ANALÝZY VIDITELNOSTI A JEJICH VIZUALIZACE
VISIBILITY ANALYSES AND THEIR VISUALIZATION

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Abstrakt

Výpočet analýz viditelnosti je běžnou GIS funkcí a je obsažen v téměř všech aplikacích, které umožňují práci s digitálním modelem terénu. Cílem projektu je nalézt nejlepší způsob výpočtu těchto analýz pro území ORP Olomouc a výsledky vhodně zvizualizovat. Prvním krokem při výpočtu analýzy viditelnosti je kvalitní digitální model terénu, vhodně zvolená interpolační metoda a následné doplnění modelu o zástavbu a vegetaci. Analýzy viditelnosti jsou obsaženy ve velkém množství softwarů, a to jak v komerčních tak i ve volně šiřitelných aplikacích. Bohužel ne všechny jsou schopné vypočítat viditelnost pro rozsáhlé území. Proto je důležitou součástí práce zhodnocení funkcionality několika GIS softwarů.

Při zobrazování výsledků bylo využito prostředí Google Earth a Google Earth API. Práce zkoumá možnosti převodu dat z ArcGIS do Google Earth a také způsoby generalizace tak, aby byla kvalita digitálního modelu reliéfu co nejvyšší, ale současně nebyla data příliš objemná a bylo možné s nimi pracovat v prostředí internetu. Při vizualizaci výsledků byl kladen důraz především na jednoduchost a intuitivnost ovládání, ale také na vizuální atraktivitu. Proto jsou vrstvy viditelnosti doplněné o 3D modely rozhleden, množství fotografií, panoramat atd. Výstupem projektu je interaktivní aplikace umožňující jednoduchý přístup k datům viditelnosti z nejvýznamnějších vyhlídkových bodů v zájmovém území, která by měla by sloužit ke zvýšení potenciálu cestovního ruchu v Olomouckém regionu.

Abstract

Visibility analysis or Viewshed is a common function of almost all GIS systems. The aim of this paper is to find out the best solution, to compute viewshed for the Olomouc region and ensure the best way of visualization of the results. The first step to analyze the visibility is making a high quality Digital Terrain Model, choice of the best interpolation method and subsequent addition of vegetation and man-made structures layer. Not all applications are able to compute visibility for a large area, so the choice of software was also very important. Currently there are many ways to transmit the analysis results to the target user. We used Google Earth for visualization.

For the representation of results Google Earth and Google Earth API were used. The project deals with the possibilities of exporting the output from the visibility analysis from ArcGIS system to Google Earth. An important part is to optimize the size of the resulting layer using various methods of generalization so that the resulting layer is sufficiently precise and not too voluminous at the same time. The project also explores the possibilities of enrichment of visualization with multimedia content, which can be for example 3D models of buildings, photos, videos or spherical panoramas as we know from Google Street View, etc. The output of the project is an interactive application that will ensure a simple and visually attractive approach to data that represent the visibility of the most important observation points in the area of interest.

Klíčová slova: Viditelnost, Vizualizace, Analýza, Generalizace, Google Earth, Google Maps, API

Keywords: Visibility, Visualization, Analysis, Generalization, Google Earth, Google Maps, API

1.   INTRODUCTION

Visibility analysis based on viewsheds is one of the most frequently used GIS analysis tools. In the past, these analyses were used primarily for military purposes.

