Generalising 3D Buildings from LoD2 to LoD1

Anna Labetski[*], Hugo Ledoux[†]and Jantien Stoter[‡]

3D Geoinformation, Delft University of Technology

January 13, 2017

Summary

The increasing popularity of 3D city models in navigation, urban planning, etc., necessitates application-specific and geometrically accurate and valid models. The concept of Levels of Detail (LoDs) indicate a model's scale of adherence to its real-world counterpart. Highly detailed datasets often contain errors or require an exorbitant level of computing power. Given the high availability of LoD2 datasets, our research focuses on three considerations for generalising to LoD1: the vertical reference, extrusion vs. downtrusion and floor plan simplification. We present in this paper an initial methodology that produces geometrically accurate LoD1 models with a reduction of over 70% of the original file size.

KEYWORDS: Generalisation, 3D, City Model, CityGML, Levels of Detail

1   Introduction

There is an increased usage of 3D city models within a wide array of applications ranging from disaster management, urban planning, navigation and noise emission, to name a few (Baig and Rahman, 2012). These models can be created and stored at different Levels of Detail (LoD). A model's LoD is an indicator of its adherence to its real-world counterpart and can indicate its usability within a specific application (Biljecki et al., 2016b). The international standard of the Open Geospatial Consortium for the representation and storage of 3D city models is CityGML (Open Geospatial Consortium, 2012); it defines the geometry, topology, semantics and appearance of objects in 3D at five LoDs (Gröger and Plümer, 2012).

While it is desirable for city models to be as close to reality as possible, having more detail does not equate to having a better model. CityGML datasets without errors are rare and those with the least amount of error tend to be simple LoD1 models (Biljecki et al., 2016a). Errors can be introduced during data collection and processing or when models are created by merging together partial datasets created by different sources. Applications require error-free models, therefore it is

---

[*]a.labetski@tudelft.nl

[†]h.ledoux@tudelft.nl

[‡]j.e.stoter@tudelft.nl

sometimes better to have an error-free model at a lower LoD, rather than a highly detailed model of a questionable quality. Furthermore, not all applications require a high LoD but are rather task-specific and data volume dependent (Baig and Rahman, 2012). For example, noise emission simulation is computationally expensive and including the exact slope of roofs has little influence on the results, thus a LoD1 model is more appropriate. In Germany, mapping environmental noise pollution is done for the whole state of North-Rhine Westphalia based on CityGML LoD1 data containing approximately 8.6 million buildings (Kolbe, 2009). Different LoDs serve different applications so in order to maintain consistency across models it is desirable to derive a less detailed LoD from a highly detailed LoD (Arroyo Ohori, 2016).

Full-scale datasets of cities at LoD3 and LoD4 are in short supply, but there is increasing availability of LoD2 datasets. Despite this and the growing body of research in relation to generalising 3D buildings, there is a limited body of work in relation to the reduction of LoD2 city models to LoD1 specifically. Furthermore, there is a void in the standardisation of 3D generalising practices and their consistency across city models. These two limitations frame the scope of our research: *What are the most important considerations and approaches in generalising LoD2 buildings within a city model to application-specific and geometrically accurate LoD1 models?*

2 Related Works

There has been a large body of work on generalisation in cartography i.e. in the realm of 2D, and many of these methods have been applied towards generalising the floor plan of a building. One such method by Haunert and Wolff (2010) utilises a technique that simplifies each polygonal ring by selecting a subsequence of its edges. Other generalisation approaches include utilising semantic information to determine which building objects can be removed as a model descends down each level (Fan and Meng, 2009). A 3D specific generalisation approach, known as half space modelling, is explored by Kada (2006) and involves approximating planes from the polygonal faces and using them as space dividing primitives to create façades and roof structures that are of a simpler shape to the original input.

3 Considerations and Methodology

There is no 'one' perfect output after generalisation because the purpose is to create error-free models tailored for the requirements of a specific application. Generalisation is therefore case-specific and can result in *multiple* valid models that differ based on certain considerations. Our research focuses on three approaches: the geometric reference, extrusion vs. 'downtrusion' and floor plan simplification.

