The Power of 3D Real-Time Visualization in Atlases – Concepts, Techniques and Implementation

René Sieber, Raimund Schnürer, Remo Eichenberger, Lorenz Hurni

Institute of Cartography and Geoinformation, ETH Zurich

Abstract. Real-time rendering engines, e.g. in virtual globes, enable easily creating 3D maps. From a cartographic point of view however, these maps are often incomplete as 3D cartography still lacks a coherent theory. In this article, we suggest a visualization concept where maps are generally treated as 3D entities. The concept builds on the notion of a Mapping Space, in which generic 2D and 3D objects and surfaces can be inserted. We present ten visualization techniques which can be applied to these elements. To illustrate the described techniques, we implement a set of 3D maps by means of the Atlas of Switzerland.

Keywords: Atlas Concepts, 3D Real-Time Geovisualization, 3D Cartography, Cartographic Representations, Virtual Globes

1. Introduction

Visualization of geodata is experiencing an ongoing and striking public presence. Along with this geovisualization boom, a strong trend towards 3D maps can be observed. 3D maps are not only visually pleasing and salient, 3D data and real-time display techniques are also increasingly available. In addition, 3D content may play an important role in communication support and spatial knowledge acquisition. From a cartographic point of view however, these 3D maps are often incomplete (Goralski 2009). The modeling process ends up with mere presentation of GIS data while omitting the final step of cartographic map creation. Yet, cartographic methods should be applied to clearly show relevant structures and processes in space and time. Early attempts by Terribilini (2001) with interactive vector-based topographic 3D maps were promising. Cartography however still lacks a comprehensive theory and coherent concepts for handling and displaying 3D data (Jobst & Germanchis 2007). As the process of visualization is highly interactive, Fairbairn et al. (2001) point out that 3D maps by their nature require a higher level of interactivity than 2D maps. Therefore, the mission of research is to explore and finally to build up such *cartographic concepts for 3D visualization in real-time.*

2. Towards 3D Real-time Visualization in Atlases

The present situation in digital atlas cartography concerning 3D visualization concepts can be depicted with one single word: flatland. The term refers to the novel *Flatland: A Romance of Many Dimensions* written 1884 by E.A. Abbott (2010), where people were used to see the world only in a one- or two-dimensional view. One day, they are getting in touch with extra-terrestrians from Spaceland, who are able to see, think and act in three dimensions. Acquiring and understanding this totally new concept, the flatlanders gain a lot of amplified sensations, particularly insight into spatial objects with their intrinsic characteristics.

This message of Abbott's novel coincides perfectly with the demand of nowadays maps and atlases: often a multi-dimensional, dynamic context is necessary to assess the complex nature and characteristics of thematic geodata. Since atlases should be able to compete with web map services, geoportals and virtual globes, visualization concepts have to be adapted to such real-time 3D web mapping environments. Relating to the classification of time dependency of the model, virtual environments are subdivided into the three categories: static, dynamic and real-time (Bodum 2005). While the static type is a representation of a specific space at a fixed point in time, the dynamic model is fixed in space but contains objects and information that change over time (e.g. animations). Real-time representations involve the coordination of changes in a model in several different spaces at exactly the same time; a criterion which is for example met by atlases based on a virtual globe visualization engine.

During the last decade, research in cartographic 3D visualization rather dealt with optimal views and design factors for static situations (Petrovic 2003, Häberling et al. 2008, Semmo et al. 2012). Efforts have also been made to the decrease of occlusion and visual clutter (Pasewaldt et al. 2011), and on the value-distance problem of comparing and measuring tasks in 3D maps (Bleisch et al. 2008). An overview of recent research topics concerning perceptive and technical aspects is given by Jobst & Germanchis (2007) and in Goralski (2009). Goralski summarizes, that sound and consistent knowledge is still missing in the field of 3D cartography. In fact, interactive 3D maps are distributed on the Web and implemented in some atlases (e.g.

the Swiss World Atlas), but there is no comprehensive concept, nor a complete set of techniques (technical overview) for 3D map visualization.

Therefore, the scope of the paper is threefold and rather ambitious: a) to introduce some conceptual ideas that could serve as an inspiring source for a sound 3D theory in atlas cartography, b) to discuss 3D techniques based on these principles, and c) to demonstrate their feasibility by practical implementation in a real-time 3D atlas environment.

