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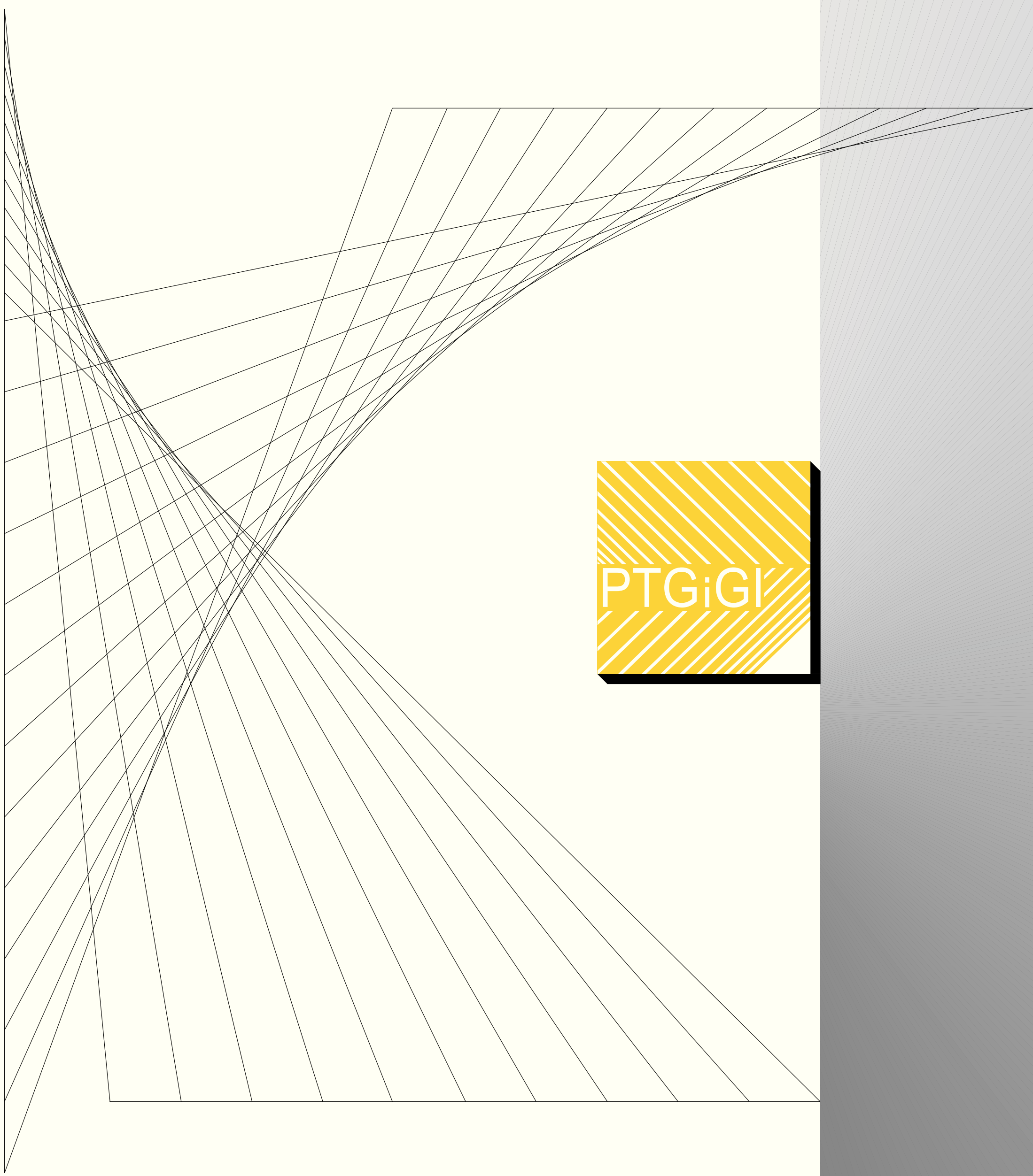

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EVALUATION OF METHODS USED FOR MAPPING THE GEOMETRY OF UNDERGROUND SPATIAL (3D) STRUCTURES IN THE COURSE OF REVITALISATION

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Abstract. The study provides a systematic description of various geometries of underground structures, giving examples of traditional and computer-assisted methods used for recording the geometry of underground structures. The methods enable the reconstruction of the structures' geometry and development of detailed drawings, a prerequisite for effective revitalisation and stabilisation old underground structures. Underlying the selection of mapping method is the analysis of the current conditions on the site, definition of potential hazards and the objectives of the restructuring programme.

