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Geovisualisation as a process of creating complementary visualisations: static two-dimensional, surface three-dimensional, and interactive

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Abstract: In the following paper, geovisualisation will be applied to one spatial phenomenon and understood as a process of creating complementary visualisations: static two-dimensional, surface three-dimensional, and interactive. The central challenge that the researchers faced was to find a method of presenting the phenomenon in a multi-faceted way. The main objective of the four-stage study was to show the capacity of the contemporary software for presenting geographical space from various perspectives while maintaining the standards of cartographic presentation and making sure that the form remains attractive for the user. The correctness, effectiveness, and usefulness of the proposed approach was analysed on the basis of a geovisualisation of natural aggregate extraction in the Gniezno district in the years 2005–2015. For each of the three visualisations, the researchers planned a different range of information, different forms of graphic and cartographic presentation, different use and function, but as far as possible the same accessible databases and the same free technologies. On the basis of the final publication, the researchers pointed out the advantages of the proposed workflow and the correctness of the detailed flowchart.

Keywords: geovizualisation, complementary visualisations, static two-dimensional map, interactive map, surface three-dimensional model, natural aggregate extraction.

1. Introduction

Geovisualisation might be treated as activities aimed at revealing the previously unknown spatial information in a highly interactive computer graphics environment (Slocum et al., 2009). The main emphasis in geovisualisation studies is placed on representing spatial phenomena, visualisation, and interface (Dykes et al., 2005). The main feature of spatial data is the location of objects, but visualisation techniques should also facilitate the comparison of other, more complex, constituent of a geo feature. By enabling interaction with the type of data that is of interest to both public users and professionals, geovisualisation contributes to the creation of publicly available Internet websites (Calka and Cahan, 2016).

According to Gahegan (2005), it is possible to use different forms of geovisualisation.−In spatial data research, it is vital to use cartographic materials (e.g., simple statistical maps) that lead the user to better understand the spatial data and draw clear conclusions (Bielecka et al., 2014). The vital role of the map in the geovisualisation process is undebatable. The development of multimedia and interactive forms of communication, especially on the Internet, is the most dynamically growing aspect of geovisualisation. In the geovisualisation process, maps and other forms of cartographic presentation are supplemented with simple and complex graphical forms of statistical data presentation. The most frequently used forms of graphical visualisation are charts and diagrams, whose task is to complement the cartographic message and facilitate a comprehensive presentation of geographic phenomena (Medyńska-Gulij, 2015).

What becomes problematic in the geovisualisation process is the combination of various mapping methods and other graphical methods of data visualisation within a single statistical map. In a pragmatic approach, it is important to adjust the number and type of mapping methods on a single map to how the statistical maps are used and to the needs of the user of the created visualization (Medyńska-Gulij and Cybulski, 2016; Wielebski, 2014). Another approach might be to create multiple visualisations from various perspectives from which the given phenomenon may be perceived (Medyńska-Gulij and Dickmann, 2015).

In the following paper, geovisualisation will be demonstrated on the basis of one spatial phenomenon and understood as a process of creating complementary visualisations: static two-dimensional, surface three-dimensional, and interactive. The main challenge was to point out a method of presenting the phenomenon in a multi-faceted way. The key question was the scope of the contemporary software for presenting geographical space from various perspectives while maintaining the standards of cartographic publications.

A map is a graphical, mathematically defined model of reality, representing it in accordance with the adopted scale and using symbols to present the features of objects and the spatial relations between them. Main elements of the map include: thematic content, title, legend, scale, and base content. In this paper, the notion of the map is identified with cartographic visualisation, which deals with the analysis and presentation of spatial data with the help of cartographic techniques, spatial information systems, and computer graphics tools (Żyszkowska, 2000).

Interactive visualisation is understood as a method of influencing the transfer of information in the process of its use; thus, it determines the relation between the visualisation and its user. The interactivity implies, on the one hand, that the visualisation can influence the user, and on the other hand, that the user can influence the range and form of the information presented in the visualisation (Macioch and Malmon, 2010). Examples of interactive visualisations were analysed by Maiellaro and Varasano (2017), who focused solely on the one-page site.

