware generation of levels of detail. This part will include the visualisation of newly generated levels of detail.

D. Assessment of continuous levels of detail. If continuous levels of detail will not prove feasible, then discrete levels will be generated, and their number will be investigated according to each use-case.

3 Conclusion

The key topic of this research is level of detail in 3D city modelling. This research will attempt to address the presented shortcomings of LoD, and improve some of the concepts. The academic benefits of this research are:

- A new refined definition of LoD
- Basis for an international standard
- Creation of context-aware levels of detail
- Storage of all levels in a single data model
- Stronger link between multiple LoDs (interlinking)

while the computational benefits are:

- Storage of less levels of detail
- More effective querying
- Removal of redundancy

This research will have benefits in practice, such as:

- Acquisition and maintenance of just one representation.
- Scalability of a dataset for different applications, and data representation focused for one application

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