3D MODELLING AND VISUALIZATION FOR LANDSCAPE SIMULATION

Davis Dinkov, Rumiana Vatseva

Eng. Davis Dinkov
Cartographic Studio DavGEO
139,Tsar Boris III Blvd, Sofia, Bulgaria
e-mail: davis.dinkov@gmail.com

Prof. Rumiana Vatseva, D.Sc.
National Institute of Geophysics, Geodesy and Geography
Bulgarian Academy of Sciences
Acad. G. Bonchev Str., Bl. 3, 1113 Sofia, Bulgaria
Tel.: +3592 9793370; e-mail: rvatseva@gmail.com

Abstract
Building three-dimensional (3D) models and photorealistic visualizations of environment is important in many applications ranging from virtual representation of landscape to analysis and monitoring of land cover/use, as well as landscape management and planning. The aim of 3D modelling of landscape is to produce according to the user needs sufficiently reliable and accurate digital three-dimensional model of the earth's surface that can be visualized dynamically through selected software or can be used to produce static cartographic or presentation products. Basic data in 3D modelling includes GIS datasets for relief, land cover, hydrography, buildings, roads and tourist infrastructure, as well as remote sensing data such as satellite and orthophoto images, Radar, LiDAR, etc. The first step is to generate a 3D model of terrain using remote sensing data, next is to prepare the basic data for landscape simulation (geology, soil, vegetation, hydrography, etc.). Depending on the type of visualization of 3D models (dynamic or static) the needed software for presentation is used. One of the advanced results is the flight simulation at selected height above ground for landscape observation. Presented applications of developed 3D models and photorealistic visualizations are case studies of national park, Natura 2000 site and tourist resorts in Bulgaria.

Keywords*: 3D modelling, 3D map, 3D visualization, GIS, landscape simulation*

INTRODUCTION

Today, the rapid development of information technologies (hardware and software) allow the creation of a virtual world that provide new possibilities for interactive communication, orientation and environmental management and monitoring. 3D landscape modelling and visualization facilitate an attractive representation of environment by generation of perspective views based on different types of digital data - geographical, geological, architectural, biological, etc. In addition, the availability of geospatial data sets is increasing rapidly including all their aspects, such as geographic coverage, spatial and temporal resolution, thematic content, format (both raster and vector) and accuracy. Furthermore, the technological advancements improve capabilities for data capturing, storage, management and presentation in three dimensional space.

Recently, precise landscape modelling and mapping make available the development of many different applications that are designed for the creation of 3D maps and visualizations. An advanced technique is applied in landscape visualization, such as multi-perspective views for interactive visualization and 3D panoramic maps. As 3D maps offer a better perception and understanding of landscape spatial relationships, they are very suitable for tourist applications, scientific presentations, regional planning and management.

During the last decade, researchers discussed and proposed cartographic standards, design principles and visualization techniques to further increase the effectiveness and expressiveness of 3D landscape modelling and mapping. The most basic term *3D map* is defined by Haeberling (2002, 2005) as a computer generated perspective view (representation) of a three-dimensional integrated geodata model with cartographic content, i.e., in accordance with cartographic symbolisation and generalization conventions. Considerable research has been done in connection with cartographic design principles, acquisition and realistic visualization of 3D geodata, interactive communication and user-oriented maps (Haeberling, 2005; Haeberling et al., 2008; Pegg, 2012; Bandrova et al., 2012; Semmo et al., 2015). Today 3D modelling and mapping represent key components to a growing number of diverse applications and have varied range of users for such purposes as city planning, landscape monitoring, utility and transportation management, tourist maps, and 3D mapping services.

In this paper, the static 3D perspective views are presented as they reflect in the highest level of detail the real world and may be used for environmental monitoring or for creating 3D panoramic maps. Different visualization techniques are illustrated for basic landscape elements, e.g., vegetation, rocks, sand, water, etc., as well as 3D symbols for buildings, trees, sport and leisure facilities, etc.

3D MODELLING AND MAPPING PROCESS

3D mapping includes four general process steps *concept, modelling, symbolization and visualization* (Figure 1) that have an impact on the final quality of the map and running through iteratively (Haeberling, 2005).

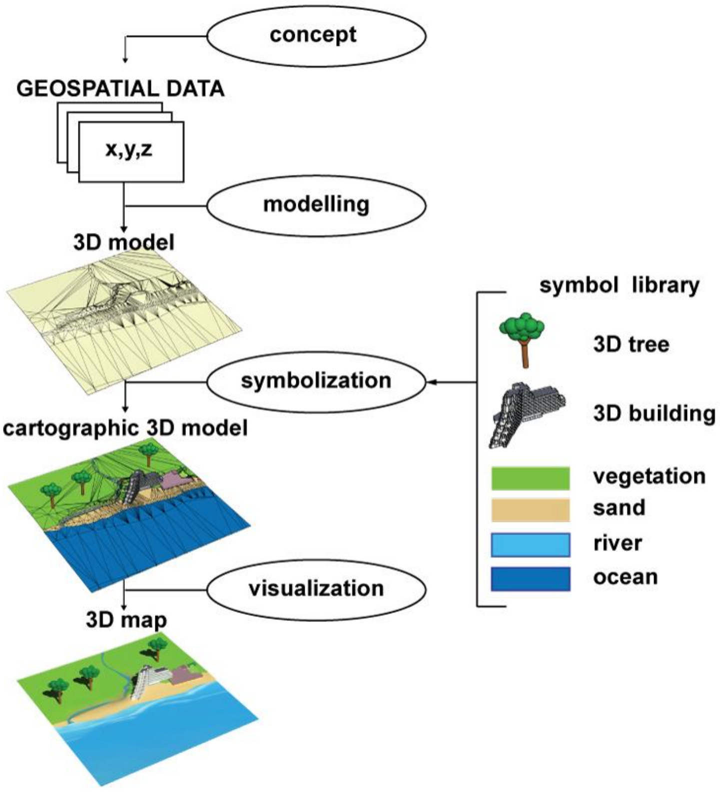

Figure 1. Schematic 3D landscape mapping process (modified, Source: Terribilini, 2001)