It is believed that the first recorded use of Line of Sight dates to the beginning of the 18th century when a French military engineer, Prestre de Vauban (1603-1707), created a map of the siege of the town of Ath in Belgium. The upper part of the map (Figure 1) contains Line Of Sight, the lower part contains Weapon Fan that depicts the action radius of artillery batteries [11]. Visibility analyses can be also highly important for the reconstruction of historical military operations.
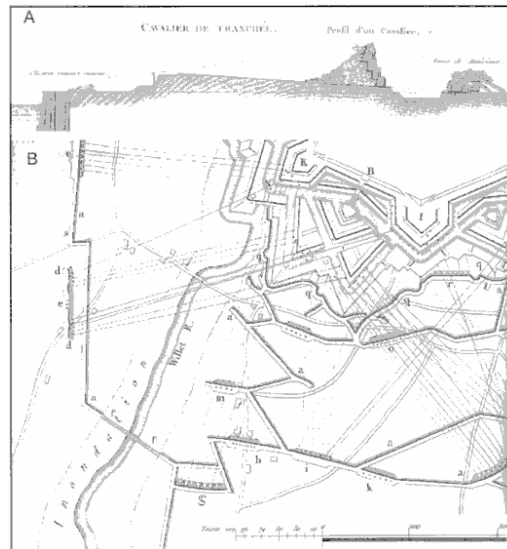
Figure 1: One of the first examples of the use of Line Of Sight. The siege of Ath in 1706. [11]

With the spread of GIS in the private sector there emerged a wide range of uses in many spheres of human activity. Viewshed analysis has been used in a wide range of applications, including radio communication or localization electrical generating windmills [3] or lookout towers. Other field of use of visibility analyses is archaeology, where these methods can be used to detect archeological sites [10, 4], spatial planning [7] and many other spheres of human activity.

Sector, where the outcomes depend on the manner of visualization of the results, is use of visibility analyses in tourism. Even if we count on calculations of extreme quality, it does not necessarily mean that they can be used in practice; this is only possible when they are represented in a suitable manner and made accessible to a target group of users.

The Google Earth and Google Maps tools have become popular in the wide public in a relatively short period of time. Their big advantage is the continuous refinement of source data and the creation of new functions. These tools can be effectively used for displaying various types of information, like overlay layers, texts, pictures or videos. One example is the project of the Crisis in Darfur [5].

This paper deals with visibility analyses in the region of Olomouc. Results of the study should be used for the propagation of the studied region and that they can serve as a basis for the creation of new scenic view points in the landscape or the construction of new observation towers.

2.   METHODOLOGY OF COMPUTATION OF VISIBILITY ANALYSES

The GIS environment offers three main methods of computing visibility analyses. These methods are called differently in different applications. In this study, the functionality and terminology from ArcGIS are used.

Line of Sight

Line-of-sight analysis determines whether two points in space are intervisible. [2] In practice, only the initial and terminal points are determined, and possibly the elevation of the observer. The software divides the line into segments that are visible from the initial points and segments that are hidden behind an obstacle [12]. Some applications combine this method with terrain profile, making a colour differentiation not only of the line segment but also of the curve that represents this profile.

Viewshed

Viewshed is created over a DTM – Digital Terrain Model using an algorithm that estimates the difference in elevation in the observer's cell and the target cell. To determine the visibility of the target cell, each cell that lies on the line connecting the observer and the target must be examined by Line of Sight. If there is a cell with a higher value between the observer and the target cell, it is blocked. In such a case the target cell is marked "Not Visible". [16]

Visibility

Visibility is the last method offered by ArcGIS. In other applications this tool can be called Multiple Viewshed. The Visibility function provides answers to two basic questions: "What places are visible from the given observation place?" and "How many observation places is the given object/place visible from?" The Visibility command also enables a visibility analysis using a line theme.

3.   CREATION OF A DIGITAL SURFACE MODEL

In terms of accuracy and reality of the output of visibility analyses, the quality of input digital terrain model is the most significant element. In order to get an accurate image of the Earth's surface, it would have to be scanned with the techniques of remote sensing, like laserscanning, for example [6]. However, these methods are extremely costly, especially if it is necessary to obtain data for the range of district of Olomouc (800 km^2). That is why the terrain was interpolated from contour lines with the basic interval of 5 m, then adding man-made structures, forests and line vegetation.

3.1.   Creation of a DTM

It is important to base the process on sufficiently accurate elevation data, as well as to choose a suitable interpolation method and its setting.

