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CONCEPTS OF 3D TERRAIN MODELING AND GEOMORPHOMETRIC ANALYSIS IN MININIG[*****]

Abstract

This paper describes the concepts of 3D terrain models and their application in mining. The methods of terrain (relief) by spots elevation and contour lines are commonly applied on geodetic plans and topographic maps. Appearance of the technologies has changed the way of modeling and analysis of geospatial data, i.e., applying the concept of digital terrain models (DTM). This approach emphasizes the importance of geomorphometric analyses and monitoring changes on the field in time. Application of 3D geodata models in digital format (raster or vector) becomes increasingly used in mining. Therefore, it is important to describe the concepts and features of 3D geodata models and potential applications and monitoring changes in the field in time and space.

Keywords: *concepts of modeling, 3D model, DTM, geomorphometric analysis, application in mining*

1 INTRODUCTION

There is aged tendency to present the third dimension with sufficient quality during modeling (visualization) of the Earth's surface on geodetic and geographical maps. This was achieved with some success by elevation isolines, hatching, shadowing and relief maps [4]. However, this is changed with appearance of the new technologies and their application, mainly by digitalization of topographic maps, geo-information system (GIS), global positioning system (GPS) recordings, and lately by remote sensing and laser scanning of objects and attributes [2]. Acquisition and modeling of spatial data became more efficient and of high quality.

This paper is directed toward research and application of presentation of 3D methods for reviewing the spatial changes of terrain at the excavation area and changing surface configuration. Mining industry in the Republic of Serbia is one of the lar-

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gest industries during last several decades, mainly related to the production of construction materials and other mineral resources. The main task is to precisely model the surface features (terrain) and monitor changes of mining fields. This includes procedures for management of geo-spatial resources in real and close-to-real time, which should be based in acquisition and processing of series of spatial-time data. Simultaneously, concepts and development of 3D model are based on application of terrain digital modeling technology.

2 OVERVIEW OF THE CURRENT SITUATION

2.1 Presentation the 3D Terrain Model on Topographic Maps

Presentation the third dimension on maps was achieved by various methods with different success. The geometrical method of relief presentation was the most commonly used [2], with isolines and elevation marks. Presentation of terrain elevation with this method is related to geomorphological properties and elevation. Such presentation should provide realistic spatial interpretation on unevenness, distribution of individual shapes and their connections, character and degree of surface articulation of Earth and capability for quality and quantity assessment of terrain. Also, such approach enabled creation of relief maps, beside those printed on paper, which had some practical use for optical analysis of terrain and identification of geomorphological features of the Earth's surface. However, these maps could not be used for analytical assessment and analysis of terrain [4].

Topographic maps also have the other details related to the quality and quantity [4], beside isolines as the main carrier of metrical information. These are symbols and other elements of geographical expression, used for presentation the typical shapes (sinkholes, mines, mounds, hollows in plains, rocks, gravel or soil deposits, rocky ground, gullies, ravines and similar). These shapes are presented on topographic maps by isolines depending on a map scale. Other-wise, they are presented by hatching-hyphens, symbols or conditional marks [3].

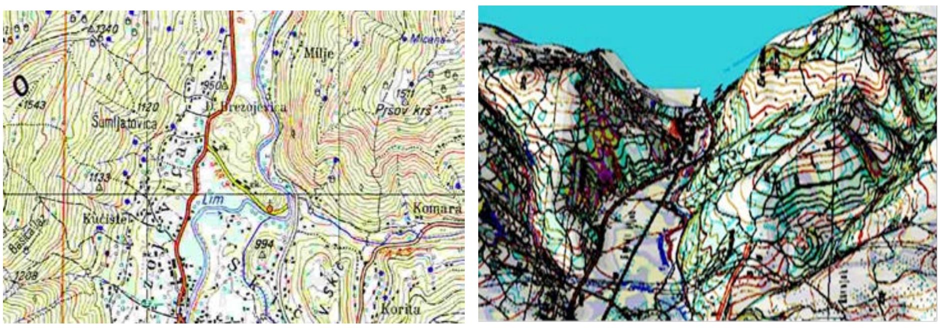


Figure 1 *Terrain presentation on topographic and relief maps* [2]

2.2 Presentation and Visualization the 3D Terrain Model in GIS Environment

Introduction the phrase "digital terrain modeling" is attributed to two American engineers from the Massachusetts Institute of Technology. A definition that they provided in mid-1950-ies is "Digital Terrain Model (DTM) is statistical interpretation of continuous ground surface by large number of selected points with known X, Y and Z coordinates in arbitrary coordinate system" [1].

