Cartographic Enrichment of 3D City Models—State of the Art and Research Perspectives

Stefan Peters, Mathias Jahnke, Christian E. Murphy, Liqiu Meng and Alias Abdul-Rahman

Abstract This paper reports on cartographic enrichments of three dimensional geovirtual environments including the representation of 3D city models. In the recent years 3D city models have become effective and powerful tools that support the simulation and visualization of our real world in a more and more realistic and detailed way. At the same time, there is a growing interest in comprising more information in the virtual living environment in addition to interior and exterior geometric features, roof and facade textures. A lot of information is related to houses, floors, flats, rooms, etc. but also to persons or specific features at certain urban locations. The paper presents the state of the art of cartographic principles in 3D city models, discusses approaches of cartographic enrichments with the aim to bring added values to the visual exploration of 3D geovirtual environments and reveals missing cartographic design rules within this area.

Keywords 3D city models · Cartographic enrichment · Information mapping

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S. Peters (✉) · A. Abdul-Rahman
Department of Geoinformation, Universiti Teknologi Malaysia, Johor, Malaysia
e-mail: stefanpeters@utm.my

A. Abdul-Rahman
e-mail: alias@utm.my

M. Jahnke · C.E. Murphy · L. Meng
Chair of Cartography, Technische Universität München, Munich, Germany
e-mail: mathias.jahnke@tum.de

C.E. Murphy
e-mail: christian.murphy@tum.de

L. Meng
e-mail: liqiu.meng@tum.de

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1 Introduction

For many centuries, maps are one of the prime presentation media for spatial data. The digital area during the end of the 20th century has changed cartography and brought along interactive, multidimensional, customized and context-based visual exploration methods for geoinformation. Recent developments in purchasing, managing, and visualizing 3D geodata, in particular virtual 3D cities and landscapes, reveal new potentials for 3D cartography (Pasewaldt et al. 2012). An appropriate representation and interactive use of 3D urban models is crucial for every likely application such as urban planning, 3D navigation, spatial analysis of urban data or emergency management.

A 3D geovirtual environment (3D GeoVE), such as 3D city or landscape models, attends to manage, analyze, explore and visualize geo-referenced data and information (Döllner and Buchholz 2005b). Usually, the representation of a 3D city or landscape models is composed of a database that stores the 3D geometrical, semantical as well as cartographic model, and the visualization system that renders it upon a request.

Digital 3D city models are defined as digital models of urban areas representing the relief surface, buildings, infrastructure and vegetation. Their components are described and visualized by 2D and 3D geo-referenced spatial data. 3D city models support visual exploration and analysis of urban geographical data within a single framework (Döllner et al. 2006). Furthermore, virtual 3D city models enable analysts and decision makers to investigate complex spatial and spatio-temporal processes and phenomena in urban environments. “While in 2D GIS applications exploration and analysis of thematic spatial-related objects and associated thematic information is a common practice, the potential of virtual 3D city models as a medium to communicate complex urban information spaces has not been explored extensively” (Döllner et al. 2006). This paper aims to discuss current cartographic aspects in 3D GeoVEs, including standards, limitations and possible research questions. We will introduce 3D city models in general, followed by a detailed review of cartographic rendering of 3D city models. By discussing the limitations of existing cartographic principles for 3D GeoVEs and identifying research gaps concerned with the visual improvements of 3D city models, we aim to provide an anchor point for future research on cartographic enrichment of 3D GeoVEs.

1.1 Data Capturing and Construction of 3D City Models

An automatic, fast as well as cost efficient construction of 3D city models is still an ongoing research topic. However, recent progresses in 3D geographic data acquisition (e.g. using LIDAR technology or image processing), data management and 3D visualization, have driven 3D city models towards widely used and effective solutions for numerous applications. Moreover, advances in cloud processing

(Döllner et al. 2012) allow to run and render large 3D city models in real time. “In practice, the creation and maintenance of virtual 3D city models is based on a number of independent data sources since the sustainable management of 3D city models requires tight links to existing administrative work flows and databases. As a major challenge, these data sources have to be integrated in a systematic and pragmatic way” (Döllner et al. 2006).

1.2 Standards for 3D City Models

However, the common information model CityGML, can be seen as the most established and widely used open data standard for 3D city models in the geoinformation community. CityGML is an official Open Geospatial Consortium (OGC) model, representing a GML-based format for storing and exchanging virtual 3D city models. Moreover, it supports thematic and semantic properties, aggregations and taxonomies. CityGML provides class definitions, normative regulations, and explanations of the semantics for essential geographic features of 3D city models. Furthermore, the model provides an easy extension by further thematic models (Kolbe 2009). The fields of architecture, engineering, construction, and facility management as well as the field of computer graphics provide their own standards. Building information models (BIM) are typically exchanged using the Industry Foundation Classes (IFC). Furthermore, CityGML is complementary to 3D computer graphics standards like X3D, VRML, or COLLADA and geovisualization formats like KML (Wilson 2008). Although advances in 3D city modeling as well as established standards allow to conglomerate distributed data from different sources, 3D data matching of overlapping but differing geometrical and semantical 3D geoinformation is still a challenge.

2 Visualization Aspects for 3D City Models

2.1 Perspective Views

The commonly used central perspective view in 3D GeoVEs offers a more natural access to geoinformation in comparison to the plane view in classic orthogonal 2D maps (Jobst and Döllner 2008). User interactions allow to reveal the visually hidden information in each static view. An alternative solution is the multi-perspective view, e.g. (Lorenz et al. 2008), deforming and distorting the view simultaneously throughout the viewer’s frame. Pasewaldt et al. (2011) extended this approach towards a view-dependent multi-perspective view.