In the *conceptual* phase, the user context and the product specifications had to be defined. Thus, choosing the map type is depended on knowledge and experience of users, possible future users and the necessary geospatial data.

The *modelling* step contains the processing of original thematic data sets (both raster and vector data) including transformations of data format and structure, objects geometry and semantics. From the original geospatial data a complex structured 3D landscape model is created that allows to investigate in details the landscape as a static model, as well as to implement dynamic and interactive functionalities.

The *symbolization* step involves adding the graphic attributes to the single objects of the 3D landscape model. Thus, the graphic appearance of each object class is defined as in the legend construction for classic maps, and cartographic generalization rules are considered. It should be noted that the construction of legend does not affect the graphic appearance of the objects when they are attributed graphically. Thereby, the landscape model is transformed into a cartographic 3D model.

In the last *visualization* step the cartographic 3D model is displayed perspective on the designated media. Cameras are used to setup a viewing position or moving viewpoint path. The final rendering process transforms the cartographic 3D model into a 3D map with projection parameters and simulation of lighting and shading effects in order to obtain a photorealistic image. Rendering includes set-up of parameters of the final image (e.g. size, resolution) and parameters of the output file format.

In this study, 3D landscape models were created and visualized by applying the four process steps mentioned above using the professional 3D GIS software VNS (Visual Nature Studio) (3D Nature, 2008). VNS allows to model the real world in very high level of details and facilitates an attractive representation of environment by generation of 3D models and realistic visualization. 3D modelling and visualization are performed in VNS by several main structural elements (Figure 2) as follows:

1. *Terrain* – import a Digital Elevation Model (DEM). A DEM file is a grid of elevation points taken across a landscape at regular intervals, via satellite, aerial photography or by surveyors on the ground. The terrain surface can be modelled also based on imported vector data or a surface created in an external application (Arc ASCII Array, Arc Grid, Arc Export Grid, ASCII Array, DTED, DXF, GTOPO30, Images: BMP, IFF, PICT, Targa, JPEG, PNG, TIFF, ECW.
2. *Land cover* – import vector data. The cartographer can edit polygons by adding details and roughness to make the terrain look more natural. Then can be applied foliage and ground texturing to that landscape using groups of Ground Effects, Ecosystems, and Environments – groups of Ecosystems.
   a. Ground – Ground Effect forms the ground beneath everything else.Ground Effect places materials on the terrain. The Ground overlay is a color or texture that is rendered on terrain polygons.
   b. The Ecosystems can include things like dirt textures, rock textures, strata, grass, shrubs, deciduous trees, conifer trees, palm trees, cacti and even 3D Objects such as boulders.It is possible also to have separate Ground texturing with satellite imagery, strata, photographic texturing of dirt, rock or fallen leaves, procedural textures to simulate ground detail or other texturing. Ecosystems are used to cover terrain with everything from a base level of detritus (Ground overlay) to undergrowth (Understorey), and full-blown trees (Overstorey).
   c. Environments - Environments control the render order of unbounded Ecosystems. An unbounded Ecosystem must be part of an Environment to render. In its common form a single Environment is global and unbounded. Complex models may contain several vector-bounded Environments. Many more than two Ecosystems can be combined in one Environment. Arranging their order in the Environment list and adjusting the Rules of Nature can achieve quite complex and realistic spatial arrangements.
   d. Snow - Snow covers Ecosystems (Material Ground Overlay) and Ground Effects. Ecosystem foliage is not affected. Snow covers ground wherever it exists and the Snow transparency is less than 100%. Transparencies between 0% and 100% create a blend of colors between the snow and either Ecosystem or Ground, whichever would render if there were no Snow.
3. *Thematic vector data* - import or digitize Vectors to show thematic data like rivers or political boundaries.Vectors are geographically referenced points connected by straight-line segments. The shape of the terrain may be changed by applying Terraffectors™(VNS modul) to Vectors. Vectors may place individual trees or entire forests. Trees can be 3D Objects, 3D-shaded Image Objects or animated Image Object sequences. Vectors can also be used to place roads, lakes, streams, snow, areas where shadows are cast, and individual 3D Objects.
4. *Environment* - simulates sunlight to shade the terrain and foliage, and creates a gradient sky; allows to apply atmospheric effects like haze, fog and sunbeams; add multiple levels of clouds to the sky; and animate the sun, moon and stars.
5. *Cameras* - Cameras are the device used to setup a viewing position or moving viewpoint path. Cameras contain settings that often mimic properties of a real camera rig (not just the camera itself): Position, Orientation, Lens/Zoom, Targeting, Terrain-following, Stereo, Panoramic. Cameras contain some settings that have no clear real-world analog: Floating, Orthographic, Projection.
6. *Rendering* - transform the cartographic 3D model into a 3D image with projection parameters and simulation of lighting and shading effects in order to obtain a photorealistic image. VNS is geo-referenced and includes an internal calculator to position the sun by local solar time related to the latitude and longitude of the DEM. A program algorithm uses the latitude and longitude of the DEM to compute the azimuth and altitude of the sun and translates that to the Latitude and Longitude of the overhead sun position. Rendering includes set-up of parameters of the final image and the output file format.

