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Towards the Automated Construction of Digital Cities

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ABSTRACT

Digital cities become essential frameworks and infrastructures for a growing number of applications and systems across almost all IT domains. The construction and sustainable management of digital cities and their underlying virtual 3D city models represent major challenges for many disciplines in geosciences and computer sciences. This overview outlines different concepts and techniques that facilitate generation, maintenance, and visualization of complex, massive, and distributed digital cities and raise the degree of automation. As ultimate vision, there is the idea of a universal approach to derive and synthesize multi-resolution models of geospatial reality in real-time.

1. ABOUT DIGITAL CITIES

Geovirtual environments (GeoVEs) offer an intuitive, innovative, and challenging media to manage and interactively explore, analyze, and present spatial information in its three dimensional context (Dykes et al. 2005). GeoVEs can be based on virtual 3D city models, which are increasingly established as part of modern spatial data infrastructures (SDI); they represent spatial and related, geo-referenced information and include models of terrain, sites, buildings, vegetation and water as well as models of roads and transportation systems. A first standard for the exchange of virtual 3D city models, CityGML (Kolbe et al. 2005), has been introduced by the Open Geospatial Consortium (OGC) in 2008, facilitating development and deployment of interoperable GeoVE technology. As their main strength, GeoVEs allow for visually fusing heterogeneous geoinformation within a single framework and, therefore, can create and manage complex geoinformation spaces (Döllner et al. 2006). Hence, GeoVEs implement the idea of "digital cities" - the virtual counterparts of real-world urban areas and the human habitat (Leberl & Gruber 2009).

An increasing number of applications and systems incorporate GeoVEs as essential system components such as urban planning and redevelopment (Fig. 1), facility management, logistics, security, telecommunication, disaster management, location-based services, real estate portals as well as urban-related entertainment and education products. Consequently, a large number of potential users and usages require an efficient and effective access to and tools for GeoVEs and their contents.

The requirements on GeoVEs and their underlying virtual 3D city models vary between different domains. On the one hand, in the context of tourism, entertainment, or public participation, a high degree of photorealism is required. For instance, if the aim is to give a realistic impression of a planned environment, the quality of a 3D visualization is directly related to the similarity between the virtual 3D city model depiction and the actual situation after implementing the planning in the real world. On the other hand, in domains that attempt to provide analytical and exploratory functionality, visual details of buildings are not of primary interest. Instead, the 3D representation serves as a medium to convey spatial-related thematic information in a comprehensive way or as data structure for analysis and simulation computations.

