Towards Comprehensible Digital 3D Maps

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Abstract. Digital mapping services have become fundamental tools in economy and society to provide domain experts and non-experts with customized, multi-layered map contents. Because of continuous advancements in the acquisition and provision of virtual 3D city and landscape models, 3D geovirtual environment have become commonly used tools for the visualization of 3D geoinformation. In particular, 3D mapping services represent key components to a growing number of applications, such as car navigation, education, or disaster management. However, current systems and applications providing digital 3D maps face drawbacks and limitations, such as occlusion, visual clutter, or insufficient use of screen space, that impact an effective comprehension of geoinformation. To this end, cartographers and computer graphics engineers developed design guidelines, rendering and visualization techniques that aim to increase the effectiveness and expressiveness of digital 3D maps, but whose seamless combination remains to be achieved. This work discusses potentials of digital 3D maps that are based on combining cartography-oriented rendering techniques and multi-perspective views. For this purpose, a classification of cartographic design principles, visualization techniques, as well as suitable combinations are identified that aid comprehension of digital 3D maps. According to this classification, a prototypical implementation demonstrates the benefits of multi-perspective and non-photorealistic rendering techniques for visualization of 3D map contents. In particular, it enables (1) a seamless combination of cartography-oriented and photorealistic graphic styles while (2) increasing screen-space utilization, and (3) simultaneously directing a viewer's gaze to important or prioritized information.

Keywords. Digital 3D Maps, 3D Mapping Service, Context-Aware Mapping

1. Introduction

For centuries, maps have been essential resources for humankind to aid orientation, navigation, exploration, and analysis tasks. With the digital revolution in the last quarter of the 20th century, 2D digital maps started to foster an interactive communication of geoinformation, allowing, for the first time, to customize map contents to tasks and contexts based on a service-oriented architecture (SOA) (Beaujardiere 2006). Recent advancements in the acquisition, provision, and visualization of 3D geodata, such as virtual 3D city and landscape models, yield new possibilities for 3D mapping services. Today these services represent key components to a growing number of applications, like car navigation, education, or disaster management. In particular, mapping services based on 3D geovirtual environments (3D GeoVEs), such as Google Earth™ or the OGC's Web View Service (WVS) (Hagedorn 2010), provide users various information overlays to customize visualization to tasks and contexts, such as thematic or topographic maps. The customizations often focus on embedding 2D overlays for points-(or areas-)-of-interest, for instance to highlight public transport networks, traffic information and landmarks, or to modify the map presentation (e.g., photorealistic or non-photorealistic). A photorealistic presentation tries to visualize geoobjects as realistic as possible, which eases the mental mapping between a visualization and reality. By contrast, a non-photorealistic presentation abstracts from reality and provides the prerequisites to simplify and filter detailed elements as well as to clearly encode displayed information of complex geoinformation (Döllner and Kyprianidis 2010). A specialized class of 3D GeoVEs is the digital 3D map (D3DM), which is based on a generalized data model and utilizes a symbolized (abstracted) visualization of 3D geoobjects.

Figure 1. Digital 3D map of the virtual city model of Chemnitz showing a route: A view-dependent, multi-perspective view is used to increase the screen-space utilization by bending the background upwards. A cartography-oriented stylization is applied off the route to lower visual complexity.

In contrast to traditional 2D maps, D3DMs utilize a central perspective view, which is similar to the human's 3D visual perception, offering a natural access to geoinformation (Jobst and Döllner 2008a) and immersion (MacEachren et al. 1999) into the geodata, and thus increasing a user's effectiveness on spatial tasks (Tan et al. 2004). During the last decade, cartographers discussed and established guidelines to further increase the effectiveness and expressiveness of D3DMs (e.g., (Häberling et al. 2008; Pegg 2012; Jobst 2006)). However, current products, systems, and applications providing D3DMs still face a number of drawbacks that impact the comprehension of 3D map contents: **(D1) Occlusion.** Due to overlapping of 3D geometric representations, hidden map content cannot be perceived in a perspective view. **(D2) Visual Clutter.** Because of perspective distortion, the size of distant map objects decreases. As a result, they are no longer recognized as single objects and are perceived as "visual noise" (e.g., because they occupy only one pixel). **(D3) Insufficient use of screen space.** In perspective views at pedestrian level, a large amount of the screen-space (e.g., 50 percent) is occupied by the horizon or visual clutter. In this area no (or just few) information can be communicated. **(D4) Unlimited number of cartographic scales.** Due to perspective distortion, a 3D digital map includes an unlimited number of map scales. This complicates the estimation and comparison of spatial relationships.

