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The Concept of Three-Dimensional Visualisation of Urbanised Areas for a 3D Real Property Register in Poland

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ABSTRACT

Virtual three-dimensional visualisations are a relatively new chapter in the history of terrain modelling in Poland. The visualisations prepared in Poland are considerably varied due to the adopted method of data processing and presentation. One of the main factors determining the course of works and their final result is the choice of the optimum data source for the task performed. The increasingly popular photogrammetric methods, including laser scanning, make it possible to create fully functional and visually attractive models. However, with their application, a complete visualisation of an extensive area (e.g. a mid-sized city) would entail significant expense and require a huge workload due to the unavailability of ready input data. This publication describes an alternative, economical and fast method for preparing simplified three-dimensional visualisations of a territory with an almost unlimited surface area, developed for a selected part of Poland. Based on their visualisations, the authors propose using data from local databases linked to nationwide digital geodetic resources for the needs of a 3D real property register. This work contains a detailed description of methods used in creating visualisations and an evaluation of the quality of the project deliverable including a list of observations regarding different categories of the presented objects. In addition, the summary of this article suggests potential solutions to improve the process of visualisation by using different types of data modification.

Keywords: 3D visualization; real property register; digital geodetic resource

INTRODUCTION

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be carefully reviewed and key publications cited.

In the 1980s and 90s, in Poland three-dimensional terrain models were mostly physical mock-ups. The dynamic development of information technology taking place in the past few decades, in combination with the latest developments in computer graphics, facilitated the construction of tools for creating more and more advanced virtual models [1]. Software available on the market makes it possible to create 3D images in almost any form and with any content. The desired effect is conditioned by accessibility of source data [1, 2]. Such data should be current and reliable. Therefore, it should derive from a verified database that is updated on an ongoing basis. One such database appears to be the real property register (cadastre) which – in Poland and many other countries – performs a reference role in relation to maps and other cartographic presentations created on its basis. Unfortunately, numerous studies [3,4], show the real property register system in Poland requires continuing modernisation in connection with poor quality of data. Countries neighbouring on Poland and having a similar history – such as the Czech Republic, Slovakia [5,6], and Croatia [7] – experience similar problems in real property register data quality. Thus, a cadastral map seems to be insufficiently reliable as a basis for 3D visualisations of urbanised areas.

According to Siejka et al. [8], it can be supposed that – as far as developing real property registers is concerned – analyses will be used based on 3D visualisation techniques and real time systems. In Poland, the 3D real property register is at a preliminary stage and the search for how it can be created still continues. Visualisation methods for building a 3D real property register in Poland are proposed by Karabin, Bakuła et al. [9]. The above-quoted authors propose using data from a geodetic database of the utilities network in 3D visualisations creating, e.g. models of the metro tunnel in Warsaw. These publications showed that it is possible to obtain a visualisation of the metro tunnel with sufficient accuracy for a real property register. In turn, the authors of this publication create a visualisation using a master map as the most accurate and current geodetic resource on a national scale. The case study of the town of Świdnik described hereinafter shows that this is possible and satisfactory in terms of economy, technology and time. The resulting model could be incorporated in the 3D real property register and applied in many areas of real property management.

In the case of terrain visualisation, the main input information is the relief, which makes it possible to generate a three-dimensional model of the Earth's surface to which the location of other objects can be referred. Another important element determining the realism of the form and enriching the visualisation is information about terrain cover and the location of objects with reference to the surface. Through mapping flat objects onto a formed plane, a so-called 2.5D model can be generated [10]. On the other hand, full 3D visualisation requires images of the objects that, in addition to a range marked by flat coordinates, have elevations and a specific shape.

As mentioned before, the selection of the source of data about terrain is a key decision determining the shape of the visualisation, its specificity and accuracy, as well as the complexity of the data processing and model designing procedure. Laser scanning methods, growing in popularity, provide many options. Models created by such means, expanded with georeference, can have a high level of specificity of the presented objects and present the reality in a very impressive manner. However, the use of this method, in particular for visualisation of large areas where the optimum technique is airborne laser scanning, requires advanced equipment and significant financial expenditure on the operation of such equipment. In connection with the aforementioned, at present, the concept of visualising an area using this method is subject to considerable limitations that in many cases may render the activities unprofitable.