2D static or analogue visualisation is a graphical presentation of spatial data on tangible or intangible features. The presentation might take the classical form of a paper printout or be presented on a computer screen (Medyńska-Gulij, 2015). Various examples of 2D static visualisation were presented by Wielebski (2014), who focused on the road network.

3D surface visualisation is a closed 3D model presenting a chosen fragment of the terrain at a particular moment in time. Prechtel (2014) pointed out that despite great accessibility of data and the successful work on standardising the 3D modeling, it is not standard practice to present the end users with large-format references to topography in the form of 3D models. He proposed an automated strategy for creating closed 3D representations of a complete urban landscape.

The authors of the following paper set out to present the process of the complementary creation of geovisualisations for a single spatio-temporal phenomenon by a parallel creation of three consistent visualisations: static two-dimensional, surface three-dimensional, and interactive. Another important objective was to test the available coding method, which was used to create individual parts of the visualisation and to combine them into one geovisualisation. Yet another aspect was the use of free software and official databases while working on both the individual components and the final product. The element that was emphasised the most was the workflow design with a minimum of redundancy and formats used. In order to verify the correctness, effectiveness, and usefulness of the proposed workflow, the researchers tested it by attempting a visualisation of the natural aggregate extracton in the Gniezno district in the years 2005-2015.

2. Methodology

2.1 The concept stage

The research was conducted in four stages: the concept stage, the data acquisition stage, the data processing stage, and the publication stage (Figure 1). In the concept stage, three models were created for the various publication methods – it was done in such a way that the user of the final cartographic product could use each of the publications on its own, but also two or all three of them at the same time. That was why the particular components of the models (such as the title, the legend, photographs) were located in similar places on every model. The physical phenomenon of changes in extraction area size and the progress of open pit recultivation was presented on the basis of the Gniezno district. The time period to be covered was was steered by the possibility of acquiring data from spatial databases (with special emphasis on geoportals) (Bielecka and Medyńska-Gulij, 2015). For the purposes of this study, the timespan from 2005 to 2015 was taken into account. The authors decided to accomplish this goal via the most efficient of the possible methods of data acquisition and processing, i.e, via a parallel conversion of raw data and its use for the three visualisations, in order to make the time-consuming process of spatial data processing as effective as possible.

For each of the three visualisations, the researchers proposed a different information range, different forms of graphic and cartographic presentation, and different use and function, but as far as possible the same databases and technologies.

● Static two-dimensional visualisation:

- Information range (title): *The area of natural aggregate extraction and its changes in the years 2005-2015 – for the chosen open pit mine*.
- Components: the map title, the cartographic content, a photograph field, an orthophotomap field for every year, the legend, the scale bar, the chart, the imprint.
- Forms of graphic and cartographic presentation: the outline range of the open pit mine over a topographic map base, a bar chart, an orthophotomap, photographs from a pedestrian perspective, the legend.
- Form of publishing and use of the product: permanent record in the form of an A3 printout and a PDF file, a complete (read-only) document to be used for a report on the state of the phenomenon and the spatio-temporal changes.
- Sources of data: acquisition in the office (BDOT [Baza Danych Obiektów Topograficznych – Polish for „A Database of Topographic Objects”], MIDAS) and in the field (field inventory of the extraction range over an orthophotomap and a topographic map base; photographic documentation of the area and the recultivation of the open pits).
- Software: graphical, GIS, spreadsheet.

● Surface Three-dimensional visualisation:

- Information range (title): *A 3D model of the chosen open pit mine in the year 2015*.
- Components: the title, the 3D model, an instructions window, a point location window, the imprint.
- Form of graphic and cartographic presentation: an orthophotomap superimposed over a DEM image – a 3D model; a table with coordinates defining the location of a given point.
- Form of publishing and use of the product: The model is saved in the form of a JavaScript code which opens as an Internet website; interactivity: a possibility of watching the virtual landform (containing the data for one time period) by rotating it on the screen, without introducing changes.

