Concepts for Cartography-Oriented Visualization of Virtual 3D City Models *

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Summary: Virtual 3D city models serve as an effective medium with manifold applications in geoinformation systems and services. To date, most 3D city models are visualized using photorealistic graphics. But an effective communication of geoinformation significantly depends on how important information is designed and cognitively processed in the given application context. One possibility to visually emphasize important information is based on non-photorealistic rendering, which comprehends artistic depiction styles and is characterized by its expressiveness and communication aspects. However, a direct application of non-photorealistic rendering techniques primarily results in monotonic visualization that lacks cartographic design aspects. In this work, we present concepts for cartography-oriented visualization of virtual 3D city models. These are based on coupling non-photorealistic rendering techniques and semantics-based information for a user, context, and media-dependent representation of thematic information. This work highlights challenges for cartography-oriented visualization of 3D geovirtual environments, presents stylization techniques and discusses their applications and ideas for a standardized visualization. In particular, the presented concepts enable a real-time and dynamic visualization of thematic geoinformation.

Zusammenfassung: *Ansätze zur kartographischen Gestaltung von virtuellen 3D-Stadtmodellen*. Virtuelle 3D-Stadtmodelle repräsentieren ein wirkungsvolles und mannigfaltiges Medium in Geoinformationssystemen und -diensten. Häufig wird eine Vielzahl an 3D-Stadtmodellen photorealistisch dargestellt. Eine effektive Kommunikation von Geoinformation beruht allerdings darauf, wie wichtige Informationen innerhalb eines gegebenen Anwendungskontextes gestaltet und kognitiv verarbeitet werden können. Eine Möglichkeit wichtige Informationen visuell hervorzuheben, beruht auf nichtphotorealistischer Bildsynthese, die künstlerische Darstellungsstile umfasst und durch ihre Ausdrucksstärke und kommunikativen Aspekte gekennzeichnet ist. Deren direkte Anwendung resultiert jedoch in einer primär monotonen Gestaltung, bei der kartographische Gestaltungsaspekte nicht berücksichtigt werden. In diesem Beitrag stellen wir Ansätze zur kartographischen Gestaltung virtueller 3D-Stadtmodelle vor. Diese koppeln Techniken der nichtphotorealistischen Bildsynthese mit semantischen Informationen für eine nutzer-, kontext- und medienadäquate Repräsentation von thematischen Informationen. Wir identifizieren Herausforderungen einer kartographischen Gestaltung in 3D geovirtuellen Umgebungen, präsentieren Bildsynthese-Techniken zur kartographischen Gestaltung und diskutieren deren potentielle Anwendungen und Ansätze für einen standardisierten Visualisierungsprozess. Im Besonderen ermöglichen die vorgestellten Ansätze eine echtzeitfähige und dynamische Gestaltung von thematischen Geoinformationen.

1 Introduction

Virtual 3D city models and, more general, 3D geovirtual environments, play an important role for communication of and interaction with complex, 2D and 3D geoinformation. They represent key elements in a growing number of applications, systems, and services, for example, in mass-market systems (e.g. Google Earth or Ovi Maps 3D), expert tools for urban planning and development, disaster management and environmental information systems. Although most virtual 3D city models abstract from reality to serve comprehension, photorealistic renderings commonly suffer from an inefficient communication of geoinformation. As soon as a compact, yet attractive presentation is required, perceptional, cognitive and graphical design issues need to be considered.

Non-photorealistic rendering (NPR) is known to enhance communication aspects (GOOCH et al. 2011). It generally builds on two principles: highlighting of important or prioritized information, and

* This is the authors' version of the work. The definitive version is available at http://www.schweizerbart.de/journals/pfg.