Previous work showed how view-dependent multi-perspective views (MPVs) (Pasewaldt et al. 2011) and cartography-oriented visualization (COV) (Semmo et al. 2012) can be used to partially overcome drawbacks D1–D4. MPVs, on the one hand, enable the seamless combination of different 3D perspectives in a single view and thus feature less occlusion, a reduced number of cartographic scales, and an increased utilization of screen space. COV, on the other hand, facilitates guidance of a viewer's gaze to important or prioritized information, thus providing saliency-guided visualization. Both techniques adapt visualization to different contexts and contents with respect to user interaction or dynamically changing thematic information, but have not been applied concurrently in a single system.

This work presents a prototype that combines MPVs with COV and discusses the potentials for comprehensible D3DMs (*Figure 1*). For this purpose, a classification of visualization techniques, cartographic principles, and their suitable combinations are identified that aim to increase the expressiveness and effectiveness of D3DMs. According to this classification, a prototypical implementation demonstrates the benefits of multi-perspective and non-photorealistic rendering techniques for the comprehension of D3DMs. In particular, the prototype enables (1) a seamless combination of cartography-oriented and photorealistic graphic styles while (2) increasing screen-space utilization and (3) simultaneously directing a viewer's gaze to important or prioritized information.

The remainder of this paper is structured as follows. Section 2 reviews related and previous work in cartographic theory and computer graphics that aims to improve comprehension of 3D geoinformation. Section 3 reviews cartographic design aspects that clarifies the visualization of D3DMs and thus increases their comprehension. Section 4 presents a visualization system for comprehensible D3DMs. Based on the design aspects of Section 3, the system is evaluated and discussed in Section 5. Finally, Section 6 concludes this paper.

2. Related Work

Cartographic Generalization & Stylization. Generalization and symbolization are fundamental methods in map production to facilitate effective communication of geoinformation (MacEachren 1995). Cartographic generalization relies on model transformations (generalization operators) that transform geodata into human-readable maps (McMaster and Shea 1992). They are applied to the primary, secondary and tertiary cartographic model (Gruenreich 1992). Typical operators comprise aggregation, displacement, enlargement, and typification of geoobjects to solve geometric issues in 2D map design, such as overlapping, or visual clutter. Previous work proposed a formal classification of generalization operators designed for 2D mapping services (Foerster et al. 2007).

However, they differ from issues known from D3DMs, such as the degree-of-abstraction (i.e., ranging from realism to abstract representations (Kraak 1989; Dykes et al. 1999)), depth perception (Pfautz 2000), and perspective distortion (Pegg 2012). Therefore, new design principles for digital D3DMs are necessary, or existing principles must be extended. This work gives an overview of design guidelines for D3DMs in conjunction with 3D computer graphics methodologies that aim to solve these issues.

Design Principles for Digital 3D Maps. To date, no design standards for D3DMs have been established. Researchers agree that 3D map design should account for application space, level of interactivity, and the audience of purpose (Dykes et al. 1999). Approaches in cartographic theory identified cartographic variables (Jobst 2006) and design principles for D3DMs (Häberling et al. 2008), comprising modeling, symbolization, and visualization as three major production stages for effective map design. However, the presentation of 3D map objects in perspective views can be manifold and complex, thus 3D map objects need to be generalized to display relevant information to a user in a clear and efficient manner (Petrovic 2003). Some generalization methods exist for 3D GeoVEs, such as generalization of 3D building models (Glander et al. 2007) or digital terrain models (Glander et al. 2011). However, these approaches are feature-specific. This work, instead, does not focus on specific generalization techniques, but explores a combination of different level-of-detail and level-of-abstraction approaches for various feature classes.

3D Computer Graphics & Visualization. Cartographic generalization has been used for 3D GeoVEs in previous work, e.g., in the automated design of tourist maps (Grabler et al. 2008), panoramic maps (Degener and Klein 2009), and bended maps (Lorenz et al. 2008). Certain rendering techniques addressed major challenges that occur in D3DMs. For instance, deformation techniques have been successfully used for focus-&-context route zooming (Qu et al. 2009) or highlighting (Möser et al. 2008) to reduce occlusion in areas that are of particular interest to a user. MPVs have been used to increase screen-space utilization and to reduce the number of cartographic scales in perspective views (Jobst and Döllner 2008a). The system presented in this paper is based on a framework for visualizing generalized 3D models in geovirtual environments (Semmo et al. 2012) to combine cartography-oriented design and view-dependent MPVs (Pasewaldt et al. 2011) to further improve comprehension of D3DMs.

