True-3D in Cartography - Current Hard- and Softcopy Developments

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Abstract According to statistically indicative studies carried out by the first author in the 70s and 80s, more than 60 % of all users of topographic or hiking maps are not able to derive relief information spontaneously. Stereoscopic vision seems essential, for not only an optimised perception of relief but also for other spatial information. If the geodata visualisation is realised in a way that allows a three-dimensional observation beyond perspective viewing, we talk about "true-3D". This term applies to both flat map-like displays and solid landscape embodiments. Both types belong to what is generally called the hardcopy branch of these products. For some years, lenticular-foil maps have been the most prominent examples of hardcopy 3D maps, However, softcopy displays have recently been undergoing a very dynamic development triggered by the TV and game industry. In North America, Europe and Japan various companies and research centres are competing in the realisation of large-format static and small-format portable computer-displays. They have the big advantage that, first, dynamic datasets (e.g. films) can also be displayed and, second, wireless Internet connections enable real-time access to databases. Very recently, physical landscape models of high photorealistic quality are also gaining increasing importance.

Keywords Cartography · Three-dimensionality · True-3D · Autostereoscopy · Geodisplays · Solid landscape embodiments

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1 Introduction

The need for “true 3D” is backed up by previous studies carried out by the first author in the 1970 and 1980s, which show that more than 60 % of all users of topographic or hiking maps are not able to derive relief information spontaneously. The participants were members of alpine climbing courses with academic educations.

“True” 3D? Is there also an “untrue” or “false” or “pseudo” 3D? Yes, there is. Pseudo-3D depictions are visualised perspective-monoscopically on planar media, e.g. on a monitor screen. They are not autostereoscopic. True-3D visualisations can be parallax-3D or full-3D. While parallax-3D geovisualisations only use selective bi- and monocular depth cues, full-3D geovisualisations use all bi- and monocular depth cues (Buchroithner 2001). Thus, the authors define any scene which can be stereoscopically seen, but not only because of the perspective, as “true-3D”. In this sense, physical landscape embodiments can also be considered “true-3D”. The (only) difference is that in the latter instance we apply natural stereovision (solid models), in the other case we use a special way of artificial stereovision. Hence, one might also talk about displays with touchable reliefs and planar (“flat”) true-3D displays. The essential thing is the provision of two distinct stereomates to the viewer’s eyes, whether created “artificially” or not.

Stereoscopic displays can be analogue, these are the so-called hardcopy displays or they can be digital, the softcopy displays. Furthermore, they can be divided into non-autostereoscopic and autostereoscopic displays. Non-autostereoscopic displays require glasses or similar viewing aids to provide a spatial impression, but autostereoscopic displays allow a spontaneous spatial perception without any additional viewing means (see Knust and Buchroithner 2012). There exist single-user displays for only one user at a time and multi-user displays. With the latter multiple users can perceive a spatial impression simultaneously. The users of stereoscopic displays can be head-tracked, meaning if the viewer moves in front of the display the stereomates are tracked to keep the spatial impression. Furthermore, the ability to visualise 3D images can be switchable or not. Switchable displays can also be used on a normal 2D screen.

By means of an overview of the historical development and technical status Buchroithner (2007) tried to explain the importance of three-dimensionality in cartography. Both physical landscape models as well as pseudo-3D and true-3D autostereoscopic visualisations on planar displays were investigated. Besides reasons for the advantages and necessities for true-3D representations, the author also gave a short preview on the interactive and dynamic possibilities of future 3D visualisation.

In a recent publication Buchroithner and Habermann 2010 introduced the term relief aesthetics, a term which still needs to be defined and investigated in more detail and which has a close connection with relief intensity (German: Reliefenergie, see Bill and Zehner 2001), a parameter which might also allow the quantification of the aesthetic value of the relief of a landscape. In conjunction

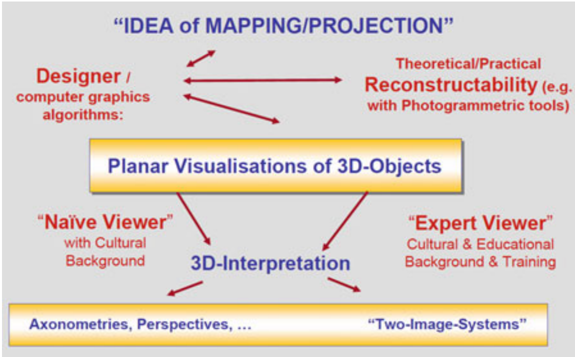

Fig. 1 Visualisation and interpretation of 3D scenes based on planar visualisations of 3D objects (from Weiss and Buchroithner 2012)

with cartographic depictions this is an issue which still awaits more in-depth research, aimed at answering the question: to what degree the relief intensity of a landscape determines the possible aesthetics of a map, and—vice versa—how the method of relief representation in a map may bias the aesthetic appearance of the latter. We believe that the level of aesthetics of a cartographic product also facilitates the user's generation of her/his mental ("cognitive") map.

Regardless of these aspects of relief aesthetics, the question of how to optimally convey the cartographer's "3D message" remains. Figure 1 describes the process from an idea of the "map maker" to its spatial interpretation by the viewer via a planar representation. In this regard the designer has to consider that an expert viewer "reads" and interprets a 3D scene in a different way than a "naïve", inexperienced viewer does. The planar visualisation of physical three-dimensional objects is the link between the concepts, algorithms and in general the reconstructability by means of computer graphics and/or photogrammetric tools on one side and the mental reconstruction and, further, interpretation on the other side. It is a model for the 3D object.

A difficult situation arises where, besides the relations between positions of points and objects in Euclidean space, there are hidden and obvious assumptions packed into a visualisation. The viewer interprets the visualisation after having put it into a certain context, be it the explicit verbal description of what should be seen in the picture, or the viewer's own knowledge or imagination. Of course, these facts also rule visualisations in Cartography (Weiss and Buchroithner 2012, Fig. 2).