2.2 Photorealism and NPR

Various applications for 3D city models, such as tourism or city planning, require a high degree of photorealistic representation of the urban objects. Such realistic impressions highly enrich the quality and quantity of the visual information content. Photorealistic representation of virtual 3D city models refers to the surface texture (respectively to textured model objects e.g. building facades and roofs) based on aerial and ground-based laser scanning data in combination with (oblique) aerial or satellite imagery. Also atmospheric effects, lighting, and shading may improve the realistic impression. Moreover, 3D photorealistic map presentations which display geographic objects in the most realistic way may facilitate mental mapping (Döllner and Kyprianidis 2010). However, photo-realistic visualization with a high degree of detail causes major problems for comprehensible visualization of 3D city models. Numerous highly detailed and textured objects might be occluded. They could also be subjected to perspective foreshortening and they may generate visual noise and overload the users with too much information (Glander 2013). Unlike photorealism, non-photorealistic rendering (NPR) abstracts the presentation from reality and offers simplified and filtered detailed elements as well as clearly encoded visualized geographic information (Döllner and Kyprianidis 2010). Visual details, such as those of buildings, are not of primary interest. Thereby an illustrative visualization achieves an effective and comprising visual display. Thematic information is encoded through an abstract visualization which allows explorative analytical functionalities.

2.3 Level of Detail (LoD)

Changing representation scales, performance optimization and different user- as well as usability demands require a concept for modeling and rendering objects in a 3D model at different LoDs. Most applications for virtual 3D models use the five step LoD concept as suggested within the CityGML standard (Kolbe 2009). According to Biljecki et al. (2014), the term detail can be loosely referred to the complexity and presence of geographic objects and their compartments. Thus, the term LoD is rather incomplete. Alternative terms had been introduced, such as level of completeness (Tempfli and Pilouk 1996), level of quality (Döllner and Buchholz 2005a), and level of abstraction (Glander and Döllner 2009). However, the conventional term LoD is well recognized in the GIS community. Most 3D city models use the CityGML standard for the LoD concept, which differentiates between five consecutive LoD. With increasing accuracy and structural complexity, this concept scopes from LoD0, which includes a 2½ terrain model, to LoD4, in which building details including furniture are modeled. Nevertheless, different LoD approaches have been investigated, addressing geometry, texture, semantics, the type of object, and application specific LoD concepts, e.g. (Döllner and Buchholz 2005a;

Hagedorn et al. 2009; Löwner et al. 2013). Biljecki et al. (2014) provided a comprehensive LoD analysis including major drawbacks of existing LoD concepts. Further, the authors introduced a formal and consistent framework to define discrete and continuous levels of details, enabling a finer distributions of LoDs than presently available series. Glander (2013) suggests techniques for multi-scale representations of 3D city models, which allow varying degrees of detail at the same time and support directed user attention.

2.4 Geometric and Cartographic Generalization

For an effective communication of geoinformation, cartographic symbolization and generalization are crucial tools (MacEachren 1995). For 3D city models, it is also conceivable to derive lower LoD models from higher ones. However, common 2D cartographic generalization principles (Hake et al. 2002; McMaster and Shea 1992; Slocum et al. 2009) do not adequately address all demands of 3D GeoVEs. Thus, various new generalization approaches for 3D city models have been developed, addressing in particular the geometry or façade texture of building, i.e. (Kada 2002; Mao et al. 2009; Trapp et al. 2008). According to Beck (2003) and Willmott et al. (2001), the decrease of geometric complexity ensures high and constant frame rates and thus allows to perform real-time rendering of highly complex virtual 3D city models. The multifarious and complex visualization of 3D geographic objects in perspective views demand generalization in order to represent relevant information to a user in an appropriate and efficient way (Petrovič 2003). However, existing generalization methods for 3D GeoVE are mostly feature-specific (Pasewaldt et al. 2012).

2.5 Cartographic Design

Appropriate cartographic representations increase the effectiveness, expressiveness, and readability of visualized 3D city models. Beside the conceptual phase of every cartographic product, in which user context, use situations and thematic contents are identified, Häberling et al. (2008) distinguishes between three design steps namely modeling, symbolization, and visualization. Based on this design classification, also shown in Table 1, the authors accomplished a user survey to identify altogether 19 general design guidelines that assist the cartographer to reduce visual complexity and improve comprehension in 3D GeoVEs. These guidelines address in particular the abstraction degree, the dimension degree, camera aspects, and lighting aspects.

The representation of every 3D city model can be regarded as interactive visual exploration since it involves user interactions, such as zoom, pan, rotate etc. Standard cartographic rules, valid for classic thematic and topographic 2D maps, do

Table 1 Design classification for 3D GeoVEs. *Source* (Häberling et al. 2008)