3. A Review of Design Aspects for Digital 3D Maps

The International Cartographic Association (ICA) defines a map as “a symbolized image of geographical reality, representing selected features or characteristics, resulting from the creative effort of its authors execution of choices, and is designed for use when spatial relationships are of primary relevance” (ICA 2000). According to this definition, a perspective view in a 3DGeoVE is not a D3DM per se. Häberling et al. suggest that the term 3D map is applicable to 3DGeoVEs if the virtual environment is based on a generalized data model and utilizes a symbolized visualization of classified map objects (Häberling et al. 2008) (e.g., by using the class model of CityGML (Kolbe 2009)).

The aim of a map is to successfully communicate geoinformation between a cartographer (the map producer) and a user (the map consumer). Geoinformation is encoded using a semiotic model and is transferred by the map. For a successful communication, the map consumer must understand the semiotic model to decode the information. Further, a map should satisfy the needs of the map consumer to improve the communication process: the map should be readable, comprehensible, and visualized in a way that the information can be memorized easily, and that not only rational but also emotional aspects (Kolacny 1969) are addressed. According to Broderson, the geocommunication process is successful if the map producer and the map consumer "agree" on aspects of location or space (Brodersen 2007).

Design Steps	Design Aspects	Design Variables
Modeling	Models of map objects	Model geometry, semantic attributes and position
Symbolization	Graphic appearance	Shape, size, color
	Textures	Pattern, pattern repetition rate and orientation
	Animations	Size and texture alteration
Visualization	Perspective	Parallel and perspective projection
	Camera Settings	Viewing inclination

Table 1. Excerpt of design steps, aspects and variables proposed by Häberling et. al. (2008)

In order to achieve this agreement, cartographers developed different high-level design guidelines for D3DMs that are summarized in the following:

(A1) Decrease of visual complexity by classification, symbolization and abstraction. Häberling et al. define the following three design steps for D3DMs: (1) modeling, (2) symbolization, and (3) visualization (Häberling et al. 2008). For each design step, the map producer can choose between different design aspects to configure the map to fit a user's needs and ease the communication process (*Table I*). Modeling includes aspects of filtering raw geodata and mapping these to a 3D geometric representation of map objects suitable for rendering. The visual appearance of the 3D-geoobject (e.g., color, texture and degree-of-abstraction) is configured during symbolization. The visualization step defines the mapping of a 3D geometric representation to the presentation medium and is controlled by parameterizing the virtual camera (e.g., the field-of-view, and projection), as well as using scene specific parameters (e.g., lighting, shading, and atmospheric rendering effects). Based on this classification, Häberling et al. performed a user study to identify atomic design guidelines that assist the map producer to reduce visual complexity and improve comprehension.

(A2) Decrease of occlusion and visual clutter. Although Häberling et al. proposed different design variables for parameterizing the projection of the virtual camera (e.g., orthographic and cylindrical projection), the perspective projection is the most applied projection for digital D3DMs, mainly because it facilitates the human visual system and thus produces a familiar visualization. According to Jobst and Döllner (2008) the perspective view comprises a number of drawbacks, such as occlusion of map-objects and visual clutter due to perspective distortion in the distant parts of the D3DM, which reduces the effectiveness of geocommunication. To reduce occlusion, Häberling et al. suggest a viewing inclination of 45° (Häberling et al. 2008) and generalization to minimize visual clutter. An alternative approach is used in panoramic maps: Landscape artists combine multiple perspectives in one image and distort (e.g., enlarge) map-objects (Patterson 2000).

(A3) Increase of user involvement. The design process of maps can be described as a feedback loop between the map producer and the map consumer (Peterson 2005) where the map producer designs the map according to the consumer's feedback. Reichenbacher demands "the ability of flexible systems to be changed by a user or the system in order to meet specific requirements" (Reichenbacher 2007a). An optimal map should "present as much information as needed (by a user) and as little as required" (Reichenbacher 2007b). Service-based D3DMs fulfill this requirement, because a user's feedback is directly transformed into a new version of a map. This direct feedback-loop changes the strict separation between the role of the map producer and map consumer (Jobst and Döllner 2008b). The consumer itself becomes the map producer. Instead of exposing all map design parameters, which possibly overwhelm a user, the D3DM should interactively react on a user's context. For example, the map provides an overview while a user follows a navigation route. When a user is faced to make decisions, e.g., which road to travel at a cross road, the map focuses on the cross road, assisting with detail information.

