E3S Web of Conferences **526**, 01012 (2024) https://doi.org/10.1051/e3sconf/202452601012
SEP 2024

Use of laser scanning and 3D software in mining design

Katarzyna Dusza-Pilarz[1], *Mariusz* Kirej[1], and *Justyna* Jasiołek[2*]

[1]KGHM PM S.A. "Rudna" Mine, 50 Henryka Dąbrowskiego St., 59-100 Polkowice, Poland
[2]AGH University of Krakow, Faculty of Geo-Data Science, Geodesy, and Environmental Engineering, Department of Photogrammetry, Remote Sensing, and Spatial Engineering, 30 Adama Mickiewicza Al., 30-059 Krakow, Poland

Abstract. The article presents the results of laser scanning measurements in horizontal and vertical headings of copper ore mines in Poland. Laser scanners are used primarily for the inventorying of large chambers or workings that are difficult to access. The point clouds obtained from the measurements are processed in CAD programmes, the study then examined examples of their use in underground mining. The examples included the use of scans for modernisation projects and for designing new mine workings. This paper explores the integration of laser scanning and 3D software as a powerful toolset for enhancing various aspects of mining design. Through the accurate capture of spatial data using laser scanning technologies, detailed representations of mining environments can be generated, enabling engineers to create precise digital models of underground workings, open-pit mines, and associated infrastructure. Furthermore, the integration of 3D software facilitates the manipulation and analysis of this captured data, allowing for the development of comprehensive design solutions. By leveraging the capabilities of 3D modelling and simulation tools, mining engineers can conduct virtual assessments of proposed designs, identify potential risks and inefficiencies, and optimize operational layouts to maximize productivity and safety. This paper reviews the methodologies and applications of laser scanning and 3D software in mining design, highlighting their contributions to key aspects such as geological modelling, slope stability analysis, ventilation planning, and equipment optimization.

1 Introduction

Classical geometry surveys are time-consuming and require the facility to be halted for the duration of the survey, and the completeness of the condition information critically depends on the number of points selected for measurement, which form the core of the design to be plotted [1 – 3]. The more accurately measured points of the excavation, the better the design is matched to the existing infrastructure. Laser scanning technology, also known as LiDAR (Light Detection and Ranging), is used for precise surveying and mapping of mining sites [4, 5]. It captures detailed 3D data of the terrain, including surface topography,

* Corresponding author: jasiolek@agh.edu.pl

structures, and geological formations [5, 6]. This data provides a comprehensive understanding of the mining area, aiding in accurate planning and design [6 – 8]. Laser scanning allows for the creation of highly accurate as-built documentation of mining infrastructure [9,10]. By comparing scanned data with design plans, it can be identified any deviations and make necessary adjustments to ensure compliance with safety and operational standards [11].

Terrestrial Laser Scanning (TLS) enables thousands of points to be measured remotely with great precision [4, 12]. 3D software allows to process and visualize the vast amount of data collected through laser scanning [13]. So, utilize this software we can create detailed geological models of the mining site, incorporating information about rock types, mineral deposits, and structural features. Finally, such models help in determining optimal mining strategies and identifying potential hazards [14].

The scanner sends a laser beam towards an object, which reflects it back to the device. The angle is recorded simultaneously with the distance measurement. The distance, measurement angle and horizontal are polar coordinates (d, α, β), which are then converted into Cartesian coordinates (x, y, z). The measurement can be performed under any conditions and is independent of time of day, weather, lighting [15].

For many years, laser scanning has been used in many different fields. From materials engineering to the creation of 3D models of the earth's surface. For the inventory of historical monuments, the creation of 3D models of cities, the inspection of products or the review of engineering structures (monitoring of tunnels, condition of bridges, etc.) [16].

Recently, laser scanner measurements have also found application in underground mining [17]. The introduction of the new technology, in parallel with traditional measurements, allows a large amount of data to be acquired in hard-to-reach mine workings, while maintaining high measurement accuracy and ensuring an adequate level of safety.

The measurement results in the actual shape of the three-dimensional object in digital form [18]. Scanning of the object is usually performed from several stations, so that a three-dimensional model can be created without so-called "shadows" and "blind spots".

