Generalization of buildings within the framework of CityGML

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1 author:

Siddique Ullah Baig
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A three-step strategy for generalization of 3D building models based on CityGML specifications

Siddique Ullah Baig · Alias Abdul Rahman

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Abstract  3D building models of the world exhibit multi-scale properties. Different level-of-details (LoDs) are important for different applications. Therefore, generation of multi-scale representation of 3D building models to fulfill the demands of these applications is a generalization problem. In order to generalize 3D buildings, different pieces of information need to be preserved or removed to restrict the amount of data represented on a certain LoD. In this work, a three-step strategy based on simplification, aggregation and reconstruction of generalized buildings represented in City Geography Markup Language (CityGML) is proposed. The minimum length of edges (threshold value) for removal of amount of data is restricted to generalization specifications of CityGML characterized by differing accuracies and minimal dimensions of objects for each LoD. The main part of this paper is simplification of ground plans. For this purpose, a new approach is proposed to restrict number of edges, curves, and corners of ground plan of 3D building model on a certain LoD. Algorithms for simplification with the aim to derive LoD1 from exterior shells of buildings at LoD3 are implemented and tested on a number of buildings of Putrajaya city. The experiments showed that length of edge as threshold value is directly proportional to the size of generalized models.

Keywords  3D · Simplification · Aggregation · CityGML · City models

Introduction

City Geography Markup Language (CityGML) as Open Geospatial Consortium (OGC) standard is one of the modelling tool used to model and represent components of buildings such as outer shells, openings (windows, doors), outer building installations, interiors (chair, table, decorations, etc.) at different level-of-details (LoD1–LoD4) (Gröger et al. 2007). Furthermore, different LoDs of building models are important for different applications for efficient visualization and analysis purposes. But, direct rendering of these models can increase rendering time due to detailed data associated with buildings Mao et al. (2011). Therefore, generation of multi-scale representation of 3D buildings to fulfill the demands of these applications is a generalization problem. For this purpose, insignificant or detailed pieces of data need to be removed to restrict the amount of data on a certain LoD.

Several methods are applied to restrict the amount of data on a certain LoD by removing complicated
edges, points, corners, etc. of 3D building models. In some cases, removal of transitional vertices is made as basis of generalization or larger edges are trimmed or averaged and a shortcut based on displacement is created to replace larger lines with generalized lines. In order to simplify components of 3D building models, generalization strategy is tailored to define which edges or vertices need to be removed or replaced by generalized edges.

Ground plans of 3D building models consist of a combination of features like points, lines and curves. Simplification methods such as point-reduction (Douglas and Peucker 1973), edge move (Buchin et al. 2011) and removal/adjustment of shortest edge (Fan and Meng 2009, 2012; Mao et al. 2011; Sester and Brenner 2004) and (Baig and Rahman 2013) can be applied to simplify ground plans. Edge move is a local operator to preserve the orientation of the edge but can always be performed on a non-convex polygon while preserving area, orientation and topology (Commandeur 2012). Additionally, in edge move, the basis of generalization needs to be defined to determine which edges need to be removed/adjusted. Similarly, adjustment/removal of shortest edges cannot be applied on curves as curves cannot be stored in their original shape in geo-data structures similar to line or polygons. Therefore, independent methods are necessary to simplify specific parts of ground plan.

In this paper, a framework based on three-step strategy is proposed. These steps include simplification, aggregation and reconstruction operations. Size and shape of generalized buildings are restricted to CityGML generalization specifications. The main part of this research is simplification of ground plans. For this purpose, a new simplification approach is proposed to restrict number of lines, curves and corners of ground plan of 3D building model on a certain LoD. In case of curved shapes, vertices of edges are taken into account for simplification instead of edges while non-curved shapes are simplified based on removal of shortest edge approach. Curved parts of ground plans are transformed down to the level of points and certain transitional points are removed to generate generalized edges while edges are considered for non-curved shapes.

With the aim to complete generalization, simplified structures of ground plans of walls and roofs need to be adjusted accordingly. For this purpose, height of the bounding box or length of highest wall at LoD1 is considered.

Algorithms for generalization with the aim to derive LoD1 are implemented and tested on a number of buildings of Malaysian city of Putrajaya.

Generalization specifications of CityGML are discussed in Sect. 2 followed by a framework and workflow based on three-step strategy for generalization of 3D building models in Sect. 3. Implementation and result are described in Sect. 4. Finally, the concluding remarks are presented in Sect. 5.

**CityGML generalization specifications**

The important aspect of CityGML is generalization specifications provided for different LoDs. They are characterized by differing accuracies and minimal dimensions of objects. Table 1 shows all object blocks as generalized features with ground plans of at least 6 m × 6 m have to be considered in LoD1 while 4 m × 4 m in LoD2. In the detailed model at LoD3, the minimal size of side of generalized object should be 2 m × 2 m. Generalization specifications of CityGML for LoD1 are made as basis of generalization in this paper.