3.1 Geometric Reference

The first consideration in generalising from a LoD2 model to a LoD1 block model is determining the geometric reference. This concept can be defined as the boundaries of the captured feature determined for a specific model (Biljecki et al., 2016c). In this paper we focus on the vertical reference of a building (Figure 1). Our methodology allows multiple approaches for deriving these references based on the z values of roof and ground polygons; the possible indicators are mean, median, mode (with a test to determine if a true mode exists), maximum, minimum, percentile and percentage. Utilising the semantic information, the polygon faces of the roof are extracted and from these the eaves and ridges are identified. The z values from these are then included as the input for the calculation of the aforementioned indicators.
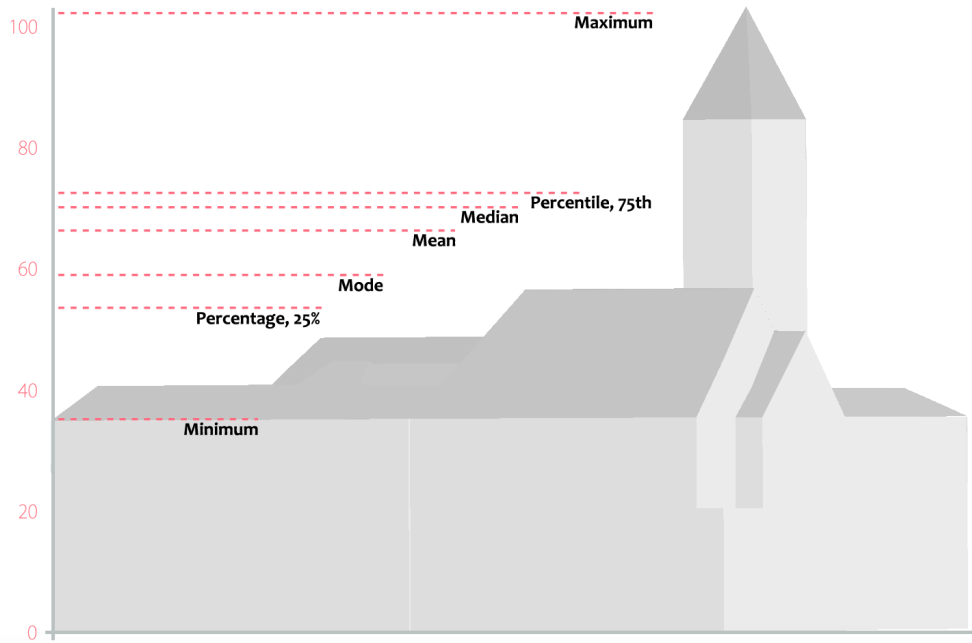

Figure 1: Example of potential roof vertical references for an individual building

3.2 Extrusion vs. Downtrusion

The next consideration in generalising from LoD2 to LoD1 is to determine which shape of the building should be prioritised for preservation: the floor plan or the roof plan. A union of all of the ground polygons or the roof polygons is performed in order to determine the perimeter of the building. If the ground is selected then the walls of the building will be created by extruding the building from its lowest vertical reference to its highest. Alternatively the building model can be constructed by 'downtruding' from the roof plan down to the base elevation of the building (Figure 2).
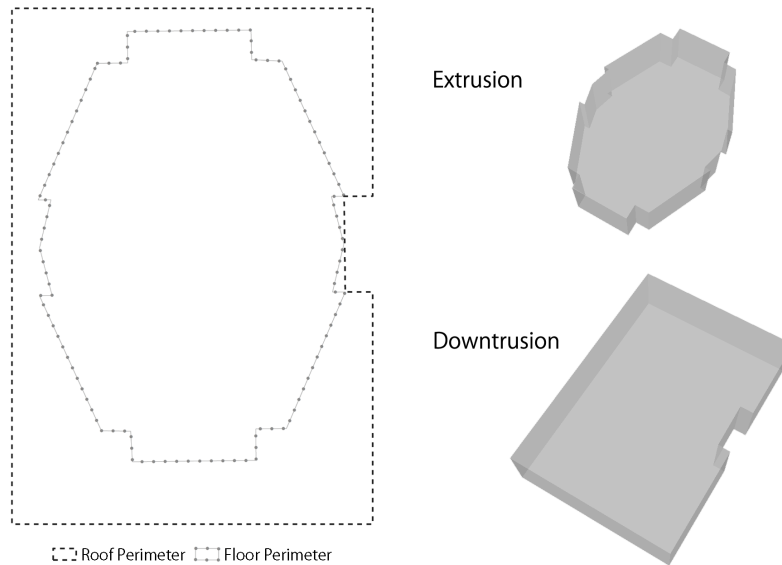
Figure 2: Extrusion and 'Downtrusion' possibilities for the same building

