Application of Geovisualisation Techniques in Coastal-zone Management

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SUMMARY

3D landscape visualisation is increasingly used in spatial sciences and planning. Currently available visualisation tools permit creating highly realistic representations of landscapes based on geodata, such as digital elevation models, aerial photographs, or remote-sensing data. However, in contrast to traditional 2D representations, photorealistic 3D landscape visualisations offer a higher degree of visual clarity, thus contributing to a better understanding of spatial structures and processes and promoting visual thinking. Photorealistic landscape visualisations can be generated with the aid of either pure landscape-rendering systems, which usually do not support interactivity, or real-time visualisation environments. This paper presents selected examples of 3D and 4D landscape visualisations and discusses the properties and applications of a 3D real-time visualisation environment developed at the Department of Physical Geography of Kiel CAU.

1 INTRODUCTION

Methods to visualise landscapes and landscape processes in three dimensions are increasingly used in regional planning. Based on a steadily growing volume of geodata with a high degree of geometrical resolution, such as digital elevation models, topographical data, and aerial or satellite images (see the numerous examples given in Traub, 2006), today's visualisation environments are capable of rendering landscapes in three dimensions with a photorealistic effect (Fig. 1). Compared to

Figure 1: Landscape visualisation of the flood barrage of Eiderstedt (Germany).

conventional two-dimensional maps, these visualisations are more illustrative, enabling the information contained in maps and plans, which is generally abstract and difficult to interpret for non-experts, to be communicated in a format that is more easily understood (Lange, 2001). 3D landscape visualisations are of particular interest in the context of integrated coastal-zone management which aims for general public participation to gain acceptance for future protection, preservation, and development measures in coastal zones at an early time.

2 LANDSCAPE VISUALISATION – WHAT FOR?

Landscape visualisation is a branch of geovisualisation, a new research discipline that has been gradually establishing itself in the spatial sciences since the 1990s. Following the definition of Mac Eachren and Kraak (Mac Eachren, 2001), geovisualisation as an interdisciplinary field integrates "methodological and technical approaches from ViSC (visualisation in scientific computing), cartography, image processing, information visualisation, explorative data analysis, and geographical information systems in order to provide theoretical approaches, methods, and tools for exploring, analysing, synthesising, and presenting geodata" (Fuhrmann, 2001, p. 173). Accordingly, realistically representing (known) landscape structures, processes, and interactions for presentation purposes is not the sole objective of landscape visualisation as we know it today. Rather, it also aims to develop new insights from, for example, the analysis of spatial distributions, patterns, and developments in inaccessible landscapes (high mountain ranges, arctic regions, rainforests) e.g. by integrating spectral aerial photographs, satellite data, and elevation models generated from stereo data (cf. Bolch, 2003). It also contributes to visibility analyses in three-dimensional spatial representations and observations of relief-dependent phenomena such as diurnal insolation and shading, the duration of insolation, or the identification of areas inundated at various flood levels (cf. Huber, 2003; Buziek, 2000). From the point of view of geography, 3D landscape visualisation appears particularly valuable because it serves to

- improve spatial visualisation by providing realistic three-dimensional representations of landscapes, landscape structures, and processes (see Kääb et al., 2003);
- illustrate abstract information contained in two-dimensional maps through realistic images of landscapes and landscape objects;
- support planning decisions by visualising planned interventions and their impact on the appearance of the landscape (see Buhmann et al., 2002);
- reconstruct the historic development of landscapes and vegetations (see Fuest, 2003;);
- visualise landscape permutations (see Lange, 2001; Buhmann, 2002; Dunbar, 2003);
- prepare excursions with the aid of virtual landscapes (see Glässer, 2004); and
- visualise landscapes in three and four dimensions for schools, museums, and tourism.