3. The 3D Visualization Concept

In order to benefit from both the 3D map and the 2D map mode, a *3D-based visualization concept* for atlases will be pursued where all maps are generally treated as 3D representations. A 2D map is intrinsically considered as a special case in the 3D mapping environment, e.g. by setting the viewing perspective to an orthogonal view. Vice-versa, 2D maps should also be available in a 3D viewing mode, eventually augmented with additional information. By applying this concept in a real-time 3D visualization environment, the map of the Swiss Last Glacier Maximum (20.000 BC) can be either used as a 2D overview map, but also as a 3D panoramic view (fig. 1). The root idea of fusing 2D maps and 3D views is inspired by Abbott's novel, by user feedback from the Atlas of Switzerland 3.0 (2010), and it has formerly been formulated in Huber & Sieber (2001).

Figure 1. Fusion of 2D and 3D map modes (Swiss Last Glacial Maximum).

The fusion into a single 3D world results in some important advantages for atlas users and authors. It eases seamless visual transitions between 2D and 3D, and allows re-using most of the data and geometry, which minimizes map production and map revision times.

To be successful with this fusion concept, new ways of 3D thinking in cartography are required. Until now, most of the maps in atlases were in fact constructed or thought to be on a planar canvas, where different map layers were applied, each one on top of the other. But still the configuration was that of a Mapping Plane. Though the idea in 3D mapping is rather to build up a *Mapping Space* instead of using a Mapping Plane.

In the Mapping Space, the map can be extended vertically to build up different *map levels*. The level structure distinguishes three main levels: *base level*, *sub level*, and *supra level*. While the base level is thought as a 3D reference level, sub and supra levels are dedicated to depict under- or overlying structures. Thus, the conceptual model is creating a “real 3D” mapping environment. Phenomena on/near the ground profiting from a 3D representation comprise e.g. mountain huts, bridges and tunnels, or glacier surfaces. Stringent examples of sub level elements are the incorporation of geologic structures into a topographic 3D model, or the existence of infrastructure in the underground (fig. 2). On the supra level of the Mapping Space, atmospheric data and flight trajectories can be visualized amongst others.

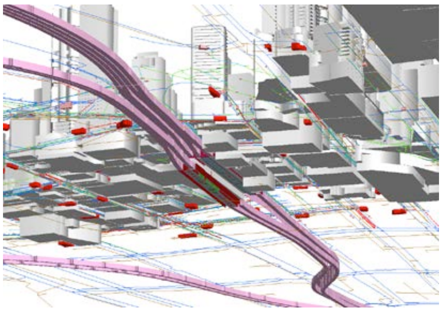

Figure 2. Example of sub level mapping (Dobson 2009).

Besides displaying topographic map elements or layers, the third dimension in the Mapping Space also enables embedding temporal and thematic data. Regarding time, space-time-cubes (Chrisman 2001) can be named. Heat maps with intensity values on the z-axis can be taken as an example for theme. Additionally, the Mapping Space can be used to *structure information*. For instance, thematic data can be ranked along the z-axis by categories like interest or importance in order to provoke attention.

In general, the 3D visualization concept can be applied to vector data (points, lines, polygons, and solids) as well as to raster data. Generic and real 3D models, geometric 3D primitives (e.g. cubes, spheres), volumetric bodies and curved surfaces, or voxel representations are thus possible. As a prerequisite, all data included in the Mapping Space have x-, y-, and z-coordinates.

To summarize, the real-time 3D visualization concept incorporating ideas of 3D *Map Fusion* and a *Mapping Space* can serve for efficient and visually appealing presentation of geo-referenced information.

4. Techniques for 3D Map Visualization

While digital 2D mapping techniques for atlases are well-established, cartographic knowledge concerning 3D representation techniques is still evolving (Räber & Sieber 2012). For visualizing 3D maps, specific techniques have to be developed that can be used within the Mapping Space. In the following, ten different techniques are portrayed which open the gallery of 3D map visualization possibilities: Map and depth abstraction, generalization, translation, anchoring, rotation, extrusion, scaling, arrangement, surface properties, and map projection. Certainly, the list is not exhaustive and has to be completed successively, and their applicability in an atlas environment has to be tested. These conceptual considerations are technically based on a 3D visualization platform, preferably a virtual globe.

