LANDSCAPE VISIBILITY ANALYSIS AND THEIR VISUALISATION

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ABSTRACT:

Visibility analysis or Viewshed is a common function of almost all GIS systems. The aim of this project is to find out the best solution, to compute viewshed for the Olomouc region and ensure the best way of visualisation 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. Visibility calculation is contained in a large number of software applications, but not all 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. One of them is the use of Google Earth. 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.

1. INTRODUCTION

Visibility analysis based on viewsheds is one of the most frequently used GIS analysis tools [4]. In the past, these analyses were used primarily for military purposes. With the spread of GIS in the private sector there emerged a wide range of uses in many spheres of human activity. One of them is the use of GIS in tourism. And it is this sector where the results depend on the manner of visualisation of the results. 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. The project deals with visibility analyses in the region of Olomouc. This region has a great potential, which can be documented, among others, by the fact that last year an observation tower was constructed in the town of Přáslavice and, this year, construction of an observation tower will start on the Velký Košíř hill. The authors believe that the results of the study can 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.

2.1 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.

2.2 Viewshed

Viewshed is created over a DTM 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". [17]

2.3 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?" We can illustrate this functionality with an example: Several important buildings are analysed (e.g. churches) and it is examined from what places in the area of interest the highest number of these buildings ïs visible at the same time. The Visibility command also enables a visibility analysis using a line theme. A detailed examination of the result shows that it is only a combination of the visibility from individual break points in the line. [18]

3. USE OF VISIBILITY ANALYSES

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 are also highly important for the reconstruction of historical military operations.
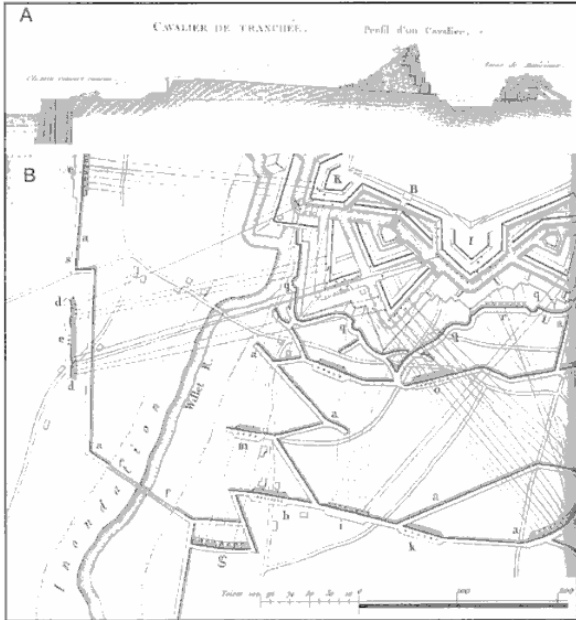

Figure 1. One of the first examples of the use of Line Of Sight and Weapon Fan. The siege of Ath in 1706. [11]

Visibility analysis is widely applied to military and project fields, of which viewshed computing is the important factor [10]. They are employed, for example, in radio communication, localization electrical generating windmills [3], as well as in archaeology [9], spatial planning [7] and many other spheres of human activity.

3.1 Communication

In radio communication the term "Commshed" or "Communication Viewshed" is used. There is also one term specific to this field: "Fresnel zone". Even though the straight line connecting the transmitter and receiver antennas is free, it is necessary to have sufficient free space in the area that surrounds this line; this area is represented by the first Fresnel zone. If this area is not empty, the signal is always attenuated. Fresnel zone has the shape of a rotating ellipsoid [19].
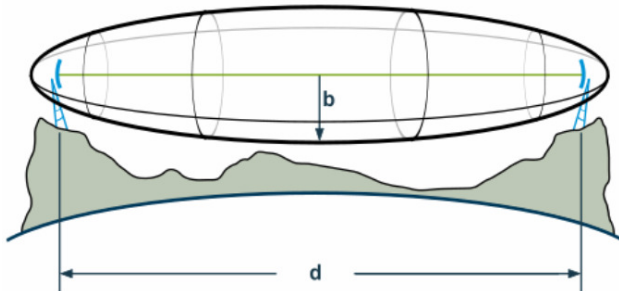

Figure 2. Fresnel zone. The value *d* is the distance between the transmitter and the receiver, *b* is the radius of the Fresnel zone. [19]

To analyse the spread of radio signal the ArcGIS application Cellular Expert can be used.