**Generalization framework and workflow**

The fundamental structure of the proposed 3D generalization framework is shown in Fig. 2. It consists of following four operations: extraction of exteriors from CityGML dataset; projection of exteriors as ground plans; generalization of ground plans and re-projection as generalized LoD. Generalization operation is the main part of this study which operates on ground plans.

CityGML schemas use the groundsurface type to define the ground plan of a building. On the other

| CityGML generalization specifications |  
|--------------------------------------|  
| LoD1 | Objects blocks as generalized features | >6 × 6 m/3 m  
| LoD2 | Objects as generalized features | >4 × 4 m/2 m  
| LoD3 | Objects as real features | >2 × 2 m/1 m  
| LoD4 | Constructive elements and openings are represented |  

Table 1 CityGML specifications for generalization of LoDs (adopted from (Gröger et al. 2007)
hand, it can be derived from the exterior shells of buildings modelled in CityGML by projecting the wall on the ground and connecting the footprint into a closed polygon (Fan and Meng 2012). However, this method is based on the exterior shell generated by their algorithm which is quite complex and time consuming (Mao et al. 2011).

In our case, firstly, outliers of 3D buildings decomposed down to the level of nodes at LoD3 except doors and windows are separated. An example of outer shell reconstructed from coordinates of nodes extracted from CityGML is presented in Fig. 1 in a three-dimensional space. Secondly, coordinates of nodes of ground plans are projected onto the ground and stored in a data structure without height or “z” values. Thirdly, algorithms for generalization with the aim to restrict lines, curves and corners of ground plan on a certain LoD are implemented using MathWorks libraries of Matlab. Arrangement of original and generalized points and edges based on generalization specifications of CityGML (see Table 1) is described in Sect. 3.1. Lastly, in order to complete generalization, simplified structures of ground plans and roofs are adjusted accordingly at LoD1 as part of reconstruction process. For this purpose, height of the bounding box or length of highest wall is considered as height of the building at LoD1 and walls with lower height are stretched to the bounding box or plane of flat roof.

Generalized structures are converted to LoD1 and exported with the aim to visualize using LandXplorer CityGML Viewer 2009.

Simplification of 2D footprints

Generalization based on simplification of footprints is one of the efficient methods to modify or eliminate insignificant details from 3D buildings. Footprints of 3D building models may contain corners, offsets and intrusions/extrusions. Therefore, generalization strategy is adopted based on certain characteristic of neighbourhood and a threshold value to reduce transitional points, selection and replacement of corners, edges, offsets, etc. However, the fundamental criteria to remove/adjust potential points, edges and polygons are still subject to the research. Besides selecting points (Douglas and Peucker 1973) and edges (Sester and Brenner 2004) by a threshold value, angles in Fan and Meng (2012) and areas in (Bose et al. 2006) are made as a basis of simplification operation.

In this study, to avoid removal/addition of important parts of buildings, geometry-based rules based on CityGML generalization specification (see Table 1) are imposed. Additionally, in certain cases similar to (Fan et al. 2009), an important object, which lies on the edge need not to be removed. If more than one smaller parts make a pattern consecutively and which are smaller than threshold, all of them needs to be taken into consideration collectively similar to (Baig and Rahman 2013). Features should be treated together if the removal or the modification can affect the neighbouring feature or if there is an overlapping between the two smaller features.

Two cases for simplification of two types of neighborhood of ground plans e.g. edges and curves are described in this study. Extracted ground plans down to the level of transitional vertices and points are processed for this operation. An example of simplification of a building with different types of features (curves and lines) is presented in Fig. 3.
features of footprint of are shown in blue while generalized lines are highlighted in red.

**Case 1: shortest edge**

Removal of shortest edge consists of three steps: selection of shortest edge \( s_n \); testing to determine whether this edge is shorter than the CityGML generalization specification at LoD1; and extension of neighboring larger edge. Simplification process for removal of smallest edge \( s_n \) taking neighbouring edges like \( s_{n-1} \), \( s_{n+1} \) and \( s_{n-2} \) into account is illustrated in Fig. 4. Larger neighboring edge \( s_{n-2} \) is extended until it intersects \( s_{n+1} \). A new edge \( s_{n-2}, s_n \) is produced. Due to extension of \( s_{n-2} \), size of associated vertical edge \( s_{n+1} \) is decreased. The challenge due to removal of shortest edge is to adjust the neighboring edges while maintaining the length, orientation and association with each other. \( s_{n+1} \) and \( s_{n-1} \) may be parallel and \( s_{n+1} \) is shorter than \( s_{n-1} \) or vice versa or they can be non-parallel. In this case, simplification process is tailored to address these challenges. This process is repeated to remove other smaller edges. Result of simplification of footprint of a building model is presented in Fig. 5.

