PRINCIPLES OF CARTOGRAPHIC DESIGN FOR 3D MAPS - FOCUSED ON URBAN AREAS

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ACKNOWLEDGEMENT

This paper was supported by the Project LO1506 of the Czech Ministry of Education, Youth and Sports and the Project SGS-2016-004 Application of Mathematics and Informatics in Geomatics III.

Abstract

The cartographic design of 3D maps (a term 3D map can be defined as computer-derived perspective view with cartographic content) is still under the strong influence of map authors' preferences. It comes from the wide range of different parameters, which should be taken into consideration during the process of the map's creation. This process comes from the concept phase, through modeling stage, follows by symbolization step to the final visualization itself. Such parameters and the process itself are well known in the classic 2D map design. More importantly, they are standardized for a long time. On the contrary, the standardization of the process dealing with a creation of 3D maps is still ongoing and in development. This contribution aims to outline the already deployed principles in the 3D map's creation process and elaborates a workflow of such a process with certain cartographic and other variables. The process contains data preparation (steps from concept to visualization), definition of cartographic aspects (which are divided into the variables together with their definition and design) and the derivation of cartographic principles for a design of 3D maps. Note that this paper focuses on the cartographic principles of the mentioned process, not on technical issues of a visualization of 3D data.

Keywords: *map, cartography, design, process, principle, urban area*

INTRODUCTION

This paper aims to discuss the principles of cartographic design for 3D maps. The cartographic design is one of the steps in the workflow of a 3D map's creation. The scheme of such a workflow is depicted in Figure 1. The cartographic design is related to the symbolization part of the workflow, consisting mainly of definition of the graphic appearance of the displayed objects. The particular examples will be explained on instances of 3D map of urban areas, while urban areas are places with higher density of population comparing the areas around them.

The terms "3D map" and "3D scene" need to be stated here for the purposes of this paper. A 3D map is understood as an analogy to a classical 2D map, so the term 3D map stands for a representation of a 3D model based on cartographic rules and variables. The 3D scene is then a space in which the 3D model is perceived on the base of a camera viewing and projection.

DEFINITION OF A 3D MAP

The term "map" has a lot of different definitions, see for example Andrews (1996), Čerba (2011) for numerous definitions of such a term. To define of term "3D map", the suitable definitions should be presented. Several suitable definitions for the purposes of this paper dealing with the term "3D map" are listed below.

A definition of a map is proposed as:

- "A representation or abstraction of geographical reality: a tool for presenting geographical information in a way that is visual, digital or tactile", ICA (1992);
- "A symbolised image of geographic reality, representing selected features or characteristics, resulting from the creative efforts of cartographers, and designed for use when spatial relationships are of special relevance", Wood (1993).

Continuing, a 3D map can be defined as:

- "A 3D map is determined as a digital, mathematical defined, three-dimensional virtual representation of the Earth, surfaces, objects and phenomena in nature and society. Represented objects and phenomena are classified, designed and visualized according to a particular purpose", Bandrova (2001);
- "Maps are used to visualize geospatial data, that is data that refer to the location or the attributes of objects or phenomena located on Earth", Kraak & Ormeling (2011);
- "3D map - modern computer-generated perspective view with cartographic content", Heaberling (2005);
- "3D map - a generalised representation of a specific area using symbolization to illustrate physical features", Heaberling et al. (2008).

Looking at the above mentioned definitions, 3D maps are a special type of maps, portraying 3D data. Usual approach of such a portrayal consists of showing:

- A sphere as a reference surface for draping imagery or vector data in small scales;
- Terrain (generalized) as a reference surface for draping, while zooming in medium scale;
- Detailed terrain, draped 2D geodata, 3D features.