Since then, numerous similar definitions have been provided in other references, where some related to the similar concepts while the others were quite different, hence requiring attention.

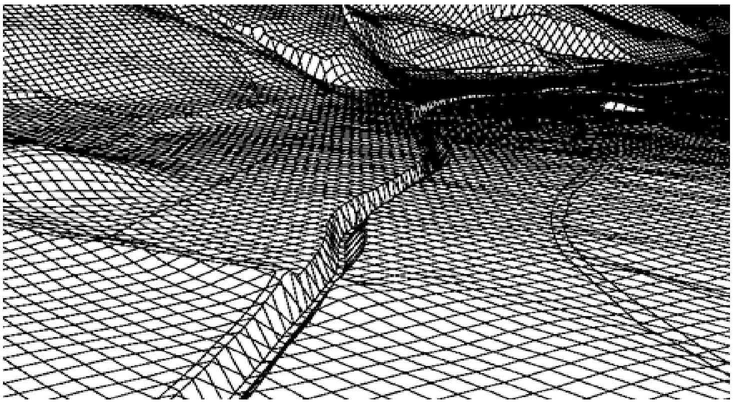


Figure 2 *Digital terrain model [4]*

Therefore, DMT as statistical interpretation of continuous surface of the Earth can be classified in two groups, according to the retention of elevation data. The first group includes points distributed over even mesh, thus representing the Grid. The second group is based on mesh of irregular triangles, i.e. Triangulated Irregular Network), where the three-dimensional points make a mesh of triangles which cannot be overlapped. Both data structures present a derived presentation of DMT [1].

3 CONCEPTS OF TERRAIN MODELING AND POSSIBLE 3D INTERPRETATIONS

Purpose of DMT is aimed to forming a mathematical model for accurate interpretation the terrain surface, thus enabling various analyses and applications. In order to perform the efficient analyses, having in mind that 3D models commonly comprise a large amount of data, a special data organization and structuring is required. Therefore, the process of 3D model development compri-ses from selection and implementation of data structure and suitable development method. Terrain surface is most frequently presented by set of points and lines distribu-ted over the surface in suitable manner and organized in proper structure for easy data handling [1]. Also, the other components of 3D model are methods used for definition of topographic surface in geometrical and geomorphological sense, for given data structure. In general, terrain surface can be presented in three ways:

- isolines,
- by function with two variables, and
- volumetric model.

Terrain interpretation with isolines represents the cross-sections of terrain surface and horizontal planes and selected elevations. These sections are curved lines, which are called isolines, the most commonly used for interpretation the terrain on analogue maps. This mean of terrain presentation has high quality regarding geomorphology, since it encompasses all important attributes of terrain relief [1].

Also, the terrain surface is not explicit in mathematical interpretation the Earth's surface with isolines in digital form. It is implicitly given by sections of the surface with horizontal planes (figure 3). There fore, this approach for modeling of terrain surface is not enough exact method, since it does not interpret the terrain elevation between two successive isolines [5]. This issue is very important at location with typical relief features such as tops, bo-ttoms, water drains, watersheds, excava-tions, etc.