Keywords: geometry, mapping, spatial (3D) structure, underground objects, graphic recording, revitalisation

Introduction

Old underground structures and sites are a vital part of the country's cultural and natural heritage. They demonstrate the level of technological advancement during the exploitation of natural resources, providing an excellent example of successful interactions between human activities and geological surroundings. Nowadays old underground features are considered to be a part of world cultural heritage and natural reserve areas, often they are granted the status of natural monuments. Stabilisation of old underground features and structures, as a part of an investment project, involves restoration works undertaken in degraded or abandoned plants and objects. Thus, the life quality of local inhabitants is improved, new features can be added and social networks restored. In order that underground sites can be effectively revitalised and stabilised, it is required that that their geometry be reliably mapped for the purpose of restoration projects, followed by geological and hydro-geological analyses.

Geometry of underground structures and features

Underground features emerged in the course of geological processes (caves, caverns) or due to human activity (mine workings, pits, underground passages, canals, sewer trenches, cellars, storage rooms etc). Their geometry developed as the result of natural forces or due to man-made activities, or both [5]. Accordingly, the geometry of underground sites and features can be categorised as:

- regular, geometric shapes based on cross-profiles involving straight line sections, second-order curves and B-spline curves extending in the direction perpendicular to the curve surface,
- irregular (amorphous) pattern, where the cross-profiles of the underground surfaces are defined by the B-spline curves (Fig. 1).

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In the case of irregular structures and features, their projections cannot be geometrically defined due to fluctuations of curve parameters. To graph a third-order rational B-spline, the control points should be located and re-located and their weighing factors selected accordingly, which requires the construction of an infinite number of varied-shape curves (Fig. 2).

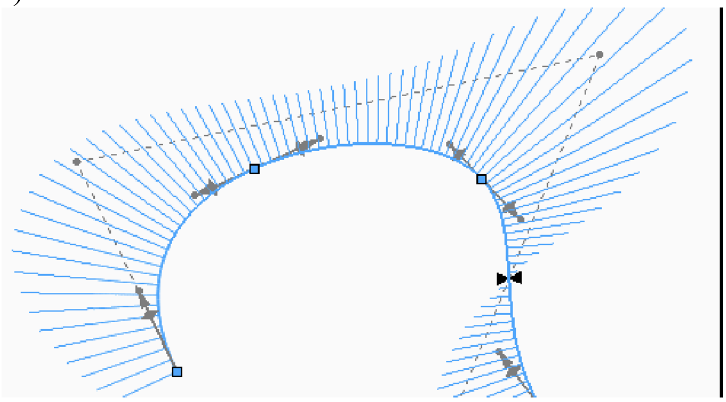

Figure 1: Local control of a B-spline curve with the curvature crest (www.cns.pl)

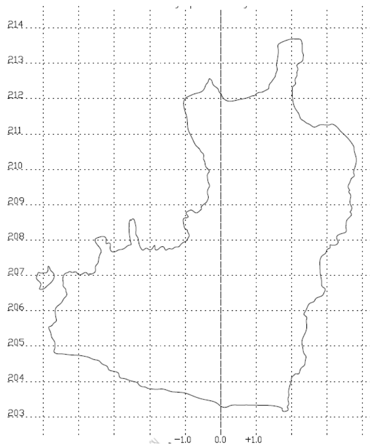

Figure 2: The vertical section curve along the horizontal axis in the Dragon's Den at the Wawel Hill in Kraków (Apply Capnor Poland 2011)