3.2 Spatial planning

In spatial planning visibility analyses are often used in the case of construction of industrial areas and similar extensive structures. The computation of visibility can determine to what extent the view of the surrounding skyline will be blocked, etc. The analyses are also often used for the visualisation of wind plants. One can determine not only where the planned structure is visible from, but also how this area might change when using different types of wind plants. These studies are often supplemented by photo visualization or a viewpoint study, so that the impact on the change of the panorama is represented as illustratively as possible.

3.3 Other uses

Visibility analyses can also be used, for example, in tourism. Apart from the areas dealt with in this paper they can be used to monitor e.g. the visibility of historical trails, as done by the project of Rock Springs Field Office in Wyoming. In this case, compared to the previous applications, viewshed on a line, not point, was used. Visibility analyses are not limited only to the Earth, as can be shown by the USGS project that uses visibility analyses for places where the modules Spirit and Opportunity plan to land during their exploration of Mars, which is part of the project Mars Exploration Rover.

4. CREATION OF A DIGITAL SURFACE MODEL

4.1 Creation of a DTM

In terms of accuracy and reality of the output of visibility analyses, the quality of input digital terrain model is the most significant element. It is important to base the process on sufficiently accurate elevation data, as well as to choose a suitable interpolation method and its setting. Nevertheless, it is not certain that the result will be satisfactory. The terrain also contains man-made structures, vegetation, forests, etc. 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. That is why the terrain was interpolated from contour lines with the basic interval of 5m, then adding man-made structures, forests and line vegetation.

Preparation of input data

The DTM was interpolated from contour lines that were subsequently converted from lines into points using the ArcGIS 9.3 command Feature to Vertices. This step was necessary because out of all interpolation methods only the Topo to Raster tool enables the use of a line layer as input data. However, this method is not accurate enough. We chose the Split Sample Validation method to test the accuracy of the digital terrain model. This method enables the selection of a given group of points that does not enter the interpolation and that serves for the comparison of the original (input) and the computed values. The Random Selection tool is usually used for the selection. The ratio of points that will enter the interpolation and points that will be used to check the correctness of the computed DTM was determined as 85:15. This ratio was selected, because 15% of points is enough to check the validity of DTM.

Comparison of interpolation methods

Svobodová [8] argues that the three most frequently used methods of spatial interpolation of grid DTM are the methods of IDW, Kriging and Spline. Ondráčková [13] also compares these three methods. 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. This means that in our 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 checked points.

First, the area of interest was divided into squares with the length of their sides of 4km, using a script for ArcView GIS 3.3. Then, the highest and the lowest points were determined in these squares and the difference between them calculated. Thus, we got the value of relative relief division.
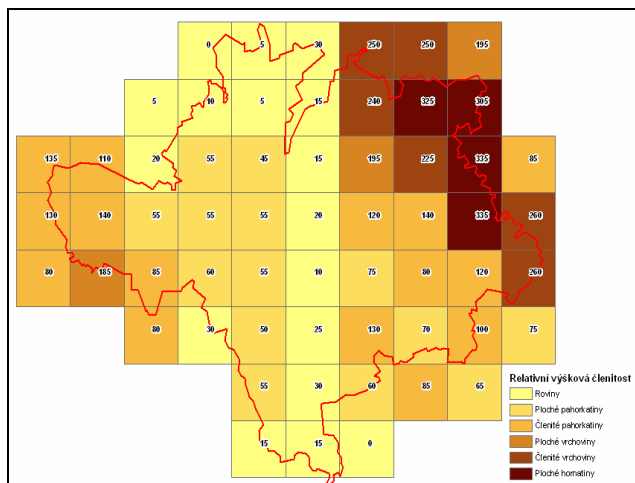

Figure 3. Relative relief division in the area of interest

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 [13]. The resulting grids were tested by the RMSE method and the grid with the best result was then used as a DTM for the visibility analyses.

