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DESIGN OF A GIS DATABASE FOR SURFACE MINING

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ABSTRACT:

The mining industry is the branch that provides necessary mineral raw materials for a whole series of economic activities, with the main beneficiaries being the energy industry (through coal consumers), companies specialized in the processing of uranium concentrates, chemical industry, food industry, construction materials industry, non-ferrous metallurgical industry, etc. Thus, in accordance with the Romanian mining industry strategy 2017-2035, one of the objectives of the industrial policy in the mining field in Romania is the development and implementation of a database system for the mining sector. Specifically, the goal consists in a development of a tool for tracking and implementing the Mining Law, which allows the collection, storage, administration, modification and analysis of data regarding licenses and permits. At the same time, the development of a visualization and geographic information system (GIS) of mining exploration and exploitation perimeters, as support for the promotion of concessions for mineral resources, is being pursued. In this way, there is a tendency towards the automated and computerized management of the production processes. The development of such systems with practical applicability requires the design, development, and implementation of specific models and databases. The structure and quality of the designed data models directly influence the exploitability and analytical capability of the systems. This paper analyzes the possibilities of designing and implementing a database for the management of the surface mining activities. In the first part of the paper, the basic principles regarding the design and population of databases are presented, as well as their correlation with user requirements and exploitation needs. In the second part, a data model was proposed for the management of mining activities, in accordance with the main stages in the life cycle of a mining operation. In the end, several scenarios for the exploitation of GIS databases were presented, as well as their interconnection with data sources external to the system.

1. INTRODUCTION

The extractive industry is the leader of the global economy, both by volume, value, employment, as well as by the dependence of all other branches of the economy (Guvernul Romaniei, 2017), in fact of the entire society. Currently, no industrial field can progress without a management based to an increasing extent on the computerization of both the activity and its management, and coordination (Gankhuyag, 2018). As a leader of the world economy, the extractive mining industry cannot make an exception from this rule in any of its components, from the prospecting phase to the delivery of the extracted raw materials to the processing industries (Ali, 2017, Kostetska, 2020).

While in the past the role of mining software products was only to create and manage mining plans and sketches, the requirements have evolved later on. As a result, nowadays mining software products aims at including both graphics storage and processing functionality, as well as mining operations management (Botin, 2010), from the prospecting and planning stages to the extraction, processing and delivery of the ore (Li, 2000).

Thus, in order to ensure the development of useful and efficient software tools, it is necessary for them to be focused on the mining field. Moreover, the advantages would be is the software is designed and adapted to the specific requirements of a mining operation. In this sense, emphasis is placed on the design, development, implementation, permanent adaptation and maintenance of tailored GIS, which also allow the storage of geolocation information (Radulescu, 2011). Such a system can only be useful and effective if it has been developed and implemented based on a specific and dedicated data model.

The purpose of this paper is to design the GIS database template for the management of mining operations in Romania, with a specialization on mining operations to date. The ArcGIS 10.3 software was used to implement this data model (GIS database) and the following workflow steps were undertaken (Kim, 2012): inventory and assessment of government regulations, inventory and assessment of environmental quality standards, sorting and grouping parameters, class design and characteristic attributes, creation of a GIS database, creation of a dictionary of the GIS database (Calina, 2018).

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The design and implementation of a GIS database has many advantages for the decision-makers and management of the mining company, among which we mention the following ones: integration of the information in one database, data optimization to avoid redundancy, reduction of data volume, data management in a uniform structure and format, convenient search engines, management of spatial data and integrated attributes that can be used as input data for GIS analysis (Tsangaratos, 2010, Suh, 2017) to enable the informed decision-making and inform development strategies (Bringezu, 2016).

2. MATERIALS AND METHODS

In order to ensure the quality and practical applicability of the designed data model, it is necessary to clearly identify the requirements and needs of the final beneficiary (needs analysis) (Calina, 2018), related to the type of mining operation.