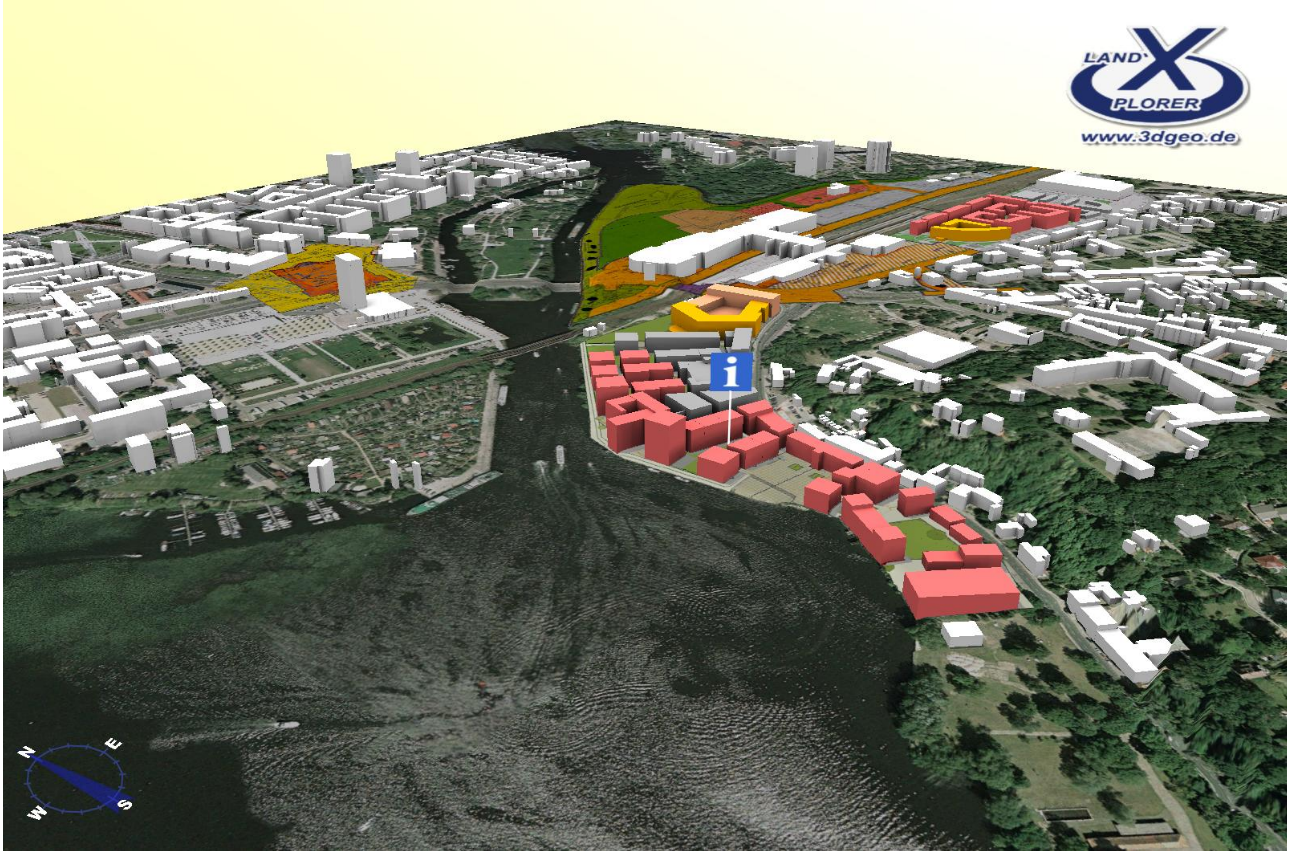

Fig. 1: The virtual 3D city model of Potsdam, Germany, based on complex data sets and dynamic data fusion.

GeoVE technology is faced with

- *complex data*, i.e., a multitude of formats and models of geodata,
- *massive data*, i.e., large-scale data that typically exceeds TB for major cities, and
- *distributed data*, i.e., data that is stored across networks and by different organizations and stakeholders.

For GeoVE technology automating the generation, maintenance, and provision of virtual 3D city models is essential to achieve sustainable, up-to-date, and cost-efficient models. In the following we outline a few aspects that require dedicated automation strategies.

2. GENERATION OF SITE AND BUILDING MODELS

Besides well-known high-resolution digital terrain modeling, GeoVEs require models for sites and buildings, which represent a major category of city model components. Their automatic creation is crucial to cope with large-scale city models and to manage these models in the long run. A number of automated techniques that derive block models and models including roof geometry exist (e.g., Brenner & Haala 2001, Brenner 2005); the output represents LOD-1 and LOD-2 building models (OGC 2008) according to the CityGML classification. For simulation and analysis purposes, these LODs commonly provide sufficient and adequate detail. However, current techniques lack a differentiated treatment of general site models. In particular, ground-based structures (e.g., tunnel portals, bridges, stairs, sidewalks) cannot be derived with sufficient detail or cannot be generated in 3D at all. For photorealistic GeoVEs, however, these structures are indispensable at close-up range.

Another category of solutions for site and building models is based on procedural modeling and GIS data: Complex 3D structures are automatically created based on rules applied to 2D plan data or 2D CAD, annotated by additional information about their 3D position, extensions, appearance, or type. This approach has been successfully applied in the scope of urban planning (Buchholz et al. 2006). For example, near-ground structures can be “converted” into 3D models based on a set of rules and heuristics defined for a given region (Fig. 2).