- Interactive elements: the possibility of rotating the model and observing it from multiple perspectives (with the instructions window displaying information on how to use the model); the coordinates of the clicked point of the model appearing in the point location window.
- Function: Attractive presentation of the area of a given open pit in a single year.
- Sources of data: office acquisition of elevation data (x,y,z) and the orthophotomap from Google Earth.
- Software: GIS, spreadsheet, converter.

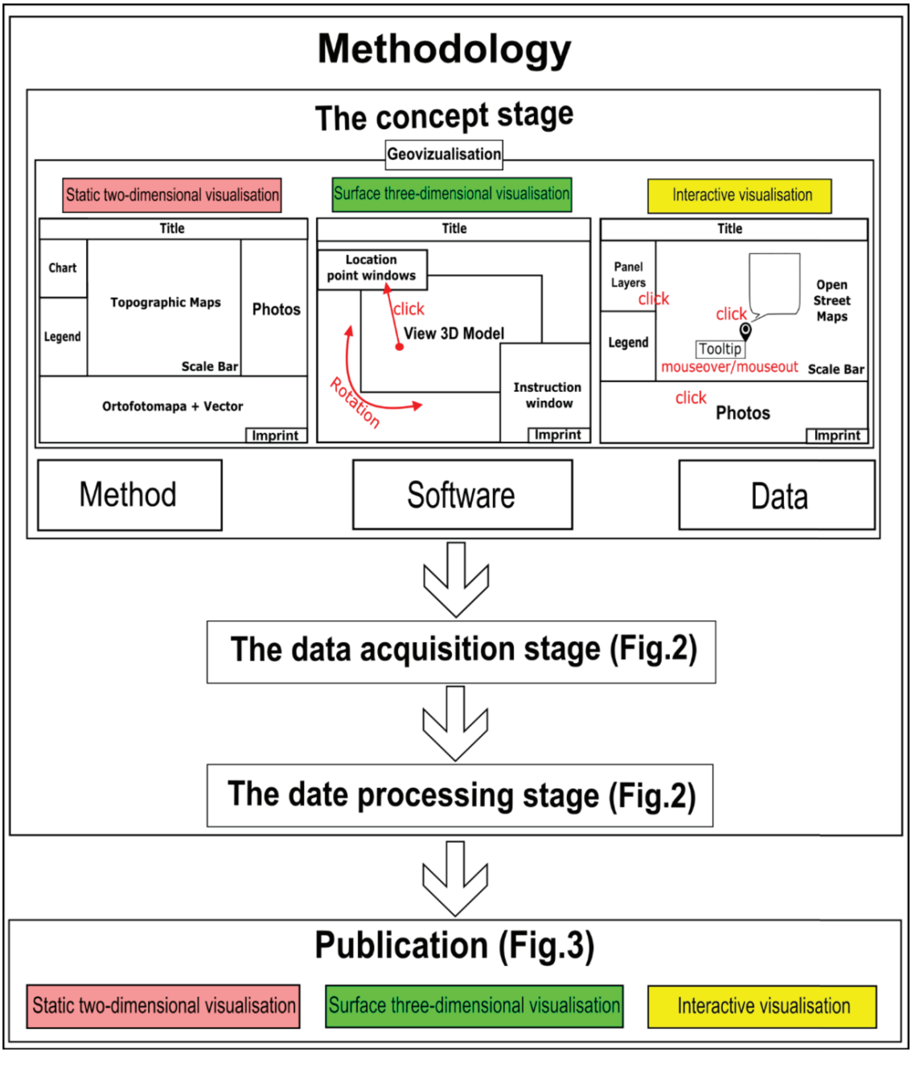

Fig. 1. The workflow for the process of the complementary creation of visualisations: static two-dimensional, surface three-dimensional, and interactive

● Interactive visualisation:

