Integrating mining software, CAD, and GIS technologies for enhanced 3D geological mapping and visualization

Kamil Saganiak[1*], and *Valentyn* Buketov[2]

[1]AGH University of Krakow, Faculty of Geo-Data Science, Geodesy, and Environmental Engineering, 30 Adama Mickiewicza Ave., 30-059 Krakow, Poland
[2]Universidad Nacional de San Agustin de Arequipa, Scientific Research Institute of the Center of Renewable Energy and Energy Efficiency, 107 San Agustin St., 04000 Arequipa, Peru

Abstract. This research provides a comprehensive overview of the methods and technologies applied for the mapping and visualization of three-dimensional (3D) mining and geological data, highlighting both mining-specific software and general-purpose engineering CAD and GIS tools. The study begins by addressing the challenges associated with the implementation of GIS-type spatial information systems within the mining industry, emphasizing their role in building robust information systems for mine technical departments. It then explores the application of spatial information systems in the environmental protection of mining and post-mining areas, where these technologies have found significant use. The final section delves into modern technologies for acquiring and visualizing spatial data, focusing on 3D data relevant to both surface and underground mining operations. The article underscores the growing importance of advanced visualization techniques in enhancing the accuracy and efficiency of mining operations and environmental management.

1 Introduction

A fundamental challenge faced by mining companies since the 1970s has been the effective modelling and visualization of geological and mining situations in three dimensions [1]. This issue represented a significant technological hurdle, as accurate 3D representations of subsurface structures were crucial for informed decision-making and operational efficiency [2]. In the latter half of the 20th century, this challenge became a central focus for IT companies aiming to develop comprehensive information systems tailored for the mining industry, commonly known as General Mining Planning (GMP) systems. These systems were designed to integrate various data sources and provide detailed 3D models to support exploration, planning, and management activities [2 – 4]. Addressing this challenge required advancements in both software capabilities and data processing techniques to accurately depict complex geological formations [5]. Consequently, solving this issue was essential for the evolution of mining technology and the development of sophisticated planning tools that continue to play a critical role in modern mining operations [6 – 8].

* Corresponding author: saganiak@agh.edu.pl

Over the years, many mining software companies have developed their own software modules that processed and visualised 3D data. They have also developed their own data formats that, in addition to handling 3D graphics, included the ability to model attribute information about mine plant objects [9]. Handling this type of data generated the need to develop their own "proprietary" data formats for storing 3D graphics and graphics-related descriptive data.

These were, and continue to be, extremely expensive computer systems. These applications were not only able to process 3D information efficiently but were also equipped with computer graphics technology to produce high-end renderings [5, 10]. These systems were additionally equipped with technologies for handling descriptive attributes attached to graphics [5, 10, 11]. This made these systems such as CAD (Computer Adied Design) with great tools for 3D modelling, SIS (Spatial Information Systems) with tools for storing spatial data in databases or GIS (Geographic Information Systems) for spatial analysis [12]. In the case of SIS and GIS, legal conditions such as the INSPIRE Directive, the widespread use of spatial data on the Internet through WebGIS technology and SDI (Spatial Data Infrastructure) have led to the creation of international standards for the exchange of spatial data.

Commercial companies that produce and implement their own GMPs software in mining plants often deliberately create a situation where mining data is very strongly tied to the application that processes it (vendor-lock phenomenon). Mining companies deal with this problem by procuring further integration solutions to ensure data flow between different systems [9, 13]. Different formats of three-dimensional data are generated to seamlessly display large amounts of data. This process results in differences in the geometry of the 3D data between the systems. In such a situation, the problem of identifying the mutual position of mining plant objects in 3D space between different industries can be observed [12, 14]. This is because there is a lack of a single – "single source of 3D object data" in the company. This raises the question of whether? and to what extent? mining companies use spatial data integration technologies in SIS spatial databases or GIS systems.

2 Literature background

The integration of mining-dedicated software, Computer-Aided Design (CAD), and Geographic Information Systems (GIS) tools marks a significant advancement in the field of 3D geological mapping and visualization. This multidisciplinary approach not only harnesses the individual strengths of each technology but also synergizes them to create highly detailed and accurate models of geological formations [5, 15]. These models are crucial for effective decision-making in mining operations, as they provide a more comprehensive understanding of subsurface structures. By combining these technologies, mining professionals can significantly enhance their ability to analyse complex geological data, leading to more precise resource estimation and better-informed strategic planning [16]. This integration allows for improved risk assessment and operational efficiency, ultimately contributing to safer and more sustainable mining practices [17]. As a result, the application of these integrated tools is becoming increasingly essential in modern mining operations.