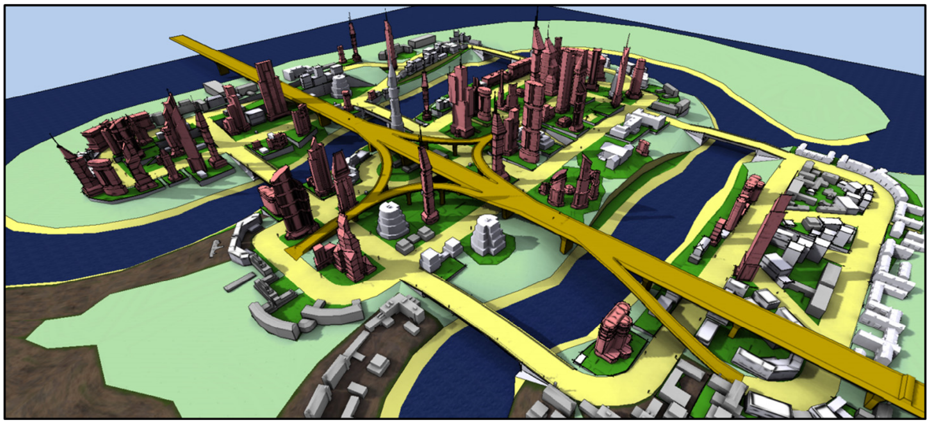

Fig. 1: Exemplary visualization of a virtual 3D city model based on feature semantics. Features are coloured and stylized according to their feature class (i.e., building, street, green space, terrrain, and water surface).

abstraction of less important information. Nowadays, various rendering techniques and abstraction concepts exist (GOOCH et al. 2011) to enable a non-photorealistic visualization of 2D and 3D *features* (i.e., abstractions of real-world phenomena, ISO 19101:2002). However, applying non-photorealistic rendering techniques to a single 3D city model results in a monotonic visualization. For an efficient communication, it requires having an adequate representation on feature level. One approach is to adopt design principles from cartography (JOBST & DÖLLNER 2008) to efficiently communicate thematic information and geospatial relationships (Fig. 1), for instance by using semantics-based information (HILDEBRANDT 2011).

In this work, we present concepts for cartography-oriented visualization of virtual 3D city models that seamlessly integrate into a visualization pipeline. These are based on semantic information to enable the communication of thematic information by principles of cartography. For this, we make several contributions. First, we identify challenges and principles for the cartography-oriented visualization of virtual 3D city models. We then propose ideas for a standardized visualization that is optimized for cartographic design. Finally, we outline application examples of our concept to show how cartography-oriented visualization can be used.

The remainder of this work is organized as follows. We review related work on non-photorealistic rendering for virtual 3D city models (section 2) before we summarize our concept of a semantics-based and cartography-oriented visualization including challenges and standardization by means of a visualization pipeline (section 3). We then propose stylization techniques on top of this concept (section 4) and outline their applications and use cases (section 5). Finally, we state ideas for possible future extensions and conclude this work (section 6).

2 Related Work

Prominent examples for a non-photorealistic rendering are computer-generated imitations of watercolours, pen-and-ink and pencil drawings (GOOCH et al. 2011). Previous work showed that NPR is able to improve visual clarity in 3D geovirtual environments (DÖLLNER & WALTHER 2003, DÖLLNER et al. 2005, Fig. 2B/C). Our work uses an edge enhancement in image-space (NIENHAUS & DÖLLNER 2003) and object-space (DÖLLNER & WALTHER 2003) to improve the perception of city structures, and techniques for the stylization of 2D textures (KYPRIANIDIS & DÖLLNER 2008) to highlight important information and filter less important information.

A context-aware abstraction has the potential to improve the perception of structures in images, as is shown exemplary for aerial images (SEMMO et al. 2010). In previous work, we already introduced and

Fig. 2: Comparison between (A) digital 2D maps and virtual 3D city models rendered with (B) photorealistic rendering techniques, and (C) non-photorealistic rendering techniques.

discussed a semantics-based, selective stylization of virtual 3D city models, the concurrent use of photorealistic and non-photorealistic stylization within one single image, and a set of style operators suitable for virtual 3D city models (HILDEBRANDT 2011). Virtual 3D city models can be enriched with semantic information by using, e.g. ontology-based approaches (MÉTRAL et al. 2009). The OGC's encoding standard CityGML (KOLBE 2009) describes an approach for modeling and exchanging semantically enriched virtual 3D city models.

First theoretical work on cartography-oriented visualization is found in the context of web visualization services (ZIPF 2005). A previous work described a first approach how to render virtual 3D city models with cartography-oriented design (SEMMO et al. 2011). We extend this work by identifying challenges for computer-generated cartography-oriented design, use cases and a discussion for a standardized visualization.

The *Open Geospatial Consortium* (OGC) proposed the languages *Styled Layer Descriptor 3D* (SLD3D) and *Symbology Encoding 3D* (SE3D) (NEUBAUER & ZIPF 2009) as standards for the stylization of 3D geoinformation. These languages represent simple adaptations of the SLD (MÜLLER 2006) and SE (LUPP 2007), which are used for 2D geoinformation, but are still in an early stage of development. In this work, we highlight the importance of style description languages and discuss their applicability for advanced visualization techniques.

