Journal of Mobile Multimedia, Vol. 11, No.3&4 (2015) 181-192


# VIRTUAL 3D RESTORATION OF AN EXTINCT VILLAGE AND ITS EYE-TRACKING ASSESSMENT

PAVLA DEDKOVA STANISLAV POPELKA

*Palacký University in Olomouc, Czech Republic*

*pavla.dedkova@gmail.com standa.popelka@gmail.com*

The objective of the project was to create 3D visualization of an extinct village and its evaluation using eye-tracking. As an area of interest, the extinct village of Čistá was selected. The village was located in Karlovy Vary Region in the Czech Republic and was destroyed in 1948. The village was destroyed to primarily to establish a military training area. Secondly, it was destroyed to create an instructional video for military purposes called "Fight in the settlement". During the creation of this video, the village was destroyed.

The main content of the project was to create an interactive web application that includes a 3D model of the extinct village of Čistá. As base data, aerial photos made in 1947 and stable cadastre from 1841 were used. Buildings were made according to historical photographs and screen shots from the instructional video "Fight in a settlement." The resulting 3D model and underlying data were loaded into Google Earth API and are available for the general public now.

The second part of the project was to test the model usability using eye-tracking. In total, 28 respondents participated in the experiment. The experiment contained two parts – the overall views of the village and tasks, where users were searching for a particular building. Recorded eye-tracking data were statistically and graphically analyzed. The results indicate that a 3D model was the most usable type of visualization for respondents.

A link to the application was placed on the web site of the project of an educational trail about extinct villages in the Slavkov Forest area. The created 3D model and application present the extinct village of Čistá to potential visitors of the educational trail.

*Key words*: 3D, Visualization, Reconstruction, Eye-tracking, Cartography

## 1 Introduction

Three-dimensional visualizations are well-established for the presentation of maps or landscape models. Today, the need to present three-dimensional (3D) cartographic content on computer monitors is growing and the possibilities for these presentations are increasing [3]. Because the world is three-dimensional, the perception of 3D information is more natural and; therefore, in some cases, the 3D visualization is more effective than 2D.

Visualization of historical objects, cities and landscapes are used in many fields of human activity, but especially in archaeology and tourism. However, most of the projects set aside the possibility of comparing historical state with present state. Thus, the user loses connection to reality and then it is hard to imagine where the objects stood. Geovisualization is more illustrative when it contains georeferenced historical maps overlaying the current orthophotomap.

Aside from a digital representation of the contemporary state, which can be used e.g. for educational purposes (case study at castle Kozel [11]), it is possible to use 3D maps to represent the historic city's face (e.g. Langweil model of Prague [16]) or view of the country (e.g. Switzerland in the 18th century [18]).

The most perfect and also the most difficult digital representation of reality is the photorealistic 3D model. With the digital reconstruction of defunct buildings, it is often very difficult to find relevant historical documentation of the exact dimension and shape of the object. In the case of modelling non-existing objects, only empirical techniques can be applied with the use of historical plans, photographs or archaeological research results.

A large amount of techniques for 3D the digitization of objects exists. The most popular methods are laser scanning and terrestrial photogrammetry. These methods are very expensive and cannot be used for the modelling of extinct objects. In this case, it is necessary to use so-called empirical techniques. The model parameters are then based on historical documents, plans or archaeological research.

## 2 3D models of the historical state of the area

When creating a historical view of the town, data for important buildings and structures are usually available. In most cases it is problematic to find information about regular structures and houses in town, but these structures create most of the area of the town and are important for modeling.

For example, the virtual reconstruction of the historical part of Livorno [4] is an important project which had the objective to create a virtual reconstruction and visualization of the urban development of the city. The model was created in three levels of detail and was presented to the audience as a non-interactive stereoscopic film. In Australia, the visualization of "City as might be" was created [5]. The city in question was Melbourne, which, as well as many others, went through major rebuilding in 1860s. Two blocks in the center were chosen for testing the procedure. The resulting VRML model showed the present and former buildings in one model. A virtual variant of the 3D model of the entire town was in the focus of the project Rome Reborn [6] carried out by experts from Italy and the USA. During the project, the city of Rome was completely created in 3D as it was in 320 BC. The buildings were modelled in height detail, despite the fact that most buildings there have not been an accessible source of information about how these buildings looked like.