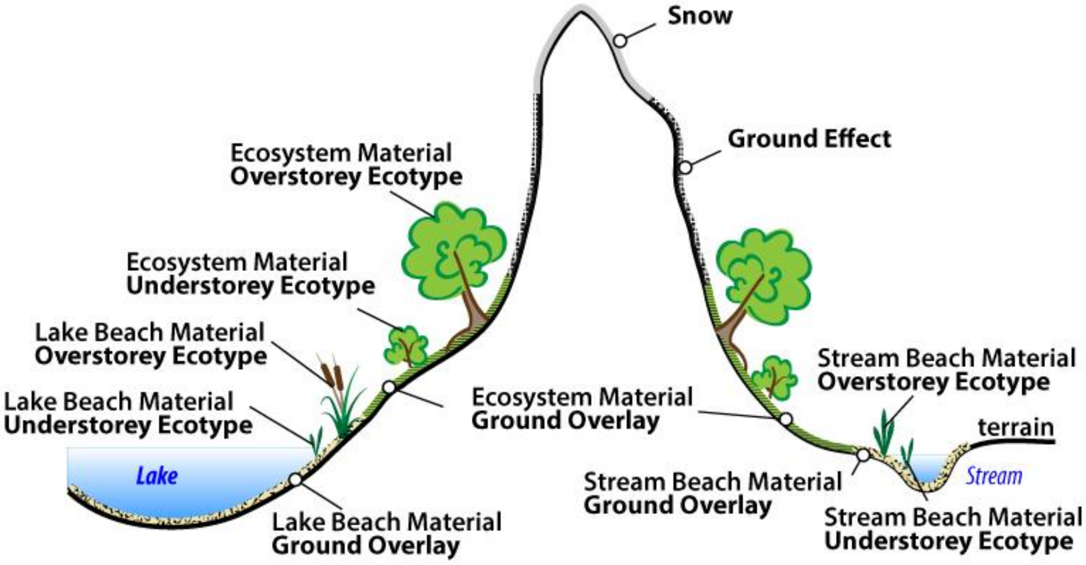

Figure 2. Main structural elements for 3D modelling and visualization in VNS (Visual Nature Studio) (modified, Source: 3D Nature, 2008)

3D LANDSCAPE MODELLING AND VISUALIZATION

3D panoramic map of Albena Black Sea resort

Figure 3. 3D model of Albena Black Sea resort

Modelling and visualization of tourist complexes requires cartographic representation of the environment, infrastructure and recreation facilities, sport and leisure facilities. The coverage of such maps is usually about 10 km^2, which allows to design a 3D model with very high precision and details. In this study we present the main stages of producing a 3D panoramic map of Albena Black Sea resort in Bulgaria with VNS software.

Preliminary work and input data

For the creation of 3D model of Albena resort (Figure 3) were used digital data from large-scale topographic (cadastral) plan in scale 1:1000 in AutoCAD DXF digital format (Fugire 4). For updating and completing the information the field

GPS data was acquired. The obtained geo-referenced data from cadastral plan and GPS measurements were processed in GIS environment and geodatabase was developed with vector layers for relief, hydrography, infrastructure, buildings and facilities (Figure 5).

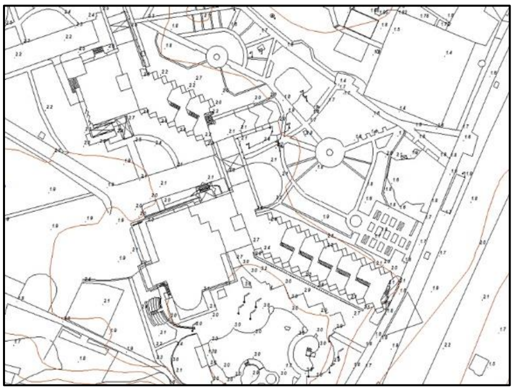

Figure 4. Albena Resort – cadastral plan 1 :1000

Figure 5. Albena Resort – GIS layers

Terrain 3D modelling

GIS layer that contains 1-meter elevation contours and elevation points was used to generate a TIN model (Figure 6). The figure 6 shows that the generated surface is not consistent with the location of the infrastructure, buildings and facilities and the terrain “cross”some buildings or “cover” some swimming pools. To achieve the correct terrain surface data for boundaries of all facilities , roads and alleys were used as a structural lines of the relief. Additional control and vertical planning was made of the streets and alleys network and of the parking lots and playground around swimming pools. As a result the terrain model represents an exact location and height of all elements (Figure 7).