Thus, the authors of the present work propose an alternative solution to professional terrain scanning methods involving the use and correct processing of the available, conventional data. In the Polish reality, the most accurate presentation based on geodetic information is a large-scale master map forming a basic compilation of geodetic information and the basis for creating derivative maps. It is used, among other things, for cadastral purposes. The master map is prepared in the scales from 1:500 to 1:5000 and contains comprehensive information about terrain from the following databases: EGIB (Land and Buildings Register), BDOT500 (Topographic Objects Database in the scale 1:500), GESUT (Geodetic Register of Utilities Networks), PRG (National Register of Boundaries), PRPOG (National Register of Basic Geodetic Control Networks) and BDSOG (Database of Detailed Geodetic Control Networks) [11]. Pursuant to the Geodetic and Cartographic Law, from 1 January 2014 master maps should be prepared and stored in a digital form in geodetic and cartographic record centres [12]. Using such data considerably facilitates creating derivative maps. In the case of using scanned analogue maps as references, time-consuming digitalization – where objects with vector geometry are created and the right values are assigned to them – becomes a must.

It should be underlined that a master map is, in principle, two-dimensional. Its form is determined by both the nature of source data (spatial objects measured and marked as points, lines or surfaces) and the purpose of the map – the form must allow, among other things, printing of extracts. However, the information provided by the master map, in addition to flat coordinates describing the geometry of objects, also contains elements of elevation data describing surface relief. Heights are given both as free natural elevation points (measured on the ground) and artificial elevation points (measured on hardened surfaces) and as the ordinates of elements of utilities networks (for example, an ordinate of the upper surface of a catch pit that is level with the ground surface, for the needs of creating an elevation model, may be deemed an artificial elevation point).

Based on the aforementioned methodological assumptions, the authors of this paper undertook to design an experimental 3D model for a 3D real property register of the town of Świdnik (Fig. 1). The research methodology mainly involved the use of data contained in the digital databases underlying the master map. The obtained results were used to discuss the effects of works in comparison with the popular commonly available photogrammetric visualisation Google Maps 3D View and two-dimensional source data imaging.

METHODOLOGY

Data preparation

The project works comprised an experimental 3D vector visualisation based on a fragment of the complete, digital master map of a 20.35 m^2 area in the town of Świdnik in eastern Poland [13]. The visualisation was prepared by means of ArcScene 10.4 software using available textures. Part of the works, mainly regarding the modification and supplementation of object files, were performed using QGIS 3.6.4 and ArcMap 10.4. The required data in the form of shapefiles containing geometric information with descriptive attributes was sourced from the District Administration Office in Świdnik. A visualisation required processing of elevation data into a vector model of the surface as well as mapping and elevating the objects as three-dimensional objects [14]. The following step was a qualitative analysis and description of the visualisation of selected elements and their comparison to the master map and to 3D raster visualisation offered by Google Maps, prepared as a combination of satellite images and UAV images. The analyses focused in particular on the efficiency of use of the master map information. In addition, other significant visible elements of reality were identified that cannot be spatially visualised only on the basis of the master map. The work further presents proposed additional sources of information to be used for supplementing the missing data and suggestions regarding the modification of the method of entering geodetic data into digital databases as well as possible expansion of the databases by additional attributes.