### *2.1 3D models of extinct areas*

The creation of 3D models of extinct areas has its specifics and problems. Most of it is caused by the lack of documentation and consequent inaccuracy and uncertainty of created model. This kind of visualization is suitable for viewing of the modeled area as a whole and getting the idea of its configuration and usage of space.

Přemysl Štych at Charles University in Prague has devoted himself to problems of visualization of extinct areas. Under his lead, several studies with different area scope, processing procedure and visualization capabilities were created. Oktábec [19] investigated the 3D reconstruction of the area of middle Povltaví area. Animations of the area were created with special attention on differences in the extinct landscape due to the construction of Orlík dam. Jelének [12] investigated the visualization of the areas of the extinct villages of Padrť and Zadní Zaběhlá in the military area Brdy and of Košťálov village near Czech-Austrian border. The work was focused not only on built-up area, but also on overall view of selected area. Košťálov is one of the villages located within the newly planned cycling path after the extinct villages in the Czech Canada. The trail gradually creates a cycling path of a few extinct villages on both Czech and Austrian side of the Iron Curtain and is implemented by the Centre for the Future based in Slavonice [15]. Koucká [13], in her work "3D reconstruction of extinct part of city Dobříš", compared the options of creation and export of 3D objects in Google SketchUp and Bentley MicroStation softwares. Chosen extinct parts of the square of the city were documented very well, which is the reason why the model seems very authentic and impressive.

Project GEPAM [17] is the activity of the University of Western Bohemia and the Technical University of Dresden that reminds victims of Holocaust. As a result of this project, a virtual 3D model of the Main Fortress and the Small Fortress of Terezín and the historical part of the city of Dresden was created. The model reflected the state of the area in the period of the Second World War. The model contained not only the geometry but also included related descriptive data about each structure. As there was a huge amount of data, visualization with the use of different Level of Detail was used for the geometric spatial part. The 3D model will be presented partly online and partly through local information kiosks in the City Museum in Dresden and in Terezín Memorial [7].

## 3 Extinct villages in Bohemia

Czech borderland is one of the areas where numerous villages went extinct and thus the characteristics of local landscape were changed. Until now, these extinct villages were of interest from an archaeological and historical point of view. According to contemporary sources, around 130 villages, almost 3 000 settlements and almost another 50 000 uninhabited structures were abandoned during 1945–1960 [14].

The objective of the project was to visualize the extinct village of Čistá (Lauterbach), located in the Prameny military area. The military area was established for military-strategic and training reasons. Its foundation was confirmed on May 5$^{th}$, 1946 by the Czech government. The military area was 361 km$^2$ and included 44 villages. The siege of towns and villages, cooperation of tanks and infantry were the main tasks being trained in the area. Čistá village was shot down during training assault. During this training, the military training film "Fight in a settlement" was made. This film became one of the sources of information used for the creation of 3D model of the settlement.

## 4 Visualization of the extinct village Čistá

The aim of the project was to create a 3D visualization of the extinct village of Čistá. The resulting web application includes a georeferenced 3D model of the village and two underlying maps of the area.

### *4.1. Data*

Due to the fact that the village became extinct more than 60 years ago and its extinction was not planned in the long term, there is not much information available. As the base data, aerial photos taken in 1947 and the Stable Cadastre from 1841 was used. Buildings were made according to historical photographs and screen shots from the instructional movie "Fight in a settlement". These documents were provided by the Regional Museum in Sokolov. In the Archive of the Czech Office for Surveying, Mapping and Cadastre (hereafter referred to as ČÚZK) in Prague, the Imperial Imprint of Stable

Cadastre from 1841 was found. Unfortunately, no maps and/or foundations from later sources were available.

Another source of data was the Military Geographical and Hydro Meteorological Office in Dobruška (hereafter referred to as "VGHMÚř"). Aerial imagery in the ČR was conducted in 1935, but between 1947 and 1956 aerial photographs were used in greater extent for the creation of the map for the first time. Čistá village was imaged for the first time during 1947. Imagery was made before the destruction of the village, which was crucial for the creation of the model. The location of the buildings in the village, roof projections and shapes of the roofs were derived from the aerial image. A Summary of all used data sources is in Table 1.