The synergy between mining-dedicated software, CAD, and GIS tools allows for a robust workflow in the creation and management of 3D geological models [5, 18]. Ensuring seamless data exchange between different platforms is crucial for maintaining data integrity and accuracy. Modern mining software is often equipped with functionalities to import and export data in various formats, facilitating interoperability between systems [19]. Tools like MineSight and Surpac, for instance, allow for the importation of spatial data from GIS and CAD environments, ensuring that geological data can be utilized across different software platforms without loss of fidelity [20, 21].

The integration process is greatly enhanced by the ability to combine geological data with spatial information to produce detailed 3D models. These models are not only crucial for visualizing underground formations but also for analyzing the spatial relationships between different geological features [12, 22]. CAD tools provide precise control over the design and manipulation of these models, while GIS offers the ability to incorporate and analyze spatial data, such as topography, drill hole data, and surface infrastructure. This integration of CAD and GIS with mining-specific software ensures that 3D models are both detailed and comprehensive [5, 12, 17, 23].

Advanced visualization techniques are employed to interpret and present geological data effectively. Visualization tools within mining software, as well as CAD and GIS platforms, enable users to create dynamic and interactive 3D models [11, 20, 24]. These visualizations are essential for communicating complex geological information to both technical and non-technical stakeholders, aiding in exploration, planning, and decision-making processes [16, 25]. The ability to visualize data in three dimensions provides a clear and intuitive understanding of geological structures, which is invaluable for optimizing mining operations.

The practical applications of these integrated technologies are well-documented in research and case studies. For instance, a study on 3D geological mapping in Xinjiang, China, demonstrates the effectiveness of integrating geophysical data with 3D modelling techniques [12, 26]. The study employed a combination of geological, geochemical, and geophysical data to construct accurate 3D models of subsurface structures. Another study highlights the versatility of open-source GIS tools in urban and environmental contexts, which can be adapted for mining applications. Although not mining-specific, the methodologies and tools discussed in this study are highly relevant for managing mining-related environmental impacts and land-use planning [5, 27].

By leveraging the combined capabilities of mining-dedicated software, CAD, and GIS tools, mining professionals can significantly enhance their understanding of geological structures [28, 29]. This deeper understanding leads to more accurate resource estimation, optimized mine planning, and improved operational efficiency. Furthermore, the ability to visualize and analyze complex geological data in three dimensions provides a powerful tool for risk assessment and decision-making, ultimately leading to more sustainable and profitable mining practices [30].

The purpose of this research is to examine and compare the methods and technologies used for mapping and visualizing 3D mining and geological data, focusing on both specialized mining software and widely available CAD and GIS tools. It aims to evaluate the effectiveness and integration of these tools in enhancing the accuracy and efficiency of geological modelling and mining operations. Additionally, the research seeks to identify best practices and potential areas for improvement in the application of these technologies within the mining industry.

3 Methods

The use of spatial databases dedicated to the handling of land surface data is the most common, the use of GIS technology to describe workings in underground mines is also encountered. In an article [26], the authors describe the case of a mining spatial information system concept. The architecture of the solution is described, in which two groups of data are indicated: a spatial database containing vector data of, among others, workings, energy infrastructure and dust sprinkler system, and an attribute database of the ventilation management system and mine management system. The integration of the above two databases forms a spatial information management system. In this paper, the system is referred to as a graphical information management system [31]. This system is based on Oracle and SQL Server databases, where vector data is stored. Improving the usability of the information and raising the standard of management decisions is indicated as a positive value. The MAPGIS application is used for data visualisation. The authors indicate the direction of the system's development, which aims to create an intelligent and integrated spatial information system.

Subsequent authors [27] present the case of integrating a GIS system with a system of sensors and automation for the management of ventilation fans. The concept described is based on sensor data. The data is processed by a ZigBee system and then integrated with vector data from the mine's existing GIS system. The integrated data is processed in a data management server, which was based on an application from ESRI's ArcGIS package. The result was a system in which real-time, uploaded data could be visualised. This resulted in an increased risk awareness and the ability to manage safety in the workings.