Fig. 2: Example of a procedurally and automatically generated near-ground 3D model based on street information and cadastral data.

3. GENERATION OF FACADE AND GENERAL SURFACE TEXTURES

Most GeoVEs require 3D models with sufficient photorealistic appearance. These models have been created for small areas for many decades using a variety of tools, semi-automated and automated techniques (e.g., Ripperda & Brenner 2007; Bornik et al. 2001) provided by photogrammetry and computer graphics. The generation of photorealistic appearance information for large areas is one of the key challenges in order to enable practical applications and uses of GeoVEs. If for a given 3D model the appearance can be derived automatically, high-quality and up-to-date models become cost-efficient.

Capturing, processing, and aligning surface textures for 3D models, e.g., facade textures, still represent costly and time intensive tasks. Both data acquisition and model alignment involve manual steps. The automated generation of surface textures, therefore, represents a key element for efficiently creating and managing GeoEs.

One approach, the “city model factory” (Lorenz & Döllner 2006), processes a set of oblique images together with the 3D model of the corresponding region. For each 3D object and for each of its relevant surface elements, the technique automatically synthesizes a surface texture in a configured resolution, taking into account a subset of the oblique images. For each texel of such texture, the algorithm determines the best source of visual information, depending on distance, angle, and potential occluders. In addition, a heuristics allows for minimizing occlusion effects caused by vegetation. This approach has been successfully applied for a number of large-scale city models (Fig. 3).

Fig. 3: Part of a large-scale virtual 3D city model with automatically generated façade textures derived from oblique imagery.

4. MODEL FUSION

Complex GeoVEs commonly rely on data from different system and application domains such as Computer Aided Design (CAD), Geographic Information Systems (GIS), and Building Information Models (BIM).

The automated fusion of that data allows for dynamically combining and using CAD/GIS/BIM data within a single GeoVE (Döllner et al. 2007). This way, for example, urban data from different scales, different domains, and different stakeholders can be joint to produce a seamless representation. Fusing data goes far beyond plain copying, as this involves harmonizing, e.g., coordinate systems, object identifiers, or even spatial relations. Long-term model management of large-scale city models benefits from the integrated nature of GeoVEs because we can directly refer to up-to-date CAD, GIS, or BIM data sources through the GeoVE and unify their visualization and access.

For example, in (Hagedorn & Döllner 2007), an interoperable 3D viewer client is presented that concentrates on the dynamic, on-demand integration of CAD/GIS/BIM data into the GeoVE. It has been developed within the CAD/GIS/BIM thread of the Web Services Initiative Phase 4 of the Open Geospatial Consortium.

5. MODEL GENERALIZATION

Comprehensible and effective visualization of complex virtual 3D city models requires an abstraction of city model components to provide different degrees of generalization. With increasing detail and precision of virtual 3D city models, the automated, systematic derivation of less detailed, abstracted 3D models becomes an important requirement.

Commonly, generalization techniques achieve clustering, simplification, aggregation and accentuation of geometry. A large number of approaches exist in GIS and Cartography for 2D geodata. Less is known about 3D generalization and only few holistic approaches exist (e.g., Forberg & Mayer 2002, Thiemann 2002, Kada 2005). For example, the 3D generalization technique introduced in (Glander & Döllner 2007) defines a preprocessing step to cluster individual building models into cells defined by and derived from its surrounding infrastructure network such as streets and rivers (Fig. 4). If the infrastructure network is organized hierarchically, the granularity of the cells can be varied correspondingly. Three fundamental approaches have been identified, implemented, and analyzed: The first technique uses cell generalization; from a given cell it extrudes a 3D block, whose height is calculated as the weighted average of the contained buildings; as optimization, outliers can be managed separately. The second technique is based on convex-hull generalization, which approximates the contained buildings by creating the convex hull for the building ensemble. The third technique relies on voxelization, which converts the buildings' geometry into a regular 3D raster data representation. Through morphological operations and Gaussian blurring, aggregation and simplification is yielded; polygonal geometry is created through a marching cubes algorithm (Lorensen & Cline 1987).