This means that under the term 3D map, it is commonly understand a map containing Digital Terrain Model (DTM), 2D data draped on terrain, 3D models of objects (in proper scales) and 3D symbols (expressing objects, which cannot be modeled in their real proportions). Not every 3D map of course consists of all scale levels. The most common use of 3D map is a map of urban areas (sometimes called 3D city maps). Such a map then usually consists of medium and large scale layers. Urban area[10] is a location characterized by high human population density and many built environment features in comparison to the areas surrounding it. The 3D models shown at these maps have a lot of different purposes and ways of use. The 3D models can be used for various 3D analyses, spatial planning, 3D cadaster, Crisis Management and so on, not only to be presented in a form of 3D map. For a list of possible usage of 3D models see e.g. Biljecki et al. (2015).

[10] https://en.wikipedia.org/wiki/Urban_area

STEPS OF DESIGNING A 3D MAP

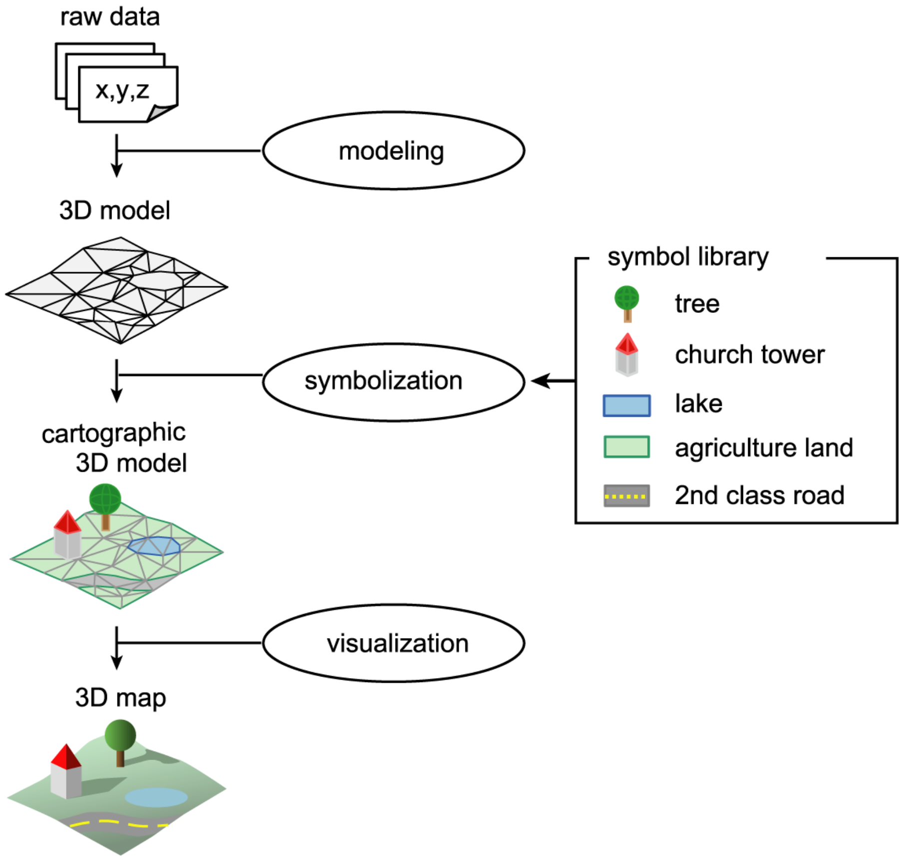

Figure 1. A scheme of 3D maps' process, adopted from Terribilini (2001), Haeberling (2002)

Every step of designing a 3D map should be considered with respect to the purposes of a 3D model (modeling part), way of communication with a user (symbolization part) and the presentation of a 3D map (visualization part). That is the main issue of designing process, that each creator of maps (a creator is not necessarily a cartographer) can percept every single element of this process in a different way. The elements of each step are discussed further.

Haeberling (2002) and Haeberling (2008) define that each step of a 3D map's creation, so called Design Steps (i.e. modeling, symbolization, visualization) can be divided into several elements. There are Design Aspects and Design Variables proposed in Figure 2.

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

Figure 2. An outline of design steps, design aspects and design variables, adopted from Haeberling (2008)

A similar workflow for a creation of 3D maps can be found in Bandrova (2005). As depicted in Figure 3, the first two steps refer to Modeling part, the next two steps refer to Symbolization part and the last one is the Visualization part.