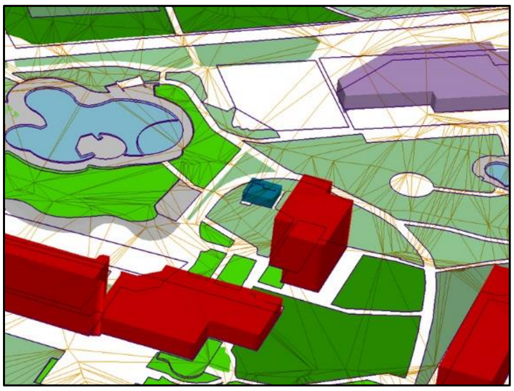

Figure 6. TIN modelled from contour and elevation points

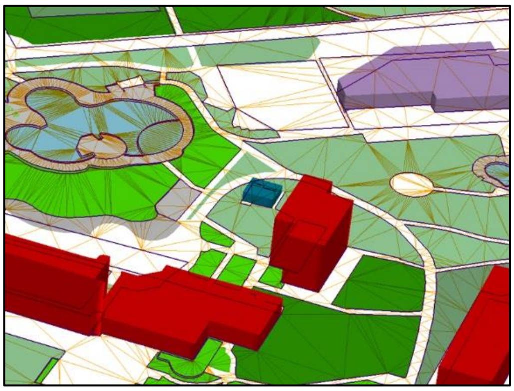

Figure 7. TIN modelled after vertical planning

Building and Facilities modelling

The architecture of Albena Black Sea resort in Bulgaria has a unique vision with its terraced hotels. The buildings and facilities were modelled with very high precision and accuracy of al details to preserve the architectural authenticity of the resort. On Figure 8 is shown a sample with detailed 3D model of Ralitsa hotel. Along with the sea tourism the resort also offers a modern sports facilities. On Figure 9 are shown a football sports complex and complex for equestrian sport.

Figure 8. 3D model of Ralitsa hotel

Figure 9. 3D model of football sports complex and complex for equestrian sport

Land cover and environment modelling

The realistic reproduction of the natural environment (parks, gardens and leisure facilities) is of particular importance in the presentation of resorts. Thereby, for the Albena resort the land cover layer requires special attention for landscape modelling in GIS. A terrain measurements were made and also a pictures of tree species and gardens were taken . In the VNS the respective ecosystems were structured with Ecosystem Materials (Figure 2), reflecting the landscape in the model (Figure 10). It should be noted that the 3D symbols of leisure facilities give the complete and realistic view of the 3D model (Figure 11).

Figure 10. Albena resort – park and gardens

Figure 11. Albena resort – leisure facilities

3D visualization and application of the model

Created 3D models of terrain, buildings and leisure facilities were integrated in the VNS and photorealistic visualization with high resolution (11200/8000 pix.) was generated. Then, the 3D panoramic map was created by adding 2D cartographical symbols, labels, framework layout and legend. Currently, the 3D panoramic map of Albena resort in Bulgaria (DavGEO, 2012) (Figure 12) is used for advertising materials, indication signs, billboards, etc.

Figure 12. 3D panoramic map of Albena Black Sea resort in Bulgaria

3D modelling of mountain regions

3D photorealistic visualization is very suitable to create an attractive and expressive map of mountain region, national park or mountain resort. In this study, several applications of 3D modelling and visualization of mountain regions are presented in different scale, coverage and level of details.

Central Balkan National Park (Stara Planina Mountain)

The 3D panoramic view of the Central Balkan National Park in the Stara planina Mountain is presented on Figure 13. Central Balkan National Park is located in the “heart” of Bulgaria, nestled in the highest and most picturesque part of the Balkan Mountains (Stara planina Mountain). With its area of 72,021.07 ha, the park is the second largest national park in Bulgaria. The highest peak is Botev 2376 m above sea level. The Central Balkan National Park preserves rare and endangered wildlife species and communities, self-regulating ecosystems of biological diversity, as well as historical sites of global cultural and scientific significance

Input data

For creation of 3D models of large mountain regions we can use available free data for relief such as Shuttle Radar Topography Mission (SRTM) data with spatial resolution 1 arc-second for global coverage (~30 meters) or ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) GDEM (Global Digital Elevation Model) data with spatial resolution 1 arc-second. If a higher accuracy is needed, a vector data is used (contour lines, elevation points and breaklines) for generating DTM, as well as remote sensing data with high accuracy (LiDAR - Light Detection And Ranging). For the territory of Central Balkan a DTM was generated based on GIS vector data – 20-meter elevation contours and elevation points. In addition, structural lines (rivers and watersheds) were used in order to obtain more precisely relief forms.