4.1. Abstraction

In 3D visualization, the first decision to make is to choose an appropriate kind of representation. The choice of the representation level will have an impact on all the later phases of the development and visualization. Concerning the degree of realism or iconicity in the model, there are different ways how an entity can be represented graphically. Bodum (2005) describes five levels of abstraction: verisimilar, indexed, iconic, symbolic representation, and language (fig. 3). Verisimilar is meant to be very close to reality containing the most detailed available geographic information. With the indexed stage, an object is composed based on different parameters. The iconic level supplies a good pictorial resemblance to a real object. A symbolic level represents the cartographic method of visualization, whereas the language level incorporates only an abstract meaning.

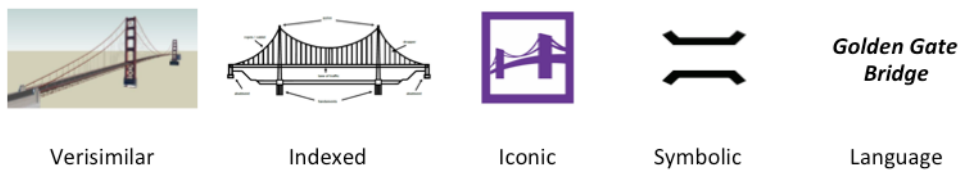

Figure 3. Abstraction levels (Bodum, 2005).

3D cartography deals mostly with iconic and symbolic representations (Imhof 1972) which allow mapping thematic information on visual variables. Additionally, labels can be inserted into the map (= language level). A special case at the symbolic level is the display of multivariate symbols (e.g. pie charts) which are composed of geometric primitives (e.g. sectors).

Depth abstraction in 3D cartography is solved by the LOD technique, resulting in more detailed information in the foreground than in the background. Thus, the LOD technique is supporting human vision behavior and coevally speeds-up map display for real-time visualization.

4.2. Generalization

Generalization operations like aggregation, selection, simplification, smoothing, and typification are core techniques in 3D cartography. Their purpose is to reduce complexity in order to emphasize the main message of the map. In a dynamic 3D environment, the concept of generalization is highly needed but difficult to achieve on-the-fly since it is computationally quite intensive. Thus, generalization of map content often takes place in some pre-processing steps.

4.3. Translation

In the Mapping Space, objects and surfaces can be shifted along the x, y, and z axis of the coordinate system. If two or more objects are spatially too close together, translation helps to displace the objects and thus avoids overlapping. Translation also enables showing multiple instances of a map in one single view. A translation in z-direction can be used for example to create stacked layers (fig. 4).

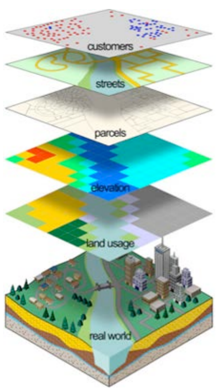

Figure 4. Translation creates stacked layers (http://www.gembc.ca/images/GIS-layers.jpg).

4.4. Anchoring

Anchoring helps to maintain the relationship between original and translated position of an object or a surface. Anchoring can be achieved by casting shadows, highlighting, stamps or footprints, and leader lines (Robinson 2011). While leader lines are better suited for point map layers with symbols or charts, highlighting is often used for choropleth maps.

Figure 5. Anchoring by means of leader lines for billboards. (http://www.openwebglobe.org/wp-content/uploads/2012/12/tut0203-358x259.jpg).

4.5. Rotation

Rotation is applied to spin and turn objects or surfaces. All three axes can be used: tilt/pitch on the x-axis, roll on the y-axis, and heading/yaw on the z-axis. The pitch can indicate for example the slope of a street, whereas the orientation of a landing runway of an airport can be described by the heading. *Billboarding* is a special case of rotation: A billboard is a flat object that always faces the camera. This direction usually changes constantly during runtime as object or camera move, thus the object needs to be rotated on-the-fly (Harris & Lastra 2001).

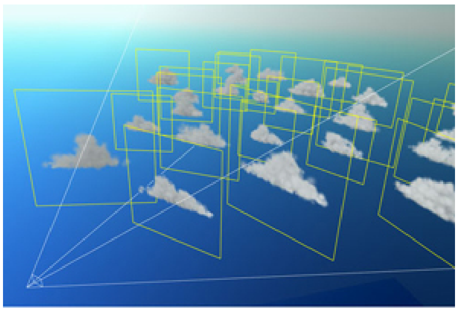

Figure 6. Billboarding (Harris & Lastra 2001).

4.6. Extrusion

Extruded objects benefit from the fact that an additional variable is available by the extrusion height. Technically, vertices of a 2D geometry are shifted and connected by a straight line (mostly the z-axis), and the emerging areas usually filled out. The extrusion technique can be used to simply highlight a location. In combination with *point features*, extrusion creates a 3D pillars with representative values, such as the population of cities.