3.2.   Comparison of interpolation methods

Sharma [8] argues that the five most frequently cited interpolation methods are TIN with linear interpolation, Inverse Distance Weighing (IDW), Spline, Ordinary Kriging and TOPOGRID. For our purpose, IDW, Spline and Ordinary Kriging were chosen. To evaluate the DTM quality we chose the RMSE method which measures the dispersion of the frequency distribution of deviations between the original elevation data and the DTM data. Mathematically it is expressed as (1). A higher RMSE value shows a greater dispersion between the interpolated and input data. The ideal value should not exceed half of the value of the basic contour line interval [9]. That means that in this case it should not be greater than 2.5.

$$RMSE_z = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z_{di} - Z_{ri})^2}$$

(1)

where Z_{di} is the value of altitude from DTM surface,

   Z_{ri} is the corresponding original altitude,

   n is the number of samples.

The input point field used for computation of DTM was divided into two parts. 85% of points were used for creation of DTM and 15 % for determination of the Root Mean Square Error (RMSE). These points were chosen randomly using RandomSelection toolbox [17] for ArcGIS.

First, the area of interest was divided into squares with the length of their sides of 4 km. Elevation range was calculated within each square. This way the values of relative height division were worked out in each square. Flat land and hilly areas are predominant in the area of interest, therefore, such settings of interpolation methods that showed the best results for these characteristics were chosen from the thesis. „Analýza morfometrických charakteristik různých typů reliéfu" [13]. This thesis deals with evaluation of interpolation methods on different types of relief. With help of weighed order there were chosen the best interpolation methods and parameter setting for each type of relief (planes, downs etc.). Eight settings of interpolation methods were chosen from this thesis.

Tab 1. Setting of the spline interpolation method

Name	Type	Weight	Points
Splinet-5-20	Tension	5	20
Splinet-01-12	Tension	0,1	12
Splinet-1-20	Tension	1	20
Splinet-5-10	Tension	5	10
Splinet-20-10	Tension	20	10

Tab 2. Setting of the kriging interpolation method

Name	Method	SemiVar	Radius	Points
Krig-u-l-25	Universal	Linear	Variable	25
Krig-o-s-12	Ordinary	Spherical	Variable	12
Krig-o-s-25	Ordinary	Spherical	Variable	25

These 8 grids were interpolated using the settings mentioned above. The resulting DTMs were then tested, so that it could be found what setting is the most suitable for the studied area. To complete this evaluation we calculated the basic statistical characteristics and then applied RMSE. These values were calculated in relation to the remaining 15 % of points that were not included in the generation of the grids. This enabled us to check the accurateness of the grids in relation to the original data.

Spline with tension with weight 5 and number of points ten seems to be the most suitable method of terrain interpolation. It had the value of RMSE only 1.14. All results are shown in Table 3.

Tab 3. Comparison of interpolation methods. Sorted by RMSE.

Name	Min	Max	Mean	Range	SD	RMSE
Splinet-5-10	193	681	286	488	101	1.14
Splinet-20-10	196	681	286	484	101	1.18
Splinet-01-12	169	681	286	511	101	1.38
Krigu-l-25	92	677	286	585	101	3.01
Krig-o-s-12	199	679	286	479	101	3.09
Krig-o-s-25	199	677	286	477	101	3.71
Splinet-5-20	190	836	286	645	101	4.44
Splinet-1-20	184	681	286	496	101	4.48

3.3. Creation of DSM from DTM

The created digital terrain model must then be complemented with man-made structures and vegetation, so that it better corresponds to the reality and the results of the visibility analyses are realistic. Unavailability of

data became a limiting factor in the case of man made structures (data equivalent to the various buildings were not available for the whole study area), therefore resulting Digital Surface Model - DSM is more accurate in the area of Olomouc city and less accurate in surrounding areas. In these areas, data of blocks of buildings from DMU25 were used [15]. The height of buildings was calculated from the number of floors which was gained from address points of the Czech Republic.

Permeability in the winter

Because in the summer the vegetation presents a much greater barrier to visibility than in the period of vegetation dormancy, we took into account two alternatives of the input DSM. One for the summer when the "permeability" through vegetation is minimum, and one for the winter when leaves fall and visibility is much greater.