For the needs of the works, the District Geodetic and Cartographic Records Centre at the

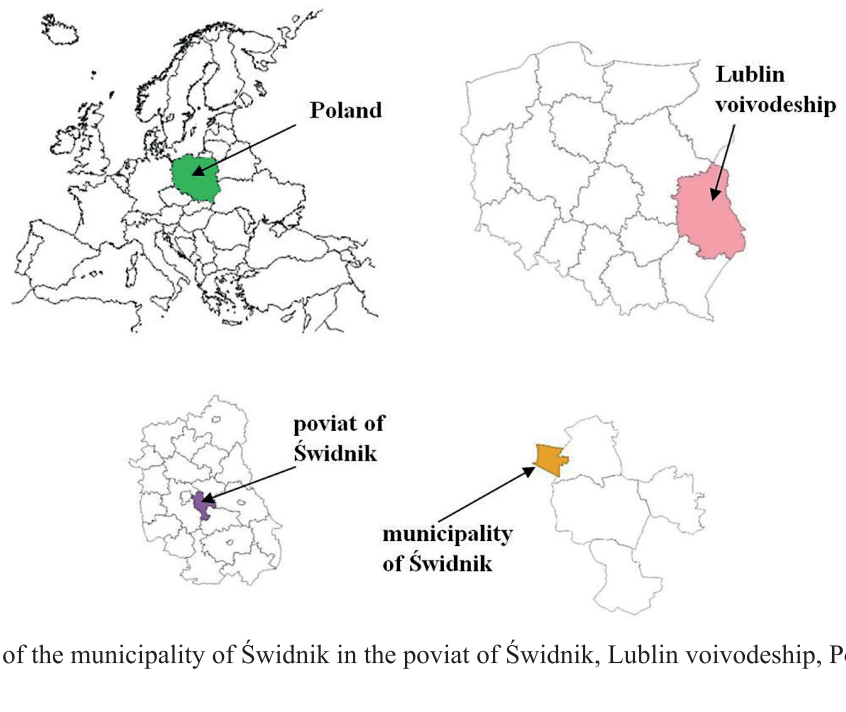


Fig. 1. Location of the municipality of Świdnik in the poviat of Świdnik, Lublin voivodeship, Poland and Europe

District Administration Office in Świdnik provided elements of the master map of the EGIB, BDOT500 and GESUT databases in the GML format. Using the EWMAPA computer programme the data was converted into shapefiles compatible with the software used at further stages of the works.

The first step towards creating a three-dimensional visualisation of the analysed area was the development of a vector terrain model [15]. The master map provides data in the form of elevation points with ordinates given with an accuracy of 0.01 m for artificial elevation points (measured on hardened ground) or up to 0.1 m for natural elevation points (measured on non-hardened ground). Elevation points have flat coordinates given according to the reference system PL-2000/8 (EPSG:2179) and elevation coordinates according to PL-EVRF2007-NH. These systems are officially in use in the Republic of Poland and are used for large-scale maps.

With regard to significant irregularity of the distribution of elevation points and the risk of local deformations of the model, the adopted model construction method was preliminary interpolation of the nearest points and the generation of a raster that was later transformed into a vector TIN model. Due to a relatively small variation in the terrain relief, any possible deviations between the interpolated and the actual values in areas not sufficiently covered by elevation measurements were deemed irrelevant to the general effect. In the case of works with a smaller error tolerance, denser elevation measurements should be considered based on own geodetic observations or, for instance, supplementation of data with ready elevation points provided by the national geodetic and cartographic records centre (one of the models available in Poland is NMT100 containing a network of points with space intervals up to 100 metres) [12,16]. However, when using external data sources, one should check their reliability and currency and the need for transforming the coordinates into the present system.

The chart in Figure 2 presents an algorithm of a possible procedure at the data preparation stage and creating an elevation model for a 3D real property register.

For the purposes of visualisation seven object categories of a 3D real property register were identified.

OBJECT 1 – Buildings

The possibility of achieving a satisfactory quality of the representation of buildings was considerably limited due to an insufficient amount of information in the database. Buildings, as surface objects, were projected into the terrain model, and then – in order to achieve a spatial effect – elevated to the height equivalent to the triple value of the attribute "number of floors above the ground" [17,18]. For technical reasons, flat surfaces of building roofs were created on separate layers constituting copies of the building layer and founded at the elevation corresponding to the conventional building height. In order to maintain significant database information, the visualisation of elevations by means of textures was given up and the colour representation was graded according to the values of the attribute "utility function of the buildings".