Figure 7. Extrusion technique for point, line, and polygon elements (ArcGIS Help)[1].

Line features are extruded to create fences or vertical walls. This effect is useful for delineating important boundaries in 3D or to depict an amount of traffic. In a 3D environment, the use of vertical walls is a valuable option to save space in narrow places and rugged areas such as cities and mountains. Vertically extruded *polygons* result in boxes. The most common usage of polygon extrusion is to convert building footprints into 3D buildings. However, it can also be used in combination with statistical data, such as property prices, or county population.

4.7. Scaling

To emphasize subtle features or to let less important features fade into background, scaling can be applied. As scaling alters object sizes, it likewise can be used to reflect object attributes. Scaling occurs along all three axes (x, y, z), mostly with a uniform scaling factor. Individual scale factors are also possible. As a prominent example, super-elevation of the terrain can be mentioned, where scaling is carried out along the z-axis.

[1] http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00q800000115000000

Figure 8. Scaling technique: Exaggeration of the terrain (http://www.turbosquid.com).

4.8. Arrangement

Arrangement concerns the composition of elements in the Mapping Space. It defines how elements are topologically aligned with respect to each other with the aim of comparing and relating different objects in a reliable sense. As an example, the order of layers in a layer stack can be mentioned (*see fig. 4 translation*). In many cases however, arrangement is already predetermined by theme, space, and time.

4.9. Surface properties

Methods from computer graphics – such as coloring, transparency, glow, texture mapping, bump mapping, and environment mapping – can be transferred into the field of cartography and be applied to surfaces of 3D objects.

Figure 9. Surface properties: Color, transparency, and reflectivity (left)[2]; texture, bump, and environment mapping (right)[3].

[2] http://glasnost.itcarlow.ie/~powerk/GeneralGraphicsNotes/Theory/mappingimages/paral laxmapping.JPG

[3] http://www.artoolkit.org/Gallery/Radiosity/Base/QuadricsTransparent.jpg

Whereas properties like color and transparency serve usually as visual variables, reflectivity, textures and bump maps allow creating more realistic 3D models. Techniques describing surface properties can emphasize characteristics of objects or can be used to draw attention to a particular object in the Mapping Space.

4.10. Projection

3D objects or surfaces can be projected in the Mapping Space onto a 2D plane and vice-versa. The projection from 3D to 2D is typically a horizontal projection (e.g. by omitting height information). This process can be called *flattening*, whereas projecting 2D information onto a curved 3D surface (terrain, artificial surface) can be named *draping*. Besides horizontal projections also upright projections (e.g. to create a geological profile) are thinkable.

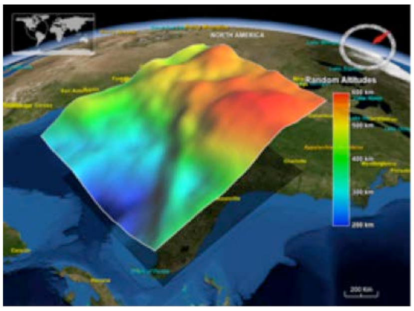

Figure 10. Projection of precipitation data onto an artificial surface (http://goworldwind.org/demos/).

The list of 3D visualization techniques is intended to finally cover most of the 3D representation types. It can be used for a general classification but also for suitability assessment within a 3D map or a 3D atlas.

5. Implementation in an Online 3D Atlas

To illustrate and apply the described techniques in an atlas environment, a set of real-time 3D visualizations is implemented by means of the *Atlas of Switzerland*. The next generation of the Atlas of Switzerland is designed as an online 3D atlas and based on a concept called *AtlasPlatformSwitzerland APS* (Sieber et al. 2011). For 3D real-time map rendering and navigation, the APS itself relies on the virtual globe *osgEarth*. osgEarth is built on the 3D graphics toolkit OpenSceneGraph (OSG) and developed in C++. It allows integrating user-defined digital elevation models in various LODs, and supports overlaying custom imagery, manifold GIS formats and web services. The virtual globe osgEarth is capable to process and display huge amounts of topographic and thematic data in near real-time. This enables amongst others an interactive exploration of the data.

Data sets in our tests cover various kinds of topics - mostly taken from the previous version of the Atlas of Switzerland. All map examples have been created by Python scripts including ArcGIS and PostGIS functions.