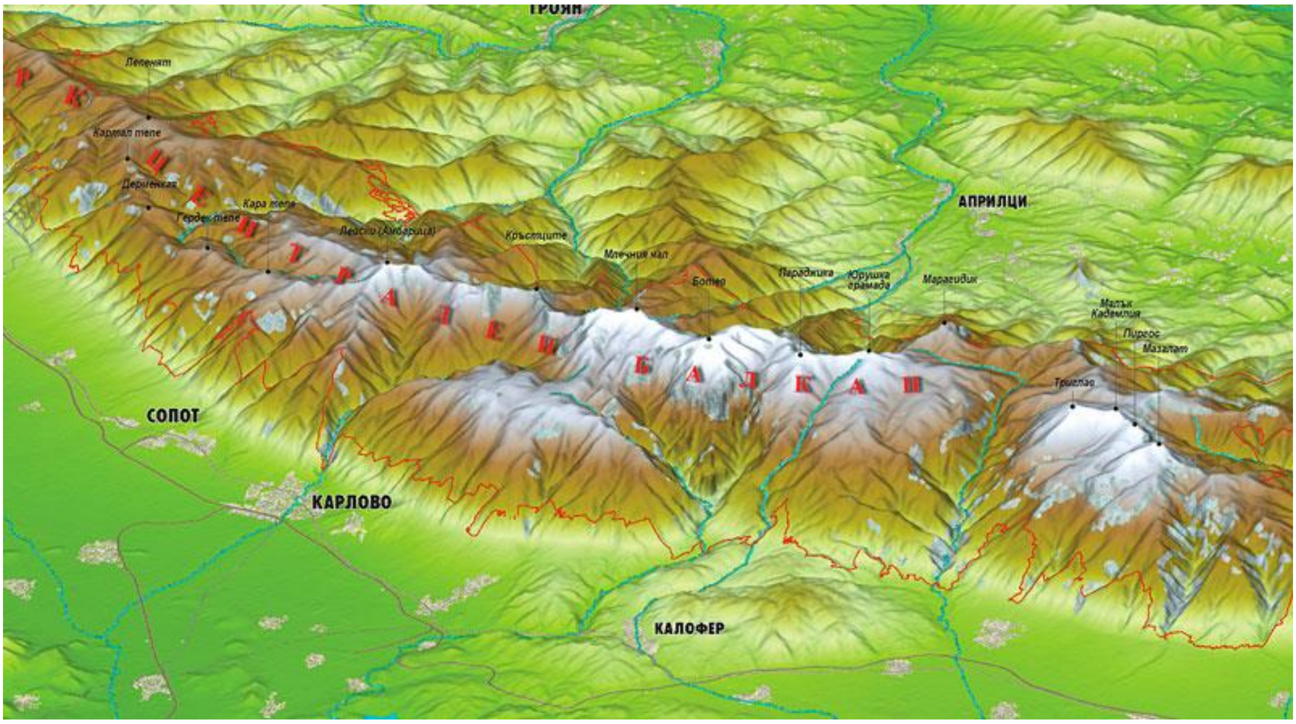

Figure 13. Central Balkan - 3D panoramic view

Terrain modelling and representation

DTM previously generated in GIS is imported in VNS for 3D modelling and visualization. 3D visualization of mountain landscapes requires a vertical scale coefficient (factor to convert DEM values to scene units) to be applied. Thus, the higher visibility of relief forms is obtained. For modelling the relief of Central Balkan we have applied an altitude coefficient (Kz) to strengthen the altitudes Kz = 2. The colouring mode “Full Blend” was used to create hypsometric colouring of the relief in smooth gradient of 8 basic colours. A snow cover was simulated for altitudes above 1750 m. Additional data for rock formations and settlements’ boundaries were extracted from available thematic map and situated in the model.

For better visualization of the relief, vector data for boundaries of protected areas, roads and hydrography were included as 3D elements of the terrain. The park’s boundary is a 3D polyline that follows the terrain surface. Roads, railways and rivers are all 3D polylines, which shape the basic terrain through defined additional characteristics such as width of roads (rivers), trenches and embankments, banquet, slopes, etc.

The labels of peaks and settlements are dynamic 3D labels, which were generated from vector point layer with attribute data about the names and elevation points of peaks. The photorealistic visualization includes also additional 2D labels and symbols. Created 3D panoramic view (DavGEO, 2014) is used in tourist map of Central Balkan National Park.

3D panoramic map of Pamporovo Ski Resort in Rhodope Mountains

Pamporovo ski resort is located in the Rhodope Mountains (southern Bulgaria, municipalities of Smolyan and Chepelare) amongst pine forests at an altitude of 1650 m a.s.l. at the foot of Snezhanka peak (1926 m). It is around 220 km away from Sofia city and 85 km away form Plovdiv city. The territory of Pamporovo resort along with the ski zone covers about 27 km^2.

In 3D maps for mountain tourism the most important task is the precise modelling of relief, ski tracks, tourist routes and facilities. The realistic and attractive representation of the environment is also of great importance (Figure 14).

Figure 14. Pamporovo ski resort – 3D render

Input data

Developed GIS geodatabase contains several layers: relief, land cover, infrastructure, buildings and facilities. The input data were obtained through digitalization of large-scale topographic map at scale 1:5000 (Figure 15) and processing digital data about woodland. Additional GPS measurements were performed for verifying and updating the ski tracks and relevant facilities. Figure 16 shows the created thematic map with GIS layers for land cover and elevation contour lines.