In summary, the theory behind the aforementioned aspects of stereovision of geo-scenes is rather complicated (see Fig. 2) and by no means resolved, both in terms of methodological structuring and terminology. To this end, the present paper only represents the interim state of developments which are in a state of flux. The reader is kindly referred to the paper by Weiss and Buchroithner 2012. Furthermore, a more comprehensive treatment of the theory and technology regarding the field of "true 3D cartography" by the authors of this article (Knust and Buchroithner 2012) as well as an overview of the role of true-3D visualisation in cartography (Buchroithner and Knust 2012) is in preparation.

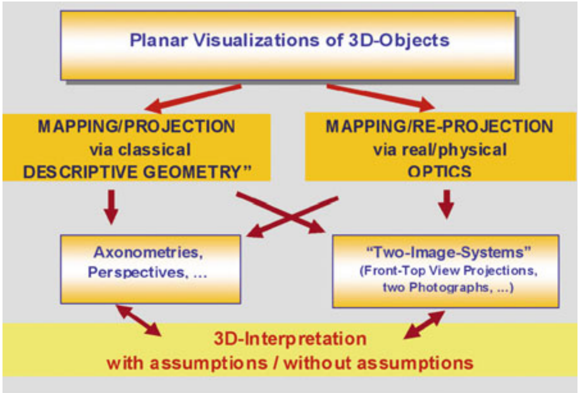

Fig. 2 Perception of 3D objects from planar "3D displays" (from Weiss and Buchroithner 2012)

2 Planar Autostereoscopic Displays

2.1 Lenticular Foil Technique

As the term says, planar autostereoscopic displays are flat displays—either analogue, i.e. hardcopies, or digital screens, i.e. softcopies. One of the well known planar autostereoscopic visualisation techniques is the *lenticular foil technique*. This method has been successfully applied to both softcopy and hardcopy displays. For several years the Dresden company mbm systems Inc., a spin-off of the Institute for Cartography of the TU Dresden, has successfully been producing lenticular foil hardcopy displays for operational use in teaching, tourism and edutainment, their major field of production being geodata visualisation.

The lenticular foil technology is an image display method used for the generation of multi-image effects like 3D visualisations or animations. In order to allow the spontaneous perception of these effects without any additional viewing aids (glasses or other means for image separation), lenticular foil displays consist of two components:

1. the lenticular image, and
2. the lenticular foil.

The transparent lenticular foil serves to separate the individual images that are seen by the left and right eyes. For this purpose, on its upper side there are a series of parallel semi-cylindrical micro-lenses (Latin "lenticulae"). The lower side is smooth and flat and coincides with the plane of the lenticular image. The latter one consists of multiple synthetic views (or in the case of "flat"—i.e. "no relief" depictions, e.g. for flipping: partial images) which are cut into small strips and interlaced in an alternating sequence. Consequently, under each of the semi-cylindrical lenses one strip of each partial image is situated (Fig. 3).

The image separation through the lenticular foil occurs according to its optical properties. The semi-cylindrical lenses focus the parallel incident sight rays onto

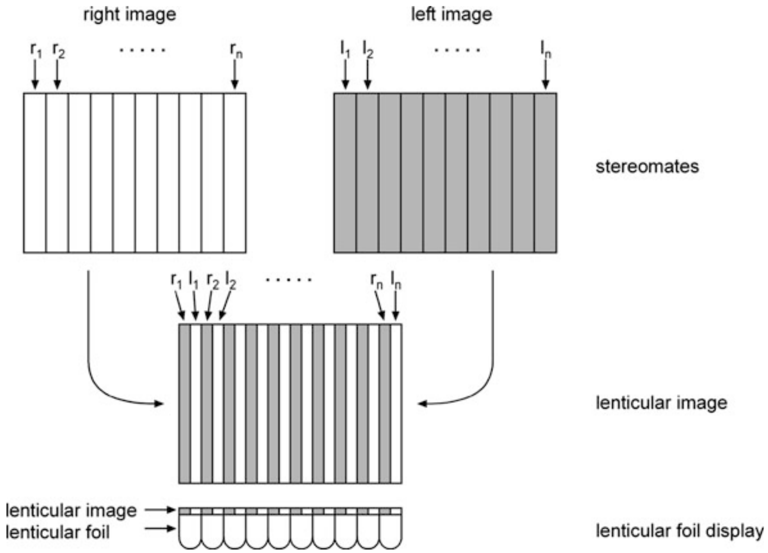

Fig. 3 Principle of the lenticular foil technique (from Gruendemann 2004a, p 15)

particular strips of the lenticular image. If the viewer changes his/her perspective by turning or tilting the lenticular foil display perpendicular to the lenses, the vision rays are focused onto other strips of the display. This enables the perception of the spatially separated image information out of one lenticular image, because from a particular viewing angle the viewer only sees one strip per semi-cylindrical micro-lens. More comprehensive information about the lenticular foil technology can be found in Okoshi (1976), Gruendemann (2004a, b), Buchroithner et al. (2004a, 2005a, b, c), as well as Gruendemann et al. (2006).

A significant strong point of the lenticular foil technology is its versatility concerning displayable effects. They can be divided into two categories: 2D- and 3D effects. Each of these major categories contains special effects (true-3D, flip, morphing, zoom, and animation). Besides 2D- or 3D effects lenticular foil displays also can visualise a combination of 2D- and true-3D effects.

Displays with 2D effect typically have micro-lenses running in a horizontal direction. Thereby a supply of the same image information to both of the viewer's eyes is achieved. Horizontal tilting of the lenticular foil display then changes the image content. For lenticular foil displays with true-3D effect, however, the semicylindrical lenses must be aligned vertically. This configuration results in the visual perception of different images of the same object(s) by the two eyes. In either case, the displays can be generated as reflectance displays (incident light/ "looking at") or transmission displays (transmitting light/"looking through").

Due to the various 2D- and 3D effects the lenticular foil technique offers versatile possibilities for cartographic visualisation. The 3D-effect is only used to visualise relief. For example, the lettering can also be displayed virtually hovering above the terrain. The flip effect can be used to compare different situations like low and high tide, to visualise short animations or to show different languages. If the user tilts the lenticular map or moves his/her head sideways, the perception of different images from the single display is obtained.

Presently, however, flexible hardcopy displays on the basis of lenticular foils are still limited in size, since the foils cannot be folded. (A rare attempt in the non-civilian domain with lenticular rubber-sheets did evidently not yield the expected results and never went into operational production and use.) Once this “problem” is solved, lenticular foil maps could be transported like normal paper maps in a backpack. Another solution would be to mount the individual foldable clips/“tiles” on linen—this had been the case with paper outdoor maps until the 1960s.