5.1. Point cloud map

A point cloud map can be seen as the 3D equivalent of a 2D dot density map. Input data for this map example were the number of inhabitants and the population density within the settlement areas of Swiss communes. Points representing a certain number of inhabitants (here: 100) were spread randomly over the settlement areas by the ArcGIS function “Create Random Points”. The points were translated in z-direction in case the distance between two points has fallen below a certain threshold (here: 1km). The z-shift contains a random component to avoid a uniform pattern when viewing the cloud obliquely. Lastly, the points were colored by population density: A yellow color hue stands for low density, whereas a brownish hue indicates a high density.

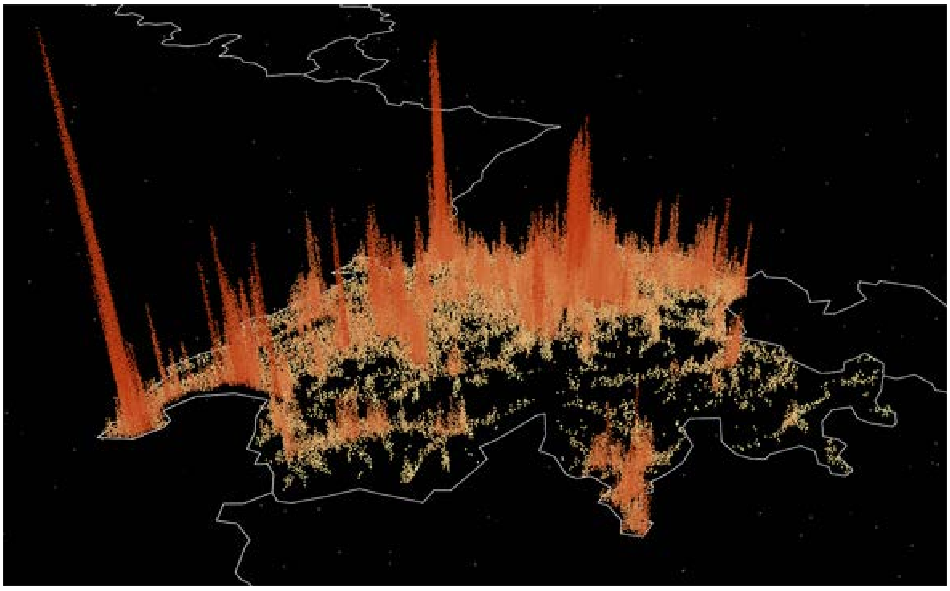

Figure 11. Translation, generalization, and surface properties techniques for a point cloud map.

5.2. 3D Flight route map

This map contains indexed and language representations of airports and symbolic representations of flight routes. Straight connecting lines between Zurich airport and worldwide flight destinations served as input data. Distances (d) of individual flights were calculated and heights (h) were linearly approximated by distance. After that, temporary lines consisting of three points - (0, 0, 0), (0.5*d, h, 0), (d, 0, 0) - were created. These lines were then smoothened in ArcGIS applying a Bézier interpolation, and y- and z-coordinates swapped. Finally, the lines were rotated and translated to their original position. Red lines represent a small traffic volume; bigger yellow lines indicate a higher amount of passengers. Models of airport were scaled along all three axes to make them also visible at small scale. Airport labels implement the billboard rotation technique.

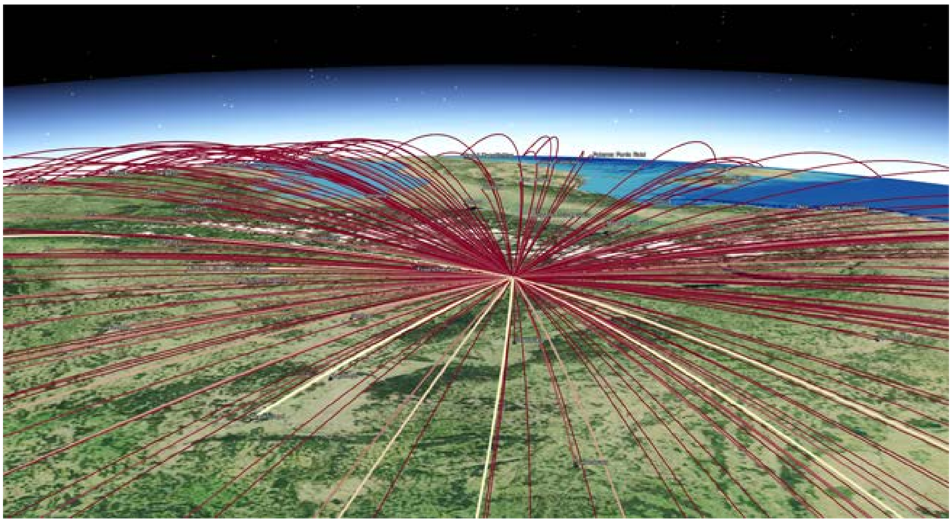

Figure 12. Generalization, scaling, rotation, and surface properties techniques for flight route maps.