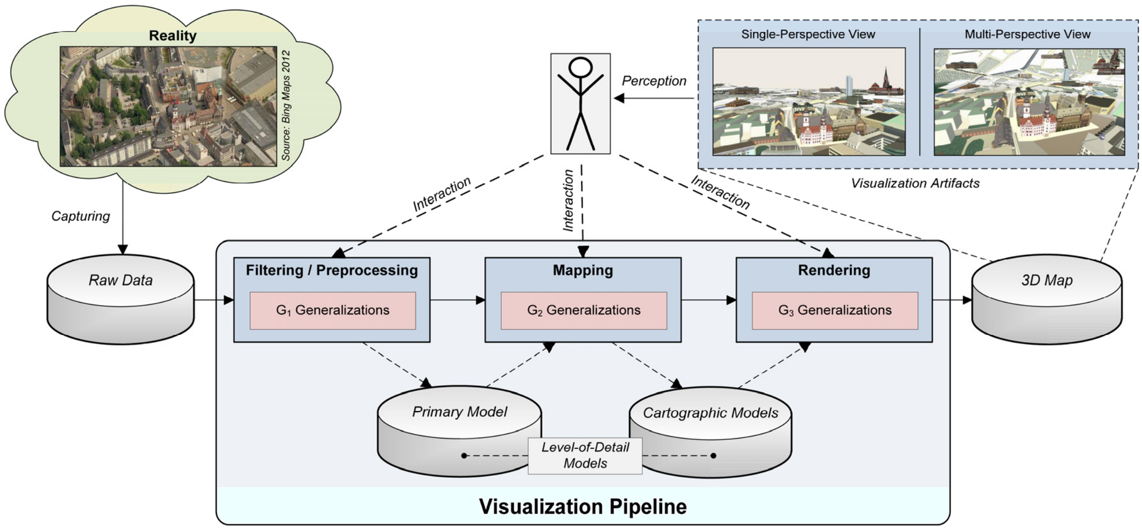

Figure 2. Visualization pipeline with incorporated generalization operators at the pre-processing, mapping and rendering stage. Cartographic models with varying level-of-detail serve as input for the rendering stage, where cartography-oriented rendering and deformation techniques are used for level-of-abstraction. The map producer can modify the cartographic models by configuring the generalization operators of the preprocessing and mapping stage.

(A4) Increase of screen-space utilization. The map is presented using an information carrier, such as paper or digital displays. The size and resolution of the information carrier for D3DMs can vary between 3.5" with 330ppi (pixel per inch) for mobile devices up to 60" with 37ppi for monitors. The size and resolution in combination with the capabilities of the human's visual system defines the minimum size boundary of a map element. If the map element falls below this boundary it becomes indistinguishable from its surroundings and, as a consequence, the corresponding pixels cannot be efficiently used for communicating geoinformation. In order to prevent these "dead values" (Jobst and Döllner 2008a) a D3DM must be device aware.

To summarize, D3DMs need to be designed in a way that reflects the context and task of a map consumer to highlight prioritized or important information, i.e., using device-aware visual abstraction and symbolization that features less occlusion and utilizes screen-space efficiently. One possibility to achieve this, is to combine cartography-oriented visualization and multi-perspective views in a system approach, which is presented in the following section.

4. Comprehensible Digital 3D Maps

The computer-aided generation of a visualization can be structured into three major stages of a pipeline (Ware 2004) (*Figure 2*). For the production of D3DMs, this pipeline is aligned to geodata as follows: (1) pre-processing of raw geodata with filtering as predominant operation, (2) mapping of geodata onto computer graphical representations, and (3) transformation of mapped geodata into visualization artifacts. *Figure 2* illustrates a visualization pipeline that incorporates generalization operators for these three stages. In contrast to traditional map design, parameterization of these stages can be (almost) interactively controlled, thus contributing to the "virtuality" of D3DMs. Interactive systems usually respond on user interaction at all three stages, i.e., the system semi-automatically manipulates the selection of data sets and objects, geometric representations, visual appearance, and the virtual camera according to tasks and contexts of the map consumer.