OBJECT 2 – Flat surface objects (roads, pavements, squares, cycling routes etc.)

Flat surface objects were visualised through an automated projection of respective layers onto the generated terrain. The result was accurate mapping of the objects. Objects denoting passages and squares were additionally sub-classified according to surface construction material and presented using realistic textures.

OBJECT 3 – Carports

Information available on the master map only allows us to determine the range of the carport roof. When creating the model, in order to improve its visual quality, the contour lines of roofs were elevated at the conventional height of 5 m above ground level, and then, on a separate layer the carport supports were created at the vertices of the contour lines.

OBJECT 4 – Fences

The visualisation of fences was created by means of a vertical, realistic texture corresponding to the linear layer on the master map. Due to the lack of information about the height of fences, a conventional height of 1.5 m was adopted.

OBJECT 5 – Trees

The visualisation of trees was performed by replacing the point symbols on the master map

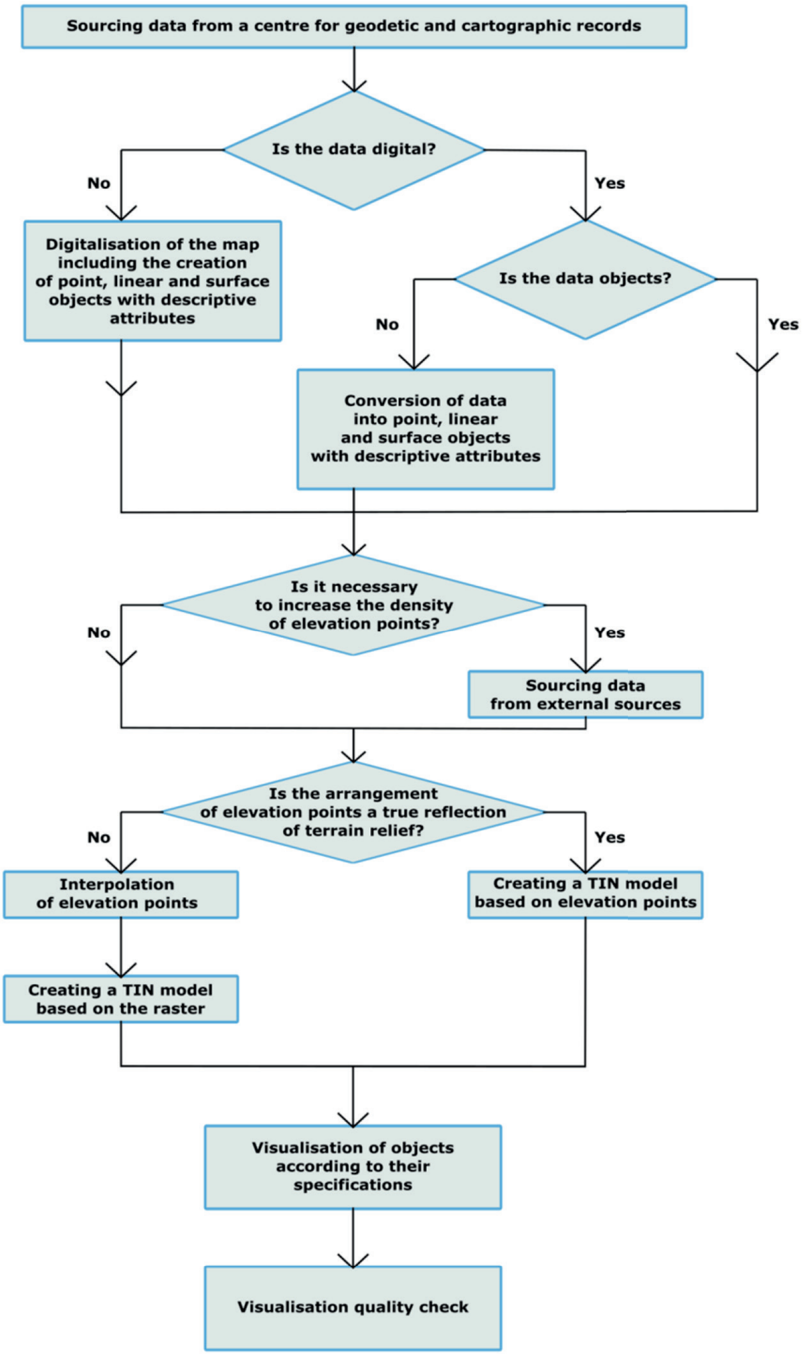


Fig. 2. Chart describing the process of preliminary preparation of data for 3D visualisation for a 3D real property register

with three-dimensional textures of a constant, conventional height of 15 m. The standard master map division into coniferous and deciduous trees was maintained and marked with appropriate symbols.

OBJECT 6 – Lamp posts

In order to visualise the light posts found on the master map, a three-dimensional representation of a lamp post was selected that was symmetrical to the vertical axis passing through the point of insertion of the object, thanks to which the effects of a lack of information about the direction of the lamp post arm were reduced.

OBJECT 7 – Conduits and other utilities

The visualisation of utilities at the present stage of works was effected by distributing the layers representing respective types of conduits at the correctly adopted altitude. In order to avoid the intersection of conduits, the optimum distance between the conduits of different networks was based on the conduit diameter.

RESULTS

The effects of visualisation split into respective elements of the master map (Figures 3–8) are presented in Table 1. Each object example was juxtaposed with its equivalent on the master map and with the view provided by Google Maps.

A number of significant problems with reliable visualisation were encountered for the specified seven categories of objects.

OBJECT 1 – Buildings