Database design and construction consist in a detailed organization of its structure. Any omissions or inconsistencies that are not eliminated at this stage are usually very difficult to fix later. Building the database is the most critical and time-consuming stage of the project. The structure of the database has a direct influence on the structure of the data stored and analyzed, and finally on the quality of the analyzes and the results obtained.

To build a database, the following steps should be implemented (Banerjee, 2014, Calina, 2018):

- Database design
  - Identification of graphic objects
  - Determination the necessary layers
  - Determination the attributes of the geographic objects
  - Defining each attribute
- Entering the spatial data
- Data editing and topology creation
- Entering the attributes
- Administration and handling the data

For the design of the data model, the following must be taken into account (Buczynska, 2020, Choi, 2020):

- the results of the needs analysis stage, as a mandatory requirement regarding the content of the database;
- the generally valid rules for designing a GIS type system, especially regarding facilities for quick updating and sharing of maps (even in real time);
- any GIS must support management staff to make informed decisions, to allow efficient management of the operational activities (especially activities in the field), to ensure easy access and even mobility (e.g., by accessing on mobile devices such as tablets or smartphones) and to enable rapid analysis of the large volumes of data (big data);
- a GIS type system is based on three interconnected and interdependent subsystems: the data registration and updating system (CRUD operations – Create, Read, Update, Delete) (Calina, 2022), the data processing and machining system (and obtaining information) and the operating system (output component);
- end users must benefit from the easy-to-use tools; to the maps configured and published in GIS, various functions and facilities for visualization, measurement, etc. are added, and tools (computer applications) are obtained and are made available to end users;
- the design principles of GIS systems intended for the mining field; thus, it is imperative to include some facilities of the following functionality:
  - mapping and visualization – the relation and visual representation of the drawn elements with their positioning on the map and in the field;
  - data management – facilities for collecting, organizing and updating data (Ren, 2019) and details regarding the location of managed elements;
  - mobility – facilities for accessing and exploiting data in the field (through the use of mobile devices);
  - monitoring – facilities for tracking, managing and monitoring assets and resources, including real-time monitoring through the integration and use of sensors;
  - a multi-criteria analysis – processing large volumes of data to discover, quantify and predict patterns and trends, leading to the increased results;
  - design and planning – the possibility of simulating and evaluating alternative scenarios and adopting optimal scenarios;
  - decision support – decision makers have a quick access in real time to the real situation, so they can adopt measures based on knowledge;
  - communication – communication and collaboration facilities with society (citizens) and other communities of interest;
  - sharing and collaboration – facilities for discovering, mapping, using and sharing geographic information.

At the same time, when designing the data model, the main stages in the life cycle of a mining operation (Craynon, 2016, Maryati, 2012, Suh, 2017) must be taken into account, as well as permanent concerns, as follows:

- exploration: based on the integration of the satellite images and historical maps, soil samples, rock samples, drilling plans and programs, geological mapping, identification and marking of areas of interest;
- feasibility assessment and authorization: aspects regarding the management of areas of interest, environmental conditions, cartography and topography, location management;
- operations: planning of mining activities, digitization of locations, establishment of exploitation and safety zones, digital modeling of exploitation and storage areas and volumetric calculations, mapping of detonation zones, mapping of mining pits, generation of models of available, exploitable resources and exploited etc.;
- logistics: stock management, which includes management, tracking and maintenance of goods, equipment and installations, as well as stocks of finished product, ores, tailings, etc.;
- health, safety and environment: tailings dam inspections, well monitoring and regulation inspections, field personnel monitoring, spill and seepage inspections, etc.;
- rehabilitation: monitoring the effects on the environment, monitoring the land surface and excavation or storage areas, reseeding analyses, monitoring endangered species, etc.

3. RESULTS AND DISCUSSION

The proposed and followed workflow for the design and construction of the data model (database) is shown in Figure 1.