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

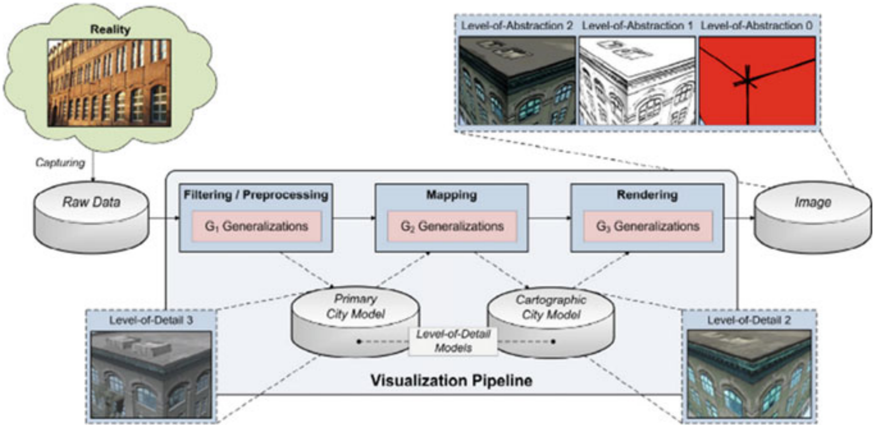


Fig. 1 Cartography-oriented visualization workflow by geometric and visual abstraction (Semmo et al. 2012a)

not exist for 3D (Häberling et al. 2008). Moreover, Pegg (2013) argued the needs of cartographic design principles for 3D city models. In the work of Semmo et al. (2012a), stylization and semantic based cartographic approaches for 3D city models are discussed. Furthermore, the authors provided an overview about the principle cartography-oriented visualization workflow for 3D city models, as illustrated in Fig. 1.

In order to consider degree-of-abstraction, depth perception and perspective distortion, new design principles are needed, and existing ones have to be extended (Pasewaldt et al. 2012). As shown in Fig. 2, Pasewaldt et al. (2012) provided a classification of cartographic design principles and visualization techniques for digital 3D GeoVEs, addressing different level-of-abstraction and LoD approaches for various feature classes.

Up to now, there are no visualization and design standards for digital 3D models. Current cartographic solutions for digital 3D GeoVEs still face a number of obstacles that influence the understanding of 3D contents, such as occlusion, visual clutter, insufficient use of screen space, and unlimited number of cartographic scales (Pasewaldt et al. 2012). According to Dykes et al. (1999), the design of 3D GeoVEs

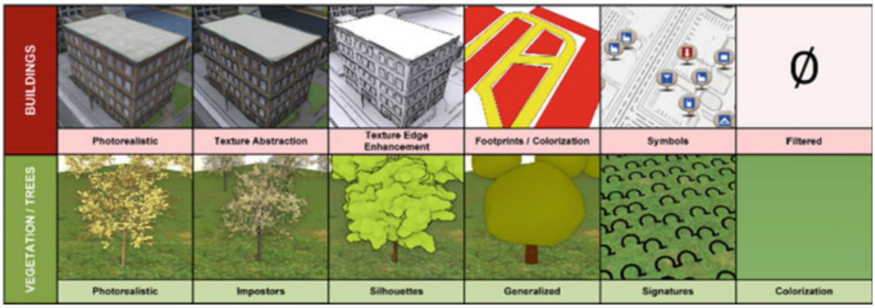


Fig. 2 Overview of cartographic techniques by the example of 3D buildings and trees. *Source* (Pasewaldt et al. 2012)

should address the needs for specific applications as well as an appropriate level of interactivity. Moreover, an appropriate typography is crucial for the understanding semantic information in 3D city models. Most of the existing studies deal with an automatic and dynamic placement of building or line labels, i.e. (Huang et al. 2007; Maass and Döllner 2007; Vaaraniemi et al. 2013). Principal design rules for texts in 3D GeoVEs, however, haven't been addressed adequately yet.

3 Cartographic Enrichment of 3D Models—Towards Interactive and Purpose Oriented Rendering

Cartographically enhanced 3D GeoVEs may improve quality and usability of the visually communicated information. On the one hand, we can use 3D city models as a platform in order to visually explore additional data or phenomena, such as the dynamics of bird swarms or the change of noise in a city during the day. On the other hand, a deeper insight into semantic information about 3D city model compartments could be provided through improved cartographic representations. One example for the latter is the thermal information of building facades, wherefore Kumke (2011) introduced various design concepts with some examples illustrated in Fig. 3. Yet, a design concept for temporal changes of thermal information, as well as the integration of those proposed design approaches into 3D city model including interactive explorative tools remain unsolved.

As discussed in Bleisch et al. (2008), the visual perception and interpretation of quantitative data, represented in an 3D GeoVEs, is not an easy task, in particular in the case of absolute data. However, due to a varying scale throughout the representation even the estimation of relative data values is not always unambiguous.

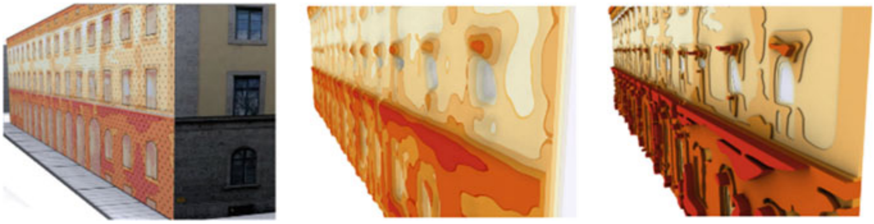


Fig. 3 Different representation of thermal information on building facades, *left* 2D isotherm surface map, *centre* 3D bi-cubic spline surface, *right* 3D isogram with discrete color scheme. *Source* Kumke (2011)

3.1 Miniaturized Non-photorealistic 3D City-Models

The visualization of 3D geoinformation is an evolving area and a challenging task in cartography. Due to the huge range of different representations of city models, ranging from block models to very detailed architectural models, and the increasing number of available city models, new approaches have to be developed to integrate additional information like semantics into the visualization. Nowadays the great advantage of 3D city models are within the city planning scenarios where the influence of a new building on the surrounded area can be very well analyzed.