Table 1. Data used for the creation of the model

| Data | Provider | Year |
|---|---|---|
| Stable Cadastre | ČÚZK | 1841 |
| Aerial photograph | VGHMÚř | 1947 |
| Photos of the village | Internet | 1920-1940 |
| Video "Fight in a settlement" | Ing. Rudolf Tomíček | 1947 |

Input data were transferred in ArcGIS 9.3 software and georeferenced to WGS84 coordinate system. Then MapTiler software was used and the aerial photo and Stable Cadastre were converted to .kmz format. Subsequently, both layers were loaded into Google Earth API.

### *4.2. 3D Model*

Čistá village consisted of 210 structures. Six of them were more significant: church, rectory, memorial, school, town hall and cemetery. All these buildings were documented, so it was possible to model them in greater detail than other houses in the village. Approximately 25 % of the structures were created using photographs or screenshots from videos. Majority of these buildings were located in or near the town square. The map in Figure 1 indicates which buildings were modeled using available sources and which were created only according to the aerial image.

Software Google SketchUp 7 was used for modeling. The foundation for every structure was its projection. That was taken from LMS or Stable Cadastre. The documented buildings (except those six important structures) were modeled first. At the beginning, the ground plan was derived from the aerial image or cadastral map. The shape of the roofs was also derived from the aerial image. The height of the buildings was deduced from the stretch of photographs over the width of the building with fixed proportions. For buildings with no photographs available, the height was assessed using overviews of the village and also according to the height of the surrounding buildings. The roofs were consequently modeled as well. Roof shapes were all well-recognizable from the aerial image.

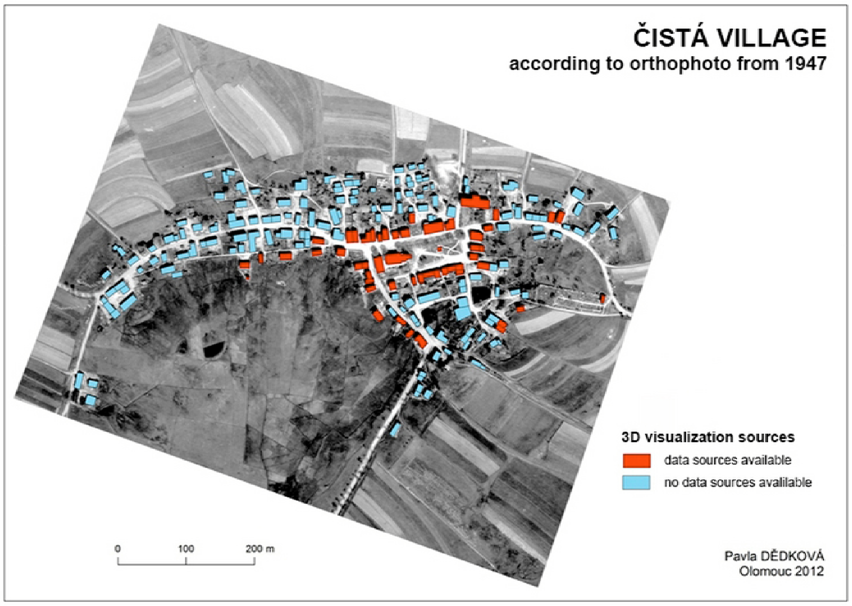


Figure 1. Map of Čistá village. Buildings that had data available are highlighted in red.

Figure 2. Comparison of the historical photo (up) and resulting 3D model (down)

Most of the documentation and sources were black and white; therefore the resulting model was decided to be black and white as well (see Figure 2 and 3). In order to create more authentic experience, textures were used for all structures. Textures were taken either from specialized web site or from images of Horní Blatná village, whose build-up is similar to Čistá. All textures were first converted to gray scale and then shrank due to size optimization of the resulting model. In total, 64 different doors, 70 windows, 66 roofs, 65 facades and 18 types of planks for wooden forefronts of some houses were used.