Today, the interlacing method is standard for the lenticular foil technique. A recent development at the Berlin University of Technology, however, aims at minimising the disadvantages of the “traditional” interlacing approach such as the reduction of the geometric (“visible”) resolution of an image and the notable restrictions of viewing zone and viewing distance. Up to 50 % of the viewing zone of a stereogram might, for example, cause a pseudoscopic 3D-perception, i.e. a relief inversion (Stendel 2012).

With the recently developed Virtual Lenticular Rendering (VLR) method the viewing range becomes wider, the edge depiction is improved etc. According to Stendel (2012) “the VLR method is an integral image technique as well but of comparatively low complexity. Instead of a high number of different lenticular plates the optical system of this technique is reduced to a single coding lenticular plate…” In contrast to the method of Davies and McCormick (Davies et al. 1988) a regular scene camera is used as a recording agent in the 3D model. Therefore, even perspective images may be realised with a high accuracy of position. Instead of half-images this method creates for each lenticular lens its own basic “images”. There are, however, further investigations necessary to optimise surface structures and lens sizes for this new method (Stendel 2012). Figures 4 and 5 show the coding process of the VLR method and the coded “parallax panoramagram” of a cube.

2.2 Barrier Stripes Technique

Another technique which is frequently applied to planar autostereoscopic displays is the *barrier stripes technique*. The stereoscopic images the viewer perceives consist of at least two stereomates which are interlaced strip by strip. In front of the display screen, a strip mask, called a parallax barrier, is mounted as a visual barrier. The strip mask consists of transparent and opaque stripes. This will, depending on the viewing angle, hide stripes of the stereoscopic image and leave others visible for the viewer’s eyes. Thus, each eye only sees information allotted to it (Okoshi 1976). Figure 6 illustrates the principle of barrier stripes technique.

Within the scope of a true-3D project for the famous Globe Collection in the Mathematical-Physical Salon at the Royal Zwinger Palace in Dresden, Germany,

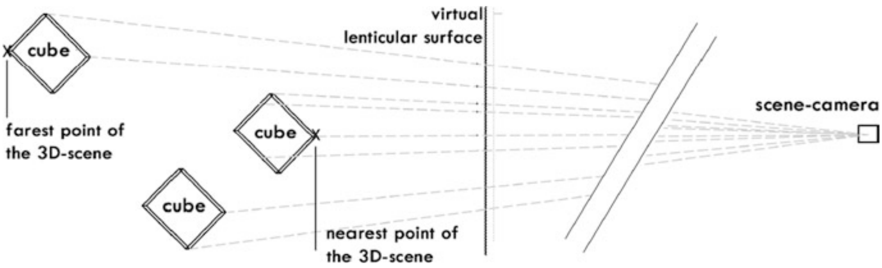

Fig. 4 Coding process by means of the VLR method using the example of a cube (from Stendel 2012)

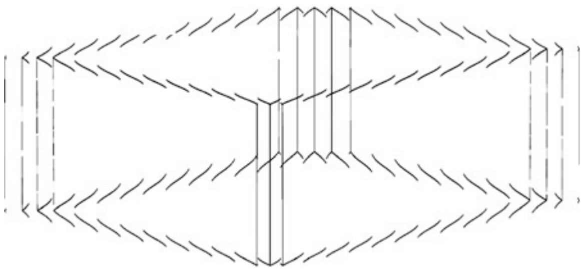

Fig. 5 "Parallax panoramagram" of a cube (generated as indicated in Fig. 4) (from Stendel 2009)

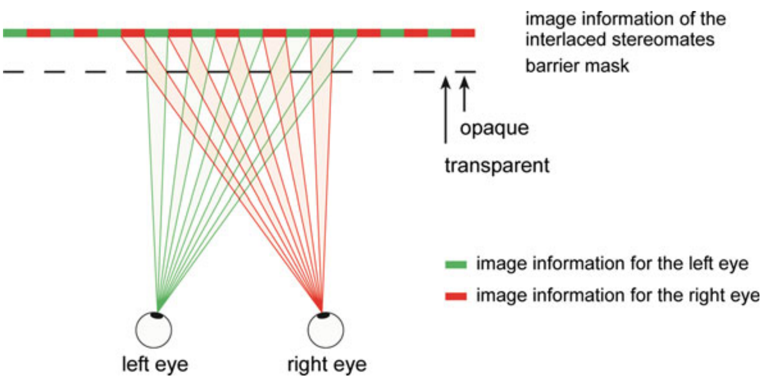

Fig. 6 Principle of the barrier stripes technique (based upon Knust 2007, p 35)

the historical globe of Willem Janszoon Blaeu (Amsterdam, about 1645, 68 cm in diameter), was visualised on a large-format autostereoscopic display (Knust 2007, 2008; Knust et al. 2012). Here a film animation about the historical terrestrial globe was generated, taking the round-the-world expeditions of the Portuguese Fernando Magellan (1519–1522) and of the Dutch Jakob Le Maire and Willem Cornelisz Schouten (1615–1617) as an example to point out various details of the globe in true-3D.

Table 1 Examples of current autostereoscopic digital displays (based on various websites of the display manufacturers; see also Opel and Bergmann 2009)

Lenticular (head-tracked):	SeeFront, SeeReal, Free2C
Lenticular (fix):	Alioscopy, xyZ, Spatial View 3DeeSlide and 3DeeScreen
Barrier stripes (switchable):	Miracube, DTI Virtual Window, Dimen C190S/C190X, Free2C_digital, Hitachi Wooo H001, Sharp
Barrier stripes (not switchable):	Tridelity, 3DInternational

2.3 *Digital Autostereoscopic Displays*

There exists a series of autostereoscopic displays on the market. Some of the major products are listed below (June 2010, Table 1). The 3DeeSlide of Spatial View Inc. in Dresden consists of a removable lens holder and a special lenticular lens foil to be mounted on an iPhone or iPod and has been available since autumn 2010 (www.SpatialView).