3 PRINCIPLES OF LANDSCAPE VISUALISATION

The development of powerful visualisation environments permits generating impressive photorealistic landscape representations today (see www.3DNWorld.com/gallery.php). Because of the high degree of vividness obtainable, complex (geo)spatial information, phenomena, and interactions may be communicated visually in a simple manner. Thus, landscape visualisation acts as a communication tool in planning processes, for instance. On the other hand, it may also be used to manipulate perceptions and influence decisions (Daniel, 1999; Sheppard, 1999, 2001). Thus, Sheppard (Sheppard, 1999, p. 28) pointed out that virtual-reality images may have a suggestive effect because their "technical refinement and realism [make it] more and more difficult to identify erroneous or arbitrary elements in a representation", and because the extreme realism of such visualisations may camouflage a lack of properly edited landscape data. In view of the lack of generally-accepted standards for the generation and utilisation of landscape visualisations, Sheppard (Sheppard, 2001, 2003) proposed the following code of ethics for landscape visualisation:

1. Representativeness: Visualisations should show characteristic or important views, landmarks, and outstanding elements of a landscape.

2. Accuracy: Visualisations should reflect either the real appearance of a landscape or simulate its expected appearance as realistically as possible. Landscape visualisations should truthfully reflect the data available at the time of their generation.

3. Visual clarity: The details, components, and overall impression of a landscape should be clearly distinguishable in its visualisation.

4. Interest: Visualisations should increase and engage the viewers' interest without 'dazzling' them.

5. Legitimacy: Visualisations should be verifiable and conform to a consistent, well-documented method, which should include information for the viewer about the simulation process used, the assumptions on which the visualisation is based, the expected degree of accuracy, and any uncertainties inherent in the representation.

4 3D/4D VISUALISATION METHODS FOR COASTAL LANDSCAPES

The value of 'pure' landscape visualisations in either 3D or 4D is limited if they do not feature any additional analytical or interactive functionalities besides visual presentation. To enhance the analytical value of visualisation environments, 3D real-time visualisation systems increasingly feature volume computation, relief modelling, profile-section generation, visibility analysis, and other options as well as interactive functions that permit users to insert, move, remove, and change objects, modify view parameters, or query thematic and geometrical attributes. This also holds true for numerous GIS products and auxiliaries such as, for example, 3D Analyst (ESRI), Imagine VirtualGIS (ERDAS), Geomedia Terrain (Intergraph) (cf. Zlatanova, 2002), and GRASS GIS (www.grass.itc.it). Next to 3D visualisation, all these systems feature a more or less wide range of 3D analysis functions. According to Jünemann et al., however (Jünemann, 2001, p. 203), most available GIS products "do not satisfy the aesthetic expectations which relevant players tend to place in realistic landscape visualisations, and the 3D/4D support they offer is inadequate". Compared to 3D CAD software systems, such as 3D Studio Max and Maya (Autodesk) or ArchiCAD (Graphisoft), and 3D landscape visualisation systems, such as Visual Nature Studio (VNS), World Construction Set (WCS) (3D Nature), and Virtual Terrain Project (VTP), the visualisation results that can be achieved with conventional geographical information systems at the moment do not constitute genuine alternatives for the generation of realistic, i.e. photorealistic landscape images. To satisfy sophisticated demands, 2D and 3D data/objects – georeferences and attributes included – are normally preprocessed under GIS and exported for downstream processing to 3D visualisation environments (cf. Coors, 2005; Lange, 2001). Jude et al. (Jude, 2005) described an interesting approach by which a so-called virtual-reality GIS (VRGIS) might be developed from GIS. Referring to the concrete application of VRGIS in coastal-zone management, they stated that