At the end of the modeling, significant buildings (church, rectory, memorial, school, town hall and cemetery) were created. These buildings were modeled in greater detail than other buildings in the village because more detailed documentation was available. Exact ground plans have been found for the church. Windows and doors were processed in more detail by adding plasticity. Also, the wall and fence were created around the school, the town hall and the church.

Figure 3. 3D model of the church


Figure 4 Web application interface

## 5 Web application

One of the project's objectives was to enable access to a model of extinct villages to the general public using Internet. This goal was crucial because results of most projects that are dealing with similar topics are not publicly available. One of the possibility how to get these models closer to the public is to publish it through 3D Warehouse. For this project, a solution from Google was used. Google Earth API offers maximum utilization of the potential of Google Earth and its 3D rendering capabilities on web pages. For final visualization of the entire model in Google Earth environment, export into .kmz format was necessary. Before the export itself, the model was divided into four parts – north, south, west and town square. This solution was used due to data requirements that caused slow loading of the model in Google Earth API (Figure 4). The application is simple and contains only checkboxes for the display of different layers (four parts of the model, orthophotomap from 1947 and Stable Cadastre) and a button for return to the original coordinates. The resulting web application is available to the general public at http://geoinformatics.upol.cz/dprace/bakalarske/dedkova12//aplikace.html

## 6 Eye-tracking evaluation

The second part was to test the model usability using eye-tracking. Eye-tracking technology is based on the principles of tracking movements of the human eye while perceiving the visual scene. A measurement device used for measuring eye movements is commonly known as an eye-tracker. Eye-tracking is one of the methods of usability studies and is considered as objective/non-biased because it is not influenced by the opinion of respondents as the other methods (e.g. questionnaire) [20].

Most of modern eye-trackers measure the eye position and gaze direction using remote methods, which rely on the measurement of the pupil and corneal reflection of a closely situated direct infra-red light source. The reflected light is recorded by a video camera or some other specially designed optical sensor. The information is then analyzed to extract eye rotation from changes in reflections [2].

SMI RED 250 remote eye-tracker was used in the study. The device has a sample frequency of 120Hz, so it records eye position every 8 ms. The human eye performs several types of movements. The most important are fixations and saccades. During a fixation, eyes are relatively steadily looking at one spot in the visual scene. Irwin [9] states that the average fixation duration is between 150 and 600 ms. The transition between the two fixations is known as a saccade. This movement is extremely fast. Saccades usually take from 30 to 80 ms and humans are almost blind during the saccade [8]. Example of eye-tracking data visualization with the use of attention map method is shown in Figure 5.

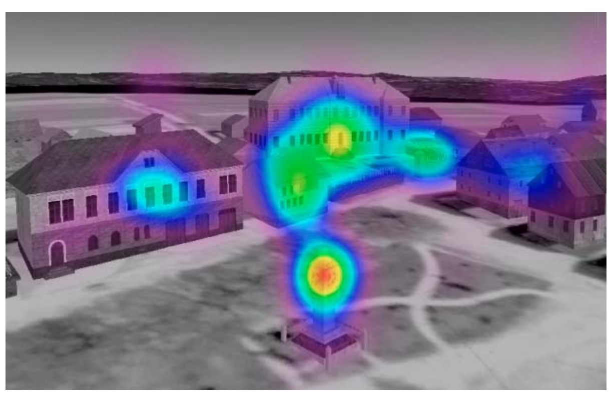

Figure 5. Sample of graphical output from eye-tracking as an Attention map

A total of 28 respondents participated in the experiment. As stimuli in the experiment, static images of the 3D model of the extinct village of Čistá were used. The experiment contained two parts. In the first one, respondents had to look for 4 seconds at the overall views of the village without any task. For these stimuli, fixation length and count were analyzed. During the second part of the experiment, respondents had to find out a particular building in the village as fast as possible. For targets, significant buildings in the village were used (church, school, etc.). Data recorded in this part of the experiment were analyzed with the use of Areas of Interest (AOI).

At the beginning, overall views of the village (Figure 6) were analyzed. For the purpose of this paper, three stimuli, showing different visualizations of the South-East view of the village, were analyzed. Each image was shown to the respondents for 4 seconds. The image order was random. Two most common eye-tracking metrics were evaluated - Fixation Count and Fixation Duration.