Table 1: Classification of underground features and structures and the mapping methods

Type of underground features	Examples	Shape geometry	Formation	Mapping method
Natural	Caves, caverns	Irregular	Geological natural	-geodetic surveys -photogrammetry 3D scanning
Man-made	Cellars, storage sites, underground sewage reservoirs, underground passages, pits, military, defence structures, transport facilities	- regular - irregular - mixed	-geological natural -man-made	- triangulation - geodetic survey - photogrammetry - 3D scanning

Methods of mapping the shape geometry of underground features and structures

Mapping the geometry of underground features and structures is a major aspect to be addressed when defining the existing geometry of a spatial structure, in particular, when defining the shape of the interior surface. The objective is to determine the exact values of geometric parameters of underground structures and features, i.e. their measurable quantities (surface areas, volume, characteristic dimensions). 3D data on location and characteristic features of underground structures are categorised into several groups:

- geometric/spatial data –providing information about the shape and absolute position of key elements in the selected reference system and about their positions with respect to other points and features (topology), descriptive data (also referred to as attributive),
- descriptive data (also referred to as attributive)- describing the quantitative or qualitative features of objects, unrelated to their position in space,
- graphic data – defining the method of presentation on the map, including the library of points, linear or surface symbols [6].

These data are acquired and stored in the database by a variety of methods, which can be broadly categorised into 2D or 3 D imaging methods. Their application range is defined by the individual needs of the underground object's user or an investor. These could be exploratory methods used in geological analyses (geophysical methods: geo-electric, geo-radar and thermal methods) or those used in inventory-taking (geodetic surveys, photogrammetry, laser scanning). In revitalisation projects of particular importance are those methods that allow the geometry of underground features to be mapped such that the specifics of the underground structure and architectural details should be taken into account. Besides, it is worthwhile to obtain a 3D image allowing the surface modelling in the course of stabilisation jobs.

Mapping of underground features and structures by geodetic methods

Geodetic measurements of underground structures and features involve:

- drawing a planimetric and contour map (scale 1: 500, 1:1000, 1: 2000);
- measurements of characteristic cross-sections (scale 1:50, 1: 100).

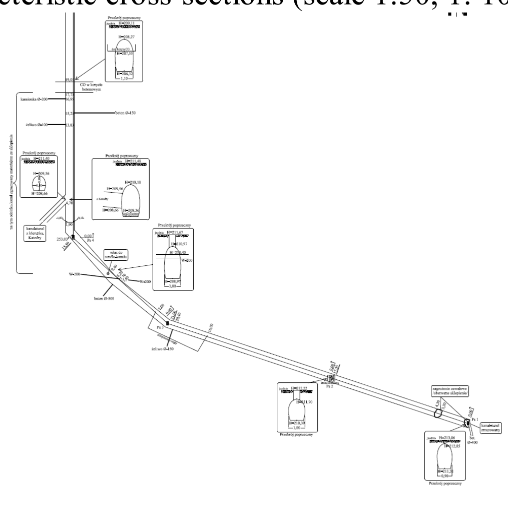

Figure 3: Geodetic survey in the old sewage reservoir in Przemyśl (Poland) [7]

One has to bear in mind, however, that complete and full mapping of underground features by the geodetic measurement methods is not possible. Geodetic measurements are taken to determine the geometric parameters (positions, shapes, dimensions) of underground features and structures (mine workings, underground passages, elements of infrastructure, cellars and the like). The horizontal and vertical networks are developed using the traverse net or geodetic quadrilaterals, providing a systematic set of control points. Relative positions of these points are established by geodetic techniques (vertical control survey net and horizontal control network) and the orthogonal projection of images and selected cross-profiles in the underground structure are obtained accordingly. The scope of the mapping work and the accuracy level are associated with the nature of geometric structures and diversity of underground features [4]. In particular, underground features and structures with an irregular geometry and the natural surface structure, such as abandoned mine workings, pits and underground passages in mines, present certain problems, which are mostly caused by:

- inaccessibility of control points - connections between the surface and underground networks;
- the need to adjust the network system to the geometry of the deposit;
- the floor structure precluding the stabilisation of control stations;
- structural deformations in the course of deposit mining- difficulty with maintaining the control stations;
- limitations imposed by atmospheric conditions inside – dust emissions [6].