	WCS 6.6	VNS 2.75	Terragen 0.9.43	Terragen 2	Forester (POV-Ray)	ArcGIS 9.1 3D Analyst	VTP	a3Dc
Usage / learning curve	-	-	++	?	-	0	-	- -
Interface for programming language	n	n	n	n	-	++	n*	++
Skriptlanguage	n	n	-	-	-	++	n	n
import of vectordata (2D+3D)	++	++	n	n	- -	0	+	+
import of attributedata	n	++	n	n	n	++	+	+
Mapprojections	n	++	n	n	n	++	++	n
Database-Connection (attributedata)	n	0**	n	n	n	++	n	n**
Database-Connection (geometry)	0**	0**	n	n	n	++	n	n**
layermanagement	0	0	n	0	+	++	+	++
rasterdata import	++	++	0*	0	0	++	+	+
grouping for mass-editing	+	+	n	n	n	0	+	++
3D realtime view	+/++*	+/++*	+	+	0	+	++	++
Querry attributedata	n	+	n	n	n	++	n	+
vector-aligned distribution of geoobjects	++	++	n	n	n	+	0	+
positioning of single objects	++	++	n	+	0	+	+	++
animation of „geoobjects“	++	++	n	n	n	n	n	++
geometrie-morphing	0	0	0	0	n	n	n	n***
construction of geoobjects	-	-	n	n	n	- -	0	n
3D text	+	+	n	0	?	0	n	++
profile generation / clipping	+	+	n	n	n	+	n	n***
vector-aligned texturing	++	++	n	n	n	- -	0	0
bump-mapping	++	++	+	+	0	n	0	n
billboard-support	++	++	n	0	n	0	+	++
placing of mass-objects [e.g.plants]	++	++	n	0	n	n	0	0
fuzzyness between different surface-textures	++	++	++	++	n	n	n	n
procedural textur generation	++	++	+	+	0	-	0	n
support for image-textures	++	++	+	+	0	0	0	+
mipmapping ("Textur LOD")	++	++	n	?	?	n	?	++
Level of Detail (LOD)	++	++	n	?	n	+	++	n***
generating random patterns for object placements	++	++	+	0	n	n	n	+
Abilities of interaction in the final product	n/+*	n/+*	n	n	n	+	++	++
stereo-view	+	+	0*	0	n	n	n	n
dataanalysis	-	-	n	n	n	++	n	-/+***
Internet-/Intranet abilities	n	n	n	n	n	n	n	++
Microsoft	✓	✓	✓	✓	✓	✓	✓	✓
Unix/Linux	☒	☒	☒	☒	☒	☒	✓	✓
Mac OS	✓	✓	✓	✓	☒	☒	☒	✓
Price in Euro (12-2006)	~500	~2450	~100	?	~30	On demand	0	n.a.

- -	Hard	✓	Supported	+	Easy	**	Only internal database
-	Limited	☒	Not supported	++	Very good	***	In process
0	possible	*	with Extension or Extra-software bundle	n	Not possible	?	No Information

Table 1: Selected software systems for 3D landscape visualisation. The table does not include 3D CAD systems such as 3dsMax or ArchiCAD, which would serve equally well for purposes of landscape visualisation.

> *"the recent development of VRGIS provides an opportunity to further develop public involvement in coastal zone management by providing the functionality to produce realistic virtual reality visualisations of different shoreline management outcomes. This may prove to be a significant advance on traditional technologies"* (Jude, 2005, p. 97).

In the following, two sample visualisation environments will be presented that feature different capabilities to display images, integrate 3D objects, animate dynamic objects, and interact with the virtual landscape on display. The first is Visual Nature Studio 2.75 (VNS), a ray tracer system specifically designed to generate photorealistic landscape stills as well as animations based on geodata records. The other is a Java-based 3D real-time environment that permits exploring landscapes interactively. One major difference between ray tracer systems and 3D real-time environments lies in the quality of the graphic display and, by the same token, in the computing time required. Thus, ray tracer systems need anywhere between a few seconds and a number of hours to generate a high-quality photorealistic image, depending on the complexity of its content. A 3D real-time system, on the other hand, must generate 15 or more images per second to give the viewer an impression of continuous, i.e. instantaneous movement. As available computing times are much shorter, the quality of photorealistic images generated in a 3D real-time environment is markedly inferior to that of ray tracer systems. The great advantage of 3D real-time environments lies in their direct interaction capability which permits users to navigate freely through the virtual landscape displayed with the aid of an input device (mouse, keyboard, trackball, etc.). Whatever technology you may choose, the objective is to generate a visualisation which realistically reflects the characteristics of the landscape displayed. The actual choice of visualisation model will depend on the purpose of the visualisation, the quality and resolution of the data, and the amount of interaction desired.