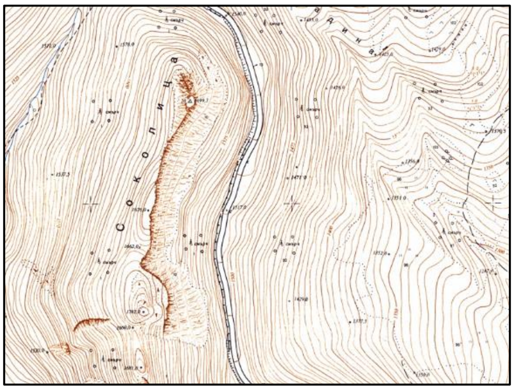

Figure 15. Pamporovo resort – Topographic map 1:5000

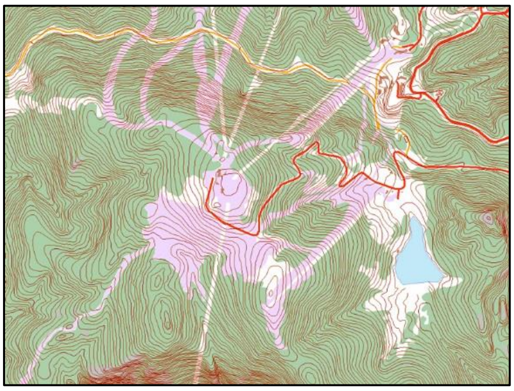

Figure 16. Pamporovo resort – GIS layers

Terrain modelling and representation

For the territory of Pamporovo we have established DTM based on vector GIS data – 5-meter elevation contours and elevation points. In addition, structural lines were constructed for providing a correct relief representation. 3D modelling and visualization was performed using VNS software. As it was mentioned before, the z axis scale should be exaggerated in 3D modelling of mountain regions. In modelling of relief of Pamporovo the vertical scale coefficient (Kz) was used for strengthening the altitude Kz = 1,5. The options for showing snow in the land cover were used as the image represents a winter panorama (Figures 17 and 18). In modelling the road network GIS polyline layers were used and an option for terrain correction according to the road section was applied (Figure 17).

Figure 17. Pamporovo – roads modelling

Figure 18. Pamporovo – Snezhanka peak model

Land cover and environment modelling

The representation of woodlands in 3D models (simulation of real trees) contributes to the realistic effect of the 3D panorama. Since the modelling is getting more complicated when 3D vector models of trees are used, we have used raster images of trees for 3D visualization of large forest areas. VNS software provides the simulation of land cover by the so-called "Foliage Effect". The Foliage Effect allows to place Image Objects or 3D Objects onto the terrain. A single object or rows of objects could be placed and defined by the points of a Vector Object. Different raster images of trees (e.g. pictures) could be used after appropriate processing. Figure 19 shows coniferous trees which were used for simulating forest ecosystem in 3D model of Pamporovo resort. These images were processed additionally by Adobe Photoshop to acquire the "snow" effect at the upper half of the tree.

Figure 19. Pamporovo – raster images of coniferous trees

Figure 20. Pamporovo – 3D models of ski equipment

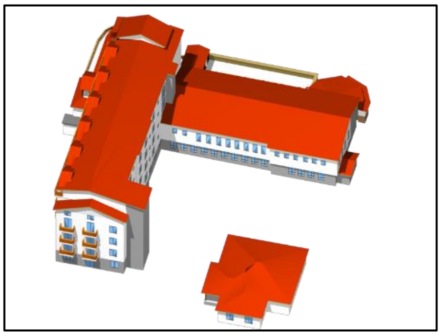

Figure 21. Pamporovo – hotel Snezhanka - 3D model

Buildings and facilities modelling

Detailed 3D models of ski equipment (Figure 20) and buildings of hotels (Figure 21) were constructed in an external program (Autodesk 3ds Max) and then were integrated into the 3D model for rendering.

3D visualization and application of the model

The rendering was performed using VNS and photorealistic visualization with high resolution (9200/6700 pix.) was generated. Then, the 3D panoramic map with 2D cartographical symbols, labels, framework layout and legend was created. The 3D panoramic map of Pamporovo ski resort (DavGEO, 2004) (Figure 22) is used for tourist maps, billboards and web applications (http://pamporovomap.com).

Figure 22. Pamporovo – 3D panoramic map

3D model of the Natural landmark "Muhnati Skali" for Natura 2000 monitoring

The Natural landmark "Muhnati Skali" is a protected area located in the "Bulgarka" Natura 2000 in the Central Stara planina Mountain. It comprises age-old beech forests of middle age over 160 years which are located between groups of bare rocks. The territory has steep slopes and sectors with inaccessible areas. There are beautiful panoramic views north to the towns of Plachkovtsi and Tryavna. The study area covers 5 km^2.

Digital geodatabase in GIS environment was developed for the Natural landmark "Muhnati Skali" monitoring. Then, 3D model was created and photorealistic image was generated using VNS software.

Input data

Developed GIS geodatabase contains data layers for relief, forest roads and trails, soil, rocks and land cover. The vegetation cover layer includes protected species of flora and habitats of European importance on NATURA 2000 (under Directive 92/43/EEC, Annex 1). Figure 23 shows a thematic map of vegetation cover for the Natural landmark "Muhnati Skali".

A thematic map of land cover based on geological and soil data for localization and visualization of rock formations and land cover was created (Figure 24)

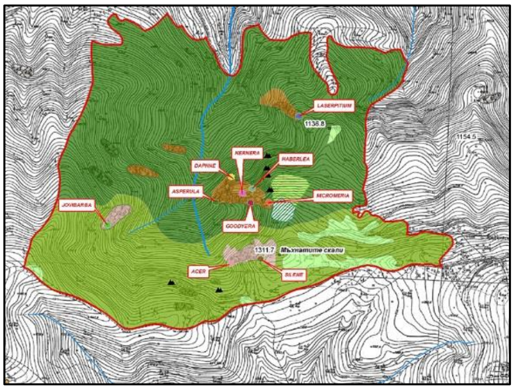

Figure 23. "Muhnati Skali"– vegetation cover

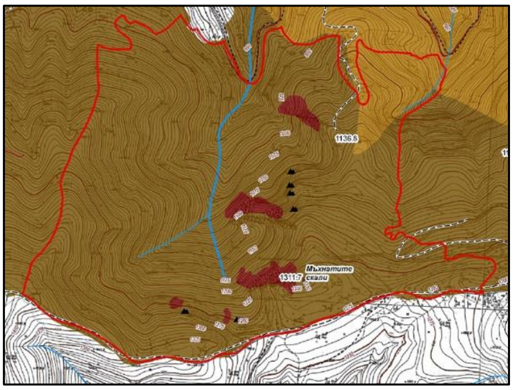

Figure 24."Muhnati Skali" – soil and relief

3D modeling and visualization

3D modelling was performed using VNS software as follows:

a. Generation of DEM from vector GIS data - 20-meter elevation contours and elevation points;

b. Development of a local database with vector data for protected area boundaries, nature habitats, rivers and forest roads;

c. Import of raster thematic maps of land cover;

d. Creation of *Ecosystems* for species of flora and rock formations;

e. Land cover settings – Ground Effect;

f. Parameter settings for light, atmospheric effects and cameras for model visualization;

g. Rendering.