The best method, which would ensure data most corresponding with reality, would be creation of 3D models of separate trees in the winter and summer version. These models would be used right in the visibility analysis. Unfortunately nowadays GIS softwares don't support analyses of real 3D data and therefore some degree of generalization had to be accepted. The differences between winter and summer season were simulated by extraction of certain part of pixels from the layer of vegetation. Effect of this operation on the following analysis is quite equivalent to the reality. It is very important to find out the most suitable settings of pixels extraction. When we just chose certain percentage of pixels with cellsize 5*5 metres, the effect was hardly noticeable. Reason for this was small size of pixel in comparison with the width of the area which represents the linear vegetation. In this case shading of individual pixels appeared. Appropriate step was to resample the vegetation grid and after this extract part of pixels. Because this operation is quite timeconsuming, the season versions were made only for areas of vegetation which are not wider than 20 metres.

We created a random grid of three different cell sizes. The spatial resolution of the first variant was 25 × 25 m, the second 15 × 15 m, and the third was of the same spatial resolution as the DTM (5 × 5m). These random grids were then re-classified into several categories. In the winter alternative, we tested variants where 50, 75 and 85 % of pixels were deleted. In the summer alternative 25 and 35 % of pixels were deleted. These layers with random pixel values were then used to multiply the vegetation layer, where the permeability changes in relation to the time of the year. The total of 8 variants of the degree of permeability of vegetation were created and then compared with the reality. The CellSize setting of 15 × 15 m and the deletion of 75 % pixels was closest to the reality. In the summer alternative 35 % of cells were deleted.

To better simulate the differences between summer and winter, type of vegetation should be included when calculating results. Unfortunately, these data were not available. So it was not distinguished if the vegetation is cofinerous, broadleaved or mixed.

Results of analyses with different setting were compared with the real visibility captured by panoramic photography. On both map and photo, easily identifiable points (chimneys, natural peaks, groups of trees or alleys) were marked. Then it had to be stated whether the object marked as visible in reality is also marked as visible in map and vice versa.

4.   OBSERVATION POINTS

The Olomouc region is an area of relatively small segmentation. Nevertheless, there is a number of interesting places that can be determined as significant observation points. The selection of these points was made using the criterion of visibility from a given point, taking into account the accessibility of this point. Therefore, it was necessary to choose a compromise between elevation of the given point and its distance from roads, etc. The total of 40 observation points was selected, with a relatively even distribution over the region of Olomouc. We elected several categories of observation points. These are: natural places, sacral and technical buildings and potential observation points. The last category corresponds to places where

there is currently no view due to a vegetation barrier but where the situation would change after a construction of an observation tower.

In the case of sacral and technical buildings the elevation of the observer corresponds to the height of the observation deck, window of the church, etc. On the other hand, in the case of natural places the basic elevation of the observer is set to 2m above the ground. The work also resulted in a study on how the share of visible land would change if the elevation of the observer changed to 8, 15 and 30 metres. To better illustrate the height of the observation tower, as well as to increase the attractiveness of the visualization, we created 3D models of observation towers that correspond to the elevation of the observer and, at the same time, depict three different types of observation towers.

These models were created in freeware software Google SketchUp, which allows export of model to kmz format which can be visualized in Google Earth application.

5. ANALYSIS COMPUTATION AND GENERALIZATION

Most of the GIS softwares, which can work with 3D data, allow some visualization of visibility analysis. Ten freeware and commercial applications, which provide computing of visibility analyses, were chosen and compared.

Freeware aplications, used for comparison, were MicroDEM, AutoDEM, SAGA and GRASS GIS.

Difference between commercial and noncommercial applications was not in the quality of results or in the user interface (which was better arranged and provided more possibilities in noncommercial softwares). The biggest and fundamental difference was in the possibility to calculate results for large areas. Most of the noncommercial applications were not able to even display the digital terrain model of district of Olomouc. Other aplications could not compute Viewshed for this area. Despite this fundamental insufficiency, these applications had many positives, for example possibility to export results of visibility analysis to video. This makes it possible to watch the change of visible area depending on movement of observer point.