3 Solid Landscape Embodiments

Landscape models allow "simultaneous landscape viewing" of both the whole embodiment and of small details in a totally interactive way. Also for laymen landscape models are easily legible. Instead of a flat map where one has to interpret contour lines and relief shading to perceive the third dimension, a landscape model allows spontaneous derivation of topographic aspects like terrain steepness. It is easier to compare height values in distant parts of a physical landscape model than in distant parts of a flat map (Rase 2012).

Solid landscape embodiments are multi-user models. They give the user a true-3D impression of the depicted situation. Hence, they are an alternative to printed paper maps and digital maps, but they will never replace them.

The largest machine-produced physical terrain model ever made (in this case from a digital data source) is a model of entire province of British Columbia, displaying the landscape at a scale of approximately 1:99,000 (12.2 × 22.6 m). Since June 2006 it is on display as the centrepiece of the "BC Experience" Geographic Discovery Center in the historic Crystal Garden in Victoria, British Columbia (www.STM_USA).

In summer 2006 an incidental discovery of a huge landscape model in China was made in Google Earth. This model at a scale of 1:500 and a size of approximately 900 m by 700 m is situated near Huangyangtan, about 35 kms away from the town of Yinchuan, capital of the Autonomous Region of Ningxia in the northern part of China. The model with man-made snow peaks and glacial lakes represents a region about 2400 km west Huangyangtan, in the border area of Aksai Chin, neighbouring the disputed frontier to Pakistan and India. It is supposed to

Fig. 7 Landscape model near Huangyangtan, China (screenshot Google Earth; © 2012 Google, Image © 2012 GeoEye, © 2012 Mapabc.com)

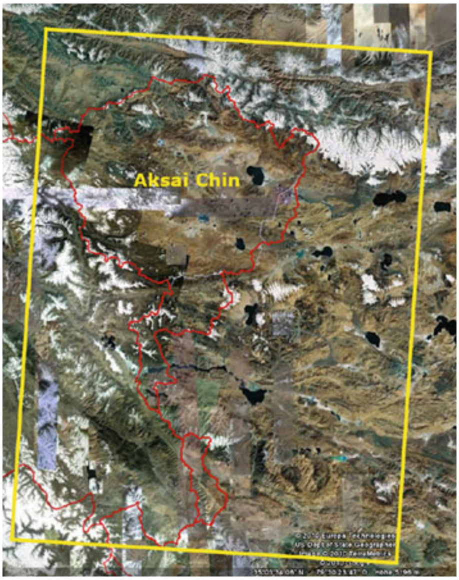

Fig. 8 Corresponding region of the landscape model near Huangyangtan, around Aksai Chin (screenshot Google Earth; © 2012 Google, © 2012 Europa Technologies US Dept. of State Geographer, Image © 2012 Terra Metrics)

have been generated for military use (Hutcheon 2006; Indian Express 2006). Figure 7 shows the landscape model on a Google Earth satellite image, Fig. 8 displays the corresponding region around Aksai Chin.

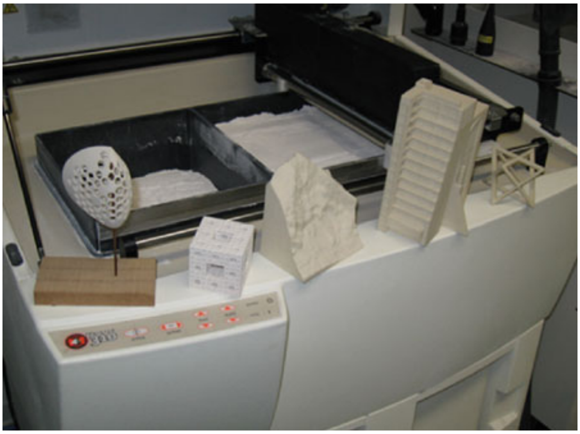

Fig. 9 Rapid Prototyping at the Institute of Geometry, Dresden University of Technology, Germany (from Weiss and Buchroithner 2012). Further explanations: see text below

3.1 Rapid Prototyping

Today it is possible to generate physical landscape models within a short time. Rapid prototyping comprises different methods, e.g. stereolithography, 3D-printing or milling. Rase (2009, 2012) distinguishes between four main groups of rapid prototyping techniques: *removal or milling* (Michelangelo Method), *aggregation* (Rodin Method), *transformation* (Chillida Method), and *laser subsurface engraving or laser etching* (Dürer Method). The removal method implies the removal of material from a block of wood or plastic to form the desired model. *Computer-controlled milling* is such a removal method. In contrast to the removal method the aggregation method works vice versa: loose material like a jelly or a powder is merged layer by layer to form a final model, e.g. by heat or glue. For example *stereolithography* and *3D-printing* use this principle to generate relief models (see Fig. 9). Since the first 3D printer by ZCorporation (www.ZCorp) has been introduced in 2001, a colouring of the model during the printing process is now possible. This has replaced a subsequent manual colouring stage. For the production of 3D models the aggregation method might have the highest potential (see also Rase 2009, 2012). Some USA companies like Cubic Technologies and Stratasys, Inc. (www.CubicTechnologies, www.Stratasys) use different types of "3D-printing" such as laminated object modeling or fused deposition modeling (FDM®). Further, 3D Systems, Inc. runs a production line of 3D-printing, stereolithography (SLA®) and selective laser sintering (SLS®) (www.3DSystems). It is hard to make statements to what extent these technologies have already been applied for the production of physical landscape models.

The central specimen created with a 3D-printer in Fig. 9 represents the famous Eiger Northface in Switzerland based on data generated by the Institute for Cartography at the Dresden University of Technology, Germany.

The transformation method forms material by pressure and heat. With the help of a mould a planar *thermoplastic foil* is transformed into a foil which corresponds to

Fig. 10 Laser subsurface engraving of the high-mountain terrain around the Großglockner (3798 m)

the 3D relief model. Before the transformation process the respective geo-information is printed onto a foil considering the geometry parameters after transformation. This method allows to produce big runs of non-planar relief depictions, and thus the individual copies become comparatively inexpensive. (Rase 2009, 2012).