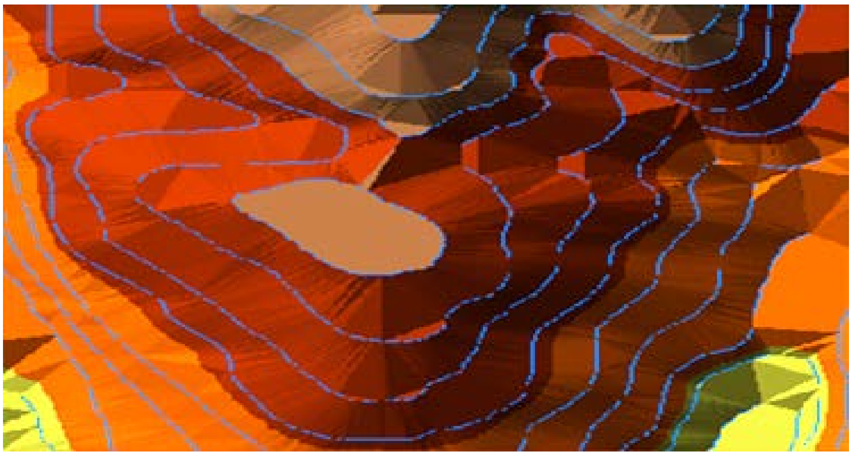


Figure 3 *Interpretation of 3D model with isolines*

The second way for interpretation the terrain surface in digital form is the use of functions with two variables, where these variables belong to the specific domain. Most often, these are functions where for given location (usually planimetric coor dinates X and Y of local coordinate sys-tem, state system or even geography sys-tem) the unambiguous value of elevation is obtained [5]. In this case, it is the 2.5D (2D+1D model. Terrain surface is inter-preted by set of points $(x\ y\ z)^T$, where:

$$z = f(x, y) \text{ explicit form of function } f \text{ over domain: } D \subset R^2 \quad (1)$$

Terrain models enabling the surface in-terpretation in such manner that several ele-vations can be obtained for single location (x, y), i.e. surfaces described by function f (x,y) in form of vector, called 3D models. With these models, all three coordinates are equally important. Therefore, the terrain surface is then described by function:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = f(u,v) = \begin{bmatrix} f_x(u,v) \\ f_y(u,v) \\ f_z(u,v) \end{bmatrix}, \text{ where: } (u, v) \in D, D \subset R^2 \quad (2)$$

The most important and in practice co-mmonly used 3D terrain models with such principles are the digital terrain models (DMT), with the main data structure in the form of Grid and TIN (Triangular Irregu-lar Network). These models are presented in Figure 4.

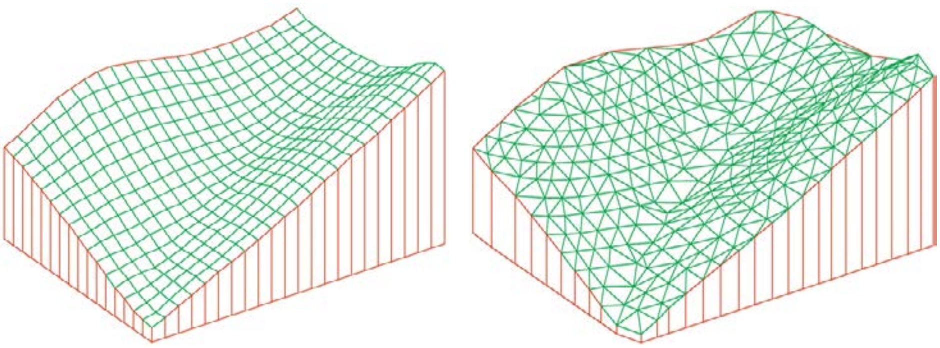


Figure 4 *Presentation of 3D terrain model in the form of Grid (left) and TIN (right)*

And, the third way for interpretation the terrain surface is volumetric model, in which spatial objects are interpreted by volumetric components [1]. Typical example is application the voxel (volumetric component, frequently in shape of cube or prism) with sufficiently small dimensions. This is similar to interpretation the appearances on digital raster images (or raster GIS) with sole difference that digital images are 2D [1]. However, this model is interprets terrain as a single body comprised of interconnected voxels set. These data model can be used for interpretation of tunnels, caves, buildings and structures, settlements, etc.