Another article [28] describes the process of integrating data stored as a CAD vector drawing of mine workings with a database of ventilation parameters stored in .xlsx (Excel) format. By going through the process of combining data from these two sources in ArcGIS software, a vector shapefile database with attributes assigned to objects was created. The authors point out how much added value the object-based map system brings [32]. Benefits in terms of enhancing the quality of the working environment, optimising the operation of equipment, support in making strategic decisions related to changes in the configuration of the ventilation system, decisions, are three of several positive aspects pointed out in the article. Mention was also made of gas surveys carried out in the most unfavourable areas of the mine using historical data, which allowed a deeper understanding of the phenomena of concentration and temperature increase depending on the fan configuration. In a subsequent publication [27, 29, 33], the authors presented the results of their analyses, describing in more detail the use of GIS tools in the research process. In conclusion, the possibilities offered by the GIS system were appreciated, indicating the possibility of analysing the environmental conditions of underground mine workings over time and the possibility of gaining knowledge while simulating many variants of gas flows in the workings.

3.1 Characteristics of the use of spatial information systems in the underground mining industry

The use of spatial information systems in surface mining brings tangible benefits related to the quality of decision-making. Also, an important element addressed in the articles presented is the increase in spatial awareness and access to location information on mine workings, which directly improves process efficiency. When using spatial databases, we are often limited to a 2D view. Using the third dimension allows for additional analytical and decision-making capabilities.

A small number of implementations of a three-dimensional mining object map model can be found in the international underground mining space. The authors [27, 30, 33] describe the concept of a three-dimensional mine model using GIS systems [30, 34]. Based on the organisational structure of a mining company located in Ghana, the scope of data implemented in a spatial database is described . The organisational units of the plant that can feed the three-dimensional model of the plant with industry data are identified. These include Production Planning Department, Geology Department and Mining Department. One of the applications raised in the paper is the dynamic visualisation of the mine's advance, which provides a platform for informed decision-making to ensure mine safety. Using the Microsoft Visual C++ 2008 programming language, OpenGL and Nokia's Qt, the authors created a 3D model of the mine. A TIN mesh was used to create the framework.

When describing the issue of three-dimensional GIS, the author of the publication [27, 35] points to its very frequent use in the aspect of visualising the earth structure, rock mass structure and geology of the areas under analysis. Faults and layers of the lithosphere can be effectively represented on three-dimensional GIS models.

In the following article [36], the authors address the topic of 3D modelling based on geo-databases. The authors multifacetedly list objects relating to the earth's surface divided into natural and man-made. The only underground scope mentioned is the geological model.

Choi, Baek and Park [12], in a comprehensive article describing the application of GIS technology in open-pit and underground mining, point to the possibility of estimating ore reserves among many applications. Conducting appropriately modelled spatial analyses can lead to the determination of the size, quality, location and geometry of deposits.

A retrospective of the development of 3D modelling technology using GIS systems makes it possible to realise how much has been achieved in 25 years in this area and what possibilities have been provided to users. The diagnosed directions of development of 3D GIS modelling systems were geo-information systems and geo-sensory databases.

3.2 Spatial information system in the surface mining industry

GIS is used in many industries, usually referring to the Earth's surface and objects on the surface. One industry making specific use of spatial databases is mining [36]. Performing a literature review, it was found that most of the publications referred to spatial data of objects on the surface - surface deformation, hydrology, impacts of mining on surface infrastructure, or on the environment.

Suh [34], along with Dyczko [38], demonstrated the application of GIS tools for imaging surface deformation resulting from underground mining activities. Both researchers explored various methods and attributes utilized for calculating deformation. Their studies involved a comprehensive comparison of these methods based on data gathered from 22 articles that analyzed spatial data. By evaluating the different approaches documented in these articles, they highlighted the effectiveness and limitations of each technique. Their work provides valuable insights into how GIS can be employed to monitor and analyze subsurface impacts on surface stability. Overall, their findings contribute to a deeper understanding of deformation processes and enhance the application of spatial data in mining engineering.

Another article [39] presents an example of a database architecture designed for a spatial information system tailored to mining activities and their interaction with the natural environment in Indonesia. The article offers a detailed description of the attribute database structure, which could serve as an inspiration for developing relational schemas in project databases. This comprehensive overview highlights how the database architecture can be adapted to meet specific needs in mining projects [12, 40]. The study emphasizes the added value of incorporating advanced relational database structures and the technologies employed. These technologies are frequently discussed in academic publications but are not always thoroughly explained [40, 41]. By providing such an in-depth examination, the article contributes valuable insights into how these technologies can be effectively applied in real-world mining projects. Research papers [42, 43] focuses on developing and implementing an integrated geodynamic monitoring system to enhance industrial and environmental safety at the mineral deposits. The study includes mapping rock mass disturbances, monitoring pit wall stability using various technologies, and creating geodynamic testing areas for accurate long-term deformation monitoring. Paper [44] investigates geodynamic processes during the development of deposits. It uses an integrated research method combining geodetic observations, theoretical calculations, and assessments of subsidence factors to propose innovative monitoring techniques for safer oil and gas extraction.