For comprehensible maps, the most important "interface" (i.e., the visual artifacts) lies between the human visual system and the data. They are perceived as visual "features which are hidden in the data but nevertheless are needed for data exploration and analysis" (Gershon 1994). A promising approach to enhance perception of important or prioritized information is to abstract from the data by selecting the appropriate spatial and thematic granularity at which the model contents should be represented (*level-of-abstraction* (LOA) (Glander and Döllner 2007)) in a context-dependent way, e.g., by using cartography-oriented visualization techniques (Semmo et al. 2012). However, cartography-oriented visualization alone neither resolves occlusion and visual clutter in 3D perspective views, nor does it address the problem of having an unlimited number of cartographic scales and insufficient screen-space utilization. To this end, multi-perspective views can be used as orthogonal approach to

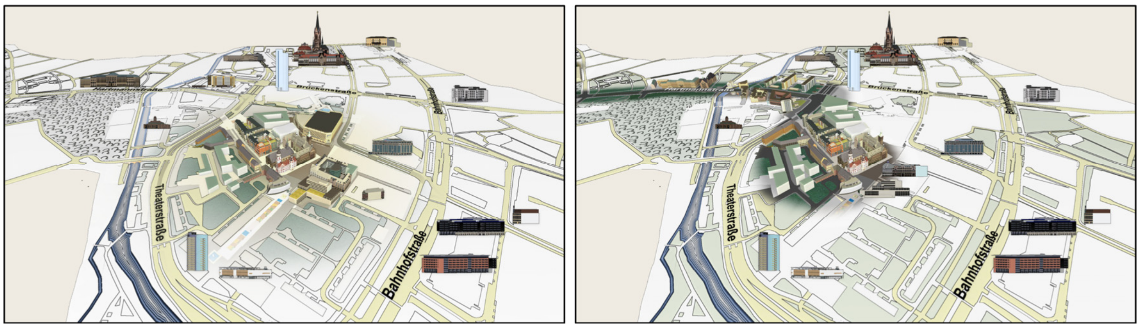

Figure 3. Exemplary cartography-oriented visualization of a virtual 3D city model: (left) area-of-interest rendered with high detail and blended with a cartography-oriented stylization in the context region, (right) a route visualized accordingly.

render D3DMs in a more comprehensible way. In the following, an approach is outlined that combines cartography-oriented visualization with multi-perspective views.

4.1. *Cartography-Oriented Visualization*

Cartography-oriented visualization uses cartographic techniques (e.g., generalization and symbolization) for geocommunication. Interactive multi-scale maps designed with cartography-oriented visualization techniques can facilitate communication of geoinformation by directing a user's *focus-of-attention* (Semmo et al. 2012). The interactive system enables a dynamic and context-dependent creation of 3D geovirtual environments by using various, user-controllable visual styles, e.g., multiple abstracted virtual representations of map contents. In 3D map design, the degree-of-abstraction can range from realism to abstract representations (Dykes et al. 1999). The realistic as well as the abstracted graphic styles have certain advantages in communicating information effectively, dependent on whether high detail and realism is desirable, or an abstract overview should be provided. The combination of techniques for photorealistic and non-photorealistic (abstracted) rendering (Strothotte and Schlechtweg 2002) emphasizes relevant or prioritized information, and can be used to omit less relevant information by considering perceptional, cognitive, and graphical design issues. The system presented here visualizes D3DMs at different LoAs in real-time, and enables smooth and seamless transitions between them. The resulting continuous visualization directs a viewer's gaze towards the prioritized information and thus can increase effectiveness of geocommunication.

The cartographic stylization utilizes generalization operators combined as function $G = (C_i, \mathbf{S}_i, c)$. C_i represents a feature class, i.e., it defines a subset of map objects that share certain characteristics (e.g., buildings, roads, or landmarks). $\mathbf{S}_i$ is a set of *stylization descriptions* $S = (lod, t_0, t_1, t_2, t_3)$ that define the visual appearance of C_i for a scalar c. This scalar is the result of a function that maps a user's context, e.g., position and viewing angle of a virtual camera, or the driving speed of a car, and maps it to an interval [0, 1]. Based on the value of c, one or multiple stylization descriptions of $\mathbf{S}_i$ are evaluated and combined to the final visual appearance of the map object. The ordered parameters $t_i \in [0,1]$ with $t_i \le t_{i+1}$ define when and how a stylization should be applied. The main idea is to define two or more stylizations per feature class and parameterize their intervals t_i in such a way that a smooth transition is achieved during interaction of the map consumer with the system. For instance, *Figure 6* illustrates building models that have been associated with a stylization operator "photorealistic" used in near view distances, which is blended with a second operator "abstract" used in far view distances. To achieve this, t_i is mapped on a viewer's distance to a map object, i.e., c increases with distance to a viewer's position.