**Case 2: curved shapes**

Building footprint contain curves which cannot be stored in their original shape in geo-data structures similar to line or polygons. Therefore, elements of curves are described by a large number of nodes. Simplification process of a curve is presented in Fig. 6. Certain transitional nodes (red color) are selected based on a threshold value. Then, original curved lines (blue) formed by two points are replaced with a generalized lines (red) represented as \( s_n, s_{n+1}, s_{n+2} \).
$s_{n4}$, $s_{n5}$ and $s_{n6}$. Alternatively, number of nodes can be reduced based on point reduction (Douglas and Peucker 1973) method but this could result in poor representations of the original curves. Simplification of a footprint of Ministry of Finance (see Fig. 7a) with curved surface is presented in Fig. 7b. Original curved lines with discrete nodes (green dots) are heighted in blue while generalized line in blue.

Aggregation of ground plans

“Direct-merge” and “Snap-merge” are two aggregation operators introduced by (Bundy et al. 1995) to move two objects near to each other for aggregation purpose. A method developed by (Anders 2005) is quite suitable for aggregation of buildings located on a straight line with same orientation. This method preserves the location of original ground plans, and creates the new by prolonging the existing ones. A number of aggregation techniques (see Fig. 8) are applied based on P-Tree like edge collapse (Garland), Convex envelope, envelope cuboids (Coors 2003). Glander and Döllner (2007) introduced cell-based clustering to merge building blocks.

In this work, in order to aggregate buildings closer within a certain threshold value (e.g. 10 m, etc.), convex envelope technique based on P-Tree is applied. The indices of the points in a data set that comprise the convex hull for the set are identified. A new polygon is created based on indices of identified points. Figure 9 shows aggregation of ground plans of two buildings based on this method.

Reconstruction of generalized models

In order to complete generalization and reconstruction of generalized building models, simplified structures of ground plans of walls and roof are adjusted accordingly. A building in LoD3 has detailed roof structures while LoD2 contains distinctive roof structures. LoD1 is the well known building-blocks without any roof structures. Polygons of flat roofs (at LoD1) do not overlap any other polygons. Planes of flat roof may be similar with the ground plan except in rare cases where length of walls varies. The projection of flat roof outline and the ground plan are enclosed within each other therefore polygons are not distorted during projection and reconstruction become easy. In order to reconstruct building at LoD1, height of the bounding
box or length of highest wall is considered as height of
the building and walls with lower height are stretched
to the bounding box or plane of flat roof. Figure 10
shows reconstructed 3D building at LoD1 from
simplified footprint.

Implementation and results

This research focused on derivation of LoD1 from
outlier of 3D buildings modeled at LoD3 in CityGML.
In order to achieve this objective, generalization of 3D
buildings is implemented in a MATLAB (version
Matlab 7.6.0, MathWorks) operated on a Core™ i7
CPU @ 2.40 GHz, 4.00 GB RAM and Microsoft
Windows 2007. A number of 3D building models of
Putrajaya city of Malaysia are used to test the
proposed algorithms.

Implementation process is divided into followingour operations: (1) projection, (2) simplification, (3)
aggregation of ground plans and (4) reconstruction of
generalized LoD. Decomposed 3D building outliers
down to the level of vertexes is used for further
processing. Vertices of 2D faces are used to calculate
length to remove smaller edges or corners of curved
shapes. Nodes of edges are moved, adjusted and
merged using programming routines of MathWorks
for simplification purposes. The output of simplifica-
tion process was stored into arrays and converted into
XML-based CityGML format. Additionally, for better
visualization, generalized models were visualized in
LandXplorer CityGML Viewer.

Initially, footprints of two buildings such as Jabatan
Pendaftaran Negara (JPN) and Ministry of Finance at
Malaysian city of Putrajaya having complicated
structures with off-sets and curved shapes are pro-
jected, simplified and reconstructed. Subsequently, the
generalization procedures were applied and tested on a
dataset containing 23 buildings of Malaysian city of
Putrajaya around MaCGDI (Malaysian Center for

Geospatial Data Infrastructure). Reduction in the size
of generalized building models is calculated. Result of
generalization (data reduction) as a result of new
experiments is presented in Table 2 based on different
threshold values (e.g. 1–6). Additionally, a graph is
presented in Fig. 11. The results shows that percentage
of data reduction is inverse promotional to value of
threshold for minimum length of edges but other
aspects like designing of building plan cannot be
ignored. Furthermore, computing time is proportional
to the threshold values as well.