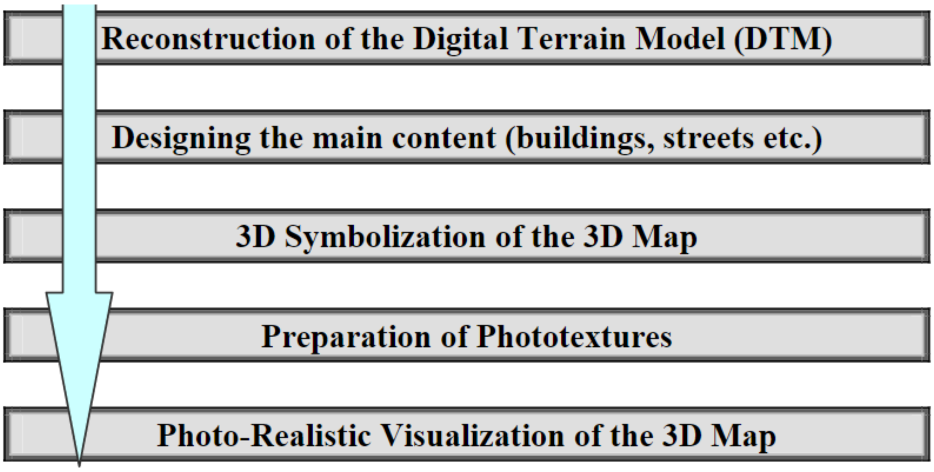

Figure 3. The procedure for creating 3D map from digital data, adopted from Bandrova (2005)

Wood et al. (2005) defines the visualization pipeline also applicable to 3D maps. The "Visual Mapping" and "Visual Representation of Data" is the part of the Figure 4 related to the Symbolization part of the design process mentioned in Figure 2.

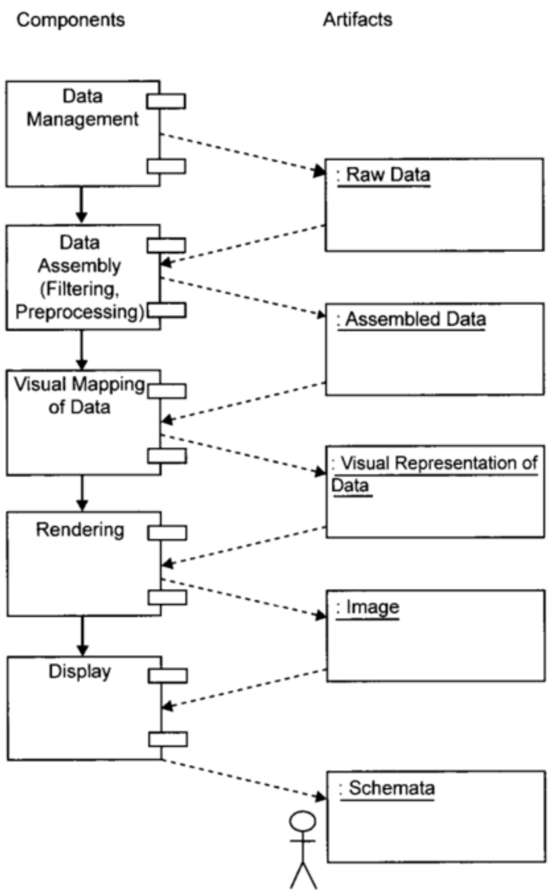

Figure 4. The scheme of a visualization pipeline, adopted from Wood et al. (2005)

The detailed overview of possible visual variables used for 3D models can be found in Rautenbach et al. (2015), chapter 2. There are stated the basic visual variables adopted from Bertin (1983) such as position, size, shape, value, color, orientation and texture, together with ones from MacEachren (1995) such as movement, duration, frequency, order, rate of change, and synchronisation (concerning dynamical phenomena). Other variables stated in Rautenbach et al. (2015) are perspective height, sketchiness and so on. But there is no differentiation of design variables for particular parts of the 3D map's creation workflow, because it deals more with 3D models, than 3D maps.The workflow of 3D model creation was examined also by authors of this paper, e.g. in Jedlička & Hájek (2014).