In underground objects with regular geometry, those measurement methods yield a most precise 2D projection. That applies mostly to objects whose structure is clearly defined (cellars, utility reservoirs, brisk or concrete shaft work) lacking the irregularly shaped natural rock elements. Development of the horizontal and vertical network of control points allows for accurate projection and mapping of 3D features. Cross-profile projections are defined by straight lines and by second-order curves. In the course of 3D modelling, the geodetic description of those objects underpins the development of a 3D model, making use of the dynamic profile delineation along the vertical axis.

Photogrammetry in mapping of underground features and structures

Photogrammetry consists in reconstruction of shapes, dimensions and relative positions of objects in the open ground basing on photogrammetric images (photograms). Photogrammetric images are taken with specialised photogrammetric cameras, equipped with aberration-free lens. In the early days of photogrammetry, the analytical photogrammetry used an analogue plotter, and the data were obtained in the form of a raster image. Nowadays digital photogrammetry uses vector data recording. Underlying photogrammetric measurements are mathematical dependencies between the type of projection (image) and 3D positioning of control points of investigated objects.

Measurement results can be presented:

- in the graphic format (maps, plans, vector representation);
- in the form of an image with metric signature (orthophotogram, orthophotomap, raster representation).

Photogrammetry relies mostly on perspective projections. The image developed on passing through the lens is recorded in the photo camera on a negative (or a CCD, CMOS matrixes). In order to reconstruct the perspective ray paths from the image it is required that projection parameters should be first established. The photogrammetric camera provides that knowledge and ensures the repeatability or stability for identical settings. Non-topographic photogrammetry (close-range photogrammetry) allows for projecting the geometry of underground spatial features, including the regularly and irregularly shaped objects. Projection can be effected through mono- or multi-image photogrammetry.

Main advantages of photogrammetry include:

- objectivity of measurements thanks to remote-control data acquisition and the lack of contact with the object being measured (for passive recording systems), which may affect the measurement results;
- possibility of measuring any number of points on the projection images, they form an archived set of data which can be used repeatedly;
- high-precision measurements, for close-range photogrammetry (principal distance below 300 m) being of the order of 1/10000 of the principal distance;
- diversity of measured objects and phenomena thanks to varied wavelength recording;
- recording of dynamic processes;
- fully-automated measurements supported by the state-of-the-art. technologies.

Mono-photogrammetry

Mono-photogrammetry of underground profiles uses the “ plane of light” projected onto the side walls of the underground features and the selected cross-profile of an underground structure can be delineated. However, the geometric constraints of mono-photogrammetry are not satisfied and the projection need to be processed accordingly basing on the known coordinates of the frame corners, well revealed in the image (programme MicroStation) [2].

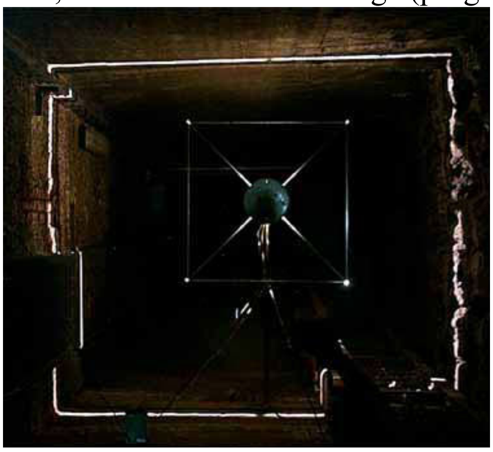

Figure 4: Recording of a vertical cross-section of an underground passage by the plane of light method [2]

This technique of cross-profile mapping in combination with geodetic measurements (projections) enables the 3D object modelling and dynamic image recording using the camera to determine the condition of an underground structure or feature.