A pre-developed point cloud can be used to inspect the geometry of the structure. The observations made enable accurate multidimensional measurement of the scanned objects. The cross-sections created based on the point cloud allow detailed information to be obtained, e.g. the shape of individual construction elements. It should also be noted that the cross-sections obtained in successive measurement cycles are fully comparable, making it possible to determine deformations and deformations.

The resulting scanning point cloud can be further processed as follows:

– combine point clouds from all scans into a single coordinate system,
– build a three-dimensional CAD model,
– create 2D drawings – plans, sections, profiles,
– create databases combining 3D graphics with descriptive elements,
– create 3D designs using a 3D CAD model.

2 Research methods of laser scanning in mining

Laser scanning and 3D software in mining design aim to advance the understanding of geological processes, improve mining efficiency and safety, and promote sustainable resource extraction practices [4, 5]. To achieve these goals, various research methods are employed, including field data collection, data processing and analysis, 3D modeling, and validation of results.

In our case, we conduct field surveys using laser scanning equipment to capture 3D data of mining sites. Subsequently, we process and analyze the 3D point cloud data [4, 6].

Utilizing geological and structural analysis techniques, we interpret the scanned data and identify key geological features, such as rock types, fault lines, and mineral deposits. Finally, we compare the results obtained from laser scanning with traditional surveying methods to validate the predictions made by 3D simulation models.

2.1 Shafts, blind shafts, reservoirs

The obligation to monitor mining engineering structures derives from the basic legal acts regulating mining activities [19, 20]. By monitoring the geometry of the structures of the objects, we mean not only obtaining information about changes in their shape, but also comparing them with the values allowed by standards and legal regulations.

The possibilities of using laser scanning in the inspection and condition assessment of structures are presented using the example of a reservoir.

The retention basins, as originally designed, were constructed as vertical pits with a cylindrical shape and a diameter of 7.5 m, Fig. 1 shows the result of scanning the retention basin without deformation.

a *b* *c*

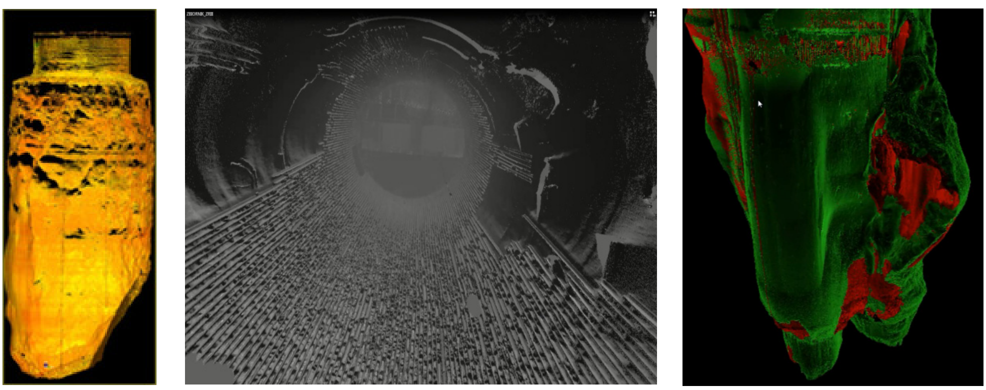

Fig. 1. The result of reservoir scanning: (a) without damage; (b) case inside the tank; (c) with visible deformations.

Part of the hopper discharge is protected on the inside by a concrete spout about 0.2 – 0.25 m thick and a steel rail lining attached to the concrete spout (Fig. 1b). During operation, backfilling of the reservoir with excavated material from the conveyor belts caused local robbing of the reservoir's stubs. This process was exacerbated by the spoil flowing through the reservoir, resulting in localised defects in the reservoir's concrete casing and the tearing of rails from the casing. The consequence of the destruction of the reservoir casing was the wedging of individual rails in the reservoir outlet windows and the stopping of excavated material transport to the surface.