5 APPLICATION OF VNS FOR COASTAL ZONE MANAGEMENT

Visual Nature Studio (3D Nature) is a 3D visualisation software that may be used to display landscapes on any scale. It permits importing a large variety of geocoded and graphic vector and raster data formats. VNS generates images of individual geo-objects and visualises their change over time. The virtual landscape to be displayed is modelled from pre-defined components grouped under specific headings (see Fig. 3). These can be described very loosely as the (building) elements that constitute a landscape. They incorporate attributive descriptions of the landscape objects to be visualised virtually (such as vegetation, terrain surfaces, and bodies of water), the geometries (2D vectors and 3D models) of the objects to be displayed (Fig. 2), and parameters describing atmospheric effects (e.g. shading, illumination, clouds, and haze). Within these components, nearly every parameter can be defined and animated freely. In this way, dynamic processes may be simulated.

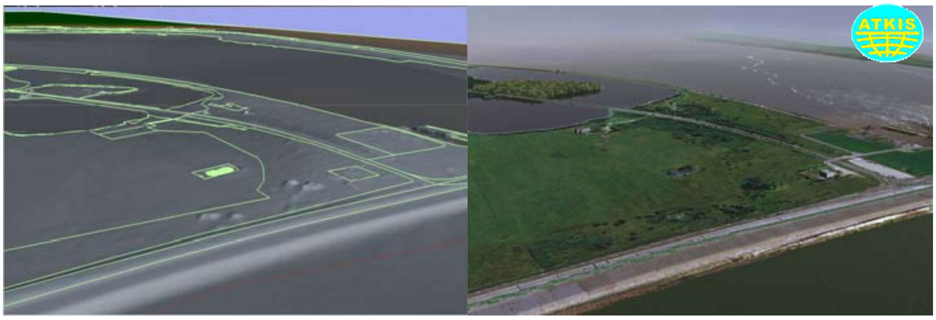

Figure 2: VNS model of a coastal landscape. Left: Imported ATKIS* vectors on the west coast of Eiderstedt. Right: The image generated from these vectors with integrated objects