Multiple image photogrammetry

Application of multiple-image photogrammetry to projections of 3D underground structures and objects is recommended particularly when dealing with elaborate architectural features and complex geological structures. An example of such application was the data recording in the St Kinga’s cavern in the Wieliczka Salt Mine. Thus obtained images (registered in 1983) allowed for adapting the procedure to difficult geological conditions and to overcome some technical problems, such as lighting, atmospheric conditions inside the cavern, irregular surface structures, reflexes and shadows cast while the recordings were taken. That is why the photogrammetry technique needed to be adapted to particular conditions on the site (relocating the camera, image taken from unstable positions). Thus obtained data would yield a 2D reconstruction of wall images with architectural details revealed.

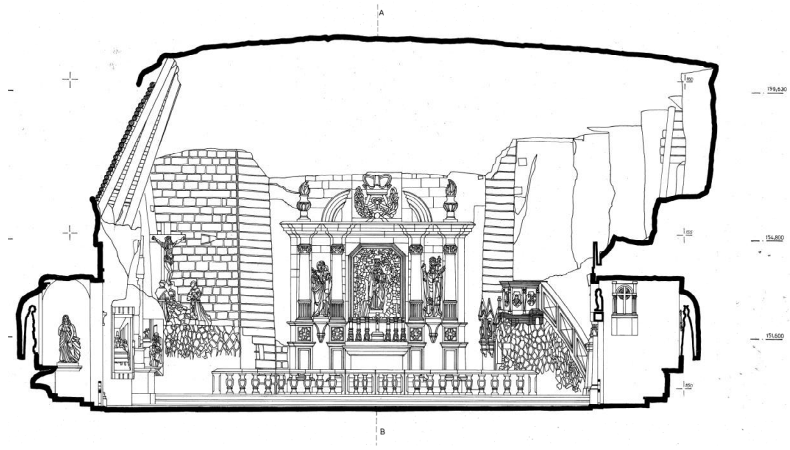

Figure 5: The Queen Kinga's Cavern in the Wieliczka Salt Mine- E-F profile- eastern wall (source: Wieliczka Salt Mine S.A., 1983)

Laser scanning of geometry of 3D underground structures and features

Laser scanning has become the basic method of mapping the geometry of 3D structures. The method allows a 3D digital representation of the actual shape of an underground object, regardless of its form and origins. Laser scanning involves the laser-assisted measurements of distance between a point of known coordinates to the investigated points, their positions are then determined in the assumed 3D system of polar coordinates. Because of a large number of measurement points (also referred to as 'a cloud of points', we get a quasi-continuous 3D representation of the investigated object's surface. Laser scanning methods rely on a variety of techniques: cloud-to-cloud registration, control station signalling, or natural control stations, yielding a cloud of points making up a 3D virtual model of an object, a true orthophoto, a vector model of an investigated object , or a 3D vector map. Besides, laser scanning can be well used for analysing deformation. Because of the specificity of historic structures underground, the method provides a complete 3D model and allows for generating an arbitrary number of cross-profiles at selected characteristic points.

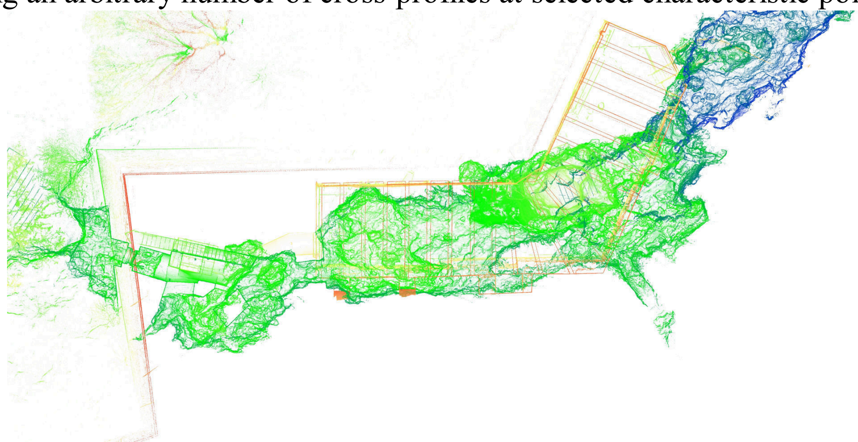

Figure 6: An example of laser scanning of geometry of a natural 3D structure (a cloud of points); Dragon's Den, Kraków (ApplyCapnor Poland 2011)

