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# A geometry and texture coupled flexible generalization of urban building models

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ABSTRACT

In the past, numerous research efforts have focused on generalization of city building models. However, a generic procedure for creating flexible generalization results supporting the fast and efficient update of original building models with various complexities is still an open problem. Moreover, building clusters created in previously published generalization methods are not flexible enough to meet the various requirements for both legible and realistic visualization. Motivated by these observations, this paper proposes a new method for generating a flexible generalization outcome which enables convenient updating of original building models. It also proposes a flexible preprocessing of this generalized information to render a legible and realistic urban scene. This is accomplished by introducing a novel component structure, termed as FEdge, particularly designed for efficiently managing the geometry and texture information in building cluster instances (both original building models and building clusters) during the generalization, visualization and updating processes. Furthermore, a multiple representation structure, referred to as Evolved Buffer-Tree (EBT), is also introduced. The purpose of the EBT is to organize building cluster instances and to employ more flexible LODs for both legible and realistic visualization of urban scenes. FEdge has an intuitive planar shape which can be effectively used in representing rough 3D facade composed by detailed continuous meshes. Each FEdge is given a unique identifier, referred to as FEdge Index. In the proposed generalization scheme, firstly each original building model treated as a building cluster instance is abstracted and presented as FEdge Indices. These FEdge Indices are then used for producing generalized building cluster instances in the EBT portably, and to support convenient model updating and flexible preprocessing of the generalization results for renderable building cluster instances. Secondly, to achieve a legible and realistic visualization of urban scene, the EBT is flexibly assigned diverse LODs maintaining more important legible information than LODs defined in CityGML for 3D building models. To make the generalization more accurate by considering the city roads and districts, an algorithm for automatic road analysis is applied in our clustering and combination. Numerous experiments considering the geometrical and textural complexity of common urban building models, as well as a typical case study of complex city scene with a large number of building models, verify the effectiveness of our generalization method and the dynamic visualization of the generalized urban models.



## 1. Introduction

3D building clusters with different levels of detail (LODs) play an important role in creating a legible image of modern urban scenes. Designed for different uses, these LODs can be categorized into discrete and continuous ones. Discrete LODs are usually used in tour maps and navigation systems, where building clusters have distinguishable and meaningful appearances. Such characteristics are needed to help individuals to recognize and comprehend different city images, such as city blocks, city districts or administrative areas. The CityGML standard (OGC, 2007) has specified five discrete LODs of city models not only for visualization purposes, but also for thematic queries, analysis tasks or spatial data mining. Continuous LODs, which require relatively strict similarity of both shape and texture between building cluster and original buildings, are always created for accelerating smooth visualization of a large virtual city. Meng and Forberg (2007) pointed out the abrupt transition between adjacent LODs can lead to building "popping" as they suddenly change from one form to another. Such a case is especially noticeable when there are only a few LODs.

Focusing on 3D urban building LODs involved in generalization, architectures studied by different researchers are similar to those with LOD1, LOD2 and LOD3 in CityGML. However, two insufficiencies

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exist in previous research approaches which deal with creating discrete and continuous LODs. Firstly, most methodologies (Kada, 2007; Glander and Döllner, 2008, 2009; Chang et al., 2008; Mao et al., 2011) represent their generalized building clusters based on only one primary textural LOD. Although it appears that they achieve a smooth visual effect, such approaches weaken important details of city images. Secondly, these methodologies focus on the smooth transition of geometric details among continuous LODs, but simplification of texture details (e.g. walls, doors and windows) with different LODs is rather limited. It is noted that a general solution of reducing low resolution image texture by photographing each group of original building models (Chang et al., 2008) is not only time-consuming but also unable to create flexible texture details. The separation between geometry and texture is not appropriate for simultaneously presenting geometrical and texture details in the generalized building clusters with different LODs.

To the best of our knowledge, a transportable and fast generalization scheme supporting substitution of original building models with different levels of complexity is not available in the open technical literature. The main reason for this is the fact that usually previous generalization methods create and store only fixed geometry and texture information of generalized building clusters for the final rendering. The update of numerous original building models requires a time-consuming re-generalization process for them and their neighboring building models, in an extreme case even for all the models in the whole urban scene. In a Client/Server platform, if a client computer only supports visualization of the generalized building clusters with multiple representation data structure, it is unable to view in the generalization result the new version of building models obtained from different sources.