Commercial applications which were tested were ERDAS, IDRISI and ArcGIS 9.3 There were no significant diversities in the quality of outcomes. All three applications seem to use very similar algorithm and therefore their outcomes are almost identical

ArcGIS was chosen for computatuion of visibility analyses in the distric of Olomouc. ESRI announced support of real 3D objects as input data do viewshed analysis. If this was done, it could be possible to use for example 3D models of particular buildings, vegetation etc. as input layer to the visibility analyses and the results would be more accurate. Unfortunately this feature is eventually not suported in ArcGIS 10. Differences between applications sufficinet for analyses of large areas are only in the user interface.

5.1. Ways of conversion into KMZ

As we want to present the results in the Google Earth environment, we must find a solution of how to convert data into the KMZ format. There are three ways to do it.

Raster layer

The easiest solution is to use the function Layer to KML, which is offered by ArcGIS from the version 9.3 onward. It is possible to specify the resolution of the resulting overlaying image that will be represented in Google Earth. But there is a problem: when an image is bigger than approximately 10000 pixels, kmz is created but the Google Earth application does not depict it. Lower resolution leads to the loss of detail and, therefore, this export alternative cannot be used.

Raster tiles

The problem of insufficient resolution can be solved by using the MapTiler freeware application, which cuts the raster into so called Tiles and creates Super-Overlay. It is a pyramid loading of layers, i.e. layers with

a different level of detail (LOD). Using tile raster is suitable especially for the representation of old aerial photos, early maps, etc. Biggest disadvantage of this method lays in the huge amount of files which are created during export and thus make transfer of application very complicated. In our case, when the overlaying layer only has two categories, it is more advantageous to use the last possibility of export of data into KML, i.e. the conversion of vector data.

Vector layer

There are several methods to convert vector data into Google Earth. The above mentioned Layer to KML function offers the easiest solution. Various extensions can also be used. The freely accessible Export to KML is of high quality. This method also has its limits. No polygon can have more than 50 000 vertices or only outline is displayed. For the work in web environment it is also necessary to generalize output layers. However this method was the one most suitable one for our purposes (we export layer with only two categories) and therefore we chose this solution to represent visibility analyses

5.2.   Generalization

As has already been mentioned above, we chose export to KMZ as a vector. First, we had to convert the layer of visibility analyses from raster to polygons. The disadvantage of this procedure is that a huge number of polygons is created. The size of such a KMZ would limit the applicability of the whole application, which is intended to work in the Internet environment. On the internet, users have certain expectations. One of them is the speed of loading content. This is why we had to use generalization. ArcGIS enables the generalization of polygons by two methods. Aggregate Polygons and Simplify Polygons. None of the methods produces a result whose quality would be sufficient but which would, at the same time, be as small as possible. Therefore, we combined the two methods.