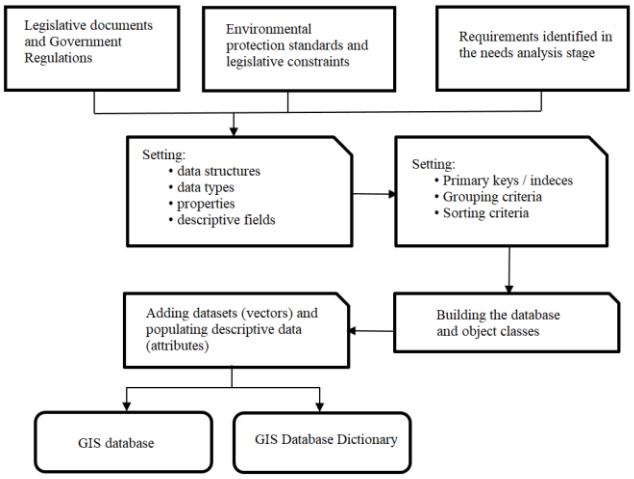


Figure 1. Workflow for GIS database design and creation (adapted from (Maryati, 2012))

Designing object classes and setting attributes is the most important step in a data model design because this step is decisive for the proper functioning of the data model relative to the requirements and needs of the beneficiaries. At this stage, the names of the object classes, data structures (fields, attributes), spatial reference systems, data types, the name and properties of each field, etc. must be determined. The names of the elements must be suggestive, so that they can be found and recognized easily (Li, 2010, Maryati, 2012). Graphical representation elements will be of point, line and polygon type.

The database dictionary is actually a set of instructions for how to interpret and use the database by the designer, analyst, operator, field agents, or end users. The database dictionary provides detailed information about the stored data, its type, and its relationship to other existing data.

The most important elements to be managed in a mining operation are those related to the geographical representation of the areas where mining activities are organized and carried out, as well as the management of environmental aspects (Craynon, 2016, Radulescu, 2011). Thus, any mining database must include at least the following information:

- Collection of background maps (basemaps): administrative boundaries, concession boundaries, quarry boundaries, mining roads, public roads, rivers/waters, contour lines, infrastructure, ponds;
- Data sets for land use: land zoning, land cover, exploitation areas, developments, soils, landfills, landfill extensions, clearing areas, planning areas;
- Data sets for environmental quality: measurement points, air quality, air currents, noise, air temperature, humidity, wind speed, precipitation;

❖ Monitoring the air quality, Figure 3.

- Data sets for water quality: measuring points, pH values, TSS (total suspended sediment), total Fe, total Mn;
- Data sets for waste monitoring: storage areas, waste dumps, chemical waste storage areas, WTP (waste treatment plant);
- Data sets for land rehabilitation: affected areas, rehabilitated areas, rehabilitation planning, vegetation cover areas, vegetation recovery areas, vegetation growth stage zoning, erosion areas;
- Data sets for flora and fauna: flora, fauna, aquatic habitat, biological zonation.

It should be considered that data model (database) is the only one component of a computer or GIS and has the role of data storage. However, it also enables diverse manipulations with the data, depending on the user's profile. Therefore, the database must be integrated with other system components and must meet the exploitation requirements from the users (Calina, 2018, Tsangaratos, 2010). An example regarding the framing of the database in an IT system is presented in Figure 2.

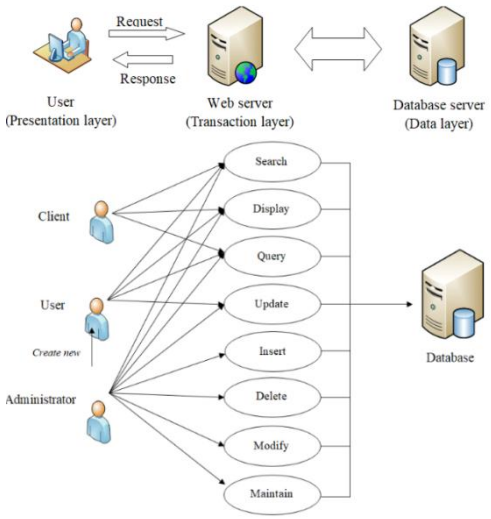


Figure 2. Interconnection of the database with other components of an IT system (Maryati, 2012)

Thus, it can be seen that the database should meet the requirements of a series of functions regarding the storage, memorization, access, modification, retrieval, processing, and presentation of the data. The type of these operations depends on the profile of the user or the direct beneficiary of the data (e.g., user, administrator, external applications, etc.).