The result of all proposed simplification and
aggregation procedures presented in this paper, to
derive LoD1 of building models of Putrajaya city of
Malaysia are visualized in LandXplorer CityGML
Viewer V. 2009. Buildings located closer to viewing
point of a user seem less generalized as compared to
those locating far from user in street view.

Concluding remarks

The aim of this study was to develop a strategy for data
reduction of 3D city models from higher level-of-
details to lower level-of-details. We investigated and
implemented generalization operations (e.g. simplifi-
ication, aggregation and reconstruction) to obtain this
objective.

Data file of original buildings modeled in CityGML
cannot be loaded in Matlab directly. Therefore, only
nodes of exteriors of buildings from these source files
were extracted and loaded for further processing.

A new method for simplification of curves along
with intrusion and extrusion is included in this paper.
Differential changes and ratios are important but are
not taken into account. A part of this paper is an
extension of our previous paper (Baig and Rahman
2013) (e.g. Case 1).
Based on vertices, the edges were generated to be used for implementation of Case 1 and aggregation purposes. These methods were implemented and tested with the aim to reduce complexity of ground plans of 3D buildings.

Secondly, all buildings were generalized into LoD1 with footprints or ground plans. Convex envelope technique was applied to aggregate building footprints.

Further research on generalization and adjustment of distinctive roof structures with walls of buildings at LoD2 would be an addition in future.

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**References**

Anders, K.-H. (2005). *Level of detail generation of 3D building groups by aggregation and typification*. Paper presented at the XXII International Cartographic Conference, A Coruña, Spain.

Baig, S., & Rahman, A. (2013). Generalization and Visualization of 3D Building Models in CityGML. In J. Pouliot, S. Daniel, F. Hubert, & A. Zamyadi (Eds.), *Progress and New Trends in 3D Geoinformation Sciences* (pp. 63–77). Berlin Heidelberg: Springer.

Bose, P., Cabello, S., Cheong, O., Gudmundsson, J., van Kreveld, M., & Speckmann, B. (2006). Area-preserving approximations of polygonal paths. *Journal of Discrete Algorithms*, 4(4), 554–566. doi: http://dx.doi.org/10.1016/j.jda.2005.06.008.

Buchin, K., Meulemans, W., & Speckmann, B. (2011). A new method for subdivision simplification with applications to urban-area generalization. Paper presented at the Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, Chicago, Illinois.

Bundy, L., Jones, B., & Furse, E. (1995). Holistic generalisation of large-scale cartographic data. In J. C. Müller, J. P. Lagrange, & R. Weibel (Eds.), *GIS and Generalisation, Gisdata 1* (pp. 106–119). London: Taylor & Francis.

Commandeur, T. (2012). Footprint decomposition combined with point cloud segmentation for producing valid 3D models. The Netherlands: Masters, Delft University of Technology, Delft.

Coors, V. (2003). *Graphical Abstraction and Progressive Transmission in Internet-based 3DGeoinformationsystems*. Doctorate, Technischen Universität Darmstadt, Darmstädter (D17).

Douglas, D. H., & 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. doi:10.3138/fm57-6770-u75u-7727.

Fan, H. C., & Meng, L. Q. (2009). Automatic derivation of different levels of detail for 3D buildings modelled by CityGML. Paper presented at the 24th International Cartography Conference, Santiago, Chile.

Fan, H. C., & Meng, L. Q. (2012). A three-step approach of simplifying 3D buildings modeled by CityGML. *International Journal of Geographical Information Science*, 26(6), 1091–1107. doi:10.1080/13658816.2011.625947.
Fan, H. C., Meng, L. Q., & Jahnke, M. (2009). Generalization of 3D Buildings Modelled by CityGML. *Advances in Giscience*, 387-405. doi: 10.1007/978-3-642-00318-9_20.

Glander, T., & Döllner, J. (2007). Cell-based generalization of 3D building groups with outlier management. In *15th annual ACM international symposium on advances in GIS* (pp. 364–367). Seattle: Washington.

Gröger, G., Kolbe, T. H., & Czerwinski, A. (2007). Candidate OpenGIS® CityGML Implementation Specification (City Geography Markup Language) 2007-06-17. 0.4.0, from http://www.opengeospatial.org/legal/.

Mao, B., Ban, Y. F., & Harrie, L. (2011). A multiple representation data structure for dynamic visualisation of generalised 3D city models. *Isprs Journal of Photogrammetry and Remote Sensing*, 66(2), 198–208. doi:10.1016/j.isprsjprs.2010.08.001.

Sester, M., & Brenner, C. (2004). Continuous generalization for visualization on small mobile devices. Paper presented at the Developments in Spatial Data Handling—11th International Symposium on Spatial Data Handling, Berlin, Heidelberg.