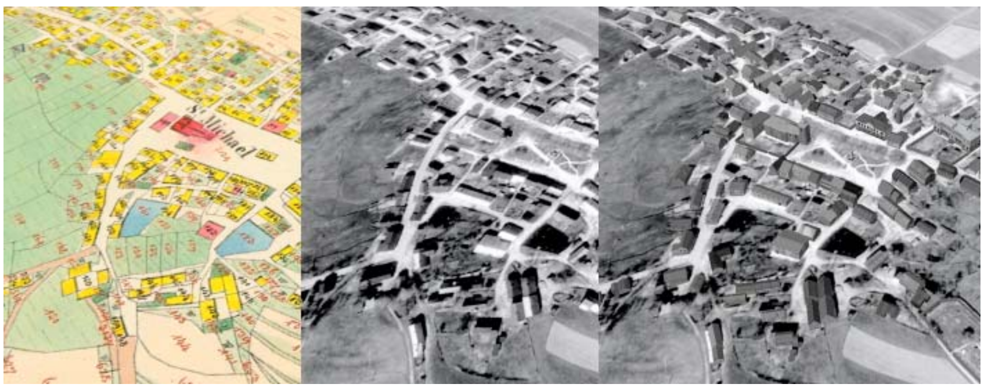

Figure 6. Stimuli showing a view of the Čistá village from the southeast in three versions

In Figure 7, the average number of eye fixation of all 28 respondents when watching the overall view of the village from the southeast was plotted. Each column represents one version of the shown stimulus - cadastral map, orthophotomap and 3D model. In Figure 8, the average duration of eye fixation is shown.

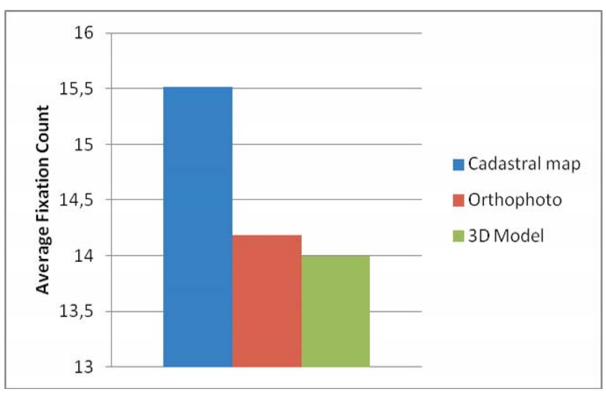


Figure 7. Plot showing the average fixation count for 28 respondents

The number of fixations and fixation duration are very common and often used eye-tracking metrics. A larger number of fixations indicates less efficient search possibly resulting from a poor arrangement of display elements [10]. From the graphs (Figure 7 and 8), the smallest number of fixations and highest fixation length observed for the 3D model version of the stimulus are visible. For the 3D model, a smaller number of longer fixations were observed, which indicates deeper perception.

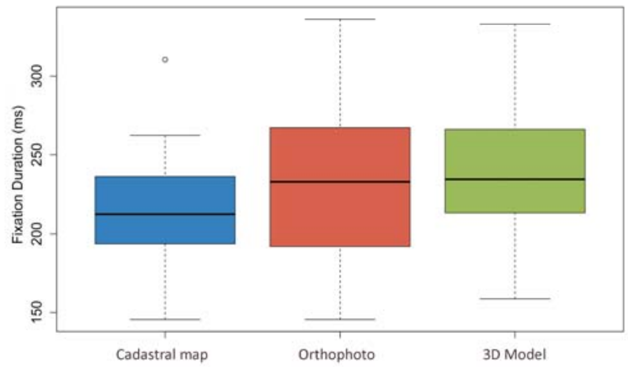


Figure 8. Boxplot showing Fixation Duration for 28 respondents

Data were statistically analyzed with the use of ANOVA and TukeyHSD. Statistically significant differences were observed for the Fixation Duration metric between Cadastral map and 3D model. These results showed that respondents' eyes roam from place to place in the case of the cadastral map and that the 3D model was the most useful tool for the visual search.