Below, there are examples of the database structures starting from the specific objectives of managing mining activities, as follows:

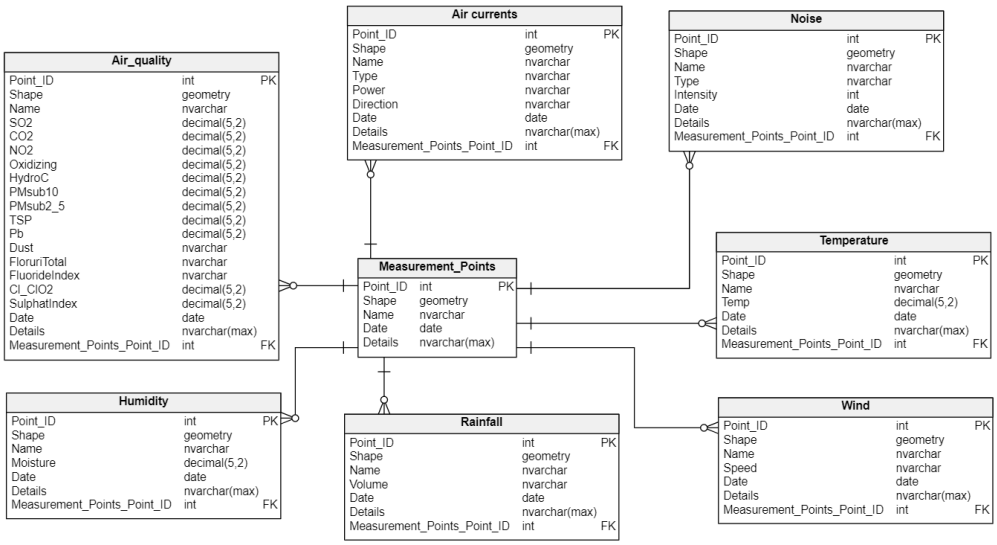


Figure 3. Database structure for air quality monitoring

- Waste management, Figure 4.

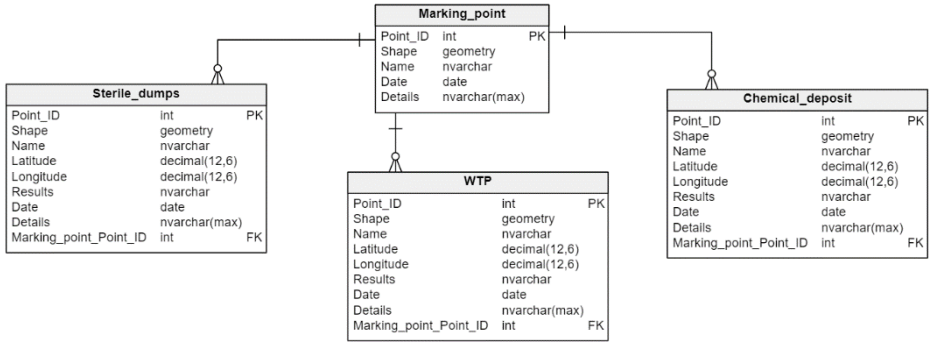


Figure 4. Database structure for waste management

- Management of the cartographic database (maps), Figure 5.