Steps of designing a 3D map - summary

This chapter examined three approaches to designing a 3D map from three research groups. Wood et al. (2005) defined a visualization pipeline, which is very general and suitable for visualization of practical any data. Bandrova (2001) stated also general principles for designing a map, though focusing on photo-realistic kind of a 3D map. Haeberling (2008) postulated not only cartographic principles for any 3D map's creation. The following text will be mainly based on such principles by Haeberling with influences of the other two. It is worth to mention, that a geodata harmonization usually precedes the modelling of 3D model (the very first step of a 3D map creation). The geodata harmonization is not further discussed in our paper, but is deeply described e.g. in Janečka et al. (2013) or Charvát et al. (2013).

PRINCIPLES USED DURING THE CREATION OF A 3D MAP

The first and profound principle is to take the user's need into the consideration through the whole process of a 3D map's creation. The second profound principle is taking the previous and next design steps of a 3D map's design process (as depicted in Figure 2) into consideration as well, during each such a step. Other principles for these steps are mentioned further.

The next part describes the steps of 3D map's creation based on Haeberling (2008), with suggestions about the issues that need to be taken into the consideration in each particular step:

Modeling - a process leading to creation of a 3D model depending not only on:

- An intended purpose of such a 3D model;
- An available source data for creating a 3D model;
- Time, money and work.

The objects (symbols, see the next step of symbolization), which are represented in 3D map, should be similar to the real objects and modeled in their real dimensions if possible. Because a 3D map represents objects of the real world as much as similar to their real appearance, this principle is self-explanatory.

The creation of a 3D model of urban areas with a DTM, 3D model of objects and 3D symbols is influenced by the technology used for the visualization of such a model. There are visualization techniques able to visualize the large amount of data (advanced visualization techniques of computer graphic), but common tools used for visualization of geographical data are not yet suitable for visualization of large amount of data (see the chapter about the use case of Terezín's 3D model). Therefore the principle of minimizing the amount of polygons (or other graphical primitives) is still appropriate to use in this stage (see the next point for the Symbolization step).

Symbolization - a process of defining a graphical appearance of the 3D model

This step is related very closely to the modeling step, see further text. Pegg (2011) describes that orientation is not really an issue for a 3D map, other factors can have a major effect on the way a 3D presentation is perceived. Recognition of symbology and 3D objects for the user is being an issue. Other issues that can affect the usefulness of a 3D map are different levels of detail and abstraction, depth perception and a changing scale. Regarding mentioned issues, there can be derived steps or rules useful for creation of 3D models. Those steps are taken over from Bandrova (2001), which operates with the term of symbol for the 3D cartographic representation of real objects (adopted from Hájek et al. (2015)).

- The symbols, which are represented in 3D map, should be similar to the real objects.
- Minimum polygons should be used when a new symbol is built.
- The symbols should be created in their real dimensions
- The symbols are designed for different purposes depending on user's needs.

Visualization - using techniques for presentation of a 3D model in a 3D map

Not every time the rules adopted from Bandrova (2001) can be abided, especially the rule about the real dimensions of a symbol. Usually for the purposes of quick visualization, the generalization of the object (e.g. Level of Abstraction - see Semmo et al. (2015), Semmo & Döllner (2015)) or the replacement of the object with an object of lower dimension (e.g. Level of Detail - see OGC (2012)), need to be taken into the consideration on top of the minimization of polygons representing a 3D object. The visualization techniques are not stated in this text closely, for more information see Wood et al. (2005), Petrovic (2003), Haeberling (2008).

Steps of designing a 3D map - summary

The process of designing itself is influenced mainly by the aim and intended purpose of a 3D map, therefore each step is related to the purpose as well. Each step of designing a 3D map cannot be done without the others taken into consideration. For example the rules stated in Bandrova (2001) and listed above, are based on each of defined steps. Particularly step B is related to both modeling (creation of a 3D symbol as simple as possible) and visualization (simple objects can be visualized more smoothly than the complex, very detailed ones). Therefore such a distinguishing of the designing steps is easy to define, but on the other hand, such steps are entwined to each other. For example, perspective view and camera adjusting can be used not only during visualization (as proposed in Figure 2), but also during the process of modeling and symbolization as well.