**ATKIS: Official Topographic vectordata from the State Office of Survey(Landesvermessungsamt SH)*

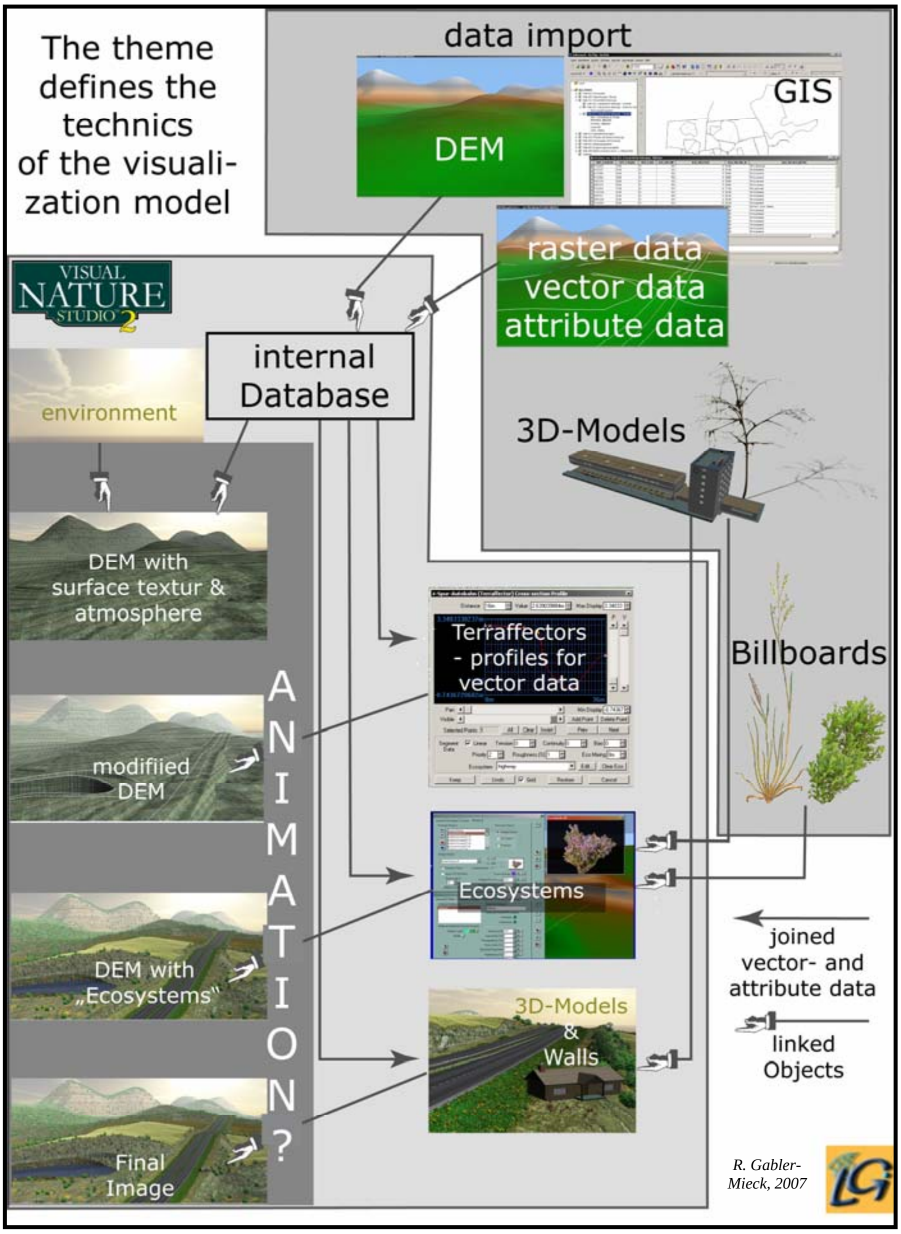

***Figure 3**:* Outline of the landscape visualisation process using VNS.

Images of a virtual landscape created with VNS are based on a digital elevation model (DEM) with the maximum possible resolution. Using so-called 'Terraffectors', this model may be modified (Fig. 4) by using profile information and available two-dimensional geodata records (e.g. ATKIS) to generate linear and polygonal landscape elements, such as roadways and watercourses, which the original elevation model does not contain, as well as other features such as dykes, which it does not show in

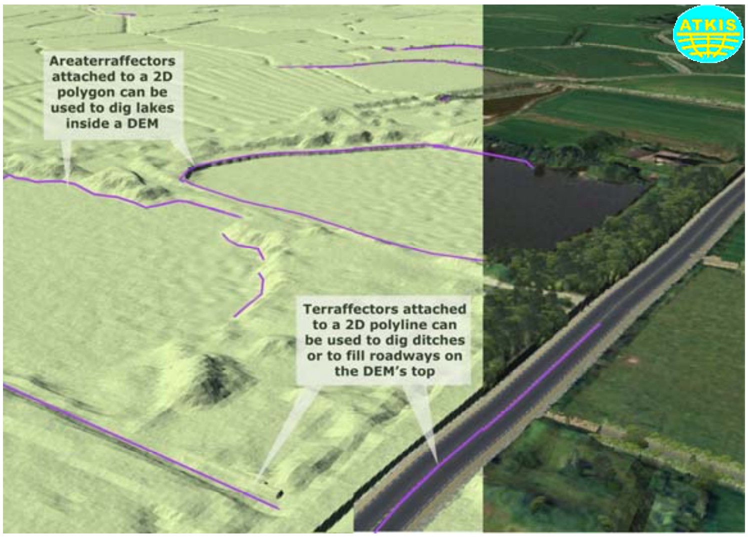

Figure 4: Terraffector function: Modification of a DEM with the aid of 2D ATKIS geometries.