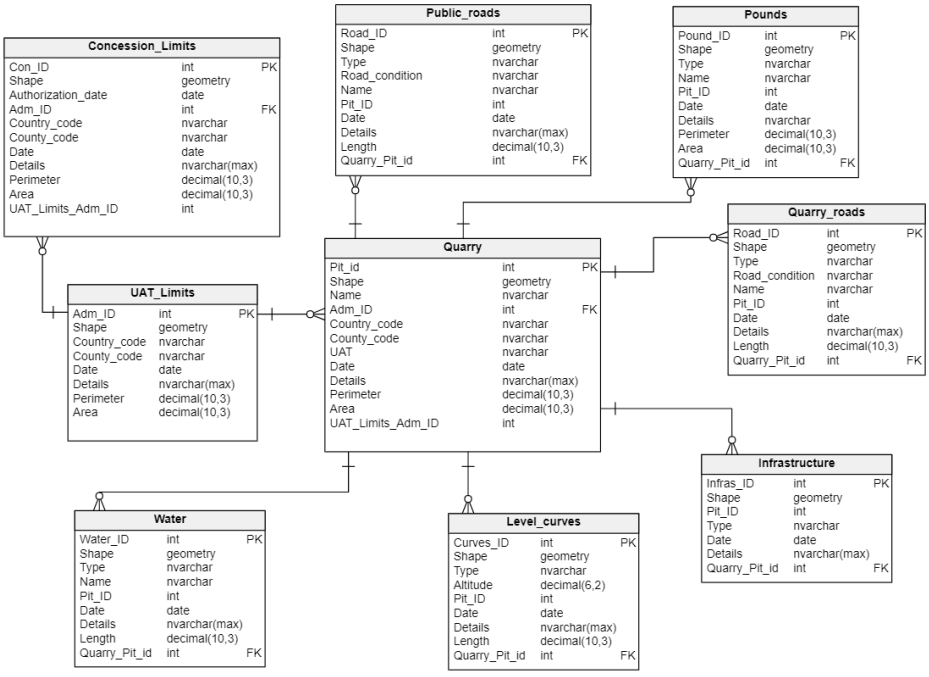


Figure 5. Database structure for the management of the cartographic fund

❖ Land use management, Figure 6.

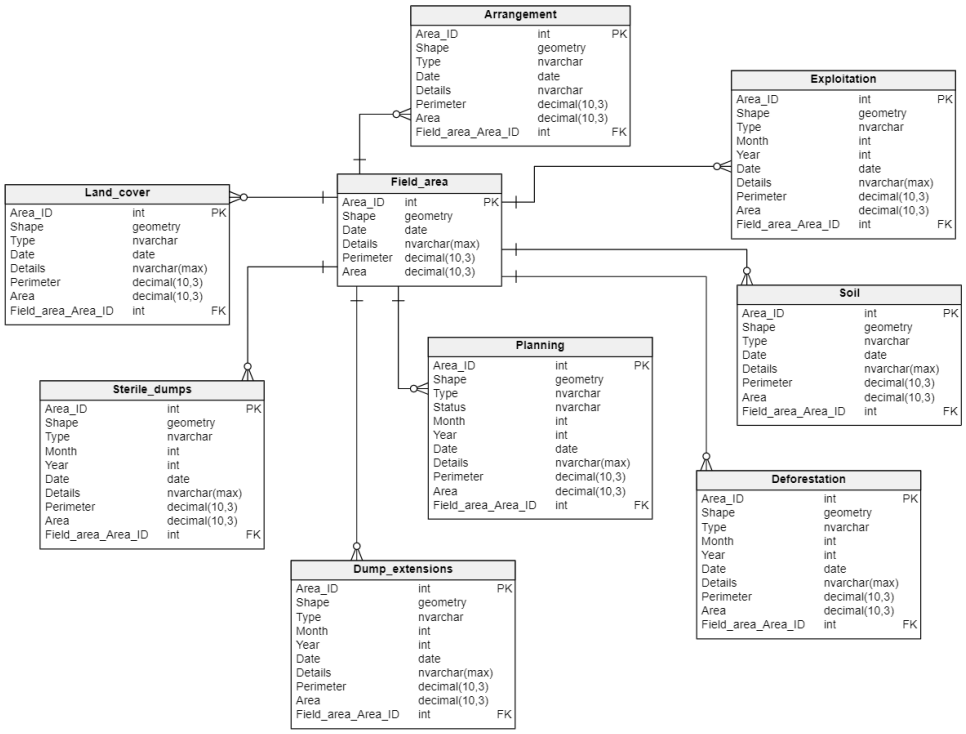


Figure 6. Database structure for land use management

ArcGIS software (ArcCatalog component) can be used to create, define and implement the designed database (intended for mining) within a GIS type system. Having the particularity of storing geolocation information, these databases are called Geodatabases. Geodatabase is a component of ArcGIS intended for structuring and managing geographic elements, generically called GeoObjects (Kim, 2012).