Figure 25 shows detail of the 3D model of the Natural landmark "Muhnati Skali" where Ecosystems and Ground Effect are marked.

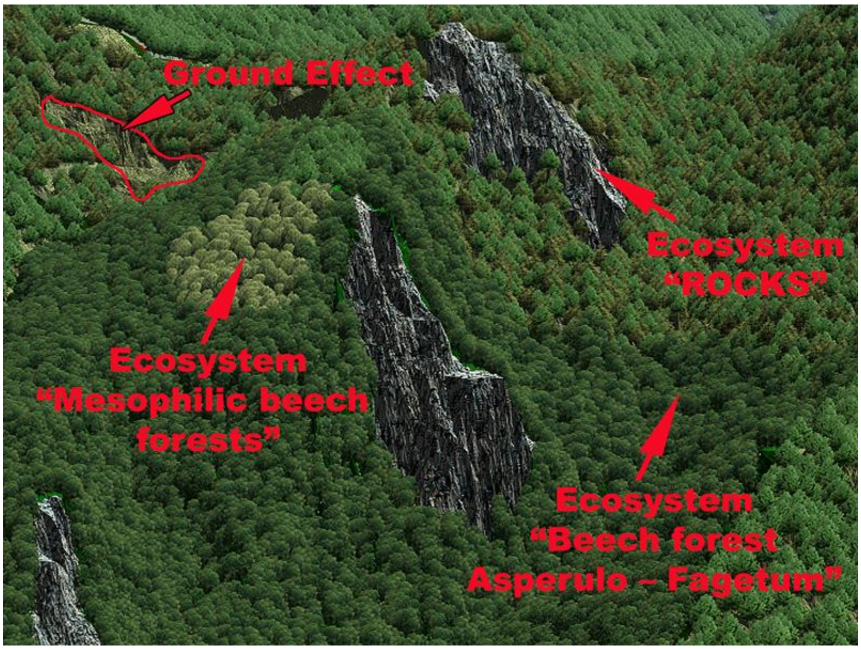

Figure 25. "Muhnati Skali" – 3D model of ecosystems

The rendered image was integrated with labels and symbols for obtaining 3D panoramic view (Figure 26).