3 Principles of Cartography-Oriented Visualization

This section discusses principles of an effective cartography-oriented visualization: design principles from traditional cartography and interactive 3D environments for effective cartography-oriented illustrations, real-time rendering techniques, and concepts for a standardized visualization.

3.1 Cartography-Oriented Illustrations

In contrast to 2D maps (Fig. 2A) and paintings by famous cartographers like MERIAN (Fig. 3A), virtual 3D city models have special characteristics in terms of their data complexity and interactive presentation. We identified the following principles for effective computer-generated, cartography-oriented illustrations:

Automated and generic abstraction techniques. A stylization of virtual 3D city models is based on abstraction techniques that should work independently from model contents. Fig. 3 exemplifies a hand-drawn map in comparison to a computer-generated stylization.

Interaction with 3D geovirtual environments. A user should be able to adapt the stylization of a 3D scene to the performed task and according to prioritized information. One example is an adaptive configuration of colour schemes for prioritized feature classes.

Real-time rendering. Rendering techniques should perform in real-time to maintain immersion (MACEACHREN et al. 1999) within 3D geovirtual environments.

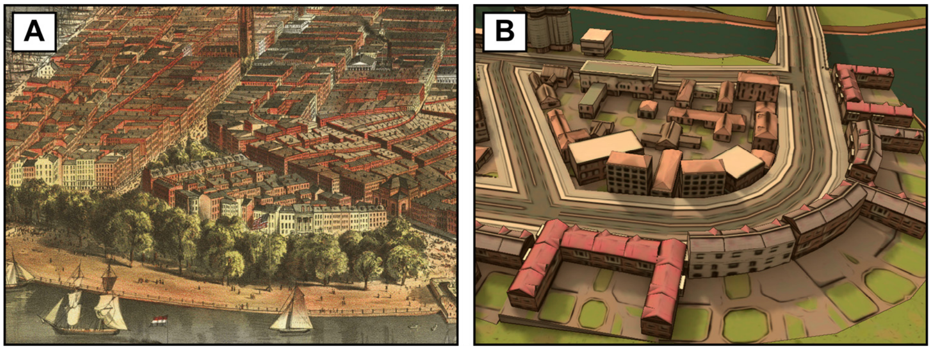

Fig. 3: Comparison between (A) a hand-drawn map (LIBRARY OF CONGRESS – NEW YORK) and (B) an automatically computer-generated, cartography-oriented illustration of a virtual 3D city model.

Frame-to-frame coherence. While navigating through a 3D geovirtual environment, the viewing direction can be continuously changed. Correspondingly, visualization techniques need to maintain a frame-to-frame coherence to avoid visualization artifacts by changes in viewing parameters, depth values and occlusion of models.

3.2 Visualization Pipeline

A cartography-oriented visualization of virtual 3D city models is primarily based on two concepts: geometric abstraction using generalization operators to transform aspects of reality into datasets or maps (e.g. for 3D city models, GLANDER & DÖLLNER 2008, or street networks, AGRAWALA & STOLTE 2001), and visual abstraction using non-photorealistic rendering techniques.

The generalization model of GRÜNREICH proposes three passes of generalization towards the computation of a *cartographic city model*: object generalization, model generalization and cartographic generalization (GRÜNREICH 1992). Common generalization operators comprise the enhancement, displacement, elimination, typification or amalgamation (FOERSTER et al. 2007), and apply at each visualization stage of the visualization pipeline (WARE 2004). Fig. 4 exemplifies a visualization pipeline that structures the visualization of virtual 3D city models into three stages.

In this work, cartographic stylization is based on level-of-abstraction (LoA) that defines the spatial and thematic granularity at which model contents is represented (GLANDER & DÖLLNER 2008). In contrast to level-of-detail (LoD), which focuses on geometric abstraction, LoA directly influences visual abstraction, e.g. performed by shading effects at the rendering stage of the visualization pipeline (Fig. 4). To use visual abstraction in the context of a cartographic stylization, it is essential to map features to feature classes. The classification of objects represents a generalization at the pre-processing stage of the visualization pipeline to enable a semantics-based rendering. Nowadays, data formats exist for an exchange and storage of virtual 3D city models with thematic information, such as the OGC standard CityGML (KOLBE 2009). However, most virtual 3D city models do not incorporate explicit thematic information (e.g. reconstructed from laser scans), and are therefore not suitable for a cartography-oriented visualization. In our concept, the appearance of 3D objects is utilized for a semi-automatic classification. Here, we distinguish between two approaches: (1) features are grouped according to their appearance (e.g. defined by textures or materials) or (2) are manually grouped at run-time.