Figure 7 shows how data is organized in a personal database (in 7 FeatureDataset elements), as well as how it is structured at the Feature Class level (with an example for the data set for storing information about mining quarries).

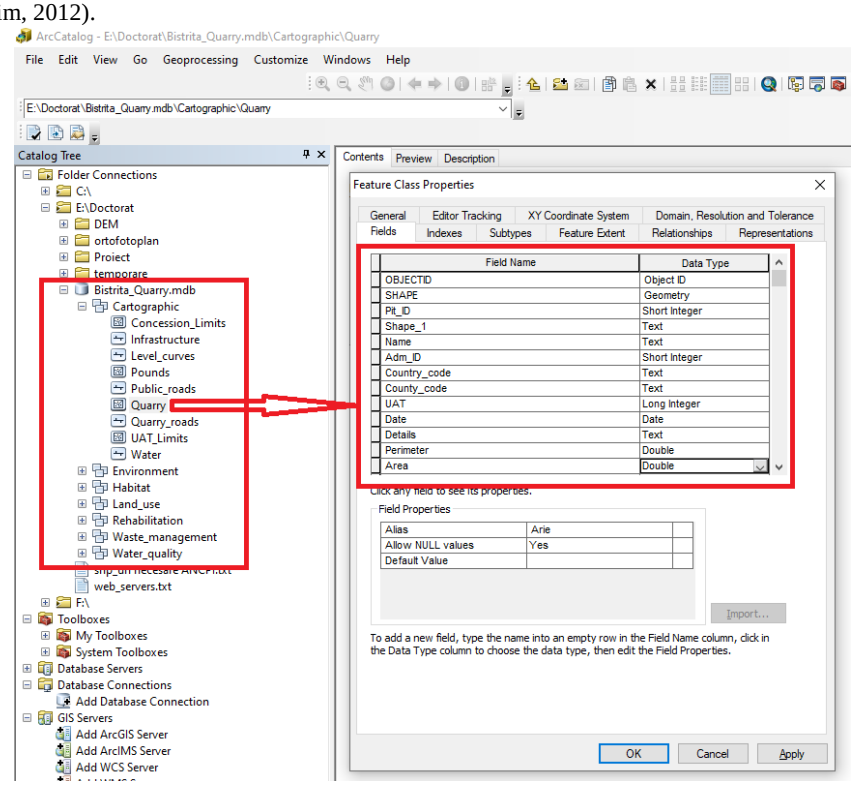


Figure 7. Presentation of the structure of a Personal Geodatabase type database

Even if the main method of data storage and organization is represented by databases, in GIS type systems data and information from various sources can be integrated and used (access to external databases, designed within other projects and made available to certain categories of users) and in various formats such as:

- available data sources (web-api online services or data sets that could be downloaded) made available by the National Agency for Cadastral and Real Estate Advertising (ANCPI) or ESRI and data sets downloaded from the Database of Global Administrative Areas (GDAM, www.gadm.org). Among these we mention:
  - web-api services for thematic layers that include building geometries and details, hydrography, and transportation http://geoportal.ancpi.ro/maps/services, TopRO5, reference system Pulkovo_1942_Adj_58_Stereo_7), as seen in Figure 8;