Although the application of cartography-oriented stylization is applied as a generalization operator in the rendering stage, the configuration of $\mathbf{S}_i$ and C_i also includes the filtering and mapping stages, and follows the design principles of Häberling et al. (2008) (*Table I*). In the following, the configuration process is illustrated by the example of landmarks and green spaces. In the first stage, multiple level-of-detail (LOD) representations are generated for each map object. The map objects are grouped based on their characteristics or semantic attributes to feature classes C_i. For landmarks, a "best-view direction" is computed, which is later used by the landmark abstraction techniques, and a polygon is generated for each green space. Design aspects of symbolization are configured in the mapping stage. For instance, glyph-based textures and cartography-oriented colorization can be used to represent signatures for green spaces. Further, an animation is defined that transforms a 3D landmark

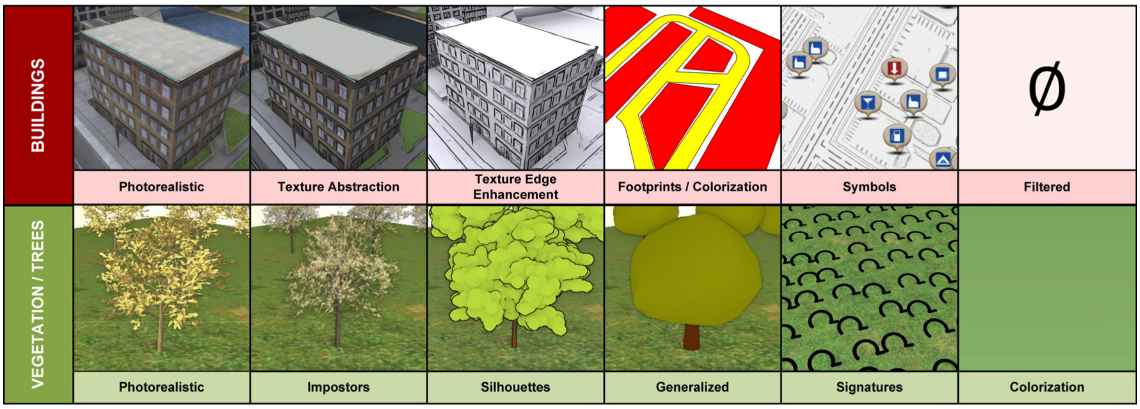

Figure 4. Overview of stylization techniques that span the range from photorealism (left) to cartography-oriented representations (right) by the example of 3D building models and tree models.

into a 2D imposter version that is viewed from the landmark's best-view direction, which correlates to landmark depictions used in tourist maps (Grabler et al. 2008).

During rendering, the stylization descriptions S are evaluated per feature class, based on the result of a context-dependent mapping function. *Figure 3* illustrates two different mapping functions for the same set of C_i and $\mathbf{S}_i$. In the left image, the mapping function interpolates a photorealistic and a cartography-oriented stylization based on the distance to a point-of-interest, resulting in a radial area-of-interest. The mapping of the right image is based on a distance field that captures a route. As a result, map objects within or close to the route are presented in photorealistic way, while the context (i.e., map objects off the route) remains abstracted.

With respect to the domain of geovisualization, the used approach considers certain characteristics for comprehensible map design: **Semantically coherent blending -** D3DMs incorporate a variety of feature classes. Due to their manifold applications, semantic information can be used to enable semantic-based stylizations and transitions (Semmo et al. 2012). **Adaptive transition rules & constraints -** The context and task of the map consumer can be dynamically changed in an interactive system, such as areas-of-interest, viewing positions, or viewing directions. The approach presented in this work can map these saliency metrics to continuously adapt the map illustration to the consumer's context or task she is performing. For instance, view-distance-based, view-angle-based, and area-based transitions can be considered.

Each stylization description S is capable of being dynamically adapted during run-time and applied in realtime. In practice, the map producer defines as many stylization descriptions as are needed to sufficiently span the range of a photorealistic to an abstract rendering of 3D map objects (*Figure 4*).

4.2. *Multi-perspective Views*

Multi-perspective views seamlessly combine multiple perspectives in a single view. This technique is often applied in panorama and landscape visualization, such as the panoramic maps of H.C. Berann (Patterson 2000). Berann utilizes a progressive perspective, where a steep viewing angle in the foreground is progressively interpolated to a flat viewing angle in the background. The foreground depicts an orthographic view on the environment showing the current position of a user whereas the perspective view of the horizon in the background assists a user to determine the viewing direction. By contrast, the degressive perspective applies a flat viewing angle in the foreground and a steep angle in the background. This leads to the impression that the virtual environment is bended towards the user, providing detailed information in the foreground combined with context information in the background (*Figure 1*).