Figure 7: An example of laser scanning of geometry of a natural 3D structure: computer-processed data- projections - Dragon's Den, Kraków (ApplyCapnor Poland 2011)

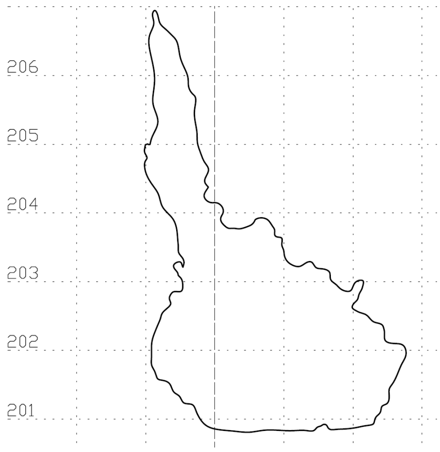

Figure 8: An example of laser scanning of geometry of a natural 3D structure (computer-processed data- vertical cross-profile 04- Dragon's Den, Kraków (ApplyCapnor Poland 2011)

When the laser scanning method is used to measure underground objects, of particular importance is creation and calibration of numerical methods developed basing on the laser-generated 3D geometry of the object. Projections are used for analysis of surface areas and inventory taking in an underground object, for defining the safety conditions inside, determining the object's or structure's stability and defining the potential hazards on the basis of the numerical model.

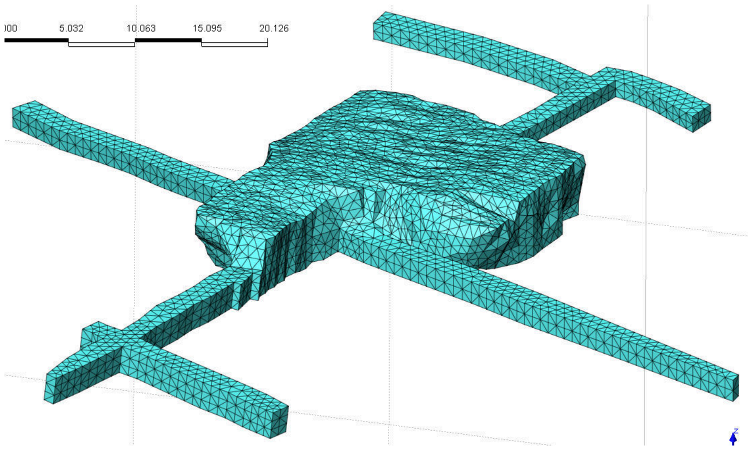

Figure 9: Development of a numerical model of the caverns Franciszek and Ferdynand in the Wieliczka Salt Mine- a grid of finite elements (tetrahedral) [3]

The numerical model is developed by the laser scanning method involving:
- readout and evaluation of laser scanning data and generation of cross-profiles containing the points from the laser scanning procedure (the spacing is taken to be 0.5 m);
- import and processing of generated cross- profiles using the AutoCad software;
- development of a 3D model of the object using the AutoCad software;
- creation of a 3D model of geological strata and processing and export of thus developed 3D model to MIDAS GTS;
- development of a finite element grid in the programme MIDAS GTS [3].