Visualizing 3D spatial information is not only a rendering task, cognitive and usability aspects have to be taken into account as well as Gestalt laws (or design rules) and knowledge concerning spatial perception are the basis for converting 3D city models into an information system. Since there is still too little knowledge about how users get along with complex 3D city models (brain processes) and what kind of impact user strategies would have on the visualization design (Slocum et al. 2001). Therefore, developing new approaches and methodologies for visualizing city data is a challenging task. Within this area, the abstract and illustrative non-photorealistic approach (Strothotte and Schlechtweg 2002) seems to be promising. The non-photorealistic visualization originates from the computer graphics domain and is called non-photorealistic rendering (NPR). Typical application scenarios are ‘Cartoon Rendering’, ‘Artistic Rendering’ and ‘Sketchy Rendering’ (Gooch and Gooch 2001) as well as technical illustrations (Gooch et al. 1998). Döllner and Walther (2003) have presented a first approach of rendering a city model in a non-photorealistic way. The challenging research question is how to transfer this ‘rendering’ approach to a city model as well as including semantics into the visualization? To answer this question we have to focus on the essence of non-photorealistic and the impact it has on a 3D city model. From our point of view non-photorealistic can be described as the opposite to photorealism, which is a kind of resembling the reality. Therefore, non-photorealism must be seen as an abstraction of reality which contains illustrative, expressive and cartoon like elements.

The model and the visualization are distinct from each other (Jahnke 2013). In this way, a very detailed model can be visualized in very abstract and illustrative way. The abstract and illustrative (non-photorealistic) visualized city model can be arranged on a continuum ranging from reality to virtuality according to Milgram et al. (1995). It can be described in particular with the parameters ‘level of abstraction’, ‘information density’ and the data transferred to a user as the ‘storage capacity’ as the third parameter (Jahnke et al. 2011b). In particular the level of abstraction is of main interest as Andrew Losowsky stated that the “Visual abstraction is a human instinct and a societal necessity” (Klanten and Losowsky 2011). These parameters gave a hint on how abstract and illustrative (non-photorealistic) the visualization is. Figure 4 applied the above-mentioned three parameters to a city model visualization and showed the influence of the three parameters on the city models appearance, which can range from realism to non-realism. A highly detailed photorealistic city model incorporates a high information density as well as a high storage capacity but in contrast a low level of abstraction (Fig. 4a). On the other hand, a block model representing a city contains a high level of abstraction and less information density and storage capacity (Fig. 4d).

The degree of freedom in choosing in particular the level of abstraction that is attended by the information density is a big advantage in city model visualization. By reducing the visualization complexity, additional (semantic) information can be integrated and visualized. Moreover, it opens many possibilities of using typical cartographic design principles and graphic variables as well for three-dimensional spatial data. Table 1 shows possibilities of the applicability of different graphic variables to feature a non-photorealistic visualization. In contrast to points, lines and areas within 2D, the graphic variables can be applied to edges and the object itself (building) in 3D (Table 2).

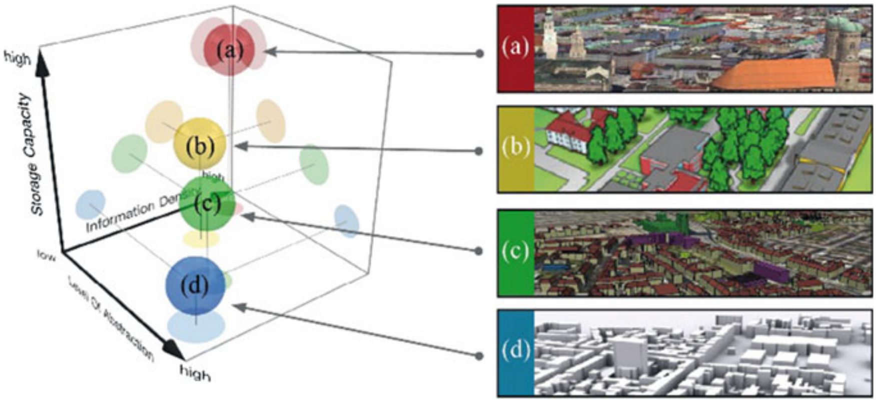


Fig. 4 Relation between level of abstraction, storage capacity and information density for different city model visualizations. *Source*: Jahnke et al. (2011b)

Table 2 Graphic variables suitable for a non-photorealistic visualization, adopted from Jahnke (2013)

Variable	Suitable for attention guiding	Suitable for edges and objects		Suitable to feature a non-photorealistic visualization	
		Edges	Objects	Edges	Objects
Color	x	x	x	x	x
Form	x	x	x	x	x
Brightness		x		x	x
Size	x	x	x	x	
Saturation	x	x		x	x

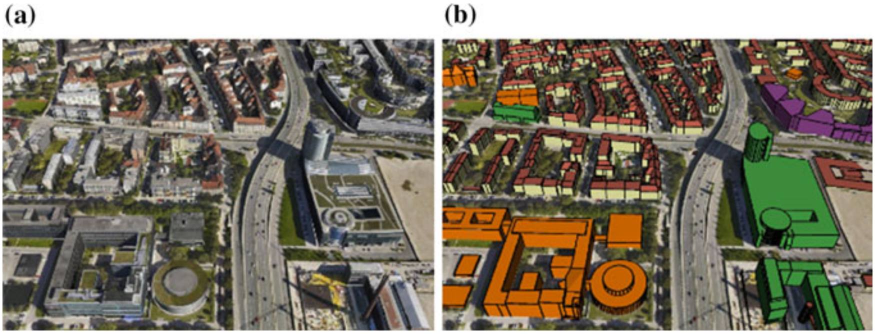


Fig. 5 **a** A photorealistic visualization compared to non-photorealistic one; **b** color applied to objects and size applied to edges (Jahnke et al. 2011a)

The graphic variables from Table 1 are showing options to integrate semantic information or attention guiding hints into a non-photorealistic visualization. Figure 5 shows the use of color for object facades and size for edges to show the type of use for different building within Munich City Centre.