Fig. 4: Example of a generalized version of the virtual 3D city model of Berlin, Germany with emphasized landmark objects.

Using 3D generalization techniques, future high-detail GeoVEs can automatically derive model instances with appropriate geometric and visual detail as defined and required by applications and systems. This way, data size as well as graphics quality and appropriateness can be adjusted.

6. SERVICE-BASED VISUALIZATION OF GEOVE

Within spatial data infrastructures, geovisualization plays an important role as it allows humans to understand complex spatial settings and to fuse heterogeneous geodata from distributed sources on the visualization level. For this purpose, the OGC as a standardization organization proposes several portrayal services for 2D and 3D geodata. In particular, such service-based visualization approaches are needed for all types of mobile IT solutions – one of the most rapidly growing sectors in software industry.

So far, there is only one widely used "workhorse", the Web Map Service (WMS), for generating 2D maps. Standards for visualizing GeoVEs such as virtual 3D city models and landscape models have not been elaborated to a similar degree (Hagedorn 2007). 3D-specific approaches, however, are required to enable visualization of GeoVE within the Web and based on web-services. For service-based portrayal of GeoVEs, two approaches are commonly used: the Web 3D Service (W3DS) and the Web Perspective View Service (WPVS).

A recent approach for interactive, web-based visualization, called WPVS++, an extension of the OGC WPVS, is capable of augmenting each generated color image by multiple thematic information layers encoded as images. These additional image layers provide for instance depth information and object identity information for each pixel of the color image. Additionally, operations for retrieving thematic information about presented objects at a specific image position, simple measurement functionality, and enhanced navigation support become possible. This allows WPVS++ clients to efficiently access information about visually encoded objects in images, to use that information for advanced and assisting 3D navigation, and thereby to increase the degree of interactivity, which is demonstrated by prototype implementations of two web-based clients.

7. USER-INTERFACES FOR GEOVE

Fig. 5: Example of a smart-navigation based user interaction. The user draws his navigation intentions onto the perspective view.

User interfaces for GeoVEs represent another principal challenge. In particular, navigation as a fundamental interaction technique required by GeoVEs enables users to explore the virtual world and to interact with its objects. For this, effective navigation techniques are needed that take into account users and their goals. They also should prevent common problems of 3D navigation, such as an intricate camera control or "getting-lost" situations due to incoherent and confusing camera views.

For example, smart navigation (Hagedorn & Döllner 2009) aims at this category of navigation techniques; it represents a special type of smart interaction and, thus, an essential element of smart graphics. The technique provides a navigation technique that allows for specifying navigation commands by sketches and gestures: Users sketch their navigation intentions on top of the perspective projection of the 3D scene (Fig. 5); the system interprets these sketches regarding the affected scene geometry, as well as the spatial and temporal context. Based on this interpretation, navigation activities are derived and automatically performed. By providing assistance and automation, the smart navigation approach can substantially simplify user interfaces for GeoVEs and, thus, represents an essential component for novel applications of GeoVEs, e.g., based on touch-sensitive displays.

8. CONCLUSIONS

This overview outlined a few principle directions of research that will help to automate and facilitate creation and management of complex, massive, distributed virtual 3D city models. Key areas include 3D model geometry generation, 3D model appearance generation, 3D model data fusion, 3D model generalization, and web-based model provision and visualization. The ultimate goal, capturing, generating, and visualizing our human habitat in real-time, is still far away but there are strong indications that a large number of promising technologies are under investigation and development that will contribute to this goal.