5.3. Multi-layered choropleth map

Multiple flattened choropleth layers were translated in this map along all three coordinate axes. By navigation through the virtual space, the layers can be accessed in detail. Percentages of persons employed in the primary, secondary and tertiary sector in Swiss cantons, districts, and communes for the years 1970, 1980, 1990, and 2000 were taken as sample data. The more people work in a sector, the darker the color is (brown = sector I, pink = sector II, green = sector III). The PostGIS function "ST_Translate" was used to shift these layers chronologically in x-, ordered by sector number in y-, and ordered by spatial region in z-direction. The initial layer position is highlighted on the base level of the globe.

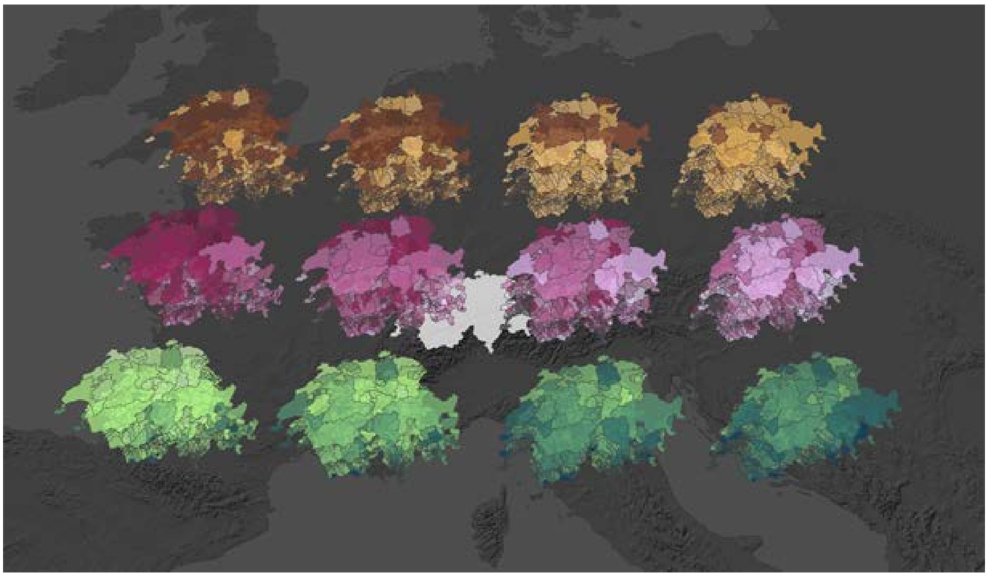

Figure 13. Translation, arrangement, anchoring, projection and surface properties techniques for multiple choropleth maps.

5.4. 3D Pie chart map

In this example, the number and capacity of wood-fired heating systems in Swiss cantons have been visualized. Sectors in a bluish hue exclude wood processing and pellet power, whereas pinkish sectors include these heating systems. Lighter colors indicate less capacity, darker colors stand for higher capacity.

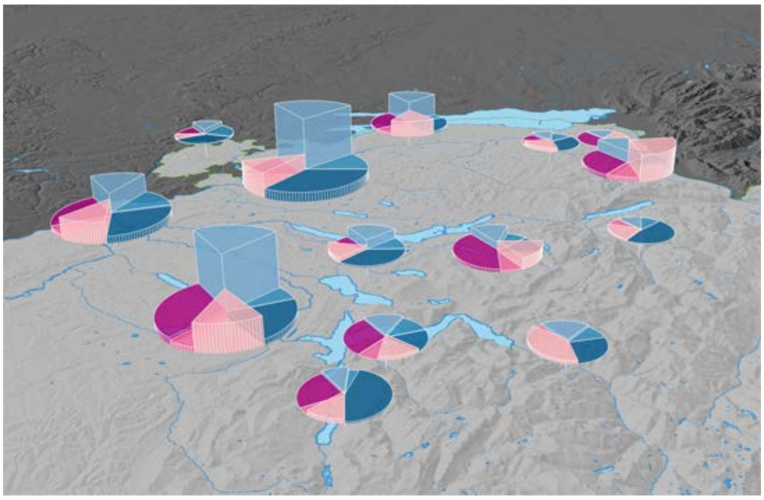

Figure 14. Anchoring, arrangement, extrusion, translation, and surface properties techniques for a 3D pie chart map.