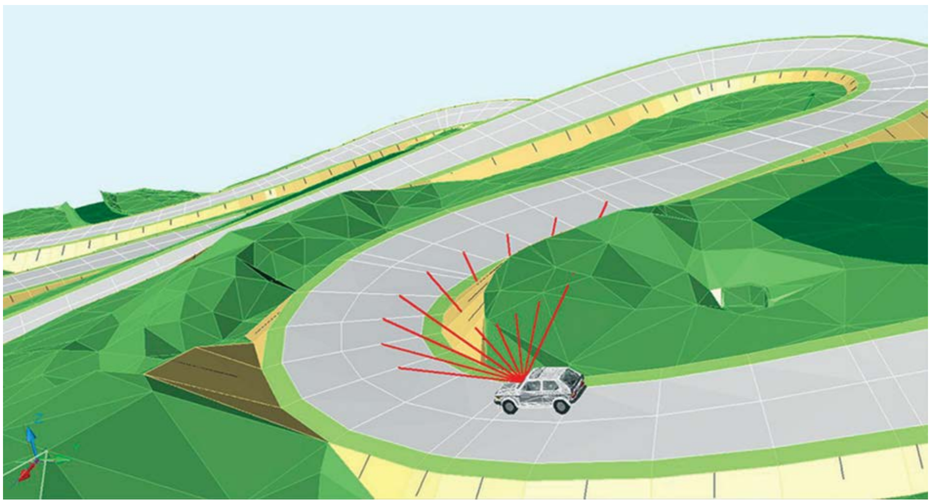


Figure 5 *Interpretation of 3D model in volumetric form*

The second type of volumetric models is the models based on interpretation the objects in space by division of space into non-overlapping tetrahedrons. This is analogous to the TIN interpretation of objects in 2.5D models, with two variables function. Finally, it should be noted that the volumetric models are mainly used for interpretation the infrastructural objects and populated places, especially cities and roads (Figure 5). Also, such models are used in construction, urbanism, geophysics, and seldom for terrain surface.

4 GEOMORPHOMETRIC ANALYSES IN MINING

Various industries require numerous analyses before, during and post operational activities on the field, for example, selection of location for implementation the projects in mining and power industries. This is difficult and long task, if it is done in classic work procedure [6]. Thereby, the quality of results depends on the surveying plan or topographic map, equidistance of isolines and their accuracy, number of profiles and accuracy of graphical interpretation, as well as education of the person reading the elevations from the surveying maps.

Development and visualization of 3D model of geo-data in digital form enables numerous geomorphometric analyses [7]. This paper describes the standard approaches to analysis and examples which can be performed with various software and applications developed for mining industry (Figure 8), such as:

- uninterrupted oversight on terrain surface (relief and sight, on site elevation read out);
- design and execution of works on terrain surface (construction, mining, energy);
- calculation of volumes (volume of earth and development of profiles between points);
- simulation and 3D animation (development of plans of terrain and mining basins);
- geomorphological analysis and soil classification (inclination and terrain exposition, geology);
- determination of soil types and seams in the Earth's structure (remote detection).

Figure 6 *Overview of the open cast mine*

4.1 Impact of the Earth Relief on Visibility between Two Points

Visibility analysis between two points on the Earth's surface can be significantly speeded up if there are 3D models and suitable technologies. Thereby, any visible point is marked with 1, and nonvisible with 0. In this manner, a file is created ready for further analytic and graphical processing, i.e. visibility between two locations on surface of the Earth. For example, let's assume that point O is a viewing point with known coordinates x_0, y_0 and elevation h_0. A task is to determine whether point P is visible from point O. By intersection of line trough points O and P with headings parallel with axes x and y, the coordinates of all amid points from 1 to 5 are provided. Elevations of these points are obtained by interpolation between the neighboring points of 3D model, shown in Figure 7 [3].

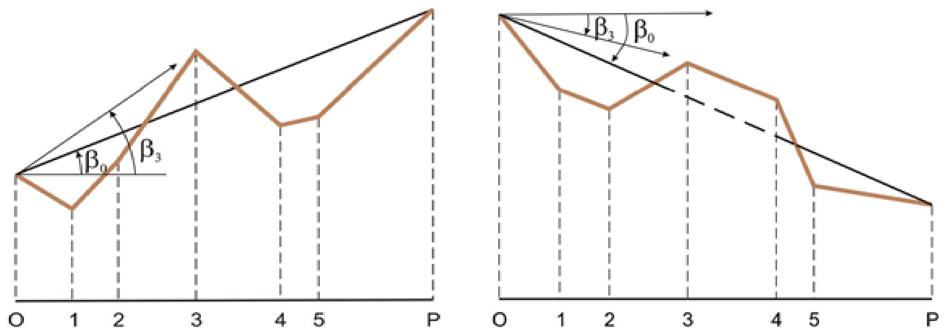


Figure 7 *Visibility between points O and P if $h_0 < h_p$ or if $h_0 > h_p$* [3]