the necessary detail. In the latter case, more precise geometrical information about the profile of the dyke in question will be required to modify the elevation model. Such profile information can be integrated into the DEM with the aid of a Terraffector component.The 'walls' modification component permits assigning height and texture to two-dimensional vector data to generate fences, walls, and hedgerows (Fig. 5). By adding roof texture information, the same component may be used to construct simple buildings ('brick models'). To generate more complex building models, it makes better sense to use a 3D CAD program and import its 3D models into the VNS. VNS shines not so much in the construction of geometries but in the many and varied options it offers of visualising a landscape photorealistically in three and four dimensions.

Figure 5: Using the walls component to construct geo-objects (St.Peter-Ording, Germany).

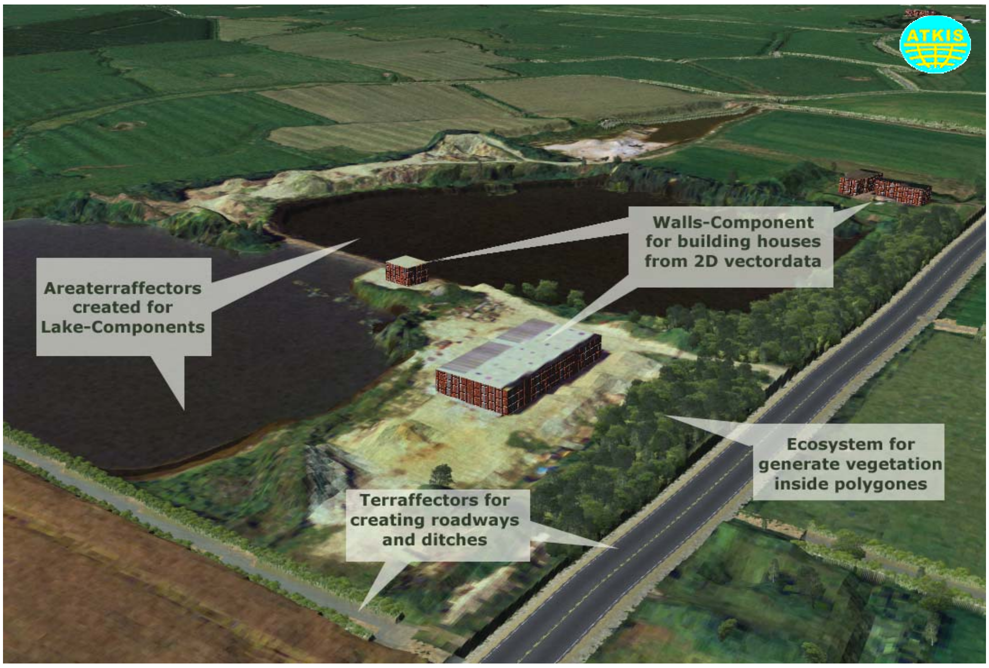

Figure 6: Terrain model with its various components.

Various approaches may be used to generate a plant cover, ranging from random distribution to the concrete positioning of individual plants by specifying coordinates. In most cases, vegetation is distributed by so-called 'ecosystem components' (Fig. 6). Using the database integrated in VNS, individual ecosystem components can be associated with vector objects of any kind via their attributes. Population densities as well as the height of individual objects may be defined either by variable parameters or by attributes derived from relational databases. These parameters may be animated at will. In most cases, so-called billboards are used to represent plants. Billboards are raster graphics that always turn in the direction of the viewer, creating a three-dimensional impression. Unlike 'genuine' 3D plant models, however, billboards cannot generate adequate shadow effects. On the other hand, the memory space required by billboards is many times smaller than that of 3D models, which is why it makes sense to use this technology to visualise large landscape segments.