First step of generalization was Aggregating of Polygons with Aggregation distance set to 50 m, minimum area of 50 m^2 and minimum Hole size of 100 m^2. Using this function led to the greatest reduction in the size of file. Smoothing of generalized polygons was achieved by the subsequent application of Simplify Polygons method (with setting PointRemove and Offset of 1 m). The final size of individual visibility layers ranges from 500kB and 1,5MB.
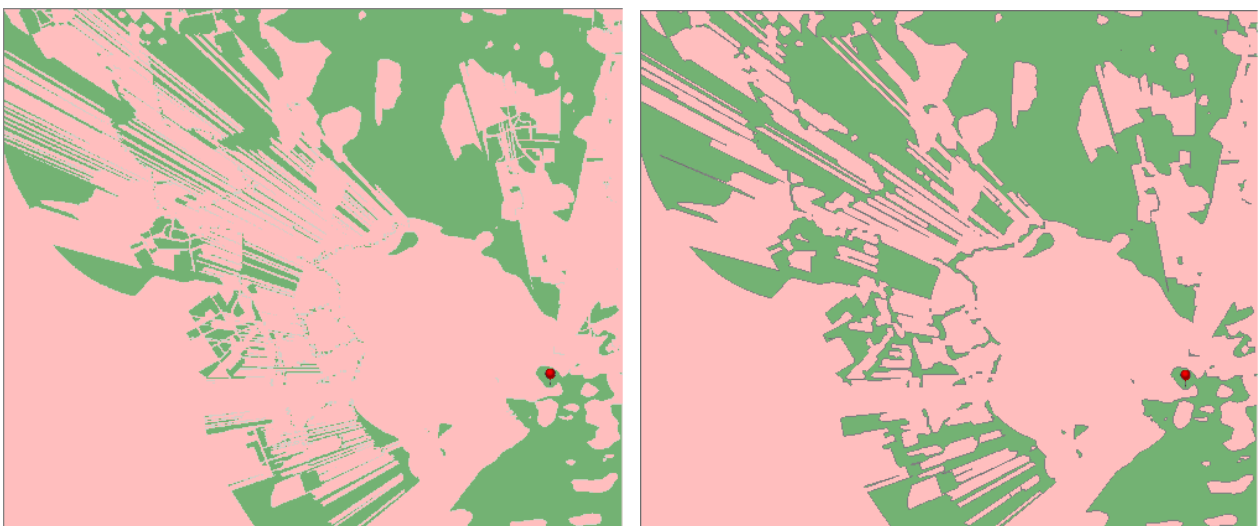

Figure 2: Comparison of original and generalized data

6.   VISUALIZATION OF RESULTS

Visualization capitalizes on strenghts of human perception abilities. The human brain has an impressive capacity for the understanding and assimilation of graphically presented information. The results of the viewshed analyses were visualized via Google Earth and Google API.

6.1.   Google API

The use of API presents the first method of visualization of the results. We chose the combination of Maps API and Earth API. The first alternative is advantageous especially because plugin does not need to be installed; the data are depicted directly in the window of an Internet browser [14]. The second advantage of this method is that there is the possibility to choose source data. To visualize information on observation points we created a point layer in the KML format. By clicking individual points the user can display basic information about the observation point and a photo gallery.

To represent the results of the visibility analyses we chose the method of JavaScript form which enables the user to select the observation point, time of the year, elevation of the observer, and whether they want circles of visibility to be displayed or not. After this selection a checkbox appears that enables the activation and deactivation of these layers. The transparency of visibility layers was set to 65%, so that the map base is visible.
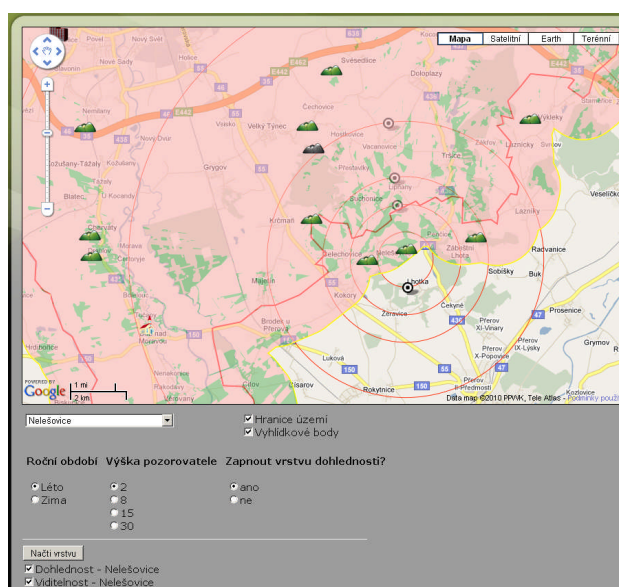

Figure 3: Illustration of the visualization of visibility analyses in Google Maps.