Further on, it is checked whether elevations of all amid points intersects with line trough points O and P. In case of no intersections, there is visibility between O and P. However, if only one elevation has intersection with line OP there is no visibility. Also, if neither condition is met then it is necessary to calculate tangent of angle β_0 from point O to point by formula [3]:

$$\tan\beta_0 = \frac{h_p - h_0}{\sqrt{(x_p - x_0)^2 + (y_p - y_0)^2}} \qquad (3)$$

An example, presented in Figure 8, shows the selected location (point) and determined visible territory which are of lighter color and nonvisible one of darker color [7].

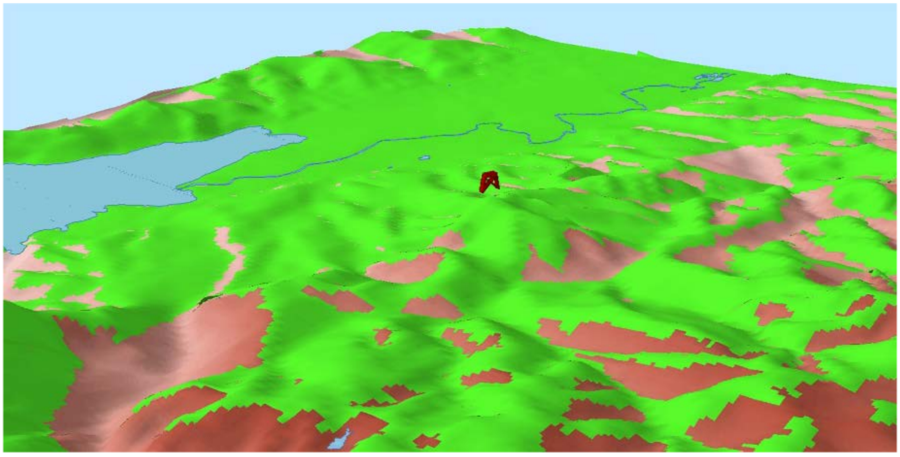


Figure 8 *Terrain which is visible and nonvisible from selected location*

4.2 Terrain Inclination

Terrain inclination (S) is an important topographic parameter. It is defined by gradient, i.e. vector which indicated direction of largest growth of scalar function z=f(x, y). Also, inclination can be defined as the change intensity of elevation in direction of largest slope [6].

$$S = \sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2} = \sqrt{z_x^2 + z_y^2} \qquad (4)$$

Terrain inclination in a point is defined as an angle in vertical plane between tangential plane on terrain surface and horizontal plane in selected point. This example is shown in Figure 9.

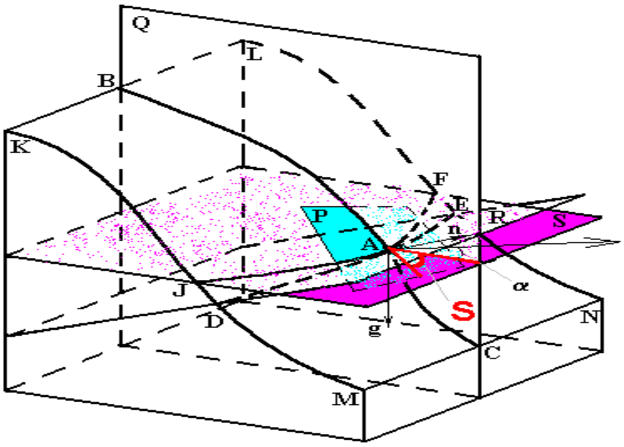


Figure 9 *Calculation of inclination angle*

Considering that the most of the Earth's surface is under inclination, angles are representing and have impact on gravitational force thus generating numerous geomorphological processes. Among other things, terrain inclination has influence on surface water flow velocity, soil moisture and saturation, intensity of geomorphnological processes and similar. The following must be considered in calculation of terrain inclination [10]:

- larger resolution of DMT results with greater accuracy of calculated terrain inclination;
- the average value and dispersion of calculated inclinations decrease with increase of distance (dimension of grid cell) of DMT;
- impact of DMT resolution is larger along the typical terrain shapes (steep slopes, edges of the mine, cuts, ridges and similar).