The variable “size” can be applied to objects but with the drawback of masking surrounded buildings. Therefore, the variable “form” seems to be sufficient to apply deformation to an object for coding semantic information or a more cartoon like style (Fig. 6).

Another advantage of the non-photorealistic visualization approach is the inherent change of LoD when increasing the level of abstraction and reducing the information density. Different levels of detail can be applied as well for individual buildings as shown in Fig. 7. According to (Cole et al. 2006) the varying level of detail can be used to guide the user’s attention to different areas within the city model.

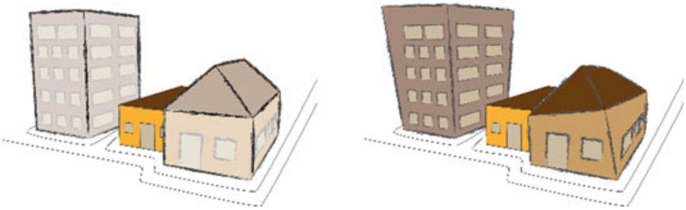
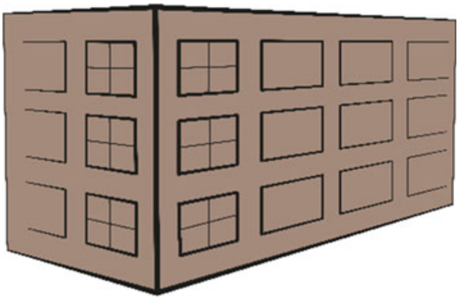


Fig. 6 The graphic variable form to apply deformation to a building (Jahnke 2013)

Fig. 7 LoD applied to an individual building (Jahnke 2013)



Within a 3D visualization the user's viewpoint influences very much the perception of the 3D city model. A viewpoint close to the ground shows only the direct surrounded buildings while a bird like viewpoint gives a good overview but less detail. To overcome this drawback annotations may be helpful. The advantages of a non-photorealistic visualized city model are the degree of freedom in choosing the design style as well as adopting the information density to the use case or purpose and the applicability of cartographic design rules. This includes as well a user or purpose oriented design. Therefore, when designing non-photorealistic visualizations usability evaluation or engineering are needed. The usability of a city model visualization is not tackled within this paper, but it is an inherent and very important area when to design feasible and suitable visualizations (Hermann and Peissner 2003; Mayhew 1999).

3.2 Storytelling or Visual Narratives Using 3D GeoVEs

Visual storytelling originates from the graphic design domain and is in most cases used for transferring information to a user. Losowsky stated, "The essence of visual storytelling is this combination of emotional reaction and narrative information." (Klanten and Losowsky 2011). This brings the designer to the point of not only integrating raw information but as well bringing some sense of emotion into the design and to the user. Therefore, the reaction of the user is important whether he or she is agreeing or disagreeing. Nevertheless, if visual storytelling is used in the cartographic domain the usability plays an important role in terms of not only visualizing some information but also conveying the information in a suitable manner to gain more insights and support decision-making. Any visualization, which is intended to communicate a story, can be seen as a visual narrative while the narrative is the visual or verbal representation of a story and a story in this case can be seen as a sequence of events (Pimenta and Poovaiah 2010). The visuals and the text (story) complement each other.

An overview concerning maps and narratives is given by Caquard and Cartwright (2014) while Straumann et al. (2014) gives an example on how to construct narratives from photograph-taking-behavior. Roberts (2014) gives an example for cinematic cartography. Cinematic cartography is an emerging field covering the relation from cinema and cartographic depictions and the influence on each other, while the cinematic use of cartography has had less impact on cartographic theories (Caquard and Cartwright 2014). Based on an exhaustive literature review of online publications and magazines, Segel and Heer (2010) identified seven different genres or arrangement styles, which are common in information visualization and feature the idea of visual story telling or visual narrative. These are namely the ‘magazine style’, the ‘annotated chart’, the ‘partitioned poster’ the ‘flow chart’. The ‘comic strip’, the ‘slide show’ and the ‘film/video/animation’ (Fig. 8). These different styles refer to the ordering of elements within the visualization.

Therefore the 3D city model can play a main role within visual storytelling approach. A map or in this case a 3D representation can have two different roles in visual storytelling. The first is the role as a background information on which other information like personal trip information can be visualized. The second role is a more essential role when the map or model stays in the foreground and the narrative makes no sense without displaying the 3D city model (Fig. 9). At this point we need to distinguish between a story a map tells and the events of a story in which a map or model plays a distinct role. To sum up, a map should be seen as some sort of visual storytelling (Klanten and Losowsky 2011). According to the two defined roles the