6.2.   Google Earth

Online tools, such as those pioneered by Google Earth, are changing the way in which scientists and the general public interact with three-dimensional geospatial data in a virtual environment [1]. It is possible to create a complex project with various types of multimedia content in Google Earth. Apart from higher speed, in comparison to API, Google Earth offers better functionality and better interface for the user. Compared to the version for Google Maps panoramic photos and 3D models of observation towers can be displayed.

There are three possibilities how to make links to KMZ files (outcomes of visibility analyses in our case) in Google Earth.

First possibility is to create a link to external webpage in the description of observation point. This external webpage contains a javascript form which allows user to select which layer should be displayed. This layer is then downloaded and visualized in Google Earth. It would be more suitable to put the form directly into the observation point description but this is not possible for technical reasons (description cannot contain javascript, iframe, etc.). The disadvantage of this method is unnecessary burdening of user by switching to an external site where user can choose what he wants to see.

Second possibility is creation of folder structure in the left bar of Google Eearth application. This structure would contain checkboxes and radiobuttons which would help user to set the layer which he wants to see.

This procedure is not suitable for large amount of layers. We have 40 observation points and thus the folder structure would be complicated and 'stretched.'

Last possibility is to put links to KMZ files directly to the description of observation points. User doesn't need to leave Google Earth environmnent. This method can only be used when there are not many outputs related to the observation point. In our case, eight visibility layers are peak value and therefore it is not a problem to insert the links into the description. If we had more layers, we would use the first possibility. In our case, third approach was chosen, thus placing a link directly to the description of each point.

After clicking the point a description is opened and the user chooses one of the links and the required layer is downloaded from the Internet and displayed. Apart from these visibility layers it is possible to display visibility circles for each point, a 3D model of one of three types of observation towers or a panorama photo. All these objects are displayed directly in the Google Earth environment as KMZ files. Example of visibility analysis visualization in Google Earth is shown on figure 4.
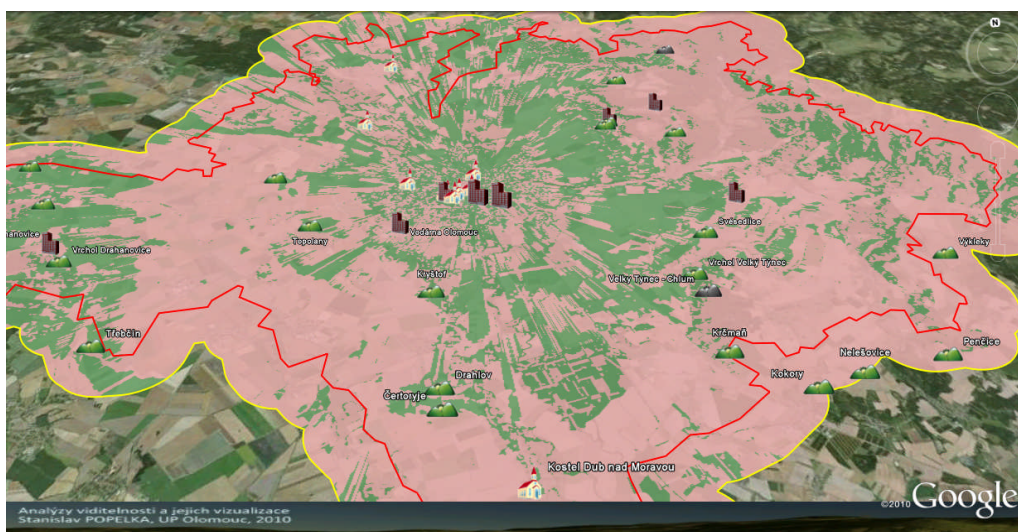

Figure 4: Viewpoint description in Google Earth.

7. CONCLUSION

This extensive study deals with the computation of analyses of visibility from significant observation points in the region of Olomouc. The main prerequisite to get high-quality visibility analyses was to create a digital terrain model of sufficient accuracy and complete it with man-made structures and vegetation. Two alternatives of DTMs were created, representing the landscape in the summer and in the winter. The total of 40 observation points was selected. If these were sacral or technical buildings, the elevation of the observer corresponded to the height of the building. If it was a natural hilltop, we computed the visibility in the current situation, as well as the visibility after a construction of an observation tower of 8, 15 or 30 metres.