The visualisation of buildings using available data made it possible to create prisms the horizontal section of which reflects the actual contour lines of the buildings, whereas the height of the body of the building is the linear function of the number of floors (Agugiaro 2016a). Since respective floors of buildings are of different heights, the representation is only a partial reflection of the building's height. In addition, it was impossible to show the complete geometry of the building, including in addition its roof [19]. Roschlaub and Batscheider [20] describe an alternative, not used in Poland, system of cadastral building measurements which would be able to resolve this problem. The presented buildings have features that according to the OGC CityGML standard would classify them as LoD1 (level of detail) category [21,22], while the resources of the Head Office of Geodesy and Cartography offer free of charge LoD2 standard textures of buildings including roof shape [23]. Laser scanning and data processing would make it possible to prepare a vector model of the building with a level of detail equal to 3. This category comprises detailed representations of the whole external surface of the building [24,25]. Its simplified geometry equivalent may be the photogrammetric visualisation on Google Maps presented for the purposes of comparison.

On the other hand, an expedient effect of using the master map as a source of information may be a correct (in terms of database correctness) differentiation of buildings from the point of view of their utility function, which is difficult to achieve when the basic data comes from photographic images or scanning [26].

OBJECT 2 – Flat surface objects (roads, pavements, squares, cycling routes etc.)

The visualisation of flat objects, with regard to the availability of complete data about their geometry, mapped onto the terrain model brought the expected result. In terms of geometry, the created model practically did not differ from its presentation on Google Maps. Another advantage of the master map can be the availability of information about the type of surface of a passageway or a square, while optical methods do not allow such an unambiguous classification.

On the other hand, elevated sections of passageways and their multi-level intersections can pose a problem. The visualisation of such elements would be possible only if data about the height of each level of the road and the level of the ground is available. Then, a potential solution could be to create separate, local, invisible "surface models" and map the respective layers.

OBJECT 3 – Carports

The visualisation of carports exclusively based on the master map was practically impossible as it would be connected with representing those objects as flat polygons. The effect, assuming the elevation of roofs and indication of conventional supports, required a more flexible approach to input data. Despite adjustments in geometry, the model does not contain, for example, information about the shape of the roof and the actual position of supports. A much better effect is presented by the model offered by Google Maps, which, likewise in the case of buildings, reflects the geometry of carports and to some extent shows their external details.