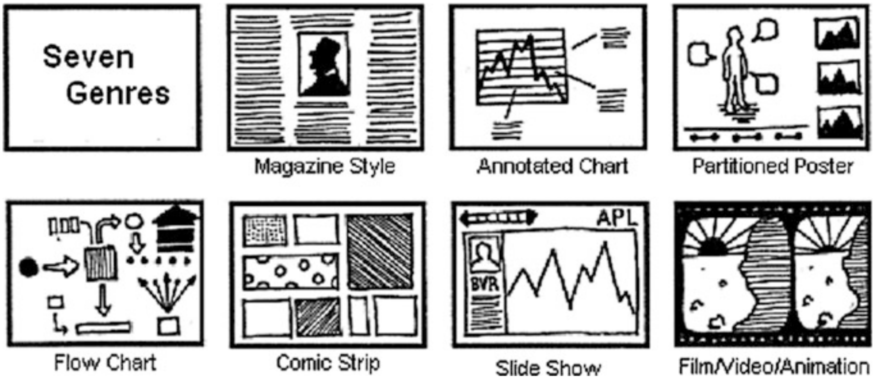


Fig. 8 Different arrangement styles in visual storytelling, from (Segel and Heer 2010)

Fig. 9 A 3D model within a visual storytelling approach from Katherine Baxter to illustrate the complexity of urban areas. *Source* (Klanten and Losowsky 2011)

3D city model in the non-photorealistic visualization approach plays the second role. From this point of view visual storytelling is closely connected with the afore mentioned non-photorealistic visualization of 3D city models. In particular the described level of abstraction is as well a main part in visual storytelling because the "visual abstraction is a human instinct and a societal necessity." (Klanten and Losowsky 2011). However, the abstraction is not only outstanding in visualization it is as well very common in everyday verbal conversation (Hayakawa 1967).

3.3 Smart Design' of Photorealistic 3D City Models

For many users a photorealistic 3D city model has become the holy grail of city models. Virtual city models supplemented with aerial and terrestrial imagery are therefore sometimes referred to as true 3D models. Users find the photorealistic depiction of city models an immersive and gripping experience. Their subjective feeling can be explained by hard facts. First, a photorealistic city model is much more similar to the real world. The realistic impression can help a user assigning a specific virtual camera view or an interactive walkthrough to a real place of the city. And second, the photorealistic surfaces of the city model provide an added visual value. Apart from modeling 3D building structures the textures of facades and roofs reveal detailed semantic information, such as the building type, building condition or touristic attractiveness. Furthermore, ground textures reveal information of the land use, such as traffic area or public green. However, the rich visual value of photorealistic 3D city models causes a high cognitive workload for the user. The extremely heterogenic radiometry of photo images are very demanding to the user. It becomes more difficult to identify clear cut building edges and planes and therefore more difficult to understand the 3D shapes in a photorealistic city model than in an abstract city model presentation.

Because the photorealistic model appears visually overloaded, the composition of photorealistic 3D city models with thematic information has to be treated carefully. There are limited design guidelines that deal with the combination of imagery and cartographic symbolization. To make thematic layers visually stand out from the city model they have to be designed much differently to the imagery. This ‘pop-out’ effect described by Ware (2010) has become a visual design rule of thumb. However, creating a pop-out effect on the heterogeneous imagery is not a simple task. A holistic design approach may be missing for the design of cartographic symbols upon photorealistic surfaces, but Murphy (2014) pointed out that non-textured symbols with high color saturations have a high potential of visually standing out from imagery. The use of transparency can add to the visual segregation. Apart from a design that enables visual segregation form the visually busy city model it is recommendable to organize thematic information into themes that the user can interactively switch on and off (Kolbe 2009). This can significantly reduce the visual complexity of an interactive virtual 3D city model.

The cartographic design of virtual 3D city models should not be limited to design of map symbols. A smart design of photorealistic 3D city models should consider the design of imagery in the same way as it considers the design of map symbolization. It has been shown on image maps, that the photorealistic imagery can be manipulated in a way that photorealistic discrete objects can be designed to visually stand out from an equally photorealistic background (Murphy 2014). A number of highlighting strategies for discrete image objects (i.e. buildings) can highlight important objects such as built landmarks and make them visually more prominent without deteriorating the image legibility of both fore- and background (see Fig. 10).

Fig. 10 Visual highlighting of photorealistic objects by ‘Light Beam Guidance’ (Murphy 2014)

The user of a virtual 3D city model expects to navigate freely through it and expects a visual optimal presentation for every current view. The visual highlighting of important city model entities should be dependent on the viewing angle and distance. Different design zones could be applied as a function of distance from the virtual camera (Jobst and Döllner 2008). Building models of importance that are in the viewer's focus should be highlighted whereas distant buildings do not have to be visually highlighted. Particularly photorealistic surfaces rendered in small scales cause visual clutter (i.e. Glander 2013). This can be resolved by integrating the photorealistic design of 3D city models into a multi-scale approach. In 3D city model multi-scale approaches zones of distance (or scales) are defined in which different generalization levels apply (Brewer and Buttenfield 2007; Glander 2013; Pasewaldt et al. 2011). The generalization levels could reach from a photorealistic 3D city model over a non-photorealistic rendering to an abstract 2D map. Building blocks that stand in the focus are thereby visualized in a photorealistic view. For city model zones that are further away from the virtual camera a more abstract view is convenient.

3.4 Additional Information Within 3D City Models

Beside semantical information about geographical objects which usually shape a 3D city model, we might also incorporate additional data, such as those of people who live or work in respective urban places. Furthermore, we could consider information about distinctive events, facts, opinions, ideas, or statistical summaries, but also data of dynamic objects as individual or a group of moving people, vehicles, animals etc. After the acquisition of such additional data, they can be related to or spatially joint with certain 3D locations/addresses, buildings, streets, areas (e.g. administrative district) or landmarks. Possible data sources for those additional data include, among others, social media (Twitter, Facebook), federal statistics and census agencies, Volunteered geographic information such as OpenStreetMap (OSM) or the internet as a database for explicit knowledge processing as investigated by Rückemann (2014). When combining different geometrical and semantic data into the same 3D city model, an automatic and evaluable data matching/integration is worth striving for, which is an important research task. Challenging additional information for 3D city models are temporal changes as well as the task to visualize spatio-temporal information of moving objects or of 3D city objects (e.g. year of construction), their dynamics/temporal changes (changes regarding geometry or semantics) or predicted future situations/scenarios. Approaches for integrating time-dependent features in 3D city models had been introduced, for example by Fan (2010). Nonetheless, different representation options of such temporal information need to be investigated in more detail, including animations, dynamic effects, user interactions, adaptive and dynamic legends, as well as integrated visual analytical tools.