3.3 Floor Plan Simplification

The final consideration is the simplification of the floor plan itself which can be achieved through the process of reducing the number of vertices. Two such methods are explored here: the *Douglas-Peucker algorithm* (Douglas and Peucker, 1973) and Kada's cell decomposition Kada (2008). The *Douglas-Peucker* approach incorporates a tolerance/threshold level to inform line reduction by commencing with a line constructed with the first and last point of the original line and splitting it down until each segment is within the tolerance (Douglas and Peucker, 1973). The Kada (2008) method employs the decomposition of space along the major planes of the building and is controlled by the minimum size of the building elements generated, which in turn is informed by the intuitive distance threshold value. While Kada's methodology is explicitly 3D, the work of Commandeur (2012) adapted the method to generalise 2D footprints specifically (Figure 3). A further distinction between the two is that the *Douglas-Peucker* approach does not enforce a rectangular shape while the Kada method does.

4 Experiments and Results

4.1 Context

This research experimented with a dataset of a portion of Berlin, Germany as the case study: the borough of Neukölln. The CityGML dataset contains LoD2 buildings only and includes semantic information, which informs us of the location of the roof, the walls and the ground for each building.

Douglas-Peucker
epsilon = 2

Kada
Tolerance: distance = 1 m, angle = 5°
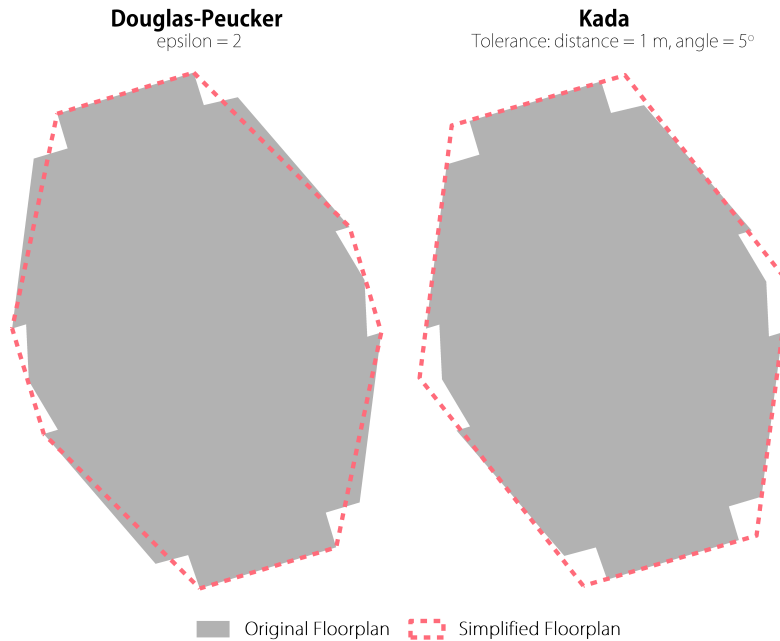
Original Floorplan   Simplified Floorplan

Figure 3: Comparison of the Douglas-Peucker and Kada floorplan simplification methods

There are 3508 buildings of which 1317 (37.6%) were found to be geometrically invalid after validating with the CityGML validation tool *val3dity*[1] (Ledoux, 2013); errors ranged from non-watertight buildings to surfaces being incorrectly oriented.

4.2   Final Output

The generalisation methodology was implemented in a working prototype utilising Python 2.7 and experimenting with various combinations of the three considerations. The generalisation results are returned as a geometrically valid LoD1 model in the CityGML format, with accompanying CSV files storing the range of roof and ground z values per building (Table 1). The output contains one block model for each building in the original dataset, this is in contrast to the input dataset where some buildings were stored as multiple individual components per building. Crucially, the file also contains a description of the generalisation parameters (eg. vertical reference) and sensitivities (eg. Kada's tolerance values), as well as the parameters and building IDs from its parent file to maintain metadata information. With the Neukölln dataset, across experiments, reductions of at least 70% were observed. In one case, the original file size of 992.4 MB was reduced by 71% to 286.5 MB, utilising a mean vertical reference, extrusion and no floorplan simplification.