- Information range (title): *The area of natural aggregate extraction and its changes in the years 2005–2015 in the Gniezno district*.
- Components: the map title, the cartographic content: a topographic map (Open Street Maps base), photographs, a panel layers, the legend, the scale bar, the imprint.
- Form of graphic and cartographic presentation: the phenomenon presented in the form of a website featuring interactive vectors with attribute data coded in information bubbles.
- Form of use of the product: an Internet website; interactivity: the possibility to choose a layer in the layers panel, a pop-up assigned to each marker, appearing once the marker is left-clicked, and a tooltip displayed when the user hovers the cursor over the marker, the possibility to see the photo in a bigger size when it is left-clicked.
- Interactive elements: markers, the layers panel, and photographs.
- Function: Presentation of the extraction area for several chosen years (with the additional option of updating the information in the future) and the state of the recultivation visualised in the photographs.
- Sources of data: acquisition in the office (BDOT, MIDAS) and in the field (field inventory of the extraction area over an orthophotomap base, topographic maps, and photographic documentation of the state and recultivation of the open pits).
- Software: graphical, GIS, spreadsheet, text editor.

2.2 The data acquisition stage

Already in the concept stage, the researchers used many geoportals and programs. Figure 2 shows the flowchart of creating the key elements of the visualisation. Websites geoportal.gov.pl and Google Earth were used most extensively, as the orthophotomap databases of those websites feature the option of searching out maps from various years. The reason for choosing multiple geoportals was to obtain as wide a scope of data for the chosen time period as possible. The thematic data selected to enrich the geovisualisation was the data from BDOT (A Database of Topographic Objects), the MIDAS geoportal of the Polish Geological Institute – National Research Institute, etc.

The data acquisition stage began with the preliminary review of information available on the geoportals (Figure 2). Then, the researchers made their choice of the open-pit mines to be included in the study. In order to make it possible to process the data further, the researchers downloaded fragments of the orthophotomaps using the Print Screen and GetMap functions. An interesting option enabling the user to download map fragments is the GetMap function offered by the website geoportal.gov.pl. Via an ordinary 'https://' link, the function allows the user to select in the browser window a section of the map from a particular time period. In the case of images that were too big or had been obtained using the Print Screen function, the Photoshop software was used for cropping (Horbiński, 2016). The method of accessing data as proposed by the authors is only an easier alternative to the official way of obtaining it from centers publishing such information. Data obtained using the Print Screen and Get Map functions is not used for further publication. It only serves as a part of the workflow and is included in the final version of the geovisualisation only to a small extent. This way of obtaining data is very time-efficient and completely free of charge.