The ability to change various object properties over time permits visualising scenarios that answer questions such as 'What if …?' or 'What did things look like at the time?', provided that the requisite data and records are available. It is a fact that, generally speaking, anything that can be represented in three dimensions can be visualised by Visual Nature Studio, independently of whether the result is supposed to be photorealistic or more abstract. Next to outstanding options to generate photorealistic environments from geodata, 3D models, and billboards extracted from photographies, VNS generates animations of atmospheric effects and highly realistic representations of moving water surfaces. A landscape modelled in VNS can be interactively explored in real time with the aid of 'SceneExpress' (3D Nature), a commercial VNS extension program.

6 APPLICATION OF A 3D REAL-TIME ENVIRONMENT – THE a3Dc EXAMPLE

a3Dc is, an interactive 3D real-time visualisation environment, it is realised under Java and its extension, Java 3D. The concept of this visualisation environment evolved from a software developed by Gabler (Gabler, 2002) to visualise interactively the 3D model of the city of Hamburg (DSGK-3D). The system, which has since been developed further, permits creating images of landscapes of any kind in three and four dimensions, together with the objects contained in them. In addition, it provides a multitude of interaction options that permit unrestricted navigation through the space displayed, querying thematic information, and positioning and animating objects.

At its present level of development, a3Dc permits superimposing maps, orthophotos, and/or rectified satellite images on digital terrain models and permits viewers to move through the virtual landscape thus generated, using a keyboard and/or navigation buttons. Further thematic layers may be added with the aid of a layer manager. Discretionary combinations of so-called layer objects may be assigned to each of these layers. Layer objects (see Fig. 7) may be

- 3D models in VRML97, OBJ, or 3DS format;
- 2D raster graphics in JPG, GIF, or PNG format;
- image data for 2.5D objects ('billboards') in GIF or PNG format;
- DGM-congruent maps in JPG, GIF, or PNG format; or
- 3D texts from ASCII text files.

The position and size of layer objects may be modified individually with the aid of freely-definable transformation parameters. 3D texts may be additionally enhanced by RGB colour data. Individual objects rendered in the form of billboards can be assigned in specific dimension (height and width) or an average value that will then be modified by a randomising function. The latter method produces more realistic images of the objects being represented such as, for instance, tree height and size variations in areas of contiguous vegetation. Each raster graphic loaded is processed by a 'mipmapping' algorithm which scales objects according to their distance, thus considerably reducing the computing time of the graphics card.

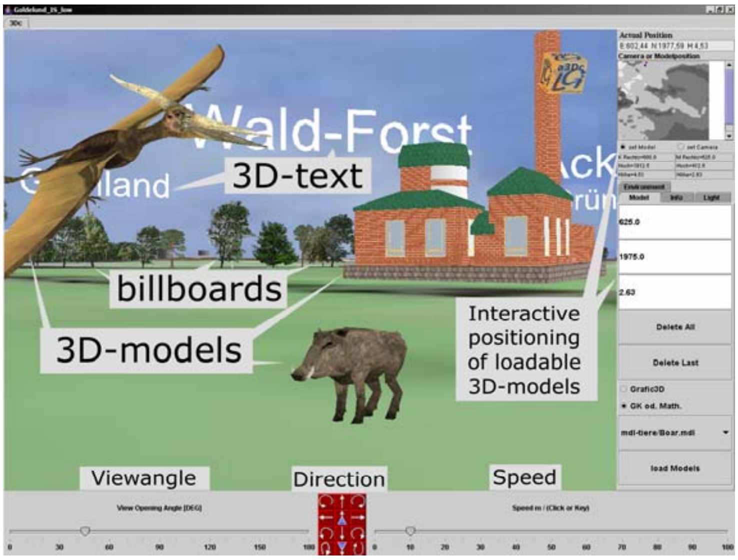

Figure 7: a3Dc interface with representations of layer objects.