The article [12] presents the results of an analysis of more than fifty scientific articles that describe use cases of GIS technology in mining. According to the authors, GIS in mining is primarily used in the environmental protection of mining and post-mining areas. This is the

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predominant application. The second area of application is to support the design of haulage operations, this is particularly the case in open-cast mining. There are very few examples of the use of GIS in mining planning or design. However, it should be noted that such applications have taken place.

4 Results and discussions

An analysis of .dwg files within the Digital Maps service was conducted to assess data consistency and quality. The examination focused on layers depicting ordinate points, revealing that despite efforts to standardize object representation, various descriptions persist. For instance, the elevation data comprises three distinct elements: two lines of equal length that intersect at their midpoint to mark the measurement point, and accompanying text that specifies the elevation. This lack of uniformity poses challenges for data processing, as it necessitates additional steps in the algorithm to achieve a consistent data format.

To address these challenges, algorithm models were developed to process vector data from .dwg files into .shp files and to integrate this data into a PostgreSQL database, as illustrated in Fig. 1. The development of these models aims to streamline the data conversion process and enhance data uniformity.

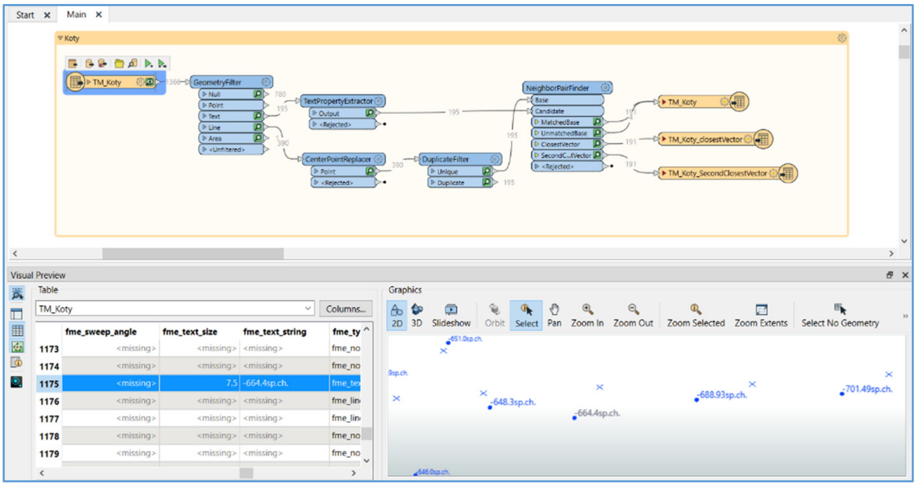

Fig. 1. Model of the algorithm processing vector data with elevation elevations from .dwg layers of coal seam maps to the spatial database format (own study).

By converting and integrating data in this way, the goal is to simplify subsequent data handling and analysis. These improvements are crucial for maintaining accuracy and consistency across digital mapping projects. Overall, the implementation of these algorithm models is expected to facilitate more efficient data management and better support for spatial analysis tasks.

4.1 Innovative solutions for the acquisition of spatial data from mine workings and their visualisation

Recently, several solutions have appeared on the global market that allow the instant measurement of millions of points in space, called laser scanning technology [45]. These devices make it possible to generate a point cloud in a matter of minutes. This measurement, depending on the technical sophistication of the device, can produce results with very high accuracy [46, 47]. By processing the point cloud, the user can generate a spatial model of the mine workings. An exemplary solution was presented by the authors of an article [41] describing the possibilities of acquiring point clouds through 3 types of equipment using the example of the Gwan-in underground mine in Gwanin-Myeon, Korea. In addition to mobile laser scanners, an iPad Pro encountered in everyday use is tested, using a flash LiDAR scanning method with a range of 5m.

Scanning solutions on autonomous mobile platforms are being designed for the exploration of pits with high safety risks [46, 48]. The use of robots or drones for mine mapping is presented as the future of surveying and GIS-integrated automatic creation of spatial models of workings. Innovative surveying technologies also have the potential to facilitate the design of new mine workings and the planning of refurbishment or reconstruction of existing workings that have been deformed or require reconstruction [41, 47, 49].