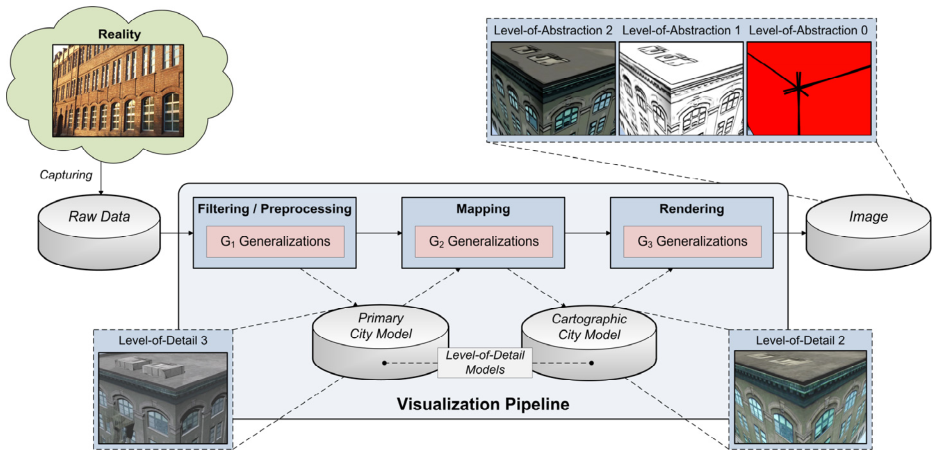

Fig. 4: Visualization pipeline (WARE 2004) that incorporates generalization operators for a cartography-oriented visualization by geometric and visual abstraction.

3.3 Style Description Languages

To enable an effective and efficient communication of geoinformation, in general, the used stylization needs to be adapted to the specific user, the user's task, the application, and the model. In principle, stylization can be described by a formal style description language. This language basically defines the mapping of geodata to geometric primitives and visual attributes. For a generic, computer-based processing, it is required that this language is defined with well-defined syntax and semantics. If such a style description language exists, we see several advantages. First, style specifications can be viewed, modified, compared, exchanged and thus reused among instances of the same system without the need to modify the systems processing of the specification. Second, if the used language complies to a standard, specifications are independent from specific systems and implementations, and can be exchanged and thus reused between different, standard conforming systems. Third, in general, standards represent the formal specification of approved concepts of a domain by domain experts. They are important to disseminate best practices and technological progress (HILDEBRANDT & DÖLLNER 2010).

For style description languages designed for 3D geovirtual environments, we identified various requirements, in addition to those already presented in section 3.1. A style description language should

- use or extend existing standards,
- be declarative to increase the level-of-abstraction,
- consider proven concepts of the visualization pipeline (WARE 2004),
- consider proven concepts for modeling geodata (e.g. feature, layer, and filter) and maintain a semantics-based and selective stylization (HILDEBRANDT 2011),
- be able to parametrize stylizations by well-defined operators defined on the abstraction level of the domain (and not, e.g. the abstraction level of technology) to compose high-level stylizations,
- be able to provide user-defined style operators,
- support the usage of 3D-specific and advanced style operators, and
- specifically support style operators working in image-space at a post-processing stage that

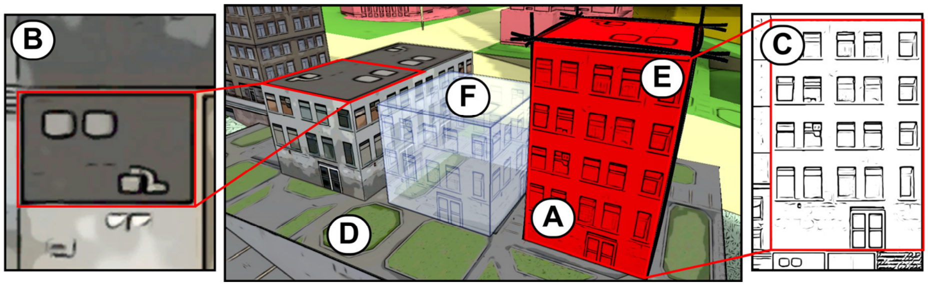

Fig. 5: Overview of stylization techniques: (A) colourization, (B/C) stylization of textures, (D/E) edge enhancement in image-space and object-space, and (F) transparency effects.

are designed to improve the rendering performance and expressiveness, and ease flexibility and parametrization (AKENINE-MÖLLER & HAINES 2008).