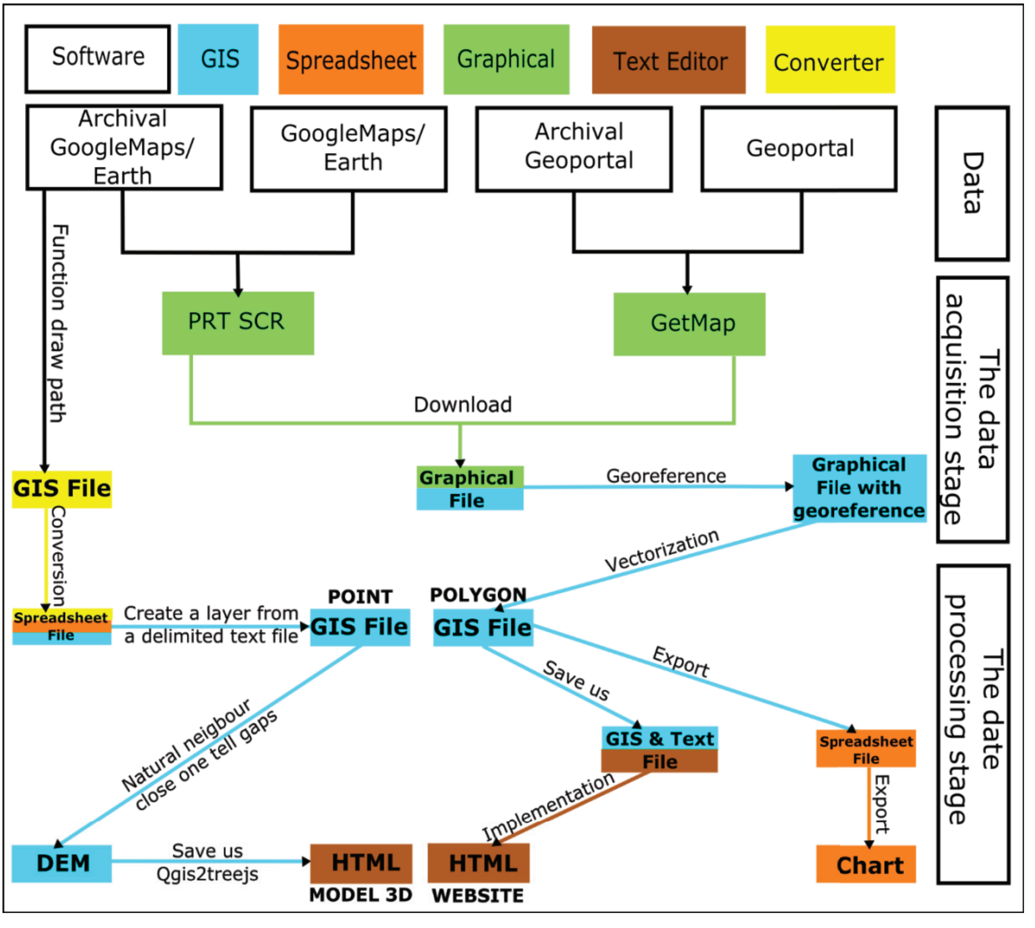

Fig. 2. The flowchart of creating key components of the visualization

2.3 The data processing stage

To present the results, the authors used certain programmes and file extensions. However, the workflow (Figure 1) and the flowchart (Figure 2) enable the use of different software and extensions instead. The subsequent stages of the research work are aimed at proving the appropriateness of the proposed workflow; the authors are not suggesting the use of exactly the same software.

The preliminary work on the acquired data involved the conversion of the orthophotomap images with the extension .jpg or .png obtained with the Print Screen or Get Map functions to a format that would be readable by the Qgis software. The condition was that the image had to have a cartographic representation. Images were georeferenced to the WGS84/EPSG:4326 coordinate system. The transformation type used was first degree polynomial for at least 3 points, while the resampling method used – nearest neighbour. The resulting file had the .geotiff extension. It is possible to omit this step while retaining the georeference for images obtained from Google Maps. However, in order to avoid simultaneously following two parallel courses of research work, the authors focused on choosing one method to accommodate all the obtained orthophotomaps.

The next step was to generate files with an .shp extension showing the borders of the studied phenomenon. The vectorisation process was divided into creating the borders with the help of polygons, and giving them attributes. The area size of a given polygon (needed for the latter statistical calculations and the resulting chart) could be obtained via the AREA operation in the attribute calculator tool.

As far as the vectors were concerned, the researchers distinguished between the attribute data (exported into an .xls file) and the vectors themselves. The data was used to plot a chart of area changes in Microsoft Excel, to be used later as part of the static 2D visualisation. The attribute information in the interactive visualisation was used in the pop-ups on the Internet website. Vectors from the .shp file were converted into the .goejson format using the function "Save as", because such a file may be used while building a web page and has a practical application in HTML website design. By launching the .geojson file in Notepad++ and adding a JavaScript code (var 'object'={content of the .geojson file}) (Duckett, 2014), an interactive vector was created.

The surface three-dimensional visualisation was created according to the authors' idea of using the data (x, y, z) uploaded into the Google Earth platform. Such an approach is beneficial when one has no access to the appropriate equipment for lidar data processing (i.e., when the speed of the processor is not sufficient). For comparison, Lidar data, which might be obtained for a fee in various institutions, contains (beside the x, y, z coordinates) also 13 other pieces of information about the points in question, such as their colour, category (water, ground, low/medium/high vegetation, not classified), etc.