Conclusions

Revitalisation of underground structures of historic value has become a top-priority investment project for numerous investors both from the public and private sector. These projects provide new encouragement to local communities, already at the stage of project development, then during implementation and when the object or structure is ready and functioning. Mapping the geometry of underground structures and features is the major issue to be addressed when planning the project. The mapping has to provide the fundamental parameters and data describing the geometry of the investigated object so that the potential hazards can be identified and the mitigation measures provided, new functions should be defined and the economic aspects should be duly addressed. Selected mapping methods are analysed in the context of their adequacy and usefulness in the revitalisation projects. The selection of a particular mapping method is dependent on the condition of the existing underground structure or feature. Geodetic methods are used to determine the parameters of objects having a defined and regular shape geometry and with simple architectural and structural details. On that basis 3D solid models are developed and the space structure of the underground feature can be parameterised. Close-range photogrammetry methods, both mono- and multiple- image photogrammetry, should supplement the geodetic methods. The main technical problem encountered while developing orthophotos and orthophotomaps is the intricate structure of underground features, requiring variations of camera positions. That happens in the case of objects featuring irregular geometry and complex geological structure (caves, caverns, mine workings). The application range of those method is therefore limited to objects with a defined interior structure. They are employed mostly in taking inventory of architectural details. The fundamental quantitative parameters of an underground object or structure can be determined and architectural and structural details are obtained in the 2D format: cross-sections, projections, wall views. Nowadays 3D models can be developed basing on photogrammetric images using computer graphics programmes. These data can be well used in scheduling of work to be completed before the underground objects can be open to the public. The laser scanning method appears to satisfy all requirements resulting from the specificity of measurements taken in underground objects. Obtaining the accurate 2D description of a 3D structure using the cloud of point approach allows for unambiguous mapping of both 2D and 3D features. Furthermore, these data exported to graphics programmes such as CAD or computational programmes MIDAS, allow a simultaneous analysis of the ‘architecture’ of the object’s interior and of its static behaviour. Practical applications and selection of mapping methods are the results of an interdisciplinary analysis, taking into account the geometric structure, geological conditions, ‘development’ plans and economic aspects in the design of the underground object revitalisation scheme.

References

[1] Bartos M., Chmura J., Wieja T.: *Organizational, design and technology issues in the process of protection of underground historic monuments*. Civil and Environmental Engineering Reports, nr 17, pp. 5 – 24, 2015.
[2] Bernasik J., Ziajka M.: *Digital photogrammetry methods for cross-section measurements of underground excavations.* Science Notebooks, AGH, Kraków, 2004.
[3] Butra J., Cała M., Dębkowski R., Szpak M.: *Comprehensive method of technical condition assessment of chamber excavations in salt mines*. CUPRUM, nr 2(71), pp. 5-16, 2014.
[4] Chmura J., Wieja T.: *Architectural detail in the design and construction of underground tourist routes.* Mining and Tunnel Construction, Vol. 2, pp. 39 – 48, 2013.
[5] Mikoś T.: *Methodology of complex revitalization, adaptation and restoration procedures of underground sites of significance with the application of mining technology*. AGH University of Science and Technology Press, Cracow, 2005.
[6] Milewski M.: *Mining Geodesy*. Publisher AGH, Scripts University nr 1105, Cracow, 1988.
[7] Wartak K., Wieja T.: *Historic sewage channels adaptation regarding to underground touristic routers*. Mining and Geoengineering, Vol. 2, pp. 573–580, 2011.

ZNACZENIE I OCENA METOD ODWZOROWANIA GEOMETRYCZNEJ STRUKTURY PRZESTRZENNEJ PODZIEMNYCH OBIEKTÓW ZABYTKOWYCH W PROCESIE ICH REWITALIZACJI

W artykule zdefiniowano systematykę geometrii ustrojów podziemnych oraz przedstawiono przykłady wykorzystania tradycyjnych i komputerowych metod zapisu geometrycznej struktury przestrzennej obiektów podziemnych. Zastosowane metody pozwalają na odtworzenie geometrii obiektu podziemnego oraz opracowanie szczegółowych rysunków stanowiących podstawę procesu rewitalizacji i zabezpieczania podziemnych obiektów zabytkowych.