Laser subsurface engravings or laser etchings, also colloquially called *3D drawings*, are generated with lasers, which engrave opaque points inside a block of glass, e. g. engrave a globe-model (Rase 2009, 2012). Figure 10 shows a small specimen displaying the high-mountain terrain around Austria's highest peak, Großglockner (3798 m) and the largest glacier of the Eastern Alps, the Pasterze.

An attractive possibility for customers who want to create their own relief models is the offer from LandPrint.com™. With the LandPrint DesignerTM software the user can interactively select an area in 3D and even can load own GPS-tracks to integrate them into the relief model. LandPrint.com™ announces that it will be possible to apply own maps or images to a generated 3D model soon. The models are colour-printed with the 3D printers of ZCorporation (www.Landprint, www.ZCorp_press).

Rase (2009) emphasizes the potential of solid 3D models, either topographic (georelief) or thematic (Fig. 11), as demonstration or discussion tools for decision makers or simply as eye-catchers. But since 3D models are haptic, rapid prototyping is not only useful to produce models to look at, but also to generate tactile maps for the blind or visually impaired (see Sect. 6 "Tactile Maps").

3.2 Handmade Landscape Models

Around the 16th century the first landscape models were generated by hand. In the 19th century relief modelling reached its heyday in Switzerland because of the technical developments in both cartography and geodesy (Buchroithner 2007; www.Bergmodelle; www.TerrainModels).

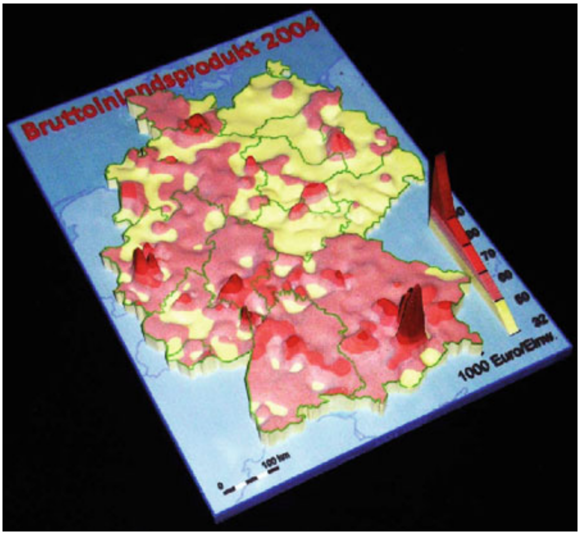

Fig. 11 Physical model visualising the gross domestic product per capita in Germany (from Rase 2009, p 4)

"Producing a steric landscape relief is comparable to making music: the finest details and nuances can only be produced by men and not by machines. My slogan is: Do not give away the most creative work to machines—to create a landscape. I want to do it myself." This statement by Toni Mair (Mair 2012), currently the world-leading relief artist, best describes why today, in a period where cartography is finding its way back to aesthetics (signposted by the founding of the ICA Working Group on Art and Cartography in August 2008—now an ICA Commission), manually generated landscape models are experiencing a sort of renaissance. There exists general consensus that machine-generated landscape models will at least in the near future not be able to replace handmade ones that are produced by "geo sculptors". Only the human processor can really polish and "fine-tune" these landscape embodiments in order to make them look as natural and vivid as the best of them are. Hence, such pieces of "geo-art" will always remain in vogue and never lose their appeal.

4 Omniglobes and Hyperglobes

Besides the analogue, physical globes, which have been existing for several centuries, since the beginning of this millennium more and more digital globes are emerging on the market. Andreas Riedl (Vienna), one of the experts in digital globes, distinguishes between hologlobes, digital hyperglobes and tactile hyperglobes. The latter ones are globes which show their cartographic image in real representation space (instead of a virtual one), i.e. on a real, physical globe body. Digital globes minimize the disadvantages of analogue globes, such as reduced portability, small number of themes and long updating cycles (Riedl 2000, 2012).

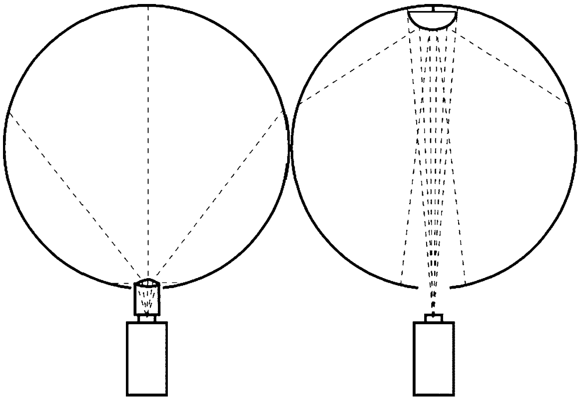

Fig. 12 Inside-projection systems of an OmniGlobe®; *left* fisheye based, *right* mirror based (from Riedl 2012)

In 2005 a tactile hyperglobe was created at the Department of Geography and Regional Research of the University of Vienna, Austria. "Therefore this department is the first European research facility which focused research activities on the visualisation of global topics under the use of spherical displays." (Riedl 2012).

The German Globoccess AG, which closely cooperates with Riedl, offers tactile hyperglobes and the authoring and presentation software for tactile hyperglobes named OmniSuite. Two types are offered: the OmniGlobe®, a spherical display which is based on an inside-projection system (Fig. 12), and the Hyperglobe® with an outside-projection system (Fig. 13). The size of OmniGlobe® globes reaches from 32 to 60 inches, that of Hyperglobe® 80–150 inches. A third possibility—which unfortunately is not yet available—is direct-projection. This could be realised with flexible OLED-Displays (organic light-emitting diodes), but they still need several years of research. With this technique the globe image would have the best image quality with high resolution, no pixel distortion and no shadows of the projection beam, etc. (www.Globoccess; Riedl 2012).

For the sake of completeness, at this point the Dresden globe project is mentioned, since it also deals with a globe, however not a haptic one like those described above (Knust et al. 2012).

5 True-3D in Geophysics and Geology

3D representations are also being increasingly used in Geology. The British Geological Survey developed in cooperation with the INSIGHT Geologische Softwaresysteme GmbH the Subsurface Viewer. With this software 2D geological maps can be created three-dimensionally. The geological models generated in this viewer are a valuable supplement to 2D geological map representations (see Fig. 14).