During the inspection of the reservoir, anomalies arising in the contour of the reservoir were highlighted. Subsequently, a decision was made to take additional measurements using laser scanning. As a result of this measurement, a significant deformation was documented. By comparing the cross-sections (Fig. 1c) obtained in successive cycles - the 2012 scanning (green) and the 2013 scanning (red), progressive changes in the contour of the reservoir can be observed.

Based on the cross-sections of the retention basin, created on the basis of a point cloud, which served as the design documentation, [21, 22] and a design for the reinforcement of the excavation floor under the basin was developed (Fig. 2), with uninterrupted operation of the basin.

Fig. 2. Executed reinforcement of the pit roof under the reservoir.

2.2 Excavations with difficult access

In the "Rudna" mine, due to the large area, there are communication and ventilation pits of fundamental importance to the mine, requiring constant maintenance. Given the age of the mine and the deteriorating stability of the main workings, they need to be rebuilt, both in anchor and support lining.

Until recently, only classic survey methods, which provide a small number of measured points, have been used for reconstruction projects. This does not allow for the accurate mapping of elements such as workings intersections, uplift of the bottom, clamping of the workings, as well as deformations of the arch lining, uneven distribution of support lining, etc. The laser scanning technology, on the other hand, makes it possible to obtain full information on the excavations, as well as on the mining equipment present in the excavation, e.g.: conveyor belts, solder pipelines, pipelines, electric cables, etc. The fast, automatic measurement allows reliable data to be provided in hard-to-reach workings. All design work was carried out in MicroStation V8i software. The cross-sections developed based on TLS data are useful in creating documentation for the corridor workings. The adaptability of laser scanning in the inventory of hard-to-reach workings is presented using the example of reconstruction projects.

2.2.1 Example of pavement reconstruction W-249

The reconstruction project consisted of selecting a suitable type of support shoring for securing the W-249 galleries. We created a three-dimensional model of the excavation on the basis of available traditional survey data. Subsequently, the elements of the support shoring were drawn in - arch-straight spurs (Fig. 3).

When the designed shoring is superimposed on the point cloud obtained by laser scanning, the difference between the actual and theoretical pit outline can be observed (Fig. 4).

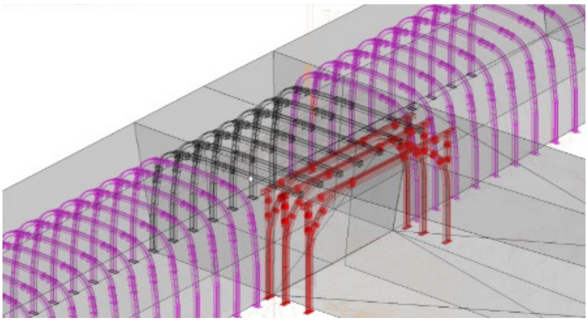

Fig. 3. 3D project with cross-sections of the excavation made with traditional methods.

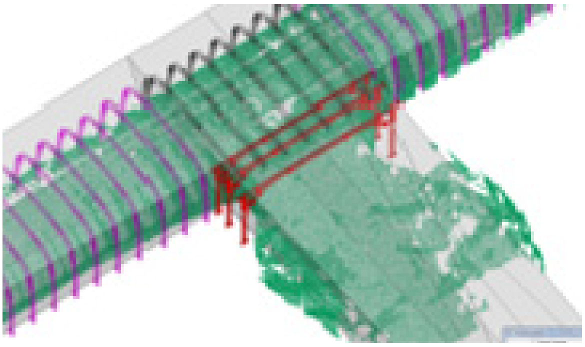

Fig. 4. Designed chock support of the excavation applied to the point cloud.

Due to the large widths but low heights of the excavation, the series of doorways was changed. Thanks to the simulation, the most favourable solution for the selection of the shoring was chosen.

2.2.2 Example of T-150 pavement reconstruction

As in the case of the reconstruction of the W-249 heading, the project consisted of the selection of the shoring. Scanning of the excavation was carried out for the project (Figs. 5 and 6).