Different real-time capable visualization techniques exist that are able to generate progressive, degressive as well as hybrid perspectives (Möser et al. 2008; Lorenz et al. 2008; Pasewaldt et al. 2011). The following concept and considerations are based on view-dependent multi-perspective views (Pasewaldt et al. 2011). One key aspect of this approach is that one configuration of a MPV, a so called *preset* P, is associated with a distinct viewing angle ϕ. The map producer can define multiple presets with different viewing angles. During map usage these presets are interpolated based on the current viewing angle. Thus, it is possible to utilize a degressive perspective

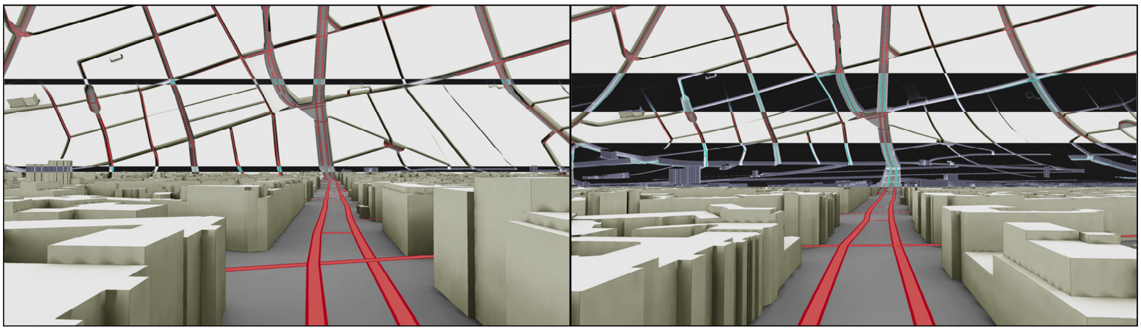

Figure 5. Comparison of two degressive MPV configurations that feature three viewport zones connected by transition zones (darkened areas). Due to the minimized transition zones of the left configuration, the number of map scales is reduced. This eases object comparison in each zone.

for a flat viewing angle of the virtual camera and a progressive perspective for a steep viewing angle without having additional configurations during map usage.

A preset is defined as $P = (C(t), \phi, s, e)$ with $C(t)$ being a parametric curve that is defined by a number of control points B_i. $C(t)$ is used to control the shape of the MPV (e.g., progressive or degressive shape). The scalars s and e define the start and end of the MPV with reference to a viewer's position.

Although the flexibility of the parametric curve can produce an arbitrary number of MPV configurations, especially the degressive and progressive perspective has been in the focus of cartographers. For example, Jobst and Döllner (2008a) discussed to what extend MPVs can increase the perception of 3D spatial relations by reducing occlusion and increasing screen-space utilization. In their work they suggested a configuration that subdivides the view into distinct *viewport zones*, i.e., zones that are viewed with a distinct viewing angle (*Figure 5*). Since the number of cartographic scales is reduced in each zone, the comparison of map objects in each zone is eased (e.g., estimation of the size). To further reduce the number of cartographic scales and enlarge the area of each viewport zone the transition between two viewport zones is minimized.

5. Discussion

The combination of cartography-oriented visualization and multi-perspective views is a promising approach to cope with occlusion, visual clutter, insufficient use of screen-space and the unlimited number of cartographic scales for D3DMs (D1-D4). The possibility to define, parameterize, and combine different stylization techniques represents a flexible approach to utilize different visualization and rendering techniques, e.g., landmark scaling and abstraction, and non-photorealistic rendering. The configuration of stylization descriptions S considers all stages of the interactive visualization pipeline and map-production workflow, and can be utilized to implement the design aspects of Section III (A1-A4). Compared to existing approaches and techniques (Häberling et al. 2008; Pegg 2012) it enables to parameterize stylizations per feature class and map scale that are seamlessly interpolated during map usage to deliver view-dependent LoAs. The transition of a photorealistic rendering to a cartography-oriented stylization during interaction has the potential to teach the cartographic semiotic model to map-illiterates. Observing how well-known 3D geoobjects – rendered with high detail – smoothly fade into abstract representations and map symbols (and vice versa, *Figure 4*) may help a user to gain cartographic knowledge and can avoid “getting lost situations” (Buchholz et al. 2005) while moving from one point-of-view to another.