The single opaque geological layers of the model of Fig. 15 hide much information. To be able to perceive all layers—whether by digital data or in physical material—one has to play with the degree of opacity versus transparency in order to make all subterranean information visible. This will be of benefit for an easier

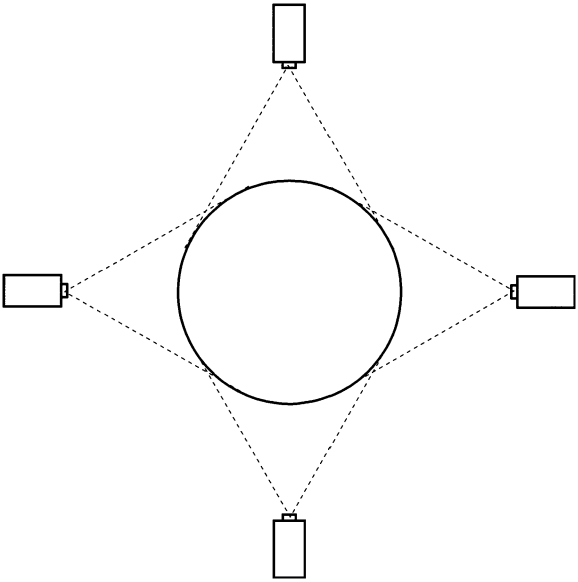

Fig. 13 Top view of an outside-projection system of a Hyperglobe® (from Riedl 2012)

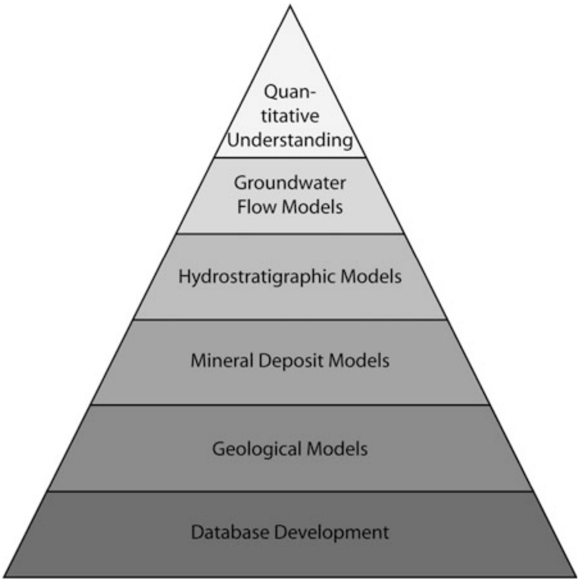

Fig. 14 From geological databases to quantitative understanding (based on Armstrong 2012)

understanding of complex tectono-geological models. It puts, however, high requirements on the production of both planar autostereoscopic and solid 3D models.

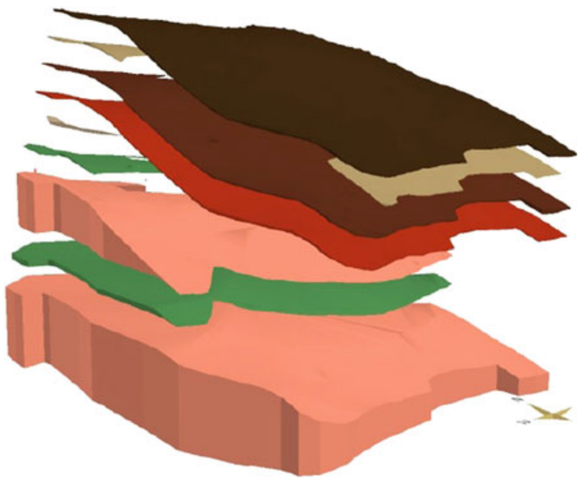

Fig. 15 Geological model split into single, hovering layers (from Armstrong 2012)

6 True-3D for Rural and Urban Landscape Visualisation

Glacier recession is one of the most critical global phenomena in the context of global climate change or global warming. A prominent project using—amongst others—true-3D visualisation methods dealt with glacier recession in the Dachstein Massif in the Eastern Alps of Austria (Bruhm et al. 2012).

The aim was to visualise the changes of the glacier coverage over the last 150 years, taking 1850, 1915 and 2002 as examples (Fig. 16). Historical and recent maps, moraine mappings, a DTM and aerial photographs from 2003 to 2006 served as cartographic data sources. The software packages ERDAS Imagine, ESRI ArcGIS, 3D Visual Nature Studio, Awaron Tucan and Digi-Art 3DZ Extreme V7 were used to generate the depictions of the three time slices. The cartographic results were containing in a range of cross-media products. That means, one and the same dataset was used to generate different visualisations: Several overflight simulations, an animation which shows the changes of the ice thickness, a lenticular foil hardcopy display which uses both the 3D- and the flip-effect and a stereo-overflight for back-projection facilities (Bruhm et al. 2010, 2012). To the authors' knowledge, within this project for the first time cross-media methods have been applied to truly three-dimensional cartographic products. Figure 16 is just a two-dimensional depiction. The original is a lenticular foil map using the flip mode to show the three different states of glacier coverage.

Regarding the three-dimensional visualisation of rural landscapes the well-established and well-tested but basic *anaglyph method* has to be mentioned here. Although it is *not auto-stereoscopic*, it is still frequently used because of its easy application both in terms of data generation for display (free online software) and data observation. An example is the Global Ice Mapping from Space (GLIMS) Project within which—like for the Canadian Rocky Mountains—anaglyphs are used to give stereoscopic impressions (Wheate and Menounos 2012). In this case