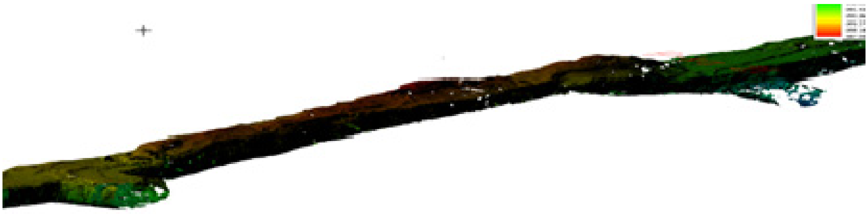

Fig. 5. Cladding formed from a point cloud.

As we can see in Fig. 8, the longitudinal cross-sections obtained by measuring by the traditional method and by scanning do not differ to a great extent.

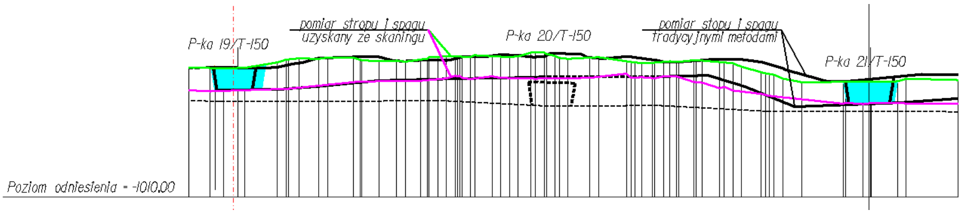

Fig. 6. Longitudinal section obtained from the point cloud and the along section applied to it obtained by traditional methods.

We can see a significant difference in cross-sections. The outline geometry of designed and excavated workings has so far traditionally been represented as an inverted trapezoid, whereas scanning provides us with the real outline of the excavated workings (Figs. 7 and 8).

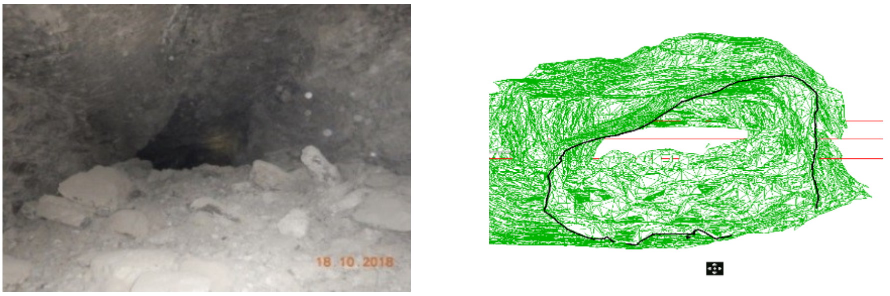

Fig. 7. Comparison of the actual shape of the excavation with the image obtained by the scanner.

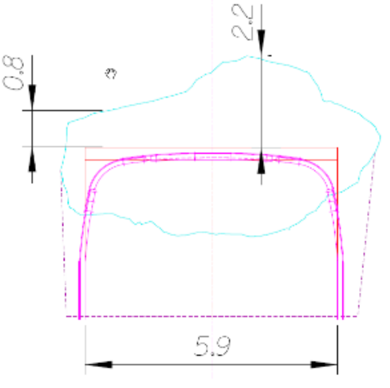

Fig. 8. The actual shape of the excavation with a designed floor scraper and an arched-rectangular chock support.

As a result of the simulation of the types of shoring used, the most favourable variants were selected. It was proposed to build the arch-shaped shoring Ł-Prw in sections of varying heights, fitting the doorways as far into the excavation as possible, reducing the amount of lining and not causing any additional load on the shoring.

During the design of the redevelopment, based on the cross-sections obtained from the scan, attention was paid to the size of the void that would remain after the doors were built in, which would also entail the need for the right type and size of infill "lining" and how this void would be filled.

3 Design of mining works in 3D

Equally important, in addition to the designed alterations, are any mining works planned to be carried out, which must first be planned and then the various options for their implementation analysed. A three-dimensional model, even a simplified one, is excellent for visualising proposed solutions, e.g. the use of lining, ventilation dams, ventilation bridges, lump breaking equipment, etc. It makes it possible to test plans for the implementation of mining works. In addition, georeferencing allows the designed workings to be oriented accurately, in the mine's coordinate system. Examples of 3D designs using traditional surveying methods (Figs. 9 and 10).

