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A cost-effective strategy for multi-scale photo-realistic building modeling and web-based 3-D GIS applications in real estate

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ABSTRACT

Web-based 3-D GIS may be the most appropriate tool for decision makers in land management and development. It provides not only the basic GIS functions, but also visually realistic landscape and architectural detail. It also gives the user an immersive 3-D virtual reality environment through the Internet that is rather different from that obtained merely through text, pictures, or videos. However, in terms of high accuracy and level-of-detail (LOD), the generation of a fully photo-realistic city model is labor intensive and time consuming. At the same time, from the aspect of computer graphics, the result is simply a geometric model without thematic information. Thus, the objective of this study is to propose a cost-effective multi-scale building modeling strategy based on the 2-D GIS building footprint that has rich attributes and to realize its application in the real estate market through a web-based 3-D GIS platform. Generally, the data volume needed for a photo-realistic city model is huge, thus for the purpose of increasing Internet data streaming efficiency and reducing the building modeling cost, a multiple-scale building modeling strategy, including *block modeling, generic texture modeling, photo-realistic economic modeling*, and *photo-realistic detailed modeling* is proposed. Since 2-D building boundary polygons are popularly used and well attributed, e.g., as to number of stories, address, type, material, etc., we are able to construct the photo-realistic city model based on this. Meanwhile, the conventional 2-D spatial analysis can be maintained and extended to 3-D GIS in the proposed scheme. For real estate applications, a location query system for selecting the optimum living environment is established. Some geospatial query and analysis functionalities are realized, such as address and road-junction positioning and terrain profile analysis. An experimental study area of 11 km^2 in size is used to demonstrate that the proposed multi-scale building modeling strategy and its integration into a web-based 3-D GIS platform is both efficient and cost-effective.

1. Introduction

Three-dimensional building models are essential for the realization of 3-D GIS applications (Coors, 2003), for example, the preparation of 3-D cadastral maps for taxation purposes based on the volume of buildings (Billen & Zlatanova, 2003), urban planning (Ranzinger & Gleixner, 1997; Wu, He, & Gong, 2010), change analysis in the landscape and land use (van Lammeren, Houtkamp, Colijn, Hilferink, & Bouwman, 2010), emergency response planning (Kwan & Lee, 2005), route planning, accessibility assessment and location analysis (Thill, Dao, & Zhou, 2011), geology volume 3-D modeling (Qi, Zhang, Liang, Wang, & Cai, 2007), prediction of regional flooding, virtual and augmented reality and so on.

The studies related to 3-D building model reconstruction are primarily discussed in the fields of Computer Vision, Computer Graphics, Remote Sensing and Photogrammetry. Generally, the procedure for the generation of photo-realistic 3-D building modeling includes four main steps, namely (1) recognition, (2) feature extraction, (3) topology reconstruction with geometric modeling, and (4) photo texture generation. Rather than automatic recognition, the most reliable and accurate results can normally be achieved by a building reconstruction system that integrates human-assisted visual interpretation capability (Gruen & Wang, 2001). A comprehensive literature review and comparisons can be found in Brenner (2005).

There are many methods used for acquiring large quantities of building models, such as Airborne Laser Scanning or LIDAR (LIght Detection And Range) data (Alexander, Smith-Voysey, Jarvis, & Tansey, 2009; Jochem, Höfle, Wichmann, Rutzinger, & Zipf, 2012), Aerial Photography and Close-range Photogrammetry, High-resolution Satellite Imagery, or the fusion of the above mentioned sensors. There are four building model schemes currently used to describe 3-D geometry: namely, the wire-frame model (Vosselman & Veldhuis, 1999), boundary representative models (B-Rep) (Huang

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& Trinder, 1999), polyhedral models (Rau & Chen, 2003), and constructive solid geometry (CSG) (Tseng & Wang, 2003). Some of the aforementioned models are either structurally too complex or require large quantities of data storage, and so are not easy to apply to volume calculations and Boolean operations. In contrast, some of them are structurally too simple and thus fail to represent main features of irregular objects and to perform spatial analysis.

The usage of photo in façade texture generation, including semi-automatic and fully automatic approaches (Grenzdorffer, Guretzki, & Friedlander, 2008; Kada, 2004; Rau, Teo, Chen, & Tsai, 2006; Zhu, Hyyppä, Kukko, Kaartinen, & Chen, 2011) and true-orthophoto generation (Habib, Kim, & Kim, 2007; Rau, Chen, & Chen, 2002) can be found in the literature as well. However, it is realized that 3-D building modeling is a time-consuming task, particularly when high accuracy, high level-of-detail, and photo texture generation is required.

Due to the large amount of geospatial data and narrow network bandwidth available, visualizing and manipulating 3-D building models and other geo-information over the Internet in real time are considerable challenges. Zhou, Tan, Cen, and Li (2006) visualized a 3-D city model based on a proposed data structure using a relational GIS database. Zhang, Yang, Tong, and Rui (2007) developed a node-based data model as topology to organize 3-D spatial objects for spatial queries. However, the façade textures used in these methods are not photo-realistic because this requires more data volume. Furthermore, when compared with a real city the illustrated city models lack detailed geometry, are distributed sparsely, and do not have tall building models.