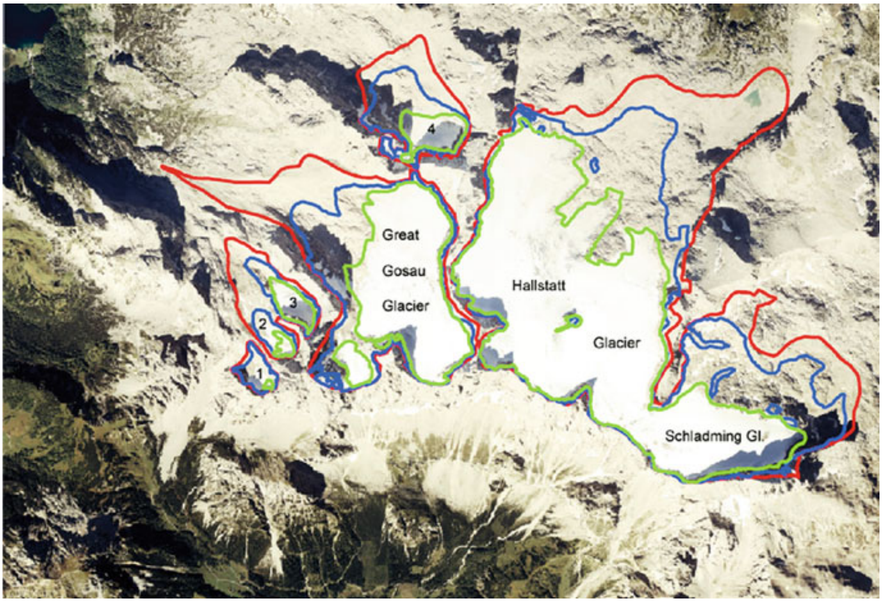

Fig. 16 Orthophoto mosaic of the Dachstein Massif showing selected glacier states. *Red* 1850, *blue* 1915, *green* 2002. 1 Southern Torstein Glacier, 2 Northern Torstein Glacier, 3 Little Gosau Glacier, 4 Schneeloch Glacier (from Bruhm et al. 2012). For further explanation see text

even time slices going back to 1905 were visualised stereoscopically. Besides traditional visualisation methods like hillshading, contouring etc. the aforementioned anaglyph images were also used to visualise surface elevation and glacier changes. Furthermore, stereoscopic perspectives and animations are generated for back-projection facility, a so-called Lab GeoWall (www.WC2N; Wheate and Menounos 2012).

True-3D visualisations of urban x, y, z datasets, so-called 3D city models, are becoming increasingly frequent. Here—like centuries ago—physical models seem to have been the preference of the city planners. In the early years of this millennium Vienna was the first European capital to introduce a haptic city model for planning purposes (see Fig. 17). It comprises 1-square metre plates, capable of being exchanged, as soon as some alteration in the respective city area requires an update of the physical city model.

7 Tactile Maps

Tactile maps are meant for blind or visually impaired people. Instead of visual perception they use their haptic sense to 'read' the maps or other cartographic visualisations (Koch 2001). Weißenburg (ca. 1752) was the first blind person

Fig. 17 City model of Vienna (screenshot from www.3DModell)

known to use tactile maps, his teacher Niessen making these maps for him (www.Kalisch).

Today, there exist traditional tactile media like relief models and tactile globes and new tactile cartographic media like virtual tactile displays, audio-tactile dialogue systems and GPS-supported navigation systems. Geiger (2008) investigated structure and function of tactile cartographic media, as well as the interactions between them.

Tactile maps can be generated fully or at least partially automatically. Technologies for the production of tactile maps are for example *thermoplastic transformation, microcapsule paper and fuser, models, tactile print* and *embossing*. With the audio-tactile dialogue systems, which use a combination of tactile and aural perception for cartographic communication, a fully matured multimedia information system is given to blind people. During recent years new technologies were developed in order to be able to also use the internet. But these technologies are not yet sophisticated enough for practical use. Multimodal dynamic computer interfaces are indicated in future development (Koch 2012).

A recent study at the Department of Geoinformatics and Cartography of the Finnish Geodetic Institute investigated the generation of haptic landscape models with rapid prototyping for visually impaired people and aimed at an operational, largely automated production chain. Input for this project were digital orthophotos and laser scanning data from a LIDAR system. Besides generating a DEM (Digital Elevation Model) and a DSM (Digital Surface Model) additional data like buildings and roads were vectorised. These data were divided into object groups and saved as different vector layers. Afterwards, all vector layers were exported to raster files for further processing. Texture for the geometry model was based on an orthophoto, which was adapted to the needs of visually impaired people. Several objects of the orthophoto like sport fields, buildings and roads were coloured to enhance them. The result was exported to a VRML file and printed on a Contex DESIGNmate CX^{TM} printer which created the 3D model like described in Sect. 3.1 and shown in Fig. 9 (Schwarzbach et al. 2012).

8 Internet-Based Stereo Visualisation

In 2006 a first real-time transmission of various large sets of geodata between a university lecture hall in Dresden and a university 3D cave in the town of Trier, 530 km great circle distance from each other, took place. This can today be realised by any private individual, thanks to adequate Internet connections.

The Spanish company Sigrid S.L. offers e.g. map server software named StereoWebMap. This software is based on OGC WMS standard and offers via internet both vector- and raster-based air campaign data as well as airphotos. Besides orthophotos and anaglyph images for visualisation on a standard monitor rendered stereomates can also be requested. This type of image is meant to be used with special stereo-hardware like stereo-projectors and can be three-dimensionally viewed with the help of polarisation glasses. One possibility is to visualise the two stereomates on two TFT (Thin Film Transistor) displays with identical polarisation, which reflect the images onto a semi-reflective glass in between. Therefore, one stereomate has to be mirrored (Fig. 18). The viewer perceives the stereoscopic impression of the scene by using polarisation glasses (www.StereoWebMap; Sanchez 2012). Thus, this technique cannot be considered autostereoscopic, but with an adequate true-3D display in the near future glasses-free viewing of these geodata provided via Internet will be possible.

Buchroithner et al. (2012) present in their paper several "stereoscopic 3-D hardware and software solutions for creating and displaying online maps and virtual globes (such as Google Earth) in 'true-3D', with costs ranging from almost free to several thousand [sic] pounds sterling." Here, only a few samples will be presented.

To create your own stereo images a free software program named StereoPhoto Maker is available. It acts as both a stereo image editor and viewer. A further function allows the easy change of geographical information in the metadata of the image (www.StereoPhotoMaker). Another freeware stereoscopic browser is the Stereo GE Browser (www.StereoGEBrowser). Using the free Google Earth browser plug-in this browser shows three instances of an image: two windows show the left and right stereomate and the third window visualises the stereo image. The user can choose different stereo methods, such as anaglyphs or side-by-side stereograms and set the stereo-base. An interesting tool is the StereoGIS (www.SimWright) from SimWright Inc., an analysis application. For imagery in a 3D stereo format the user can create, edit or extract two- and three-dimensional data products as well as DEMs from the given imagery (Buchroithner et al. 2012).