The pie sectors were composed with WKT CurvePolygons in a PostGIS table. To import them in osgEarth, all WKT CurvePolygons had to be approximated by straight line segments using the PostGIS function “ST_CurveTo Line”. The pie sectors were finally extruded by the number of wood-fired heating systems and anchored by a vertical line to the base surface. A translation by a constant z-value was necessary to avoid pie charts colliding with the terrain.

5.5. Voxel map

Raster maps logically evolve to voxel maps in 3D. One possible data source to generate voxel maps are Digital Terrain Models. In this map example, the Swiss terrain model “DHM25” was used, however with an adjusted cell size of 50m. Polygons were then generated replacing the raster cells in a defined area, in this case the mountain peak of the Matterhorn. Starting off from a base height (here: 3000m), layers were created in intervals of the cell size until the actual height (= cell value) was met. Lastly, polygons were extruded by cell size and their faces were colored.

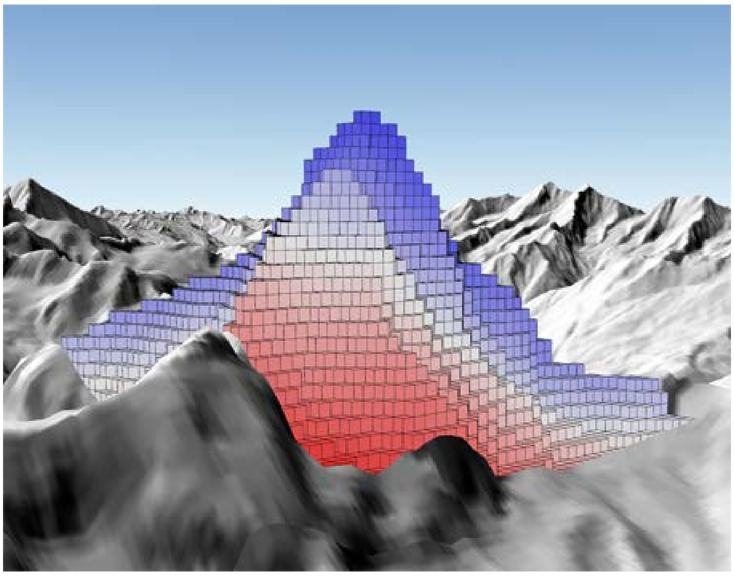

Figure 15. A voxel representation of the Matterhorn.

The set of 3D maps created with different visualization techniques clearly demonstrates the power of the conceptual ideas and the realization in an online atlas.

6. Conclusion and Outlook

Digital atlases have to find new approaches to keep pace with competing applications and to attract new user groups. As Meng (2002) states: „In fact, a cost-effective presentation that provides an eye-catching naturalistic view and sufficient interactivity is what most developers and users of geo-visualization are seeking for." For online atlases, 3D cartography seems to be a promising way to fulfill these demands and even to combine it with effective, informative presentation. This paper introduced a 3D map visualization concept based on the idea of a Mapping Space, where maps are intrinsically treated as three-dimensional entities. The Mapping Space concept allows to fuse 2D and 3D maps, but also to apply a broad range of 3D map visualization techniques. These techniques open a large field of applications in real-time 3D cartography, especially when using a generic approach for map creation. Further investigations in 3D map visualization techniques and rules should lead to general guidelines for a coherent theory of 3D cartography.