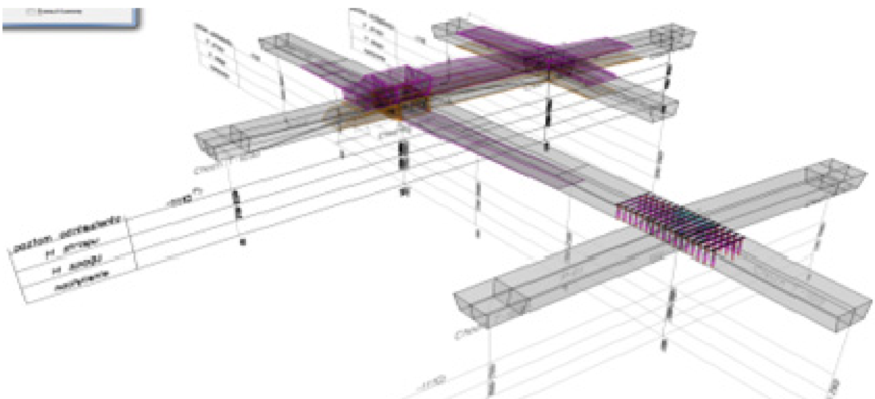

Fig. 9. A three-dimensional model of a projected intersection of excavations with "trellis" and the use of a chock support.

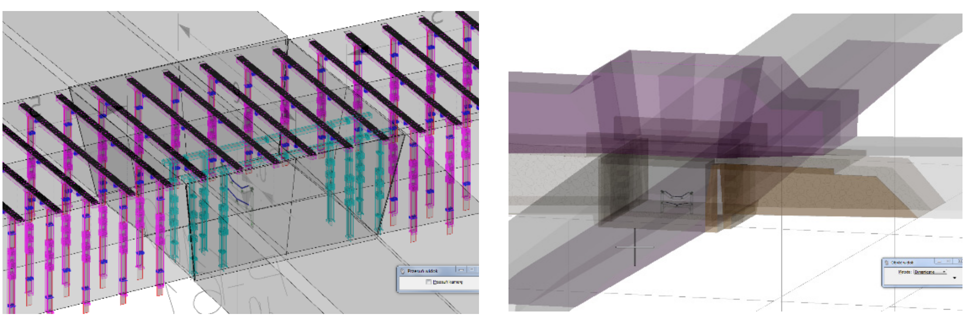

Fig. 10. Simulation of the use of chock support to secure the belt roadway (skeleton display mode) and "trellis" (smoothed display mode).

For new, rather elaborate projects in which we include the development of engineering structures (ventilation bridges, "grilles", dams), or the routing of central air-conditioning pipelines, it seems reasonable to use 3D software (Fig. 11).

Another important consideration is the ability to save spatial data in pdf format. The CAD programmes (AutoCad and MicroStation) used for design in the mine require considerable knowledge of the software. Creating design workstations is an expensive item in a company's budget (cost of training, licences, etc.).

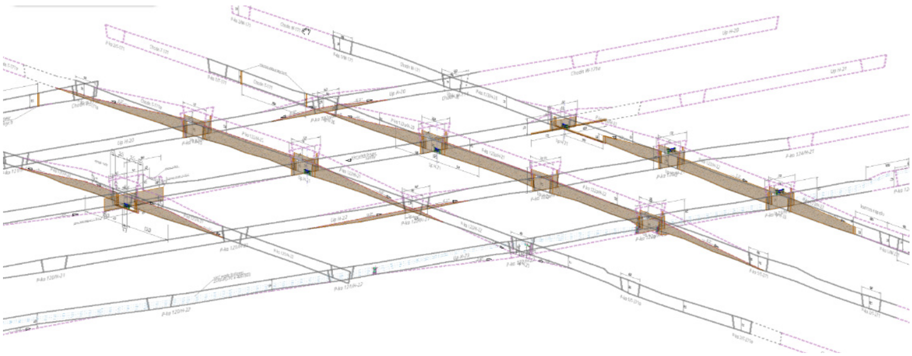

Fig. 11. Skeleton model of crossing excavations.