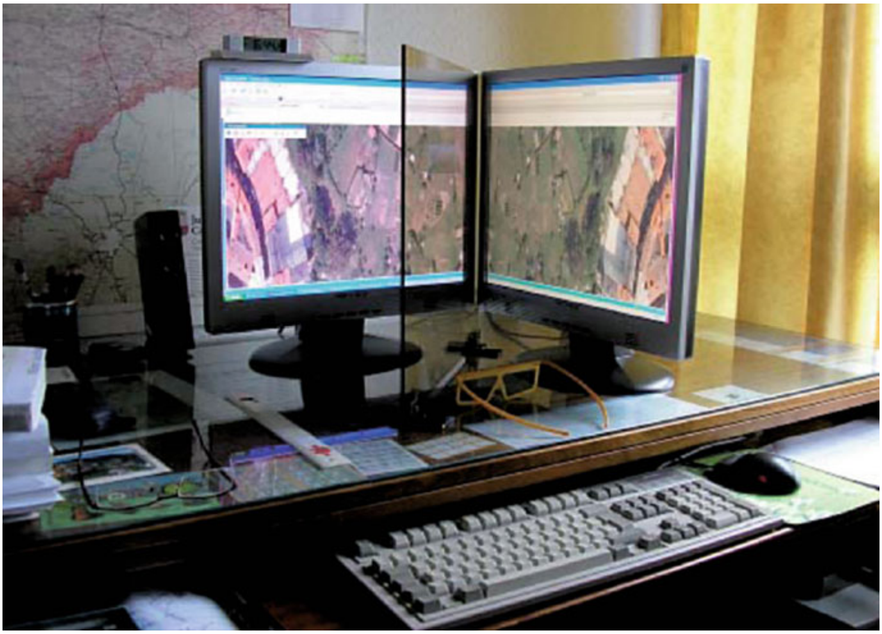

Fig. 18 Mirrored system working with a semi-reflective glass (from Sigrid 2010)

In the USA for the rapid generation of tactile street maps a web-based software tool was developed in the scope of the TMAP (Tactile Maps Automated Production) Project which was initiated by Joshua A. Miele in California in 2003. The user can generate his/her own map by defining the location and size of the final tactile map interactively via web map service. The user either can then print the map him-/herself with a Braille printer or send a request and get it by mail (www.TMAP; Dembski 2009).

9 Holography

Holographic methods allow use of all bi- and monocular depth cues. Since this technology enables the generation of 360° parallax holograms they are considered *full-3D* visualisations. It is one of the techniques with the highest potential for the creation of truly three-dimensional geovisualisations, also including transportable displays.

For holographic visualisations both the intensity of light and the phase information is stored. Therefore, coherent light is required. The wave field which contains the information about the captured object can be completely reconstructed, implying that the viewer sees the object as it has been recorded (Schenkel 1998; Schmid 1999). Holography as such, however, is a very complex technology which, to date, is also very cost-intensive. For further information the reader is referred to Buchroithner and Schenkel (1999), Buchroithner (2000), Buchroithner and Knust (2012), Knust and Buchroithner (2012).

Within the last five years holography has been experiencing a kind of renaissance, at least regarding non-civilian applications. In a mapping unit in Ankara, Turkey, the generation of so-called Holographic Relief Maps (HRMs) has been modified by using standard topographic line map data as well as a DEM and aerial photographs. These HRMs are supposed to combine the advantages of plastic relief maps with the characteristics of holography to enhance spatial perception. Not only the relief, but also the topographic and thematic map contents are spatially depicted as 3D objects (Dalkiran and Özagaç 2012).

10 Recent Developments

In recent years the term "3D" increasingly appears in the media, mostly in connection with TV screens. Leading companies like Philips, Sharp, Panasonic and Samsung informed the public at CeBit 2010 in Hanover, Germany, that they will begin mass-producing small displays, suitable for mobile devices, and predicted that it would not be long before the technology replaces standard mobile displays. 3D television sets have been available since 2010: Samsung, Sony and Panasonic had already announced 3D TV displays in June 2010 (see www.Samsung; www.Sony; www.Panasonic). This was just in time for the FIFA World Cup in South Africa, which ESPN used to kick off the industry's first 3D television network. Others like LG, Philips, Sharp and Toshiba followed soon after (www.LG; www.Philips; www.Sharp; www.Toshiba). However, for the spatial impression provided by these stereoscopic television sets the users need to wear shutter glasses or polarisation glasses, since the two stereomates are visualised on the screen in an alternating way. At IFA 2011 Toshiba presented the first market-ready autostereoscopic TV screen, (blank) featuring Quad HD with a very high resolution of 3840 × 2160 (http://eu.consumer.toshiba.eu/en/products/tv/55ZL2#-productDetailHilights). This progression from stereoscopic to autostereoscopic TV screens is faster than expert expectation. Autostereoscopic monitors have also been enhanced, along with paddles (www.Nintendo), picture frames (www.Jobo) etc.

11 Conclusion

"3D" is ubiquitous in cartography. Even at national level vocational training programmes are currently dealing with this subject (see the recent volume "The Main Problems of Contemporary Cartography" with one more paper "3D in Cartography", Knust and Buchroithner 2010).

The present article is explicitly not meant to elaborate on several "pseudo-3D" methods for dynamic relief modelling which make use of a series of different methods. For the sake of completeness companies like Northrop–Grumman Corp. and TouchTable Inc. (www.NorthropGrumman; www.TouchTable) shall be mentioned. They developed displays which are integrated horizontally on a 'table', even with added interactivity where users can actually manipulate the table and query the data by touching the planar or even relief surface.

Truly three-dimensional hard- and softcopy displays are coming up more and more. They are penetrating various domains of everyday life and scientific disciplines. Cartographers have to be both: "early users" of these new technologies and active contributors to technological developments. In addition, following the "classical definition" of cartography as a science, technology *and* art, manually generated landscape models are experiencing a renaissance. Due to the human attraction to "true-3D"(see Buchroithner and Habermann 2010) its application to geodata visualisation certainly has a bright future.

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