Table 2. Results of ANOVA for the eye-tracking metric Fixation Duration and three types of visualization (Cadastral Map, Orthophoto, 3D model).

| **Fixation Duration** | **diff** | **lwr** | **upr** | **p adj** |
|---|---|---|---|---|
| **Orthophoto - Cadaster** | 19.49881 | -6.80240 | 45.80002 | 0.18633 |
| **Cadaster – 3D Model** | 28.17788 | 1.87667 | 54.47909 | **0.03283** |
| **3D Model - Orthophoto** | 8.67908 | -17.62214 | 34.98029 | 0.71181 |

For visual data analyses, a method called FlowMap introduced by Andrienko et al. [1] was used. For the creation of this eye-tracking data visualization method, the software V-Analytics (a.k.a CommonGIS) developed at the Fraunhofer Institute in Germany was used. Flow Map represents results of discrete spatial and spatio-temporal aggregation of trajectories. Arrows represent multiple movement of gaze from one location to another. The thickness of arrows is derived from variable number of moves between defined voronoi polygons. Only arrows representing more than three moves are displayed. From Figure 9, it is visible that in the stimuli with the Cadastral map and the 3D model, the respondents' gaze corresponds with the streets of Čistá village.

The second type of tasks in the experiment dealt with the finding of a particular building in the village. In this paper, a pair of two stimuli (orthophoto and 3D model) is presented. In both images, the task was to find "School building". The respondents did not know the village, so their task was to guess, which building could be the school (larger building, near the square, etc.). Data were analyzed with the use of Areas of Interest (AOI). These areas were marked around all important places in the stimuli, as well as around blocks of building around the square. The result of the analysis is shown in Figure 10. Red circles with numbers represent the total number of fixations recorded in the particular AOI. Yellow arrows represent the number of fixation transitions. In the case of the orthophoto (left), the highest number of fixations (64) was recorded in the AOI representing the block of buildings in the south. A relatively high number of fixations (23) was recorded in the area of the pond in the bottom part of the image. In the case of the stimuli with the 3D model (right), only four fixations were recorded in the pond AOI. The most frequently visited AOIs were the town hall (52) and school (41). Both buildings look important and it was not possible to recognize which one represents the school. From this analysis it is evident that 3D visualization was much better for solving the task. Also, the total number of fixations was smaller for the orthophoto stimuli – 285 fixations versus 371 for the stimuli with the 3D model.