The development of the free and open-source QGIS software has increasingly focused on enhancing its capabilities for visualizing three-dimensional (3D) data. To explore these advancements, an experiment was conducted to map a section of mine workings in 3D using QGIS. This experiment aimed to assess how effectively the software can represent complex underground structures in a three-dimensional space. Fig. 2 illustrates this type of excavation from both an oblique and a plan view, demonstrating the software's ability to provide detailed spatial insights.

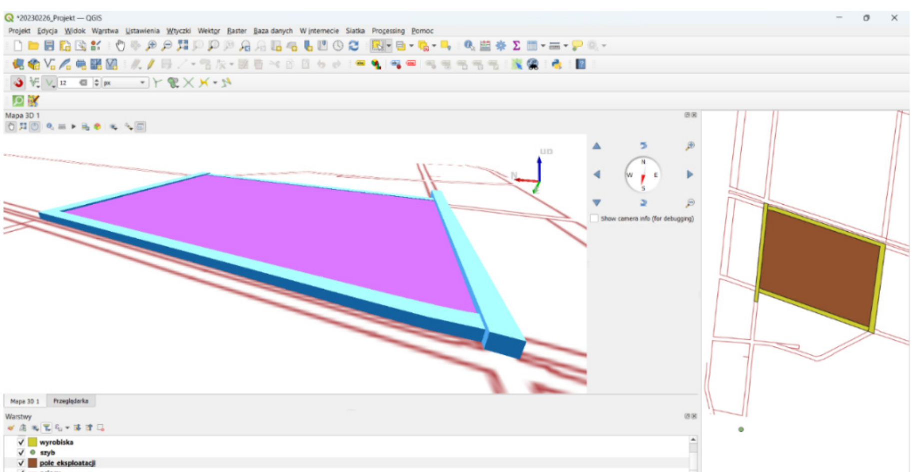

Fig. 2. 3D visualisation of mine workings in QGIS (own study).

The oblique view offers a perspective that highlights the depth and contours of the mine workings, while the plan view provides a top-down look at the layout. These visualizations showcase the potential of QGIS to improve the understanding of intricate mining environments. Overall, the experiment underscores the growing utility of QGIS in handling and presenting 3D data for more comprehensive spatial analysis.

The experiment demonstrated that free and open-source general-purpose software, such as QGIS, is capable of processing and visualizing data from mining sites, converting it from two-dimensional to three-dimensional formats. This capability is particularly valuable for enhancing the clarity and depth of spatial analysis in mining operations. It is important to note that the number of geodata sources continues to grow, reflecting a broader trend in the availability of diverse spatial data. Additionally, data collected independently from mining sites is being increasingly integrated into mining practices. This trend highlights the growing reliance on external geospatial information to inform and improve mining operations. Overall, the use of advanced visualization tools like QGIS supports more detailed and accurate analysis, which can lead to better decision-making in the mining industry.

5 Conclusions

The analysis of .dwg files within the Digital Maps service revealed significant challenges related to data consistency and standardization. Despite efforts to unify object representations, discrepancies persist, particularly with elevation data, which is represented inconsistently through various elements. This lack of uniformity complicates data processing and necessitates additional algorithmic steps to standardize the format. To address these issues, new algorithm models were developed to convert vector data from .dwg files into .shp files and integrate it into a PostgreSQL database. These models aim to streamline the data conversion process, enhancing uniformity and facilitating more efficient data management and spatial analysis.

Recent advancements in spatial data acquisition and visualization technologies offer promising solutions for mining operations. The emergence of laser scanning technology enables the rapid and accurate measurement of millions of points, generating detailed point clouds that can be used to create precise spatial models of mine workings. Innovative equipment, including mobile laser scanners and even consumer devices like iPads with LiDAR capabilities, are being explored for their potential to improve data collection in challenging environments. Additionally, autonomous platforms such as robots and drones are being developed for safer and more efficient exploration of high-risk mining areas.

The development and use of free and open-source software like QGIS have significantly advanced the ability to visualize and analyse 3D data. The experiment conducted to map mine workings in 3D using QGIS demonstrated the software's effectiveness in representing complex underground structures. With the capability to convert data from two-dimensional to three-dimensional formats, QGIS provides valuable insights into mine environments, enhancing spatial analysis and decision-making. As the availability of diverse geospatial data increases, integrating such advanced visualization tools into mining practices will be crucial for improving accuracy and operational efficiency. Overall, these advancements in data processing and visualization are set to revolutionize how mining operations are analysed and managed.

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