A further potential additional information include the ‘uncertainty’, which can refer either to the underlying data of the city model, to the above mentioned additional data, or to the data processing and visualization. According to Pang (2001), “uncertainty is a multi-faceted characterization about data, whether from measurements and observations of some phenomenon and predictions made from them. It may include several concepts including error, accuracy, precision, validity, quality, variability, noise, completeness, confidence and reliability”. Visualization guidelines and an overview about existing concepts and approaches for visualizing uncertainties of geographic data are provided by (Griethe and Schumann 2006; MacEachren et al. 2005; Peters 2014; Slocum et al. 2009). Basically, visual variables of point-, line- or polygon features correlate with the uncertainty information. Gershon (1998) distinguished between intrinsic and extrinsic visual. However, most approaches for uncertainty visualization of geodata refer to 2D solutions. A cartographic investigation of uncertainty visualization within 3D GeoVEs would involve an adaption or extension of existing 2D solutions as well as interactive tools for uncertainty-focused explorative user interactions, and a comprehensive user- and usability study.

3.5 Visual Analytics and 3D City Models (3D GeoVEs)

To take complex information within 3D city models and make them understandable for users is not a trivial task, but can be supported by visual analytical tools. According to Dykes et al. (2010), research in visual analytics may contribute directly to the exploration of 3D building models. Thomas and Cook (2005), defined visual analytics as the science of analytical reasoning supported by interactive visual interfaces. The basic concept of any visual analytical process is to combine computer advance graphics representations with human cognitive capabilities in order to provide better understanding and reasoning. The use of visual analytics for spatial and spatio-temporal processes has been extensively investigated for 2D representations. Potentials of visual analytics for urban design have been recently discussed by Batty and Hudson-Smith (2014). Visual analytical approaches are mostly data driven and application specific. Visual analytics could be used to enable users to explore and investigate urban processes within a 3D GeoVE, while additional analytical tools provide an insight into semantic information of 3D city objects respectively of the additional information. Thereby a 3D GeoVEs constitutes the frame, wherein visual analytical tools such as interactive time graphs, charts or diagrams are integrated to illustrate additional location-related qualitative and/or quantitative information. Thus, appropriate data interaction and exploring, as well as an elegant navigating through the 3D GeoVEs at the same time are crucial. Adequate solutions for such visual analytical tools need to be task- or application- respectively user-specific.

There are a limited existing works. For instance, De Amicis et al. (2009) provided a 3D web based interactive visual evaluation tool for investigating the environmental impact of new buildings. Bak et al. (2010) introduced a visual reasoning tool for investigating spatial relation between geo-referenced urban environmental variables. Moreover, Debiasi et al. (2013) developed a visual analytical tool for urban traffic simulation. Further works focus on visual decision support in flood management, such as Waser et al. (2014). A main drawback of most of these existing approaches are missing comprehensive user and usability tests. Bleisch (2012) discussed relevant tasks addressed by the field of 3D Geovisualization, a field which we can relate to visual analysis or analytics of 3D GeoVEs. However, yet almost none of those tasks are solved with help of additional visual analytical tools. Thus we see a strong demand for further investigations of task-specific visual analytical approaches in 3D GeoVEs. Instead of using 3D GeoVE as a platform for visual analytical tasks, geometrical, semantical and topological data of a 3D city model can also be investigated via visual analytics. For a very simple example, bar charts located in the center of residential blocks could illustrate statistical data such as number of houses, windows, doors, etc.

3.6 3D Topographic Symbols

To adapt symbolization is one of the principle cartographic design tools, also for 3D GeoVEs. The lack of and need for cartographic design rules and standards for 3D symbols, in particular symbols for topographic objects, in 3D GeoVEs has been discussed in various publications, i.e. (Bandrova 2001; Petrovič and Mašera 2005). Bandrova (2001) provided a first theoretical base for 3D cartographic symbols in 3D GeoVEs, including requirements and firm tools for designing such 3D symbols. The author draws the conclusion that symbol systems have to be designed for each particular application considering purpose and end-users. According to Petrovič (2003), symbols in 3D presentations have to follow cartographic design principles as used for traditional 2D maps. Petrovič suggest to use typical realistic 3D point symbols for point-like objects, in particular for natural-made objects such as trees, bushes, and waterfalls. Furthermore, he evaluate geometrical 3D symbols suitable for man-made point objects. According to Petrovič, line symbols are mostly entirely draped over/on top of the terrain model. Applying a certain extrusion to these lines might visually emphasize these objects. Furthermore, the author distinguished between polygonal 3D area symbols and volumetric 3D symbols. For the latter, examples were provided for different scales which refer to the concept of LoD, as exemplary shown in Fig. 11.