Inclination angle in case of TIN represents maximal value of inclination change along each triangle, while in the case of Grid there are several ways for calculation of inclination according to each cell of the Grid and its neighboring eight cells. During the process of terrain angle determination with Grid, the input is terrain surface raster, while the result is a raster containing tje calculated inclination of each cell in input raster. In case of TIN, calculation of terrain inclination is done over each triangle, also resulting with raster. Smaller value of inclination, whether it is TIN or Grid, indicates flatter terrain, while the larger value indicates steeper one [6].

Also, the angle of terrain inclination has significant impact for determination the properties of any area for operational activities, especially mining activities. Terrain inclination can also be expressed in degrees, as shown in Figure 10.

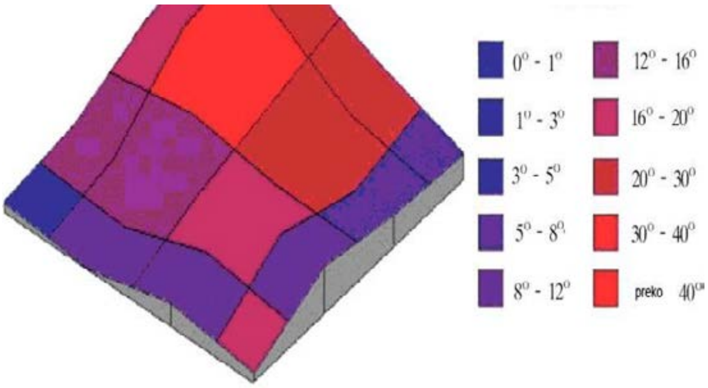


Figure 10 *Terrain inclination*

For easier analysis and reviewing development potential of a geospatial area, general terrain classification was provided in relation to the terrain inclination [3]. The example is given in Table 1.

Table 1 *General classification of terrain in relation to inclination*

Inclination angle	Terrain type in relation to inclination angle
to 1^o	Flat terrain
1^o - 3^o	Very mildly leaned terrain
3^o - 5^o	Mildly leaned terrain
5^o - 8^o	Fairly leaned terrain
8^o - 12^o	Inclined terrain
12^o - 16^o	Very inclined terrain
16^o - 20^o	Moderately steep terrain
20^o - 30^o	Mildly steep terrain
30^o - 45^o	Very steep terrain
over 45^o	Highly steep terrain

Development of science and technology has enabled performing of some human activities under fairly unfavorable relief conditions. This is, for example, case in mining industry. However, terrain inclination remains unavoidable feature with large impact on development of industry, agriculture, transport, etc.

4.3 Accuracy of Terrain Elevation Interpretation

Accuracy verification of 3D data model (obtained as previously described, including visualization of 3D model - Grid and TIN), is done using coordinates from the existing catalogues of points or in relation to the control point using GPS technology. Visual methods can be also used for verification the geomorphological features for given location, beside numerical methods of quality check of 3D data model. Accuracy assessment is performed by formula for standard deviation [6]:

$$\sigma_H = \sqrt{\frac{\sum (z_i^* - z_i)}{n}} \qquad (5)$$

where:

z_i^* - value of interpolated elevations;

z_i - value of measured (control) elevations;

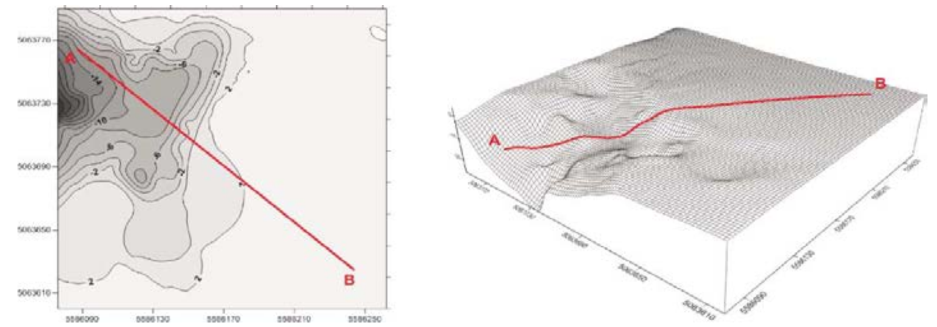
n - number of control points.