---

[1]http://geovalidation.bk.tudelft.nl/val3dity/

Table 1: Sample of Roof Geometric Reference Values from the CSV output

Building	Mean	Median	True Mode	Mode	Max	Min	Range
BLDG0003000b004fr47e	54.80	55.21	T	53.10	56.76	53.10	3.66
BLDG0003000b0047624a	52.13	52.13	T	48.96	55.29	48.96	6.33
BLDG0003000b004e466b	44.08	44.10	T	46.70	46.70	41.45	5.25
BLDG00030000009d2ff4	44.02	44.02	T	46.89	46.89	41.16	5.73
BLDG0003000b005589a8	43.15	43.15	T	43.15	43.15	43.15	0.00

5   Discussion and Future Work

The primary challenge in our methodology presents itself in the generalisation of groups of buildings and the preservation of topological relationships during the process. Currently the generalisation methods focus on buildings individually but there are potential opportunities in generalising further by aggregating groups of buildings with near identical height into one block model, eg. terraced houses (Figure 4). We intend as a future line of questioning, to extend floor plan generalisation to not only incorporate more methods, such as non-linear approaches for suitably dealing with circular buildings, but also to generalise on a city scale. This challenge extends further when consideration is paid to other city objects such as roads, bridges and vegetation, to name a few. Our future work will aim at generalisation approaches being applicable to all manner of objects while retaining spatial integrity.
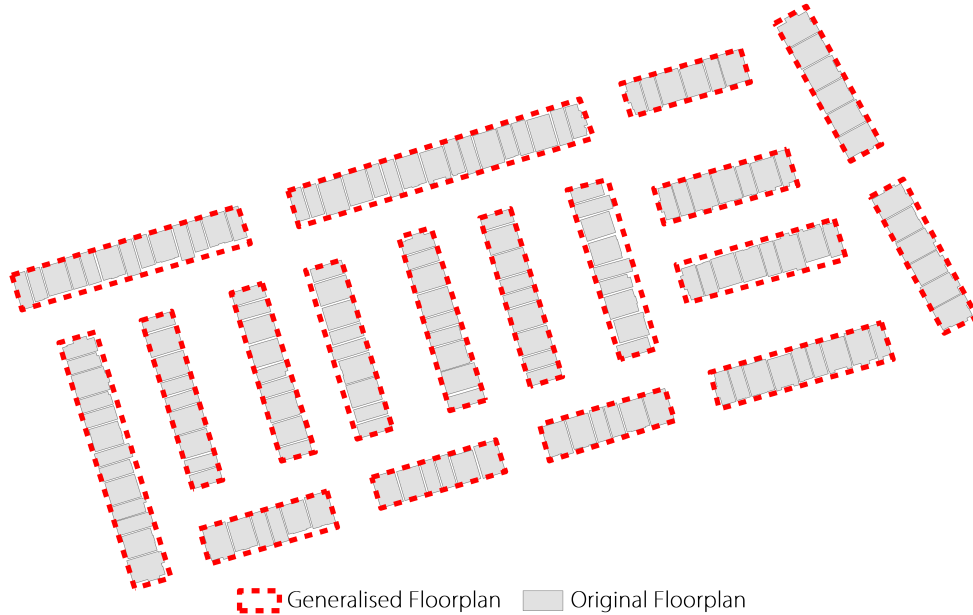

Figure 4: Floorplan of terraced houses simplified into aggregate building blocks

Experimenting with the various parameters for determining a vertical height identified a gap in utilising a traditional LoD1 model exclusively. Calculating the vertical reference of a building generates a value indicating the range of z values; a large range identifies buildings with multiple roof heights that vary considerably. A solution for preserving the integrity of these situations would be to incorporate an extension to the LoD1 model, LoD1+. This would continue to utilise exclusively flat roofs (a requirement of LoD1) but would also incorporate building partitioning into segments based on the various roof heights in order to preserve these variations. Churches with large towers represent potential LoD1+ candidates, Figure 5 demonstrates one such case.
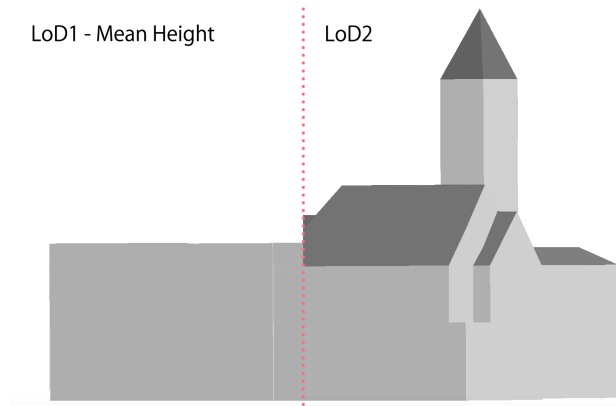

Figure 5: Example of a building with a significant range in roof z values

Generalisation provides the opportunity to repair errors and inconsistencies in overly detailed models as well as simplifying data for application-specific usage. While there are multiple approaches to generalising models, ranging from utilising semantic data to floor plan partitioning, there is no current standardised methodology and evaluation. Our work has begun a process of stringing together the various approaches that already exist but future work will need to explicitly incorporate tracking the generalisation parameters and changes to link and compare datasets originating from the same source but employing varying techniques. To encourage reproducibility, comparability and standardisation an integration of generalisation parameters into metadata and furthermore into the CityGML standard will be a future requirement.