It was noticed that in Google Earth, when the user hovers the cursor over a map fragment, three coordinates (x, y, z) appear. This data was recorded in the form of a trail resulting from the use of the path drawing function. The path was plotted within the area of the studied phenomenon and at some distance from this area. It was best if the shape created by this line was a square or a rectangle – such a shape would make it easier to fit the DEM file into the frames of the 3D model in the latter stage of the study. The reason why the researchers opted for this function was that drawing the path causes an automatic generation of points with x, y, z coordinates at certain distance intervals. This was used by the authors of the study to create a regular Grid network in reprocess uploaded date. The path was saved as a .kml file. In the next stage, the .kml file was converted to a .csv file using TCX Converter. The stage involved also overwriting the Z coordinate with the use of the function Track Modify → Update Altitude. This was necessary as the .kml file did not directly record the altitude above sea level, and after the conversion, the ALT column (coordinate z) in the resulting .csv file would be empty.

The .csv file has many superfluous columns that are not needed in the later stages of the 3D model creation. That is why the researchers decided to limit them (using Microsoft Excel) to three columns – LAT (latitude), LONG (longitude), and ALT (altitude). The .csv file containing the three columns was then imported into the Quantum Gis software. The text file was converted to .shp layer points with the function „Create a layer from a delimited text file". This process was necessary to visualise the obtained points in the Qgis software. The points were then to be used for Grid creation.

With the aid of Geoprocessing→Tools→Saga Gis→Natural Neighbour, the points were transformed into a Grid with a cell size of 0.0007(arcsecond). Due to the limited capabilities of the computer, an incomplete DEM file was created. This problem was solved with the SAGA Gis option „Close one cell gaps", which patches the gaps by comparing their height to the size of the surrounding pixels. The cell size yielded by this function was 0.0007(arcsecond). Having obtained a complete DEM file, it was possible to proceed to creating the 3D model.

For that purpose, the researchers used a Qgis plug-in called „Qgis2treejs". This plug-in makes it possible to create a 3D model on the basis of a DEM image displayed in the preview window of the programme. The conversion was performed on the DEM file containing the Z coordinate (ALT). Based on this coordinates, a 3D model was created in JavaScript code, saved as a HTML file. In order to improve the visual attractiveness of the image, a georeferenced fragment of the orthophotomap was superimposed in the window DEM→Display type→Image file. The whole model was displayed in cell size 0.0007(arcsecond), like in the case of patching the gaps, in order to avoid distorting the real image. For the purpose of the static two-dimensional visualisation, a grayscale DEM image was created.

3. Publication

The publication stage consisted in adjusting the particular elements of the three visualisations so that they fit the models designed in the concept stage (Figure 3). For the purpose of the publication, several key modifications were made. One of them was to extend the analysis to include not only the data from orthophotomaps, but also data from the BDOT database and the MIDAS geoportal. This data enriched the geovisualisation of changes in natural aggregate extraction and brought on another modification of the scheme – i.e., dividing the work methods into office work and field work and expanding the data acquisition stage. In the diagram, the meaning of the colours was retained and the same software was used. Key elements were marked with numbered bubbles, which were then interactively placed on the models, on the flowchart, and on the screen shots of the final versions. Arrows show the particular activities during the research, directions of data conversion, changes in file formats and the intermediate forms of the created components of the three visualisations.

The static two-dimensional visualisation on an A3 sheet is an example of a traditional form of cartographic communication that is of great significance to professionals and researchers in the process of compiling reports. For printing purposes, the file has a .pdf extension, but for the purpose of being integrated into the one final geovisualisation the image was converted into a .html file. The whole sheet is composed of several parts. The base map is the previously mentioned map generated on the basis of the BDOT layers. The graph presenting the correlation between the water level and the area of the mine (labelled „Graph" on the model) is a statistical presentation of attribute data. The base map window was made complete by adding the legend and the scale. Photographs presented in the visualisation are, in principle, three representative photos of the mine, showing the current state as of 2015. Those visualisations are complemented by a combination of 6 orthophotomaps with superimposed lines indicating the borders of the open pits. The images are ordered chronologically, from left to right, showing changes in extraction from 2005 to 2012.