Accuracy assessment of terrain interpretation in fact is verification and quality of 3D model, obtained from digitized isolines from the existing maps or some other available techniques for data acquisition. During development of 3D terrain model, there are also interpolation methods, which can be used for improvement the data quality. One of these is geo-statistical method called "kriging", commonly used in mining industry [8].

4.4 Graphic Interpretation of Terrain Changes and Comparison of Vertical Profiles

Intersection of vertical plane and obtained 3D terrain interpretations can show the differences in model surface in different time periods. Also, this approach can be used for determination a difference in the amounts on the bottom of the mine in one period. Line of arbitrary selected profile is shown in two dimensions and three dimensions (Figure 11, a and b), as an example of interpretation the isolines and 3D model for two periods, obtained with same method of 3D terrain model creation [8].

a) for the first period



b) for the second period

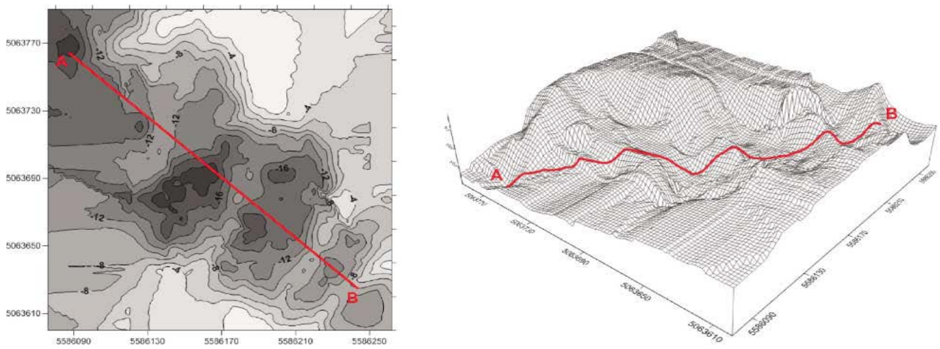


Figure 11 *Profile on the map and 3D model: a) and b)*

Figure 11 presents a graphical interpretation of 3D model comparison in different time interval, obtained with same data modeling method [8]. These interpretations can be used for reviewing differences and changes in terrain configuration and determination the excavated volume from the mine.

5 CONCLUSION

It should be noted that the main weakness in interpretation of relief on topographic maps is discretization and discontinuity in terrain elevation interpretation. In order to present the continuous Earth's surface, comprised of infinite number of points with location and elevation, it is necessary to digitize the area thus completing the model with elevation interpretation. Thereby, selection of method for development and presentation of 3D model has a significant impact on final result of terrain elevation model.

Actual interpretation the Earth's surface has an importance beyond the surveying. This is truth for numerous other industries and activities. The topic of this paper is research and application possibility of various modeling methods and terrain analysis in mining. Mining basins and open pit mines have a specific topography. Their features are sudden transition of relief features, both spatial and in time, which is interesting for analysis and interpretation of surveying data, i.e. terrain modeling in function of time. Thereby, available technology enables integration of different surveying instruments and technologies into single system, in order to obtain accurate and reliable information and to link those with operational efficiency [8].

Beside interpretation of terrain and Earth's surface, i.e. infrastructure facilities for the mining industry (such as pits, dumps and other), it is possible to obtain the new information as a result of query and analysis of 3D data model. Also, it is possible to interpret the elevation in given terrain points, to simulate slope slides, etc. Terrain inclination has a significant impact on condition and monitoring the geological and hydrological appearances. Beside this, there is a need for frequent acquisition of profiles, calculation of earth volumes, review of maximal inclination, creation of future terrain interpretations and configuration, optical visibility and similar. Having all of this in mind, as well as frequent changes in terrain surface in time, the concept of digital terrain modeling provides large methodological and technological capabilities for research and execution the mining activities.

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