References

Abbott, E.A.: Flatland (2010) A Romance of Many Dimensions. Cambridge University Press

Asche, H.: Der Atlasbaukasten (2009) Nachhaltiges Produktionskonzept im Geoinformationszeitalter? Kartographische Nachrichten, 1(9), pp. 3-12

Bleisch, S., Burkhard, J., Nebiker, S. (2009) Efficient Integration of Data Graphics into Virtual 3D Environments. XXIV Int. Cartogr. Conference, Santiago de Chile

Bleisch, S., Dykes, J., Nebiker, S. (2008) Evaluating the Effectiveness of Representing Numeric Information Through Abstract Graphics in 3D Desktop Virtual Environments. The Cartographic Journal, 45(3), pp. 216-226

Bodum, L. (2005) Modelling Virtual Environments for Geovisualization: A Focus on Representation. In J. Dykes, A.M. MacEachren, M.-J. Kraak (Eds.): Exploring Geovisualization. Elsevier/Pergamon, pp. 389-402

Chrisman, N. (2001) Exploring Geographical Information Systems, 2nd ed. New York: Wiley

Dobson, nn (2009): Sydney Underground. Geomatic and Information Technology Association Conference. Melbourne, Australia

Döllner, J. (2007) Non-Photorealistic 3D Geovisualization. In W. Cartwright, P. Peterson, G. Gartner, (eds.), Multimedia Cartography. Berlin Heidelberg New York: Springer, pp. 229-240

Fairbairn D., Andrienko G., Andrienko N., Buziek, G., Dykes, J. (2001) Representation and its relationship with cartographic visualization: a research agenda. Cartography and Geographic Information Science, 28(1), pp. 13-28

Goralski, R. (2009) Three-dimensional interactive maps: Theory and practice. PhD Thesis, University of Glamorgan

Häberling, C. (2003) Topografische 3D-Karten – Thesen für kartografische Gestaltungsgrundsätze. PhD Thesis 15379, Institute of Cartography, ETH Zurich

Häberling, C., Bär, H.-R., Hurni, L. (2008) Proposed Cartographic Design Principles for 3D Maps: A Contribution to an Extended Cartographic Theory. Cartographica, 43(14)

Harris, M. J., Lastra, A. (2001) Real-Time Cloud Rendering. Proceedings of Eurographics, 20(3), pp. 76-84

Huber, S., Sieber, R. (2001) From Flatland to Spaceland – Concepts for Interactive 3D Navigation in High Standard Atlases. XX Int. Cartogr. Conference, Beijing

Imhof, E. (1972) Thematische Kartographie. Berlin, New York: Walter De Gruyter.

Jobst, M., Germanchis, T. (2007) The Employment of 3D in Cartography – An Overview. In W. Cartwright, P. Peterson, G. Gartner, (eds.), Multimedia Cartography. Berlin Heidelberg New York: Springer, pp. 229-240

Nebiker, S., Schütz, S., Wüst, T. (2005) Model-Driven Content Management for Web-Based 3D Geoinformation Services. Proc. of the XXII Int. Cartographic Conference, A Coruña, Spain

Meng, L. (2002) How Can 3D Geovisualization Please Users Eyes Better? Geoinformatics Magazine for Geo-IT Professionals. 5, pp. 34-35

Petrovic, D. (2003) Cartographic Design in 3D Maps. Proc. of the XXI Int. Cartographic Conference, Durban, SA

Petrovic, D., Masera, P. (2005) Analysis of User's Response on 3D Cartographic Presentations. Proc. of the XXII Int. Cartographic Conference, A Coruña, Spain

Räber, S., Sieber, R. (2012) Atlas of Switzerland – New Ideas for 3D Atlas Visualisation Techniques. GeoCart2012, Auckland NZ

Robinson, A.C. (2011) Highlighting in Geovisualization. Cartography and Geographic Information Science, 38(4), pp. 374-384

Sandvik, B. (2008) Using KML for Thematic Mapping. MSc Thesis, Institute of Geography, University of Edinburgh

Semmo, A., Hildebrandt, D., Trapp, M., Döllner, J. (2012) Concepts for Cartography-Oriented Visualization of Virtual 3D City Models. Stuttgart: Schweizerbart'sche Verlagsbuchhandlung

Sieber, R., Hollenstein, L., Odden, B., Hurni, L. (2011) From Classic Atlas Design to Collaborative Platforms – The SwissAtlasPlatform Project. Proc. of the XXI Int. Cartographic Conference, Paris

Sieber, R., Hollenstein, L., Eichenberger, R. (2013) Concepts and Techniques of an Online 3D Atlas – Challenges in Cartographic 3D Visualization. Margaria, T. and Steffen, B. (eds.): CCIS Series, Berlin Heidelberg: Springer, to be published.

Terribilini, A. (2001) Entwicklung von Arbeitsabläufen zur automatischen Erstellung von interaktiven, vektorbasierten topographischen 3D-Karten. PhD Thesis 14387, Institute of Cartography, ETH Zurich