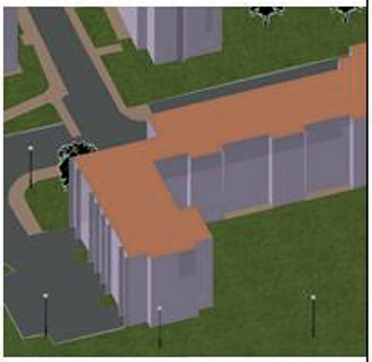
OBJECT 4 – Permanent fence

The possibility of reflecting the exact routing of the fence line was a strong point of the master map. In the case of the compared Google Maps visualisation, due to the specific features of fences (thinness, transparency) in many places these objects were either invisible or had unnatural shapes.

OBJECT 5 – Trees

As regards the representation of trees, the use of the master map made it possible to

Table 1. Presentation and comparison of the elements of own 3D visualisation with the master map and with 3D visualisation on Google Maps

Object	Master map	3D visualisation based on the master map	3D visualisation based on images
OBJECT 1 - Building and elements of the building	 *Figure 3. Building on the master map*	 *Figure 4. Own 3D visualisation of the building*	 *Figure 5. 3D visualisation of the building on Google Maps*
OBJECT 2 - Carriageway, pavement, path, square, lawn etc.	 *Figure 6. Carriageway, pavement, path, square, lawn and other surface objects on the master map*	 *Figure 7. Own 3D visualisation of carriageway, pavement, path, square, lawn and other surface objects*	 *Figure 8. 3D visualisation of carriageway, pavement, path, square, lawn and other surface objects on Google Maps*

precisely mark their trunks and split the existing trees into coniferous and deciduous trees. Both functions are a difficult and labour-consuming undertaking in the case of models based on image processing and scanning. For large-area visualisation on Google Maps, the differentiation of tree types or precise indication of the location of the tree trunk is simply impossible. However, the online service to some extent communicates information about the height of a tree, and, in addition, presents smaller trees and shrubs that are not subject to compulsory land surveying.

OBJECT 6 – Lamp posts

Likewise, in the case of fences, the representation of lamp posts based on the master map made it possible to reflect their precise location and obtain a considerably better look than on Google Maps. However, a certain problem can be a lack of information about the shape of lamp posts (the master map contains only the coordinates of the post insertion point). For the needs of graphically more advanced presentations, the deficiency of information may be supplemented, e.g. based on photographic images or a site inspection, and then additional attributes can be included in the database describing the type of the lamp post and the direction of the arm.

OBJECT 7 – Conduits of utilities networks

For visualisations of the conduits of utilities networks geodetic data provided on the master map can be deemed a unique source of information. The available data, apart from accurate description of the route of the conduits, makes it possible to, among other things, distinguish their types, diameters and routing in relation to the ground. It also contains certain information about the altitude of certain elements of the networks. In the case of visualisations of underground conduits, predominant in urban areas, photogrammetric methods, including laser scanning, turn out to be inadequate.

DISCUSSION

This publication aimed to present a self-designed method for preparing simplified three-dimensional visualisations for any urbanised area in terms of supplementing data in the 3D real property register databases. Based on the visualisation prepared for Świdnik, Poland, the authors propose using data from local, digital geodetic resources. The use of data from the master map was sufficient for most objects, but – in some situations – it was necessary to supplement the databases with conventional attributes.

The visualisation was based on a TIN model developed using elevation points deriving from land surveying. Their use makes it possible to generate a model consistent with the approximate terrain profile, but for visualisations with a higher level of detail it may not be sufficient in order to give a true representation of smaller relief forms. One of the reasons for data deficiency can be the lack of elevation points at the vertices of the visualised objects. For instance, an escarpment on a master map is always presented as a polygon with vertices indicating the measured elevation points. Thus, in a correct terrain model an escarpment should clearly stand out from the surroundings. If some elevation points are not available, the shape of the escarpment in a 3D space will not be consistent with its cartographic contour. Similarly, sections of passageways and squares, if not assigned a sufficient number of adequately distributed elevation points, can become deformed due to the presence of nearby relief forms. An alternative solution can be an intermediate raster model made by the interpolation of elevation points, and then development of a three-dimensional vector model based on the raster according to the selected criteria. Such an operation will make it possible to avoid considerable distortions in objects. However, where the elevation points are not dense, interpolation can lead to the disappearance or blurring of smaller terrain forms [27].