An attractive way to present the information is via a surface three-dimensional model of a single open pit, with the option of clicking on any point and rotating the model. The specially applied orthophotomap base makes it possible for the user to see the mine in conditions resembling the real landscape. A change can be made only by recreating the DEM file or changing the data used in its creation. The next step towards developing such a model is to combine it with the VR (Halik, 2014) technology and to change the source of data used in the creation process – the data might be obtained, for example, with the help of the UAV technology (Smaczyński, 2016).

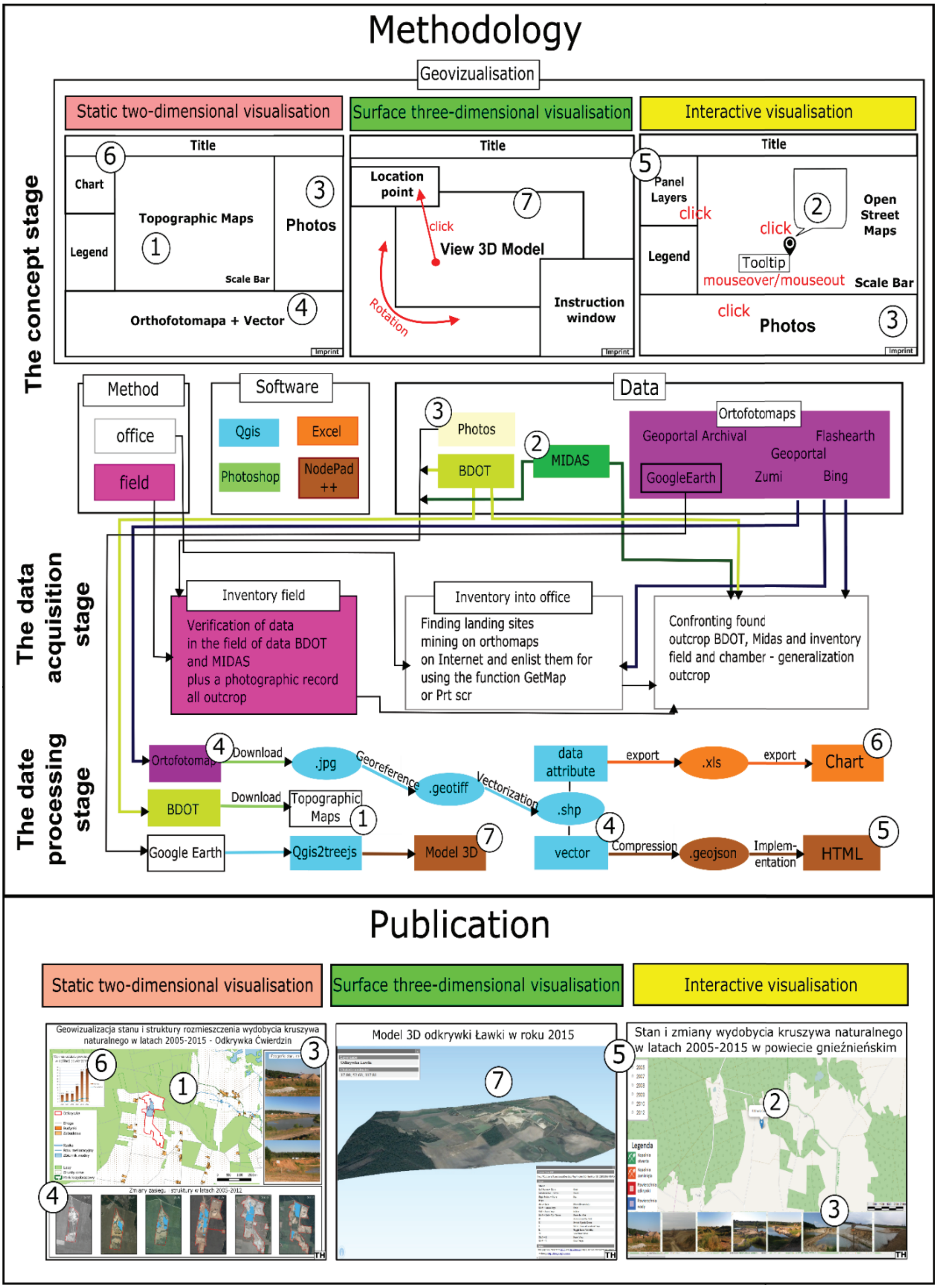

Fig. 3. The workflow for creating a geovisualisation of natural aggregate extraction in open-pit mines in the Gniezno district.