In the domain of virtual 3D city models and 3D geovirtual environments, the only relevant standards-based style description languages are SLD3D and SE3D presently proposed as drafts by the OGC. These drafts already support many of the identified requirements. However, several important requirements are not supported. Due to the lack of user-defined style operators, users are constrained to use only the fixed set of operators defined in the standards and their combinations. 3D-specific and advanced style operators are not supported. For instance, it is not possible to specify global illumination, advanced material properties or environmental effects. Further, since the drafts have no support for specific style operators working in image-space, the significant potential of this type of operators cannot be exploited. Examples of operators working efficiently in image space are global illumination (e.g. by *deferred shading*, *shadow mapping*, or *ambient occlusion)* (AKENINE-MÖLLER & HAINES 2008) and the abstraction of the image content by removing unimportant features while at the same time highlighting important features (HILDEBRANDT 2011). Standardized style description languages exist in other domains. However, these typically do not meet the identified requirements for the domain of interest in this work (e.g. specifying styling in OpenGL from the domain of computer graphics is not declarative, lacks direct support of domain concepts, and does not provide composable operators), or their application to this domain was not yet demonstrated.

To summarize, standardized style description languages have a high potential. However, current drafts for such languages in the domain of interest in this work cannot express advanced stylizations that go beyond the straightforward mapping of features to simple geometries and their colourization. In section 4 we propose stylization techniques used for cartography-oriented visualization, and in section 5 exemplify that these stylizations cannot be expressed with the current drafts proposed by the OGC.

4 Techniques for Cartographic Stylization and Implementation

This section outlines visualization techniques that serve a cartography-oriented visualization (Fig. 5) by considering the challenges and principles of section 3.1.

4.1 Colourization

The colourization of geometric primitives adopts design principles known from cartography for visual abstraction and efficient communication of thematic geoinformation. In combination with an edge enhancement, colour schemes can improve the perception of city structures. BREWER proposes conventions for using colours in cartography (BREWER 1994). For example, qualitative colour schemes can be used to communicate feature classes efficiently and ease comprehension of a city's structure. By contrast, sequential colour schemes can be used to communicate thematic information for analysis purposes, for instance to illustrate the distribution of green spaces in a virtual city model (Fig. 6D).

4.2 Stylization of Object Textures

A *bilateral filter* and a *difference-of-gaussians-filter* (DoG) (KYPRIANIDIS & DÖLLNER 2008) can be used for an automated abstraction of textures. Because these techniques operate in colour space and are content-independent, they can be applied to aerial images, terrestrial photography or synthesized textures. The stylization of textures is performed resolution-dependently to enable a view-dependent level-of-abstraction (SEMMO et al. 2010). In contrast to the work by KYPRIANIDIS & DÖLLNER (2008), the output of the edge enhancement is not combined with the quantized colour output (Fig. 5B/C). Instead, colour and outline can be blended at rendering time to stylize features of a specific class differently, e.g. to highlight important or prioritized information.

4.3 Edge Enhancement of 3D Objects

An edge enhancement of 3D objects highlights structural aspects of virtual 3D city models by emphasizing and separating features located in the background of an image (Fig. 5D/E). The edge enhancement in image-space is based on detecting discontinuities in depth, surface orientation and at boundaries of 3D objects (NIENHAUS & DÖLLNER 2003). Although the technique is feasible to stylize generic 3D scenes independently from their geometric complexity, it lacks the possibility to customize the design of enhanced edges (e.g. width, offset or stroke style). To this end, the edge enhancement in object-space provides an alternative approach by using textured, screen-aligned billboards (DÖLLNER & WALTHER 2003). A texture-based edge enhancement is a well-known method to emphasize 3D objects and communicate uncertainty, e.g. to aid city planning and reconstruction (SEMMO et al. 2011). Technically, textured strokes are used and parametrized at run-time for a flexible stylization (DÖLLNER & WALTHER 2003).