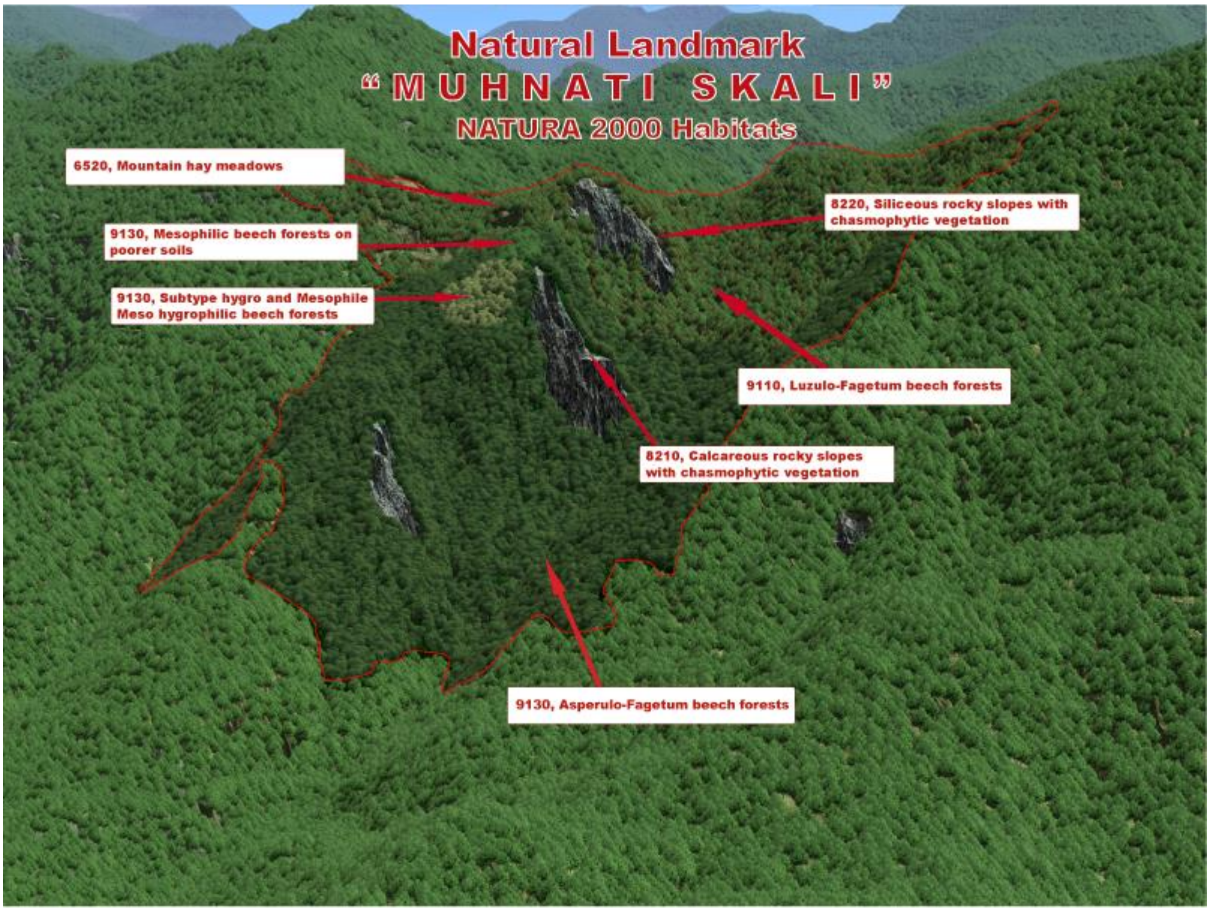

Figure 26. "Muhnati Skali" – 3D panoramic view

CONCLUSIONS

This paper presents cartographic applications of 3D landscape modelling and visualization for tourist maps and protected areas monitoring. The study is focused on technical approaches for data modelling, cartographic design and practical use of the created 3D maps.

3D landscape models are developed and visualized using specialized GIS software that allows to model the real landscape in very high level of details. Various visualization techniques are illustrated for basic landscape feature types and 3D cartographical symbols. The applied approach facilitates an attractive representation of 3D geovirtual environment and realistic visualizations by 3D panoramic maps. It offers effective means for visual communication of 3D spatial information.

Created 3D models and 3D maps are generated at different levels of detail and generalization according to user demands. The whole mapping process is aimed at better understanding not only of the modelling techniques, but also of the end user requirements. This emphasizes the high degree of customization with respect to cartographic design and applications. The present work highlights the need for more study to be done on the efficient presentation of geospatial information by providing additional context within a 3D maps.

REFERENCES

Bandrova, T., Zlatanova, S., Konecny, M., (2012) Three-Dimensional Maps for Disaster Management. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. 4, Melbourne, Australia, pp. 245- 250

DavGEO (2004) Pamporovo - 3D panoramic map. Cartographic studio DavGEO, Updated version 2012, ISBN- 978-954-363-004-2, http://pamporovomap.com

DavGEO (2012) Albena - 3D panoramic map. Cartographic studio DavGEO, www.davgeo.com

DavGEO (2014) Central Balkan – 3D panoramic map. Cartographic studio DavGEO, www.davgeo.com

Haeberling, C. (2002) 3D Map Presentation: A Systematic Evaluation of Important Graphic Aspects. Online Paper of the 2nd ICA Mountain Cartography Workshop, Mt. Hood. Available at http://www.mountaincartography.org/mt_hood/pdfs/haeberling2.pdf

Haeberling, C. (2005) Cartographic design principles for 3D maps - A contribution to cartographic theory. In Proceedings of the 22nd ICA International Cartographic Conference, A Coruna, Spain.

Haeberling, C., Bar, H., Hurni, L. (2008) Proposed Cartographic Design Principles for 3D Maps: A Contribution to an Extended Cartographic Theory. Cartographica, 43(3), pp. 175–188.

Pegg, D. (2012) Design Issues with 3D Maps and the Need for 3D Cartographic Design Principles. Available at: http://lazarus.elte.hu/cet/academic/pegg.pdf (Accessed 11 March 2016)

Semmo, A., Trapp, M., Jobst, M., Dollner, J. (2015) Cartography-Oriented Design of 3D Geospatial Information Visualization – Overview and Techniques. The Cartographic Journal, Taylor & Francis, pp. 95-106.

Terribilini, A. (2001): Entwicklung von Arbeitsablaeufen zur automatischen Erstellung von interaktiven, vektorbasierten topographischen 3D-Karten. Dissertation, Institut für Kartographie der ETH Zuerich. Zuerich. Available at: http://e-collection.ethbib.ethz.ch/ecol-pool/diss/fulltext/eth14387.pdf).

3D Nature (2008) Visual Nature Studio, LLC, Using VNS 3. Manual, www.3DNature.com

BIOGRAPHY

Dipl. Eng. Davis Dinkov is an experienced researcher and practitioner at the Cartographic Studio DavGEO. He is a PhD student at the National Institute of Geophysics, Geodesy and Geography at the Bulgarian Academy of Sciences. He graduated from University of Architecture, Civil Engeneering and Geodesy in Sofia, Bulgaria in Geodesy and Photogrammetry. He is a member of Bulgarian Cartographic Association. His research interests are focused on 3D modelling and mapping, computer graphics, GIS, geospatial analysis, remote sensing applications, thematic mapping and cartographic products publishing.

Prof. Rumiana Vatseva, D.Sc. is the Head of the Section “Geographic Information Systems” (GIS) at the Department of Geography, National Institute of Geophysics, Geodesy, and Geography, Bulgarian Academy of Sciences. Her research interests are focused on remote sensing, GIS, spatial analysis and modelling, cartography, land use and land cover, landscape ecology and protected areas. She has published over 80 research papers, including articles in peer reviewed scientific journals, as well as one book and several book chapters. She has coordinated research projects in the field of Remote Sensing and GIS applications, both at national and European level.