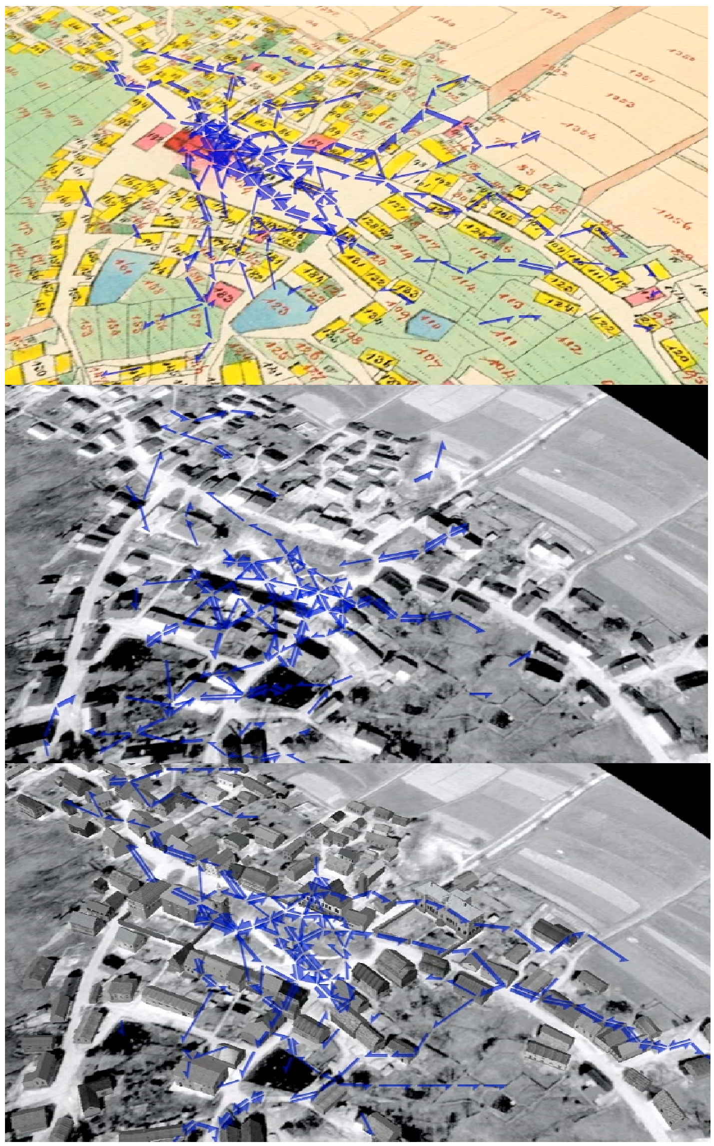

Figure 9. Visualization of recorded eye-movement data with the use of FlowMap method. In all three cases, the same settings of the method was used (5;0;5;25;r=25). Only arrows representing more than three moves are displayed.

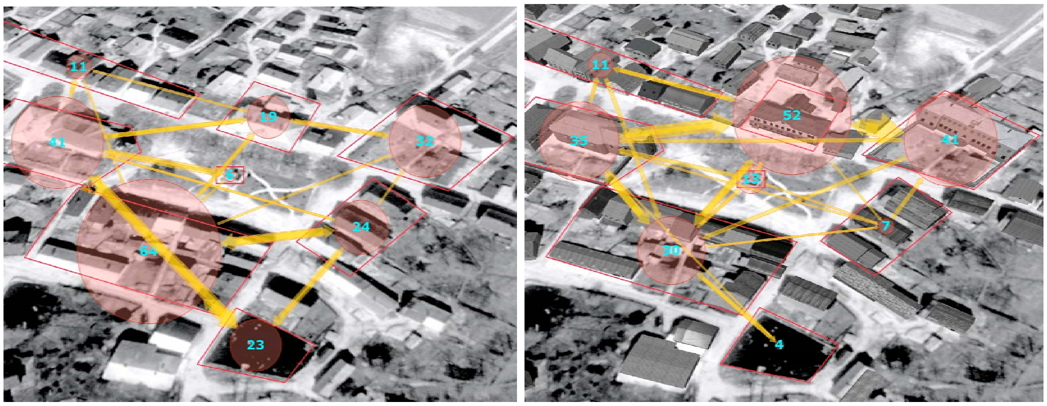


Figure 10. Result of the AOI analysis of orthophoto (left) and 3D model (right) stimuli. The task was to find "School" as fast as possible. Red circles with numbers represent the total number of fixations recorded in the particular AOI. Yellow arrows represent the number of fixation transitions.

## 7 Conclusion

The main objective of the project was to create a 3D model of the historical condition of the extinct Čistá village. The model was then published using an interactive web application. The second part of the project was the testing of user perception of the resulting 3D model with the use of eye-tracking.

During the creation of the model, 210 buildings were made. Textures were used on all of them - plasters, windows, doors and roofs. The whole model is in black and white because of the underlying data (aerial image) which is also black and white. The link to the application was placed on the web site of the project of an educational trail about extinct villages in the Slavkov forest area. The model and application were mentioned in the documentary program of Czech Television. Several descendants of former residents had contacted the author of the model after the broadcast of the program. The created 3D model and application present the extinct village of Čistá to visitors of an educational trail.

The second part of the project was the evaluation of user perception with the use of eye-movement recording. Two most often used eye-tracking metrics (Fixation Count and Fixation Duration) were investigated. A set of three stimuli (Cadastral map, Orthophoto and 3D model) with the view of the image from the South-East were investigated. The highest number of fixations was observed for the cadastral map, the lowest for the 3D model. Between these two types of visualization, the statistically significant differences were observed with the use of ANOVA. These results showed that the respondents' eyes roamed from place to place in the case of the cadastral map and that the 3D model was the most useful tool for the visual search. Eye-tracking data were visually analyzed with the use of FlowMap method, which displays data as spatio-temporal aggregation of trajectories from all respondents. In the last part of the eye-tracking data analyses, the pair of stimuli was analyzed. In that case, the respondents had to find "school" as fast as they can. From AOI analyses it is obvious that the 3D model was more useful for this task than the orthophoto.