Finally, Petrovič concludes that 3D cartographic symbols used in 3D presentations need to be further investigated and evaluated by user and usability tests. Current topographic products represent the real world mostly in two dimensions. Existing 3D approaches bond the 2D topographic map onto a 3D relief. Some of them use 3D building models and 3D objects representing landscape elements such

Fig. 11 3D symbols for different LODs (Petrovič 2003)

as trees and hedges. However, important topographic objects, represented as 2D symbol on such 3D GeoVEs, might be less or even invisible due to occlusion, viewing distance, depth perception and perspective distortion. Adequate designed and scale dependent 3D topographic symbols as well as user interactions in 3D GeoVEs such as object/layer selection or disabling, and highlighting tools (e.g. increasing symbol size) can improve the visibility of topographic objects and, thus, the communication of topographic information. Symbol concepts and standards need to be adapted to regional conventions in the same way as topographic symbolization standards differ between countries. Cartographic principles for 3D symbols are not only relevant for topographic information in 3D GeoVEs, but also for certain thematic information (layers), such as geology, tourism or urban planning.

3.7 The Problem of Invisible Objects—Revealing the Hidden

The visibility of geographic information is one of the cartographic principles, and one of the major drawbacks within 3D GeoVEs. How to deal with covered areas behind obstacles? How to minimize information loss caused by perspective distortion and large distance between object and view point? Obviously, interactive user functions, such as zoom, pan, and rotate, help to solve these tasks. However, we'd like to focus on adaptive real-time visualization solutions for the best visibility for every view perspective.

First we need to know what defines or influences the visibility of an object in a 3D GeoVE. In addition to the degree of occlusion and viewing distance and perspective, crucial visibility factors are the level of abstraction, the level of generalization as well as the cartographic symbolization of an object. A further important aspect is the visual salience of an object in comparison with its neighborhood. Instead of focusing on one object only, the task could also be to increase visual salience of several objects of interest (object group), of one or more certain locations respectively areas, or of all objects. Numerous studies were dedicated to the generalization of 3D objects and to the LoD concepts of 3D city models (Fan and Meng 2009; Kada 2002). Possible cartographic generalization methods, appropriate for increasing visibility and readability, also include object displacement or dimensional collapse (use of 3D symbol as described in the previous section). Furthermore, view dependent multi-scale representations, as introduced in (Semmo et al. 2012b) aim to improve the visibility of selected 3D city objects. In doing so, an object of interest receives the highest LoD while with rising distance a decreasing LoD would be applied to its neighborhood objects. At the same time values of visual variables (e.g. transparency, color hue and value, size, form, fill pattern, etc.) are adapted depending on certain distances or locations using either a linear transition or discrete steps. Furthermore, to increase its visual salience, an object can be highlighted by lighting effects or by applying dynamic symbol effects (e.g. blinking). To maximize information communication for respective applications and tasks, interactive tools are needed, enabling the user to adapt visibility parameters, for instance, to increase transparency of certain objects or displace/extrude objects of interests. A real-time implementation of such view-dependent interactive visibility-optimization tasks within a 3D GeoVE poses major technical challenges, in particular in the case of a web-based distributed database.

However, existing solutions, such as the multi-perspective view approach (Pasewaldt et al. 2012) demonstrate the feasibility of those ideas. Thereby, the authors suggested a combination of cartography-oriented rendering techniques and photorealistic graphic styles with multi-perspective views in order to increase screen-space utilization while simultaneously directing viewers' eyes to important or prioritized information. An example is shown in Fig. 12.

Fig. 12 View-dependent, multi-perspective view and cartography-oriented stylization applied for a route of interest in the city center of Chemnitz. *Source* (Pasewaldt et al. 2012)

4 Conclusion

We have shown that cartographic enriched 3D city models allow us to address new application and research areas and expose visual explorative solutions for specific tasks and scenarios. Approaches in the fields of computer graphics and information technology provide powerful rendering performance for multi perspective views and multi-scale representations of 3D city models.

However, within this contribution we reveal missing cartographic design rules and standards for 3D GeoVEs. First theoretical steps in this direction have been made. The non-photorealistic visualization approaches opens the usage of well-known cartographic design rules within a 3D visualization. It reduces the information complexity, decreases the cognitive workload of the user (Bunch and Lloyd 2006) and opens up space for displaying non-geometric information. With regards to visual storytelling, 3D city models or 3D representations can have two different roles: they can serve either as additional background information or they stay in the foreground while the story wouldn't make any sense without the 3D representation. Appropriate design guidelines for cartographic symbols upon photorealistic surfaces are still an ongoing research topic. First attempts include the highlighting strategies for discrete image objects (Murphy 2014). A smart design of photorealistic 3D city models needs to treat the imagery design in the same way as it does for other map symbols.

Furthermore we discussed the enrichment of 3D city models with additional multivariate or/and multidimensional information and the need for adequate cartographic solutions while incorporating such data. In addition, cartographic design concepts as well as standards for 3D topographic symbols need to be further investigated. We have also debated that cartographic enhancements for 3D GeoVEs should involve user and usability issues. Potential applications demand customized, interactive, and smart visualization of 3D city or landscape models. That could include a visually optimized representation for every current view point in real-time. The cartographer's task is to develop better 3D GeoVEs to train users to operate them. User-friendly and intuitive interfaces should provide best communication between user and data space. The user should have the possibility to change the visualization style as well as to explore data by the use of visual analytical tools. Thus, the user himself becomes the map producer. An appropriate user friendly integration of visual analytical tools require comprehensive user- and usability investigations. Many existing applications lack comprehensive user- and usability tests. Such tests could iteratively improve an application while learning from user behaviors. More sophisticated usability investigations could include multi user interaction and communication. Last but not least, designing interactive and customized legends within 3D GeoVEs is also an up-to-date research topic.

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