Printing out a 3D design also does not fully capture the visualisation possibilities. Saving the data in .pdf format gives us the opportunity for a simplified visualisation. This format is widely used and can be used by any mine worker. Its use requires simple training but allows great comfort in working with 3D data.

4 Conclusions

Accurate knowledge of the shape, volume and local deformation of underground workings is important for the proper operation and safety of mining facilities. Laser scanning technology, used in the measurement of mine workings, offers new possibilities for mining design. The time savings and high fidelity of 3D documentation make it a very useful tool. The data acquired with the laser scanner are used not only for documenting the actual state or design, but also for decision-making, e.g. with regard to safety (as in the case of a retention basin).

Of course, satisfactory results will not be obtained without interdisciplinary cooperation and the exchange of knowledge and experience. Given the emphasis on safety and economics, the emerging spatial models of the workings, supplemented by the infrastructure located therein and integrated with the map of the mine workings in a spatial database environment [23], supplemented by the surrounding geology, may become an important element of the spatial data management processes of the mine site in the future [17].

An unquestionable limitation in processing point clouds from laser scanning is the volume of data stored in the server resources of the Mining Plants of KGHM S.A. The problem of collecting and processing increasingly large volumes of spatial data is growing. This problem is already identified on the example of KGHM S.A. as one of the factors determining the further development of the mass use of point clouds in the mining practice of the mining concern [24].

References

1. Zhao, G.-F. (2015). Modelling 3D jointed rock masses using a lattice spring model. International *Journal of Rock Mechanics and Mining Sciences*, (78), 79-90. https://doi.org/10.1016/j.ijrmms.2015.05.011
2. Dyczko A., Galica D., & Sypniowski, S. (2012). Deposit model as a first step in mining production scheduling. *Geomechanical Processes During Underground Mining – Proceedings of the School of Underground Mining*, 231-247. https://doi.org/10.1201/b13157-39
3. Dychkovskyi, R.O., Lozynskyi, V.H., Saik, P.B., Dubiei, Yu.V., Cabana, E.C., & Shavarskyi, Ia.T. (2019). Technological, lithological and economic aspects of data geometrization in coal

mining. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 22-28. https://doi.org/10.29202/nvngu/2019-5/4