4.4 Transparency of 3D Objects

Transparency effects are a well-known method to improve comprehension and visibility of occluded model entities in 3D-space. Using transparency in the context of virtual 3D city models is not a new approach. For example, alpha blending can be used to enable blue print illustrations of 3D scenes (NIENHAUS & DÖLLNER 2004), e.g. to highlight construction states of building models (Fig. 5F/6C). Further, transparency effects are used in web services and systems, such as Google Maps, to aid the perception of complex structures or the architecture of 3D building models.

4.5 Real-Time Rendering

The goal for an effective, interactive visualization is to render complex virtual 3D city models at real-time and to offer a flexible, fully configurable stylization. In addition to a manual classification of features, this includes a parametrization of styles at run-time.

For a semantics-based, cartography-oriented visualization, each feature needs be mapped to its corresponding feature class. To this end, each feature is assigned – in addition to its semi-automatic classification – a unique identifier. In case a re-classification occurs at run-time, the assignments of feature identifiers to feature classes are updated, including style parametrizations.

For rendering complex 3D scenes, the graphics API OpenGL 3.2 and the OpenGL Shading Language (GLSL) are used. To parametrize the appearance of each single 3D feature dynamically, feature identifiers are assigned to fragments. This enables a mapping of fragments to feature classes and their defined stylization at real-time. For rendering transparency effects, a "*stencil routed A-buffer*" (MYERS & BAVOIL 2007) is used to buffer occluded model fragments. The fragments are then sorted dynamically in a post-process to synthesize the final image by image blending.

5 Application Examples

With a real-time, cartography-oriented visualization of virtual 3D city models, new possibilities emerge for the communication of thematic geoinformation. For example, regions-of-interest and