6   Acknowledgements

7 Biography

Anna Labetski is a first year PhD Candidate in the 3D Geoinformation group at TU Delft. She holds a Human Geography BA from the University of Toronto and an MSc in Geospatial Analysis from UCL. Her interests include statistics, open data, Python, spatial analysis and urban planning.

Hugo Ledoux is an associate-professor in 3D geographical information systems (GIS) at the Delft University of Technology in the Netherlands. He holds a PhD in computer science from the University of Glamorgan (Cardiff, UK) and a BSc in geomatics engineering from the Université Laval (Québec City, Canada). For his research, he is particularly interested in combining the fields of GIS and computational geometry. He is currently working on the validation and the automatic repair of polygons and polyhedra as found in GIS, the higher-dimensional modelling of geographical information (ie 4D+), and the smart simplification of LiDAR datasets.

Prof. dr. Jantien Stoter is full professor 3D Geoinformation, at the Faculty of Architecture and The Built Environment. She obtained her PhD degree (3D Cadastre) in 2004 and combines her professorship with jobs as researcher at both the Kadaster and Geonovum. She chairs the EuroSDR Commission "Data Modelling and Processing" and is leader of the national 3D SIG (Special Interest Group) as well as of the EuroSDR 3D SIG. Since March 2015, she is vice-chair of the OGC 3D Information Management Domain Working Group (OGC 3DIM DWG). Her research interests are 3D, automated generalization and information modelling. For her research on 5D data modelling she received the prestigious Vidi award of the Netherlands Scientific Foundation (NWO). In addition, she received a personal grant from the European Research Council (ERC) for her proposal Urban Modelling in higher dimensions.

References

Arroyo Ohori, K. (2016). *Higher-dimensional modelling of geographic information*. PhD thesis, Delft University of Technology. ISBN: 978-1-326-59638-5.

Baig, S. U. and Rahman, A. A. (2012). Generalization and visualization of 3D building models in CityGML. *Lecture Notes in Geoinformation and Cartography*, pages 63–77.

Biljecki, F., Ledoux, H., Du, X., Stoter, J., Soon, K. H., and Khoo, V. H. S. (2016a). The most common geometric and semantic errors in CityGML datasets. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-2/W1:13–22.

Biljecki, F., Ledoux, H., and Stoter, J. (2016b). An improved LOD specification for 3D building models. *Computers, Environment and Urban Systems*, 59:25–37.

Biljecki, F., Ledoux, H., Stoter, J., and Vosselman, G. (2016c). The variants of an LOD of a 3D building model and their influence on spatial analyses. *ISPRS Journal of Photogrammetry and Remote Sensing*, 116:42–54.

Commandeur, T. J. F. (2012). Footprint decomposition combined with point cloud segmentation for producing valid 3D models. Master's thesis, Delft University of Technology.

Douglas, D. H. and Peucker, T. K. (1973). Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 10(2):112–122.

Fan, H. and Meng, L. (2009). Automatic derivation of different levels of detail for 3D buildings modelled by CityGML. In *24th International Cartography Conference, Santiago, Chile*, pages 15–21.

Gröger, G. and Plümer, L. (2012). CityGML – interoperable semantic 3D city models. *ISPRS Journal of Photogrammetry and Remote Sensing*, 71:12–33.

Haunert, J.-H. and Wolff, A. (2010). Optimal and topologically safe simplification of building footprints. In *Proceedings of the 18th SIGSPATIAL International Conference on Advances in Geographic Information Systems - GIS*. Association for Computing Machinery (ACM).

Kada, M. (2006). 3D building generalization based on half-space modeling. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 36(2):58–64.

Kada, M. (2008). Generalization of 3D building models for map-like presentations. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVII:399–404.

Kolbe, T. H. (2009). Representing and exchanging 3D city models with CityGML. In *3D geo-information sciences*, pages 15–31. Springer.

Ledoux, H. (2013). On the validation of solids represented with the international standards for geographic information. *Computer-Aided Civil and Infrastructure Engineering*, 28(9):693–706.

Open Geospatial Consortium (2012). OGC City Geography Markup Language (CityGML) Encoding Standard 2.0.0.