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

Table 1. Setting of the spline 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

Table 2. Setting of the kriging interpolation method

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. The results are shown in Table 3.

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

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

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.

4.2 Creation of layer of man-made structures

According to [6], it is necessary to accurately identify building footprints and heights. For the purposes of the study we used data on blocks of buildings without their attributes. A polygon layer representing the building floor plans was another layer that was available, but only in the area of the city of Olomouc. Both layers were combined, i.e. the resulting DSM is more accurate in the centre of Olomouc than outside the city boundaries. The absence of the attribute corresponding to the height of the buildings outside Olomouc posed a problem. We got this information from the point layer of address points for the whole area and from a dbf table that contained technical parameters of the buildings. Address points do not contain direct information on the height of the structure but they contain the number of floors of each building. These data and the data on the age of the buildings and their use (in the technical parameters of the buildings) were used to determine an approximate height of the polygon (block of buildings) on the given coordinates.
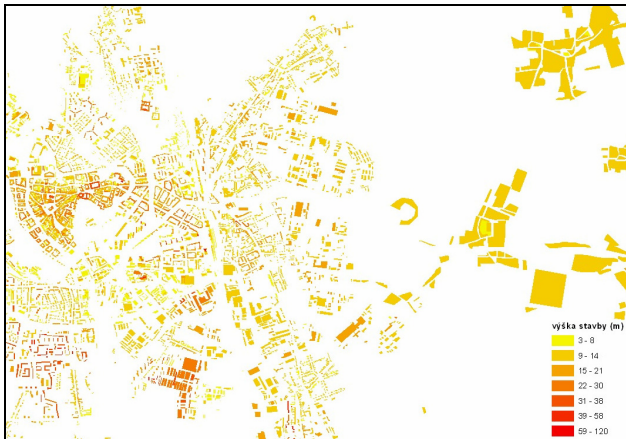
Figure 4. Illustration of a layer of man-made structures. Difference in the accuracy of data in the city of Olomouc and outside it.

4.3 Creation of layer of vegetation

We contacted the Forest Management Institute and asked them for forest management plans. These contain data on the medium tree height (in metres) for each group of forest type. This enabled us to supplement the digital terrain model with a relatively accurate height of the forest. After comparing these data with an ortophoto image we found that there was an absence of small groups of trees but, first and foremost, line vegetation around rivers or roads. These can have major influence on the visibility analysis. Therefore, these data were digitised over an ortophoto image.

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. We created a random grid of three different cell sizes. The spatial resolution of the first variant was 25×25m, the second 15×15m, 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 15×15m and the deletion of 75% pixels was closest to the reality. In the summer alternative 35% of cells were deleted.

5. OBSERVATION POINTS

5.1 Selection of 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. We selected these points using map data in combination with field research and our knowledge of the local territory. 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.

5.2 Elevation of the observer

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 visualisation, 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.

6. ANALYSIS COMPUTATION AND GENERALISATION

As has already been mentioned above, we used ArcGIS 9.3 with 3D analyst to compute the visibility analyses. The Viewshed dialogue box does not offer any setting, only the field for the input layer, i.e. DTM and point layer that represent the location of the observer. All other setting is specified via a record in the table of the point layer. In our case, the point layer contained only the OFFSETA data that specify the elevation of the observer.

6.1 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. 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. We chose this solution to represent visibility analyses.

6.2 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. [15] 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.

Figure 5. Comparison of original and generalized data.