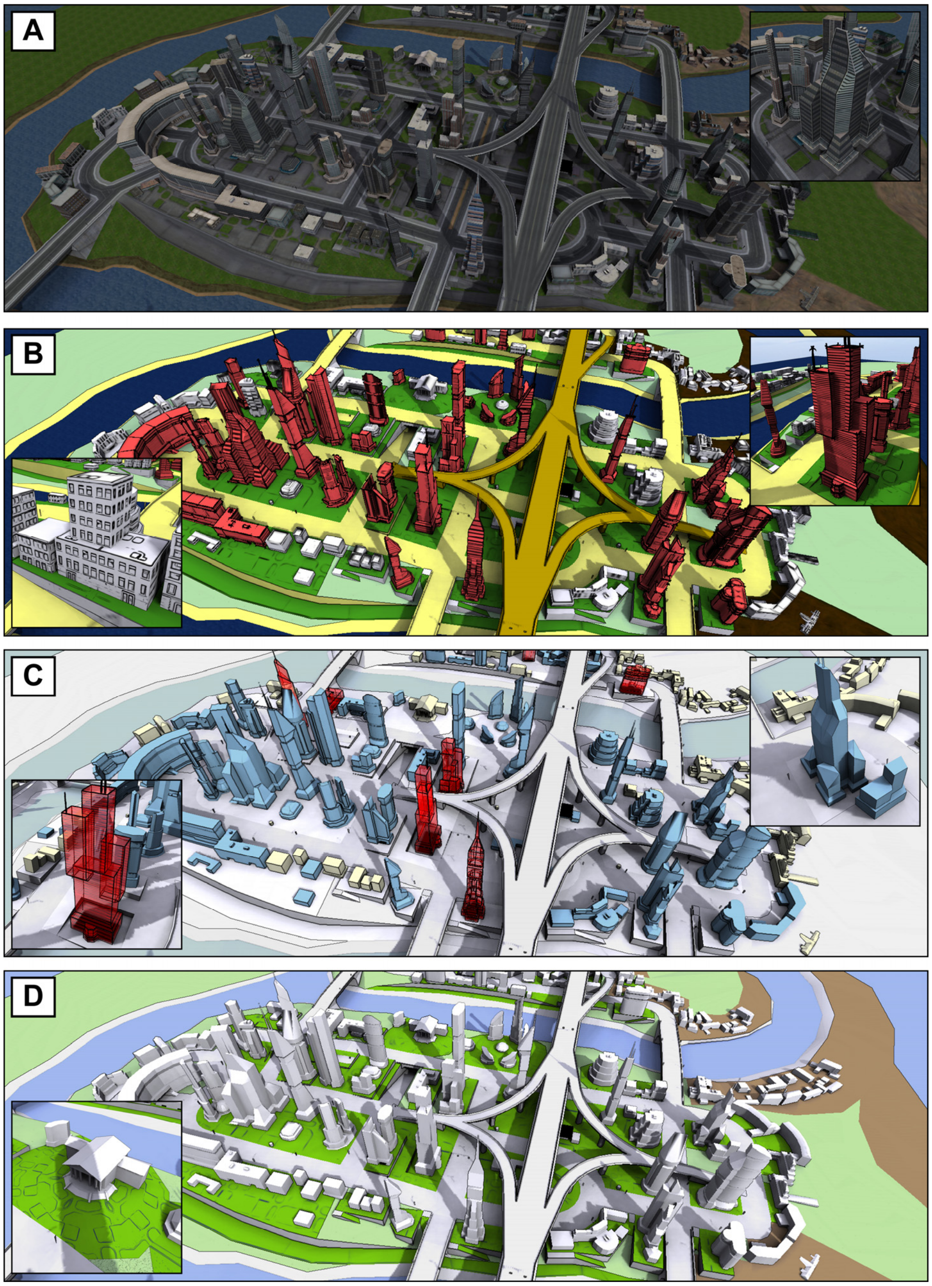

Fig. 6: Possible scenarios for a cartography-oriented visualization of a virtual 3D city model, in comparison to (A) a photorealistic version: (B) thematic overview of feature classes, (C) highlighting of construction states for building models, (D) highlighting the distribution of green spaces.

structures of a city's image can be highlighted, such as landmarks, routes and districts (LYNCH 1960), e.g. to ease orientation and navigation tasks. Further, the cartography-oriented visualization can aid a fast decision support in navigation systems by highlighting street networks and landmarks. Furthermore, thematic information can be visualized for analysis purposes by using qualitative and quantitative colour schemes (BREWER 1994), e.g. for visualization and exploration of crime maps (WOLFF & ASCHE 2009). Finally, parametrized abstractions can be used to visually enhance city planning systems with focus on architectural aspects.

The visual quality of a stylization is a well known issue in aesthetics of computer graphics. It primarily builds on style configurations that adapt to a viewer's needs, technical background and cognitive qualities. Because the presented concepts and techniques enable a broad range of configuration possibilities, not all parametrizations are beneficial. Fig. 6 exemplifies configurations for three different scenarios:

1. a highlighting of feature classes that is based on a diverging colour scheme and an edge enhancement in image- and object-space to improve the perception of a city's structure (Fig. 6B),
2. a cartography-oriented visualization that communicates construction dates and states of building models by using a diverging colour scheme and transparency effects (Fig. 6C),
3. a visualization that communicates the distribution of green spaces, e.g. to analyze life quality within an urban environment (Fig. 6D).

The presented application examples cannot be completely expressed by current style description languages such as SLD3D and SE3D of the OGC. Whereas colourization and transparency effects can be defined by material properties, no language features exist to define non-photorealistic abstraction, edge enhancement, and global illumination. Moreover, the SLD3D and SE3D are located conceptually in the mapping stage of the visualization pipeline (section 3.2). Although this concept facilitates real-time rendering, an ad-hoc modification of the stylization is not possible for complex models because of their large data volume. In summary, current proposals for standardized style description languages cannot express advanced stylizations. This concludes that we cannot realize the benefits identified in section 3.3, and that the stylizations presented in this work remain a proprietary component of individual systems and implementations.

6 Conclusions and Future Work

The semantics-based, cartography-oriented visualization of virtual 3D city models represents a promising approach for improving the efficiency of 3D geoinformation communication. The identified approaches for a standardized visualization of cartography-oriented illustrations exemplify how high-quality geospatial visualization services can be technically implemented. For instance, mobile mapping services can benefit from a cartography-oriented visualization to improve the perception of information on small screens (JOBST & DÖLLNER 2008). Further, the application examples show how cartography-oriented visualization can be used in GIS, urban planning and tourist information systems. But in order to demonstrate their effectiveness within these application domains, a validation as part of a user study is required.

To further improve the visualization quality, we see two general approaches: (1) the implementation of additional typographical characteristics of cartography for certain feature types, for example to communicate land use information or visualize street networks in an abstract style, and (2) the incorporation of interactive concepts for a dynamic, context-aware abstraction, for example to enable a saliency-guided visualization.

Currently, advanced stylizations as presented in this work are proprietary components of individual systems. To promote technical progress and to make these stylizations broadly available, future work needs to develop sufficiently expressive, standardized style description languages that are designed to improve the effectiveness and efficiency of geoinformation communication.

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