Figure 8: Various thematic applications of a3Dc on the island of Föhr. Generated from ALK data, the image on the left shows the town of Wyk on Föhr. The bottom right-hand illustration shows a3Dc being used as an information system in tourism together with the requisite navigation and query options. The top right-hand image shows a typical application of the visualisation environment for visibility analyses within the framework of repowering plans. Visualisations are based on ATKIS, ALK*, and DEM data provided by the Schleswig-Holstein land survey office, supplemented by the authors' own images and 3D models.

**ALK: official german vectordata of landed property from the State Office of Survey(Landesvermessungsamt SH)*

Each layer object may be assigned one or more of the following action options:

- **Link to HTML file:** When you click on a layer object, an HTML file that is linked to it will be displayed by an integrated HTML browser so that additional text and/or image information can be shown.
- **Show object data records:** When you click on a layer object, an object data record previously assigned to it will be extracted from a table and shown in a text field.
- **Initiate transformation:** Individual layer objects can be identified as 'activators'. If you click on such an object, a predefined affine 3D transformation will be initiated in other layer objects that function as 'reactors' (e.g. scaling a detail to facilitate viewing).
- **Animate layer objects:** Each layer object may be assigned a predefined animation path along which it moves through the scenery within a predefined period of time.
- **Move layer objects:** Layer objects thus defined may be moved within the scenery in all directions, using a mouse.

Visualisation projects generated with a3Dc are described in quasi-XML ASCII text files, paving the way for plans to upgrade the software into a web service for more general use. The 3Dc Swing Applet enables the visualisation project to be used both locally and via the internet as a stand-alone system. The uses to which a3Dc may be put in coastal-zone management are many and varied, ranging from the generation of virtual coast exploration trails for tourism and museums to using this visualisation environment to support decisions in landscape planning and shore protection. In addition, its capability to generate dynamic animations enables the system to simulate and visualise spatial and temporal changes in the landscape displayed, such as coastline modifications within a defined period of time or the potential effects of storm tides of different water levels.

One concrete example of an a3Dc application that should be quoted in this context is what is called repowering, a scheme to replace the wind power plants that are operating today by more powerful and considerably higher systems. The resultant effects on the appearance of the landscape may be judged in advance with the aid of interactive visibility analyses (Fig. 8). In a3Dc, the viewer may choose his position freely, and atmospheric and visibility conditions may be modified so that the objects planned may be viewed quasi-realistically from various distances and angles. This is feasible only, however, if the height of any objects in the line of sight is known, or if a digital surface model (DSM) is available. Visualisations may be stored as JPG raster graphics, so that the optical effect of diverse planning variants may be documented from different points of view.

7 OUTLOOK – THE FURTHER DEVELOPMENT OF a3Dc

Next to integrating additional features, such as geometry morphing to simulate dynamic processes in space, it is planned to extend the analytical functionalities of a3Dc step by step. The focus will be on query and filter routines with which any combination of objects at the various levels of information may be selected, marked, and classified. Current development activities are concerned with the dynamic simulation and visualisation of landscape processes, one case in point being the three-dimensional simulation of wind fields as a basis for optimising the protection of agricultural land threatened by wind erosion. Within the framework of scenarios in which wind obstacles (e.g. rows of trees, breaks, buildings) will be placed interactively in a virtual 3D landscape, a3Dc will be used to develop concrete proposals for wind-protection planning and implement methods to generate and visualise 3D surface landscape models from measurement data.

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URL

3DNWorld Gallery: http://www.3dnworld.com/gallery.php

VTP Virtual Terrain Project: www.VTerrain.org

Autodesk: www.autodesk.com

3D Nature: www.3dnature.com