4. Bräunl, T. (2023). Lidar: Light Detection and Ranging. *Robot Programming Practice*. https://doi.org/10.1007/978-981-19-9987-1_6
5. Cui, Z. (2001). *Management, retrieval, and visualization of spatial data from airborne light detection and ranging system (LIDAR) survey*. FIU Electronic Theses and Dissertations. Florida, USA: Florida International University. https://doi.org/10.25148/etd.fi14061561
6. Huff, T.P., Feagin, R.A., & Delgado, A. (2019). Understanding Lateral Marsh Edge Erosion with Terrestrial Laser Scanning (TLS). *Remote Sensing*, *11*(19), 2208. https://doi.org/10.3390/rs11192208
7. Issayeva, L., Togizov, K., Duczmal-Czernikiewicz, A., Kurmangazhina, M., & Muratkhanov, D. (2022). Ore-controlling factors as the basis for singling out the prospective areas within the Syrymbet rare-metal deposit. *Mining of Mineral Deposits*, *16*(2), 14-21. https://doi.org/10.33271/mining16.02.014
8. Kononenko, M., Khomenko, O., Cabana, E., Mirek, A., Dyczko, A., Prostański, D., & Dychkovskyi, R. (2023). Using the methods to calculate parameters of drilling and +blasting operations for emulsion explosives. *Acta Montanistica Slovaca*, *28*(3), 655-667. https://doi.org/10.46544/ams.v28i3.10
9. Polyanska, A., Pazynich, Y., Poplavska, Z., Kashchenko, Y., Psiuk, V., & Martynets, V. (2024). Conditions of Remote Work to Ensure Mobility in Project Activity. *Lecture Notes in Mechanical Engineering*, 151-166. https://doi.org/10.1007/978-3-031-56474-1_12
10. Kassymkanova, K.K., Istekova, S., Rysbekov, K., Amralinova, B., Kyrgizbayeva, G., Soltabayeva, S., & Dossetova, G. (2023). Improving a geophysical method to determine the boundaries of ore-bearing rocks considering certain tectonic disturbances. *Mining of Mineral Deposits*, *17*(1), 17-27. https://doi.org/10.33271/mining17.01.017
11. Dyczko, A. (2023). The geological modelling of deposits, production designing and scheduling in the JSW SA Mining Group. (2023). *Gospodarka Surowcami Mineralnymi – Mineral Resources Management*, *39*(1), 35-62. https://doi.org/10.24425/gsm.2023.144628
12. Cabo, C., Del Pozo, S., Rodríguez-Gonzálvez, P., Ordóñez, C., & González-Aguilera, D. (2018). Comparing Terrestrial Laser Scanning (TLS) and Wearable Laser Scanning (WLS) for Individual Tree Modeling at Plot Level. *Remote Sensing*, *10*(4), 540. https://doi.org/10.3390/rs10040540
13. Huff, T.P., Feagin, R.A., & Delgado, A. (2019). Understanding Lateral Marsh Edge Erosion with Terrestrial Laser Scanning (TLS). *Remote Sensing*, *11*(19), 2208. https://doi.org/10.3390/rs11192208
14. Dychkovskyi, R., Falshtynskyi, V., Ruskykh, V., Cabana, E., & Kosobokov, O. (2018). A modern vision of simulation modelling in mining and near mining activity. *E3S Web of Conferences*, (60), 00014. https://doi.org/10.1051/e3sconf/20186000014
15. Mettenleiter, M., & Fröhlich, Ch. (2000). Visuelles Laserradar zur 3D Erfassung und Modellierung Realer Umgebungen (Visual laser radar for 3D Surveying and Modelling of Real-World Environments). *Auto*, *48*(4), 182. https://doi.org/10.1524/auto.2000.48.4.182
16. Telling, J., Lyda, A., Hartzell, P., & Glennie, C. (2017). Review of Earth science research using terrestrial laser scanning. *Earth-Science Reviews*, (169), 35-68. https://doi.org/10.1016/j.earscirev.2017.04.007
17. Krawczyk, A. (2023). Mining Geomatics. *ISPRS International Journal of Geo-Information*, *12*(7), 278. https://doi.org/10.3390/ijgi12070278
18. Aukazhieva, Z.M., & Darkenbayeva, A.B. (2021). Definition and theoretical basis of laser scanning. *Engineering Journal of Satbayev University*, *143*(2), 52-57. https://doi.org/10.51301/vest.su.2021.i2.07
19. GML. (2017). *Geological and mining law (DZ.U. of 2017, item 2126).* Act of 9 June 2017, 7.
20. Dz.U. 2017 poz. 1118. (2017). *Rozporządzenie Ministra Energii z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych*. ISAP – Internetowy System Aktów Prawnych.

21. KGHM CRDC. (2016). *Technical design of the reinforcement of the pit roof under the ZR-IIIa reservoir at the R-III shaft.* KGHM Cuprum Research and Development Centre, Unpublished Booklet, 216.
22. Dyczko, A., Kicki, J., & Paraszczak, J. (2005). Decision support system to improve equipment effectiveness and reduce production cost in KGHM "Polska Miedz", Poland. *Application of Computers and Operations Research in the Mineral Industry*, 385-390. https://doi.org/10.1201/9781439833407.ch51
23. Krawczyk, A. (2018). A concept for the modernization of underground mining master maps based on the enrichment of data definitions and spatial database technology. *E3S Web of Conferences*, (26), 00010. https://doi.org/10.1051/e3sconf/20182600010
24. Kosydor, P., Warchala, E., Krawczyk, A., & Piórkowski, A. (2020). Determinants of large-scale spatial data processing in Polish mining. *AIP Conference Proceedings*, *2209*(1), 040007. https://doi.org/10.1063/5.0000335