APPROACHES FOR CARTOGRAPHIC PRINCIPLES OF 3D MAPS

“Cartographic principles are mainly related to the symbolization part of the design steps of 3D maps. There are two basic concepts of 3D cartography – photorealistic and non-photorealistic or symbolic (discussed in many chapters of Cartwright et al. (2007)). The both 3D cartography approaches have similar questions to solve. The book Dodge et al. (2008) summarizes these common problems – non-perspective projections, reference frames, object minimization and displacement, distortions, symbol transparency and shadows (this problem is related to the non-photorealistic concept, because it adds to the scene new abstract symbols). Also the interpretation of terrain visualization is different in 2D and 3D, see Popelka & Brychtová (2013)”, Jedlička et al. (2013). Döllner (2008) also deals with this two concepts.

Haeberling (2005) postulated 19 propositions of cartographic design principles for 3D maps, regardless the photo – and non-photorealistic approach. According to the authors of this paper, the last 5 propositions (of categories such as camera aspect, lightning aspect and atmospherics effects) belong to the visualization part of the design process. The first 14 propositions deal with an abstraction and dimension degree of objects shown in a 3D map.

Using of Bertin’s variables in 3D presentations is slightly different than in 2D maps. In perspective views close objects are clearly visible and bigger like distant ones, see Hájek et al. (2015) for details. Therefore we cannot use the variation of Bertin’s variations only for distinguish different object types. Every object type should have different appearances according to the distance between observation point and an object. Since we cannot perform linear transition we have to decide to limited number of discrete steps - different map symbols for the same object type; similar as map symbols for 2D maps at different scales, Petrovic (2003). It leads to use either different models according to the distance between observation point and an object - usually in different Level of Details (LOD; see more in OGC (2012)) or analogous approach consisting of filtering or altering the 3D model on the base of abstraction - called Level of Abstraction (LOA - Semmo & Döllner (2014)). The second option (LOA) could be also related to the visualization part rather than to the symbolization part, because the 3D model of an object stays the same, but its appearance is rendered differently according to the distance between observation point and an object.

Wood et al. (2005) stated, that a 3D representation in a 2D display (meant as a screen) builds on projecting three locational dimensions onto a 2D plane. Using a set of perceptual depth cues to reinforce this projection, such as perspective, occlusion, and parallax motion, a cartographic “degree of freedom” was added to visual representation variables.

The previous text indicates that there is a bulk of cartographic aspects and variables, which can be used during the design process of 3D maps. The next chapter discusses the suitable cartographic principles for 3D maps of urban areas.

Cartographic principles for 3D maps of urban areas

This chapter aims to postulate suitable cartographic principles and variables for the purpose of 3D maps of urban areas’ creation. The main purpose of such maps is to present an area of a village/town/city usually together with its surroundings.

The content of 3D maps of urban areas is defined comprehensively in the CityGML standard, OGC (2012). There is a taxonomy of appearances, thematic objects and attributes suitable for using in 3D maps of urban areas. The taxonomy of suitable parts of this standard is (adopted from OGC (2012)):

- Digital Terrain Models as a combination of (including nested) triangulated irregular networks (TINs), regular rasters, break and skeleton lines, mass points;
- Sites (buildings, bridges and tunnels);
- Vegetation (areas, volumes and solitary objects with vegetation classification);
- Water bodies (volumes, surfaces);
- Transportation facilities (both graph structures and 3D surface data);
- Land use (representation of areas of the Earth's surface dedicated to a specific land use);
- City furniture;
- Generic city objects and attributes / User-definable (recursive) grouping;
- Appearance model.

The 3D maps of urban areas are specific by the content of such maps. The most abundant objects are the "man-made" ones, especially buildings (sites) and a city infrastructure (transportation facilities). Due to the amount of buildings and length of an infrastructure, objects of such categories fill the most of the displayed 3D map. Therefore the cartographic principles for such objects are the most important for 3D maps of urban areas.