9. REFERENCES

Bornik, A., Karner, K., Bauer, J., Leberl, F., Mayer, H. (2001): High-quality texture reconstruction from multiple views. The journal of visualization and computer animation 12 (2001) 5, 263-276.

Brenner, C. (2005): Building reconstruction from images and laser scanning. Int. Journal of Applied Earth Observation and Geoinformation, Theme Issue on "Data Quality in Earth Observation Techniques", 6(3-4), Elsevier, 187-198.

Brenner, C., Haala, N. (2001): Automated reconstruction of 3D city models, book chapter. M. Abdelguerfi, Ed., '3D Synthetic Environment Reconstruction', Vol. 611 of The Kluwer International Series in Engineering and Computer Science, Kluwer Academic Publishers, Boston, 75-101.

Buchholz, H., Döllner, J., Ross, L., Kleinschmit, B. (2006): Automated Construction of Urban Terrain Models. Proceedings of the 12th International Symposium on Spatial Data Handling (SDH 2006), Springer, 547-562.

Hagedorn, B., Döllner, J. (2009): Sketch-Based Navigation in 3D Virtual Environments. it - Information Technology, (3), 163-170.

Hagedorn, B., Döllner, J. (2007): High-Level Web Service for 3D Building Information Visualization and Analysis. In ACM 15th International Symposium on Advances in Geographic Information Systems (ACM GIS), Seattle, WA, 1-8.

Döllner, J., Baumann, K., Buchholz, H. (2006): Virtual 3D City Models as Foundation of Complex Urban Information Spaces. Proceedings of CORP 2006 & Geomultimedia06, 107-112.

Döllner, J., Hagedorn, B. (2007): Integrating Urban GIS, CAD, and BIM Data By Service-Based Virtual 3D City-Models. In 26th Urban Data Management Symposium, Stuttgart, Germany, 157-170.

Dykes, J., MacEachren, A.M., Kraak, M.-J. (2005): Exploring Geovisualization. Elsevier.

Forberg, A., Mayer, H. (2002): Generalization of 3D Building Data Based on Scale-Spaces. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, (34)4, 225-230.

Glander, T., Döllner, J. (2007): Cell-Based Generalization of 3D Building Groups with Outlier Management. In ACM 15th International Symposium on Advances in Geographic Information Systems (ACM GIS), ACM Press.

Kada, M. (2005): 3D Building Generalisation. Proceedings of 22nd International Cartographic Conference, La Coruña, Spain.

Kolbe, T., Gröger, G., Plümer, L. (2005): CityGML – Interoperable Access to 3D City Models. In: van Oosterom, P., Zlatanova, S., Fendel, E. M. (Eds.): Geoinformation for Disaster Management. Proceedings of the 1st International Symposium on Geoinformation for Disaster Management', Delft, The Netherlands, March 21-23, Springer, 2005.

Leberl, F., Gruber, M. (2009): Aufbau und Nutzung einer virtuellen Erde im Internet. VGI Zeitschrift für Vermessung und Geoinformation, to appear.

Lorensen, W. E., Cline, H. E. Marching cubes (1987): A high resolution 3d surface construction algorithm. In Computer Graphics (Proceedings of SIGGRAPH 87), volume 21, Anaheim, California, 163-169.

Lorenz, H., Döllner, J. (2006): Towards Automating the Generation of Facade Textures of Virtual City Models. ISPRS Commission II, WG II/5 Workshop, Vienna.

Open Geospatial Consortium (2008): Open GIS City Geography Markup Language (CityGML) Enconding Standard, Version 1.0.0.

Ripperda, N., Brenner, C. (2007): Data driven rule proposal for grammar based facade reconstruction. Photogrammetric Image Analysis 2007, München, September, ISPRS Vol. XXXVI, Part 3/W49A, 1-6.

Thiemann, F. (2002): Generalization of 3D Building Data. Proc. Joint International Symposium on GeoSpatial Theory, Processing and Applications (ISPRS/Commission IV, SDH2002), Ottawa, Canada, July, 34(3).