Orthogonal to cartography-oriented visualization, multi-perspective views can also avoid “getting lost situations” by providing additional context information that clarify the viewing direction or current location. In addition, using the screen-space of the sky to visualize (abstracted) map objects increases screen-space utilization, which is especially important for digital mapping services, since they only serve a limited screen-space and resolution. Compared to perspective views, multi-perspective views contain a limited number of cartographic scales, especially in areas viewed from a flat viewing angle. This effect can be further increased by utilizing viewport variations with limited transition zones. The reduced number of cartographic scales can ease the estimation of topological relations. Moreover, occlusion can be reduced to visualize more map objects to aid navigation and orientation. Jobst and Döllner (2008a) argued that multi-perspective views can be counterintuitive since the

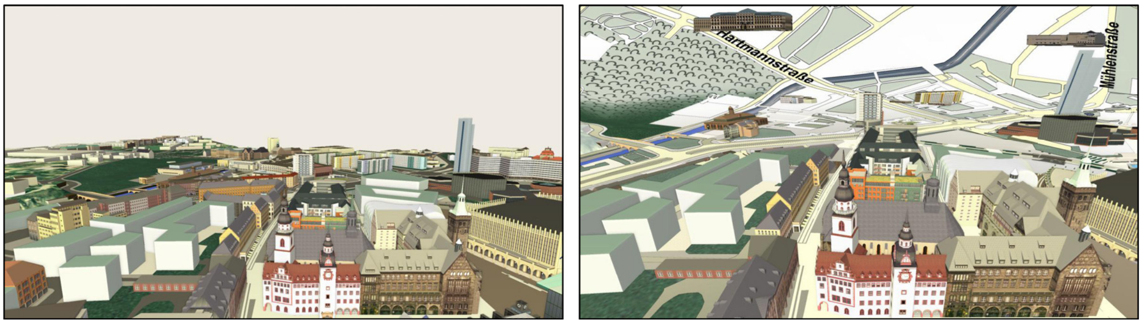

Figure 6. Exemplary perspective view of a virtual 3D city model rendered photorealistically (left) in comparison to a multi-perspective view (right) that is combined with cartography-oriented visualization (i.e., colorization, edge enhancement, labeling, waterlining, symbolization, landmark abstraction and transformation).

virtual environment is depicted in an unnatural, distorted way. To communicate that the visualization does display a bended virtual environment, a different rendering style (e.g., based on cartographic generalization and abstraction) should be applied. The system presented here allows such a configuration by utilizing a distance-based mapping function that correlates to the boundaries of the viewport zones (*Figure 6*).

One drawback of the system is that it requires different abstracted (or generalized) representations of geoobjects. Although image-space abstraction, such as color quantization or edge enhancement, can be computed during rendering, object-space abstraction (e.g., aggregation or displacement) requires preprocessing (Döllner and Kyprianidis 2010). Only few automatic preprocessing techniques exist for generalizing 3D geoobjects. Thus, manual labor is necessary to generate the input data for the presented system. Furthermore, additional storage capacity for multiple geoobject representations and computational complexity of image-space abstraction requires sufficient hardware resources and computing power on the target device to apply the system presented in this work. To cope with this, a service-oriented architecture (e.g., OGC's WVS) can be utilized for devices with limited hardware resources, such as mobile devices or navigation systems. Further, the SOA eases the integration of additional geodata-services, for example location-based services (e.g., Google Places™, or Facebook's foursquare™). These services process context information of a user by collecting bookmarked geopositions of visited places. During exploration of an unknown area, the additional information can be utilized as areas-of-interest for the cartography-oriented visualization to assist the map consumer by providing links to well-known places. To reduce bandwidth requirements, the resolution and the size of the D3DM transferred to the client can be configured with respect to the screen size and resolution of a client's device.

The combination of cartography-oriented visualization and multi-perspective views covers a large number of design aspects and variables of the digital map production workflow to produce comprehensible D3DMs. The versatility leads to the question which configuration is best suited for a certain user and a certain context. To answer this question, an extended user study is required (similar to Häberling et al. 2008) that needs to be conducted in a team of cartographers, psychologists and usability-experts. The system presented here provides a web-based framework to perform such a user study in a future work.

6. Conclusions

This paper presents a concept that combines two interactive visualization techniques capable of improving the comprehension of digital 3D maps: multi-perspective views and cartography-oriented visualization. The combination of both techniques is suitable to overcome common limitations of 3D digital maps, such as occlusion, visual clutter, insufficient use of available screen-space, and the possibility of having unlimited cartographic scales in a perspective view. In addition, it offers a tool set that parameterizes and renders digital 3D maps in correspondence to design aspects and variables known in digital map design. Moreover, the work presents a prototypical system that demonstrates the potentials of the presented concept for exploration and navigation tasks. It serves as a framework for future research on user and context aware digital 3D maps, with good prospects on the standardization of service-oriented architectures.

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