A cartographic representation of a 3D model should be investigated also on behalf of several criteria (derived from Cartwright (2007), Dodge (2008)):

- Clarity / clearness / readability of a 3D map;
- Clarity / clearness of symbols;
- Mutual distinctiveness of symbols;
- Graphic load of a map;
- Relationship among symbols;
- Subject communication of a map maker / object opinion and a view at a map.

The cartographic principles suitable for 3D maps of urban areas can be stated on the base of the previous research and the above mentioned criteria of cartographic representations as follows:

- Setting up the cartography of the 3D model for the expected maximal detail:
    - Selection of dimensionality and a representation of all portrayed objects (as a point/line/area, symbol or volumetric) and surfaces (TIN/GRID);
    - Respecting of the cartographic variables (position, size, shape, value, color, orientation and texture of the symbol) stated by Bertin (1983) during the model symbolization to express the similarity to the real object;
    - Using proper categorization of objects to easily distinguish among different objects layers and objects.
- Setting up cartographic rules of the model symbolization and visualization in less detailed views – using a cartographic techniques (as generalization) or techniques for 3D model substitution (such as LOD or LOA) for establishing an appropriate graphic load of a map in all potential levels of details.

Following the criteria proposed above leads to better perception of a 3D map. These criteria were used during a use case dealing with a creation of a 3D model of Terezín (especially Main and Small Fortress of Terezín at the state-of-the-art in 1944). See the next chapter for further information.

USE CASE ON THE 3D MODEL OF TEREZÍN

The description of works during the creation of a 3D model of Terezín City (a city in the Northern Bohemia) is depicted in detail in Hájek et al. (2015). The following chapter outlines directly the the cartographic principles of 3D map creation used during this process. The 3D model of Terezín City shows the appearance of this city in 1944, when there was a deportation camp during the Second World War. The model was created within the project "Memorial Landscapes Dresden and Terezín as places to remember the Shoah".

The cartographic principles stated in the previous chapter were fulfilled during the creation of the 3D model of Terezín City in the following way:

- Selection of dimensionality and a representation of all portrayed objects - 3D boundary representation of buildings was selected together with the representation of a terrain of the city and the surrounding fortification in the same way;
- Respecting of the cartographic variables to express the similarity to the real object - buildings (as the most profound parts of the whole 3D model) were symbolized to the real past appearance of buildings using both colors and textures. Textures were used for the representation of wall surfaces and for the representation of spatially complex objects (such as decorative structures on the buildings);
- Using proper categorization of objects to easily distinguish among different objects layers and objects – There were two categories of buildings, the first one (so called the important ones) were modeled in colors and in very high detail, and the second (non-important) were modeled grey scaled and in low detailed to easily distinguished among them;
- Setting up cartographic rules of the model symbolization and visualization in less detailed views – the most detailed models were based on less detailed ones (from LOD0 to LOD3, more in OGC(2012)), to minimize the graphic load during the visualization. That was accomplished by switching among the LOD's according the the position of a camera pointing the model.

As you can see, the mentioned principles used during the creation of a symbolized 3D model of Terezín City completely corresponds to the principles designed in the previous chapter. More information about the creation of such a model, the project itself and the historical background of Terezín City can be found in the reference stated in the beginning of this chapter and in its references. Figure 5 depicts the visualization of the 3D model of Terezín City in the web-based project platform.

Figure 5. The visualization of the 3D model of Terezín City in the project platform

CONCLUSION

This paper aims to discuss the principles of cartographic design for 3D maps. Definitions of a 3D map were investigated firstly. Then the design process of a 3D map was discussed. Three approaches of designing a 3D map were stated afterwards. Then, the cartographic principles suitable for a symbolization of 3D maps of urban areas were designed. Finally a use case for such principles was introduced.

The designed cartographic principles are based on the previous authors' works on this topic and they are designed especially for a creation of 3D maps of urban areas, reflecting the needs and use of such maps. The designed principles can serve as an inspiration for creating any 3D map of an urban area.

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