## Acknowledgements

The paper has been completed within the project CZ.1.07/2.3.00/20.0170 "StatGIS" and IGA_PrF_2014007, which are co-financed from European Social Fund, State financial resources of the Czech Republic and Palacký University in Olomouc.

**References**

1. Andrienko, G., Andrienko, N., Burch, M, Weiskopf, D., Visual Analytics Methodology for Eye Movement Studies. In IEEE Transactions on Visualization and Computer Graphics, Vol. 18, Issue 12. 2012.
2. Brychtová, A., Popelka, S. and Vozenilek, V.: The analysis of eye movement as a tool for evaluation of maps and graphical outputs from GIS. Geography and Geoinformatics: Challenges for practise and education. Masarykova univerzita. 2012.
3. Buchroithner et al. Lenticular Creation of Thematic Multi-Layer-Models, Proceedings of GeoViz Workshop, Hamburg, Germany. 2011.
4. Carrozino, M. et al., The Immersive Time-machine: A virtual exploration of the history of Livorno, Proceedings of 3D-Arch Conference,Trento, Italy. 2009.
5. Cartwright, W.E., Using 3D models for visualizing “The city as it might be”, Proceedings of ISPRS Technical Commission II Symposium, Vienna, Austria. 2006.
6. Guidi, G., Frischer, B., Lucenti I., Rome Reborn - Virtualizing the ancient imperial Rome, Proceedings of the 3D Arch 2007, Trento, Italy. 2007.
7. Hájek, P., Jedlička, K., Kepka, M., Fiala, R., Vichrová, M., Janečka, K., Čada, V., 3D cartography as a platform for remindering important historical events - Example of the Terezín Memorial, In: Modern Trends in Cartography, Vondráková, A. (eds.), Springer-Verlag, 2014.
8. Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Halszka J. and Van De Weijer, J., Eye tracking: A comprehensive guide to methods and measures, Oxford University Press. 2011.
9. Irwin, D. E., “Visual Memory Within and Across Fixations. Eye movements and visual cognition: Scene perception and reading. Springer-Verlag, New York. 1992. pp. 146–165.
10. Jacob, R., and Karn, K. S., Commentary on Section 4. Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. The mind's eye: Cognitive and applied aspects of eye movement research. Amsterdam: Elsevier Science. 2003.
11. Jedlička, Hájek, P., K., Čerba, O., Experience with methods of 3D cartography gained during visualization of detailed geographic data for purposes of documenting cultural heritage (case study at the castle Kozel). GeoCart'2012 and ICA Regional Symposium on Cartography for Australasia and Oceania. Auckland: New Zealand Cartographic Society Inc., 2012. pp. 89-100.
12. Jelének, J., 3D rekonstrukce krajiny na příkladu zaniklých obcí v českém pohraničí a vojenských újezdech. Bachelor thesis. Charles University in Prague, Supervisor RNDr. P. Štych, PhD. 2010.
13. Koucká, L., 3D rekonstrukce zaniklých částí města Dobříš. Bachelor thesis. Charles University in Prague, Supervisor RNDr. P. Štych, PhD. 2011.
14. Kovařík, D., Demoliční akce v českém pohraničí v letech 1945-1960. Dissertation thesis.Masaryk University. 2010.
15. Kučera, Z., Štych, P., Jelének, J.: Zaniklá sídla: jejich vznik, poznání a rekonstrukce. Geografické rozhledy. 2011.
16. Langweil model of Prague. In digital form: http://www.langweil.cz/. 2012.
17. Memorial Landscapes. In digital form: http://www.gepam.eu/. 2014.
18. Niederoest, J., A bird’s eye view on Switzerland in the 18th Century: 3D recording and analyses of a historical relief model, Proceedings of the CIPA conference, Antalaya, Turkey. 2005.
19. Oktábec, M., 3D rekonstrukce zaniklé krajiny středního Povltaví. Bachelor thesis. Charles University in Prague. 2009.
20. Popelka, S., Brychtova, A. Eye-tracking Study on Different Perception of 2D and 3D Terrain Visualisation. Cartographic Journal, 2013, 50(3), pp. 240-246.