To ensure full interactivity of the visualisation, it was created in an Internet browser, using the HTML, JavaScript, and CSS (Cascading Style Sheets) codes. The layers panel is divided into two parts. The base is a readable OpenStreetMap, which is an entry map leading to the website and a base for the Leaflet library. The second part of the panel is composed of 6 interactive buttons with year labels, which, once clicked, display polygon vectors for the borders of extraction areas and surface waters located within the open-pit mine. The polygons, thanks to a coded function, have an additional interactive feature. A click on an area polygon yields a pop-up with attribute data (name and area). Photos are a panel of 50 photographs presenting the current extraction area. The panel is equipped with a scroll bar, which makes it possible to see all the miniatures of the photos. Every miniature has an interactive feature. When clicked, its shows the user the photo in a bigger size, with the name and number of the open pit in question. When the full image view is on, there is an additional function of moving on to the next photograph without leaving the panel. Thanks to this function, the visualisation takes the form of a gallery.

4. Conclusion

The three published visualisations can be used separately, but what the authors had in mind was for them to be used complementarily as one geovisualisation. For the purpose of creating a single version of the geovisualisation, the authors decided to add buttons to the interactive visualisation – a hyperlink to surface three-dimensional and static two-dimensional visualisations. As mentioned before, in order to enable the combination, the .pdf file with the static two-dimensional visualisation was converted to a website format. An advantage of this step was the resulting favourable location of the information – all the study results presented as a single website with hyperlinks. Obviously, this meant that the quality of the static two-dimensional visualisation had to be compromised, but the visualisation gained in the communicative potential and the audiences.

Nowadays, when cartography develops mostly with an emphasis on vector files and the publication of maps on the Internet, less and less attention is being paid to static two-dimensional publications. Paper maps are an important element and input material for creating geovisualisations (Medyńska-Gulij, 2015) and are useful in terms of documenting the given phenomenon (Horbiński, 2016). Such publications have important features and can be useful e.g. for presenting buildings and urban features in AR (Lorek, 2016). The static two-dimensional visualisation discussed in the article has a open form (possibility of adding or updating information) that was designed for purposes such as environment management, e.g., plans of development or reduction of the presented phenomenon.

Interactive visualisation leaves room for changes; its composition is open. This is a big asset, as it allows modifying and updating the data. In case of further developments the information content could be expanded to include point phenomena and the statistical data presented could be further developed. The presented content would be greatly improved by introducing animations, e.g., in the point signatures and the corresponding legends. Adjusting the visualisation to the requirements of Responsive Web Design, with great emphasis on presenting the content on tablets and smartphones, will be the direction of development for the cartographic design.

The proposed workflows shown in Figure 2 can be treated as universal ones for the presentation of phenomena regarding changes in area and forms of land use cover. However, for this to be possible, it is necassary to use the same (or equivalent) software that was used in the study. Qgis is free software and a quickly developing programme; hence, there is a possibility of fine-tuning the elements of the surface three-dimensional visualisation in the future.

Through the proposed workflows and testing them against real data, the authors attempted to demonstrate that the creation of three visualisations is a complementary process of creating a geovisualisation in which a lot of attention should be paid to the user, but also to the effectiveness and the technological efficiency of the method. There is room for developing the proposed solutions in the future, e.g., by consolidating the 3D model and the Internet visualisation into a single file with one extension. A file format that might be used in future studies is the .czml format of the CESIUM library, which has a structure similar to that of the .geojson file and can therefore store the X, Y, Z coordinates, also offering the possibility to present the terrain in a 3D form. The Cesium Library offers also many possibilities for implementing all the three forms of visualisation. However, in order to make use of its full potential, proficiency at JavaScript coding is necessary.

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