Besides lack of a comprehensive generalization scheme, some additional problems remain unsolved when state-of-the-art algorithms of aggregation and combination are implemented. Among the different methods developed in the past for clustering and merging 2D building footprints (Bundy et al., 1995; Regnauld, 2001; Sester and Brenner, 2005), the more popular ones (Chang et al., 2008; Mao et al., 2011) produce ground plans which can better maintain the paths, districts and some other elements referred to in urban legibility (Lynch, 1960). However, clustering urban buildings exactly by the road network (Mao et al., 2011) is restricted by fast automatic extraction of road data. As for the methods which do not take into account road data (Chang et al., 2008), inaccuracy of their clustering results and the generalized ZigZag footprints make them not appropriate for accurately illustrating block districts.

Motivated by the above, our study aims at exploring a novel generalization scheme which supplies a flexible generalization outcome for convenient update of original building models, as well as for flexible preprocessing of the generalization information to visualize the urban scene legibly and realistically. In particular, we propose a novel component structure, termed as FEdge, to generally abstract building models with different complexities by using an intuitive 2D shape to represent many detailed continuous meshes. FEdge is then used to record abstracted building cluster instances (both original building models and building clusters) using indices of their FEdges. Moreover, by considering both legible city image and realistic visual effect we design a multiple representation structure referred to as Evolved Buffer-Tree (EBT) supporting more flexible LODs than those available in the CityGML. An automatic road analysis algorithm which abstracts legible information guiding the aggregation and combination is also presented. Lastly, the FEdge information, building cluster instances and EBT is stored to allow flexible preprocessing before the city models are rendered, as well as for convenient model updating in the future.

The remainder of the paper is structured as follows. Related works are given in Section 2. Our generalization framework for the legible and realistic rendering is proposed in Section 3. The generalization process and visualization methodology is specified in Section 4. Section 5 presents experimental performance evaluations. Section 6 summarizes the whole paper.

## 2. Related work

In this section, previous generalization results of 3D building models are summarized. In order to identify the advantage and disadvantage of previous generalization methodologies, their algorithms are reviewed on the three basic tasks of model generalization (McMaster and Shea, 1992): simplification, aggregation and combination. In addition, further relevant previous research efforts related to textural generalization of building clusters are also presented.

### 2.1. Generalization of 2D and 3D urban building models

According to OGC standards for CityGML (OGC, 2007), 3D building models in the urban scene typically have four LODs which consist of: (i) models comprising of prismatic buildings with flat roofs (LOD1); (ii) buildings with differentiated roof structures and thematically differentiated surfaces (LOD2); (iii) architectures with detailed wall and roof structures, balconies, bays and projections, as well as with high-resolution textures mapped onto these structures (LOD3); and (iv) architectures with most delicate exterior and interior structures (LOD4). Since the generalization of LOD4 is outside the scope of this paper, previous methods for the generalized results in the form of only the other three LODs will be reviewed next.

Most 2D generalization methods aim at obtaining generalization landscape composed by 3D building models similar to CityGML LOD1. These results were able to well abstract the geometric variances in the footprint of a projected building cluster, but seldom expressed the height variances inside a building cluster. Glander and Döllner (2008, 2009) created untextured cell blocks to replace original 3D building models in order to realize dynamic landmark highlighting according to virtual camera distance. Mao et al. (2011) concentrated on obtaining geometric generalized results of CityGML LOD1 from original CityGML models with finer LODs. However, they did not demonstrate the corresponding texture generalization. Chang et al. (2008) described a single-link clustering method for urban legibility (Lynch, 1960), and created a generalized urban scene composed by 2.5D buildings mapped with newly shot image textures. Due to the significant loss of original height information inside each building cluster, the skyline had to be maintained by an extra drawing of original buildings much taller than the generalized block. This was achieved at the cost of partially overlapped facades and a slower roaming. However, these tall buildings selected by Chang et al. (2008) are similar to those distant landmarks put forwarded by Lynch (1960) used by the general population to identify a skyline, but they are rarely used for navigation purposes.

To avoid the drawback brought by a second rendering of tall buildings, it is more appropriate to maintain accurate height information and roof details in the generalized models. Most of the 3D generalization methods and only a few 2D generalization methods allow for simplification of certain roofs, making it possible to acquire geometric generalization similar to CityGML LOD2. However, only a couple of these methods involve the corresponding textural generalization. Kada (2007) proposed a template matching technique which allows altering the roof shapes in order to accentuate certain features or to reduce the number of repetitive features like shed, gabled and hipped roof parts. His simplification algorithm was designed for solitary 3D building models, and its application in the building cluster has not been investigated. Forberg (2007)