A 3-D GIS system based on a photo-realistic city model should include not only common GIS functions, i.e., positioning, measuring, and spatial analysis, but also represent the closest appearance to a real landscape as possible which allows users to browse the whole city in 3-D virtual reality and realize the spatial relationship around a specific position. Although several visually impressive web-based 3-D city model platforms can be found on the Internet, including Google Earth, Bing Maps, the British Yell.com, Norway's FINN 3-D-kart, Sweden's Eniro, Australia's Nearmap, etc., they are restricted in terms of some mash up capability and searching functionality without sophisticated spatial analysis functions. Skyline-Global™ and Google Earth™ are two powerful 3-D visualization solutions particularly designed for a web-based 3-D virtual Earth. However, their building modeling scheme is based on computer graphics and not on GIS. Thus, a web-based 3-D GIS platform capable of 2-D and 3-D spatial analysis through the Internet is essential.

In this study, we propose the use of PilotGaea Universe™ (PilotGaea, 2012) for the realization of a 2-D/3-D web GIS application. Meanwhile, a real estate application is chosen as an example to demonstrate the performance of the proposed strategy. In this case, real estate refers to land and improvements attached to it. The business activities regarding it are closely related to the economic, banking, finance, and social sectors of a country. Real estate constitutes a fairly large proportion of a nation's Gross Domestic Product (GDP) which is the major asset for a country. From the aspect of the macro economy, real estate influences construction, banking, servicing, and other related business sectors. It constitutes a fairly large percentage of people's wealth. Still, most people carry out real estate transactions only once or twice throughout their lifetime. Moreover, taxation of real estate transactions is one of the major sources of income for the government. Therefore, a government's policy on real estate is crucial to the nation itself, its enterprise, and the individual.

In recent years, applications related to real estate have applied GIS spatial analysis and 3-D visualization tools. The analysis results, efficient assessments, and rational decision-making have been receiving more and more attention. Yin and Hastings (2007) assessed hotel development scenarios by means of 3-D GIS. Yu, Han, and Chai (2007) evaluated the benefit of high-rise apartments and suggested pricing strategies on reconstructed apartments through 3-D GIS. Yang, Putra, and Li (2007) applied this tool to evaluate urban design. Hanzl (2007) demonstrated the potential for Web-based 3-D GIS as a tool for public participation in urban planning. Nowadays, the trend toward sharing geo-information with each other over the Internet has been increasing in popularity.

The purpose of this study is to apply GIS spatial query and analysis by photo-realistic city models through the Internet on an intuitively and interactively 3-D platform. However, the bottlenecks are complex 3-D topologies, the large amount of spatial data, limitations of Internet band-width, and the development of an efficient web-server architecture to deal with clients' queries, etc. Thus, in this study we introduce a GIS-based photo-realistic building modeling tool and propose a cost-effective and multi-scale photo-realistic building modeling strategy to cope with these challenges. At the same time, we also develop a location query scheme based on 3-D Web-based GIS, which is capable of displaying a large volume of high resolution aerial ortho-images and photo-realistic building models. A system is designed to assist people in improving their decision-making in the real estate market to prove that the proposed strategy is a cost-effective and efficient 3-D web GIS application.

2. Multi-scale photo-realistic building modeling

The most essential task of 3-D city reconstruction is geometric building modeling and façade texture mapping. People can thus observe 3-D photo-realistic city models from any viewing angle and position interactively. Any scheme of building models based on computer graphics can never be perfect in every aspect, such as shape realism, topology integrity, and geo-information generalization.

In order to present 3-D urban objects in a GIS system, Gröger and Plümer (2005) suggested a "2.8-D map" topological model to cope with the 3-D topology complexity issue. This model can cover many 3-D GIS applications and is an extension of a 2-D or 2.5-D model while maintaining the 2-D algorithm and conceptual simplicity. This 2.8-D model extends 2.5-D digital terrain models by allowing for vertical walls and projections, such as balconies or ledges. In this study, we reconstruct 3-D photo-realistic building models from a 2-D GIS building layer by means of a GIS-based building modeling tool, to provide an optimal solution for both 3-D visualization and 2-D/3-D GIS application purposes.

2.1. Multi-scale building modeling

Given that most cities are greater than 10 square kilometers in size, one needs much more manpower, a larger budget, and more time to establish a photo-realistic city model. Because of the cost as well as the constraints of Internet bandwidth, server computation ability, and client's graphic card performance, the establishment of a complete city model should not be on the same scale or have unlimited detail. A multi-scale building modeling scheme is proposed here which identifies a building's significance and assigns an appropriate level-of-detail to each building with respect to its accessibility and application. Four levels of building model are adopted, namely the *block model, generic texture model, photo-realistic economic model,* and *photo-realistic detailed model.*

In order to realize this in a Web-based 3-D GIS environment we propose two types of *photo-realistic building models*, namely *economic* and *detailed* ones. Normally, the *photo-realistic detailed model* should show the structure and appearance of the most delicate buildings and also be applied to large-size and geometrically complex landmark buildings. However, the creation of such a model is labor intensive and time consuming. It requires more data storage than other types of building models requiring a large amount memory and powerful GPU (Graphic Processing Unit) to render it