Visualisation of the terrain and its objects could be more efficient if flat objects design standards took into account the measured spot heights. Spot heights could also supplement the elevation points layer and in addition would allow a three-dimensional representation of detailed objects without the need to include the points outside them. At present, only a part of the measured elevations are entered into databases, and surface objects can be only represented by projecting them onto the terrain surface.

A considerable inconvenience in the preparation of visualisations was the lack of information about the height of buildings and structures. The application of conventional heights, altitudes (for carports) or heights counted according to the number of floors (for buildings) often does not allow reflecting the actual status. An available alternative source of information about the shape of buildings is CityGML objects in LoD2 standard that can be downloaded for free from the resources of the Head Office of Geodesy and Cartography (GUGiK) via the national Geoportal [28,29]. The downloaded models take buildings heights and their roof shapes into account [30]. However, it must be considered that their contour lines do not always match those on the master map (Figure 9)

In addition, LoD2 standard does not include certain elements of buildings and carports [31,32]. The complete visualisation of buildings and structures is possible only with the application of LoD3 standard, which requires detailed measurements by means of labour-consuming and expensive surveying methods, including LIDAR technology [33,34].

The effects were far better in the case of visualisation of flat surface objects. For carriageways, pavements, squares and paths, in addition to their accurate actual routing, available information and textures made it possible to differentiate between materials used to build the surface.

Fig. 9. Consistency of the contour lines of buildings on the master map with their equivalents in CityGML format downloaded from the resources of GUGiK (red colour marks displacement)

The visualisation of objects marked as points on the master map was also a success. The use of realistic three-dimensional symbols had a positive effect on legibility and aesthetic appearance of the model. The method could be in a way improved by additional marking of the geometry of objects the actual orthographic projection onto the plane is not limited to a point (e.g. light posts and traffic lights with an arm). An example result of such a solution is presented in Figure 10.

The quality of visualisation of the utilities networks is a significant aspect for the general evaluation of the adopted method. In the prepared visualisation the routing of conduits was marked by conventional means, taking into account primarily the type of network and the direction and diameter of the conduit. However, a technical possibility also exists to create a precise model reflecting the height at which each section of the conduit is located [35,36]. A possible solution is to generate a separate elevation model containing heights indicated in GESUT database, measured at conduit bending points and ordinates of other utilities (e.g. drains). Another possibility is to present elements of infrastructural networks other than conduits [37]. The success of the project, apart from adequate technological facilities, is determined by complete source data.

CONCLUSIONS

It cannot be clearly concluded that using elements of geodetic databases for 3D visualisation is a fully satisfactory solution. There are a number of categories of terrain details the correct presentation of which requires the supplementation of data from external sources or the change of input data source and its processing method. However, information obtained from the experiment lead to a conclusion that the use of element of the master map for the purposes of simplified visualisation of extensive areas may be a good solution due to considerably lower expenditure and workload than, for example, in case of photogrammetric methods. In addition, the representation of certain objects, and in particular underground elements of utilities, requires the use of information from geodetic databases. Thus, the choice of the optimum visualisation method for the intended purpose should be preceded by an analysis of capabilities and limitations to the extent of information and technology. An interesting solution may also be an attempt to combine data from different

Fig. 10. The result of proposed extension of data with the shape and angle of rotation of light posts and traffic lights

sources for the maximum utilisation of their respective potentials [38,39].

The method of preparing simplified visualisations of urbanised areas – presented in this article – can be used for accomplishing the objectives of a real property register (including a 3D real property register), as well as performing spatial planning tasks or selected real property management processes, e.g, describing location features for real property valuation purposes.

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