Central part of the work is the visualization of the results that would be attractive and easily accessible to the users. We used the Google Earth and Google Maps API tools that enable the display of the output directly in the window of an Internet browser. In the case of Google Maps, the user can find the description and photos of individual observation points, and accedes to the results of the analyses via a form. In the case of Google Earth, there is a greater functionality and, moreover, it contains panoramic photos and 3D models of observation towers. Both types of visualization are accessible to the wide public at www.OlomouckeVyhledy.upol.cz.

REFERENCES

References from Journals:

[1] CHEN Aijun, LEPTOUKH Gregory, KEMPLER Steven (2009), Visualization of A-Train vertical profiles using Google Earth. Computers & Geosciences 35 (2009) 419–427

[2] GERMINO Mathew J.; REINERS William A.; BLASKO Benedict J.; McLEOD Donald, BASTIAN Chris T. (2001) Estimating visual properties of Rocky Mountain landscapes using GIS. Landscape and Urban Planning 53 (2001) 71-83

[3] GROOTHUIS Peter A.; GROOTHUIS Jana D; Whitehead John D. (2008) Green vs. green: Measuring the compensation required to site electrical generation windmills in a viewshed. Energy Policy 36 (2008) 1545–1550

[4] OGBURN Dennis E. (2006) Assessing the level of visibility of cultural objects in past landscapes. Journal of Archaeological Science 33 (2006) 405-413

[5] PARKS Lisa (2009), Digging into Google Earth: An analysis of "Crisis in Darfur". Geoforum 40 (2009) 535–545

[6] SANDER Heather A.; MANSON Steven M. (2007), Heights and locations of artificial structures in viewshed calculation: How close is close enough?. Landscape and Urban Planning 82 (2007) 257–270

[7] SEVENANT Marjanne; ANTROP Marc (2006), Settlement models, land use and visibility in rural landscapes: Two case studies in Greece. Landscape and Urban Planning 80 (2007) 362–374

[8] SHARMA, A.; TIWARI, K.N. (2009), Measuring the Accuracy of Contour Interpolated Digital Elevation Models, Journal of the Indian Society of Remote Sensing 37 (2009) 139-146

[9] SVOBODOVÁ, J, TUČEK, P: Creation of DEM by kriging method and evaluation of the results. Geomorphologia Slovaca et Bohemica 9 (2009) 53-60

[10] WINTERBOTTOM S. J.; LONG D. (2006), From abstract digital models to rich virtual environments: landscape contexts in Kilmartin Glen, Scotland, Journal of Archaeological Science 33 (2006) 1356-1367

References from Books:

[11] CALDWELL, Douglas R. (2004), Studies in military geography and geology. Dordrecht : Cluver academic publishers, 348p

[12] DODD, Howard Mannin. (2001), The Validity of Using a GIS Viewshed Function [online]. Blacksburg : Blacksburg, 49 p. Diploma thesis. Faculty of the Virginia Polytechnic Institute.

[13] ONDRÁČKOVÁ, J. (2009), Analýza Morfometrických charakteristik různých typů reliéfu. Olomouc, 40 p. Bachelor Thesis. Palacky University Olomouc.

[14] WERNECKE, Josie. (2008), The KML Handbook: Geographic Visualization for the Web. Addison-Wesley Professional, 368 p.

References from Websites:

[15] Digitální model území DMU25 [Dataset, CD-ROM] Dobruška. Vojenský topografický ústav Dobruška, 2003

[16] Viewshed Analysis, [cit. 2010-04-29]. [online]:<http://en.wikipedia.org/wiki/GIS_Viewshed_Analysis>.

[17] Random selection, [cit. 2010-11-29]. [online]:<http://arcscripts.esri.com/details.asp?dbid= 15156>