7. VISUALISATION OF RESULTS

Visualisation capitalizes on strenghts of human perception abilities. The human brain has an impressive capacity for the understanding and assimilation of graphically presented information [14]. The results of the viewshed analyses were visualised via Google Earth and Google API.

7.1 Google API

The use of API presents the first method of visualisation 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 [16]. The second advantage of this method is that there is the possibility to choose source data; the user can select a map, a satellite image or a representation of terrain. To visualise 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.
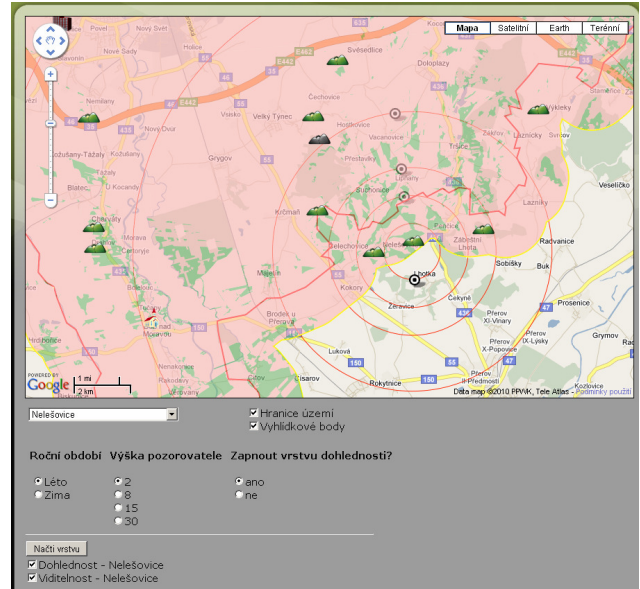

Figure 6. Illustration of the visualisation of visibility analyses in Google Maps.

7.2 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. An example of the project is Chrisis of Darfur [5].
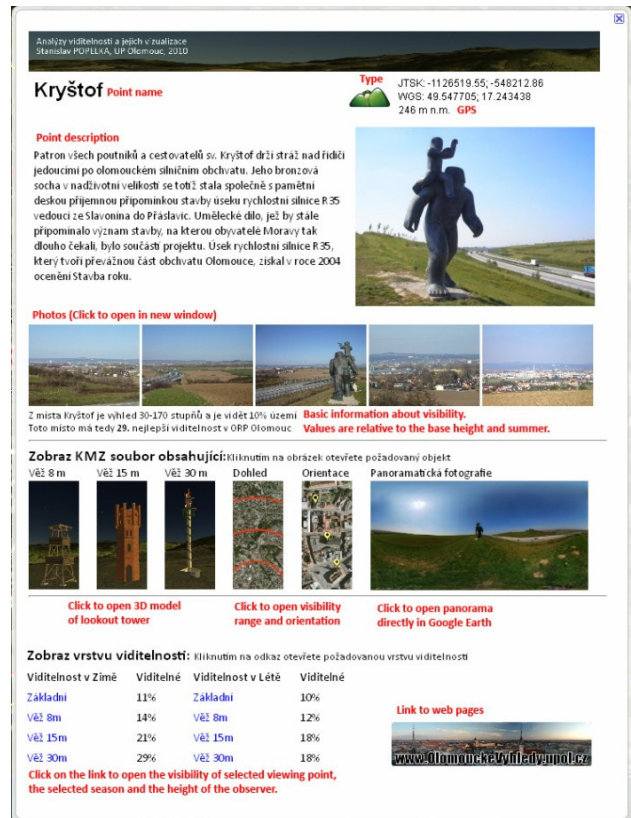

Figure 7. Viewpoint description in Google Earth.

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. Links to KMZ files that contain the results of the visibility analyses are placed directly in the HTML description of individual points. The user can, therefore, select a point directly in the map.

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. For description of one of the observation points see Figure 7.

8. 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 visualisation 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 visualisation are accessible to the wide public at www.OlomouckeVyhledy.upol.cz.

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