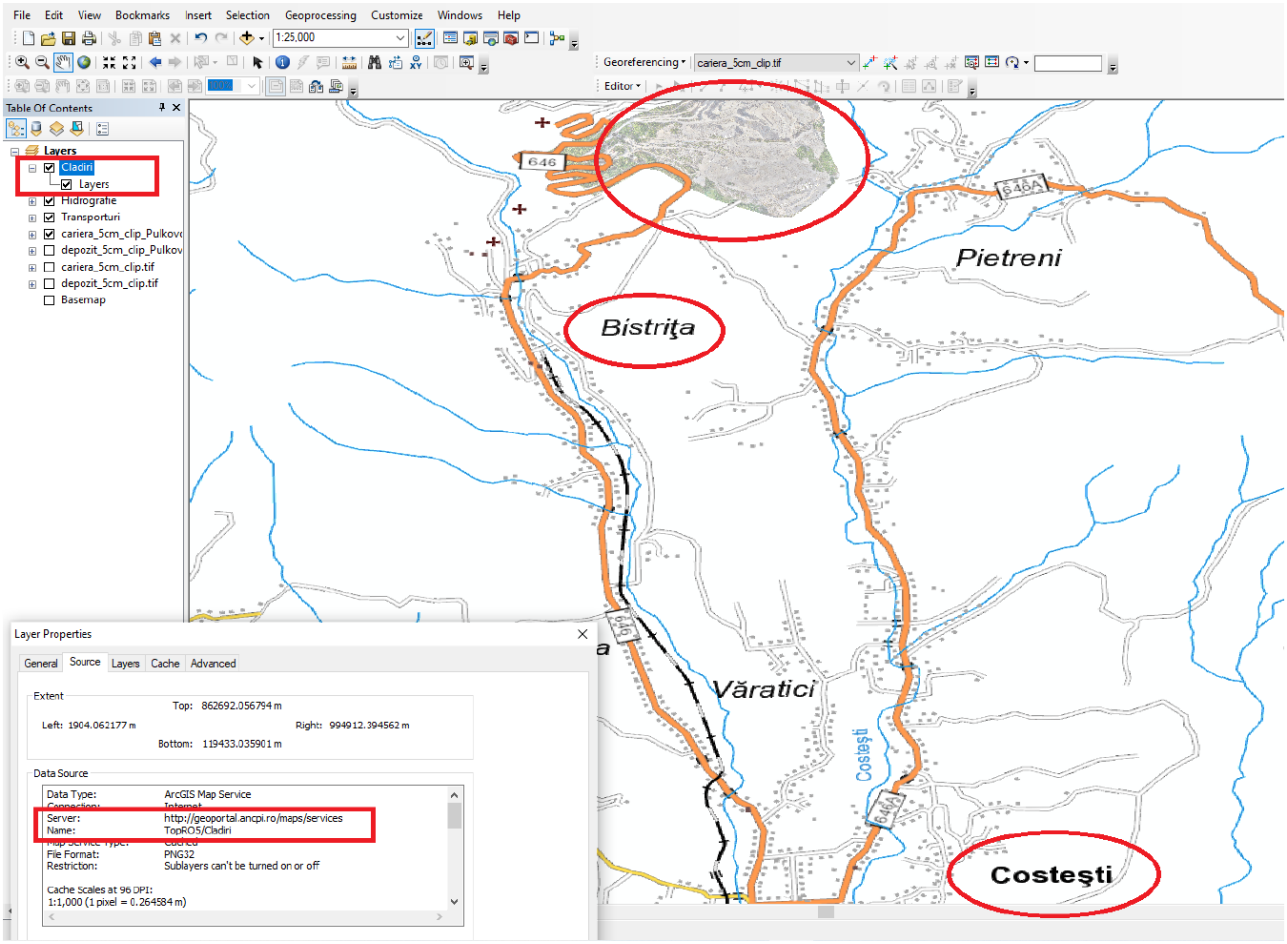


Figure 8. Web-api type source (Buildings, geoportal ANCPI accessing, Costești-Bistrița area)

  - datasets accessed and downloaded using the webgis systems made available by ANCPI - thematic layers that include geometries and details about: railways, quarries, contour quarries, buildings, constructions, waterways, roads, religious buildings, dwellings, administrative boundaries, localities, nomenclature of map sheets, leveling, forests, national parks, caves, railway bridges, road bridges, coordinate points and known elevations, electrical networks, reservations (area type and point type). Even if these datasets are available for the entire surface of the country, the datasets in the area of interest can be accessed and included in the working environment. Accessing such sources is exemplified in Figure 9.

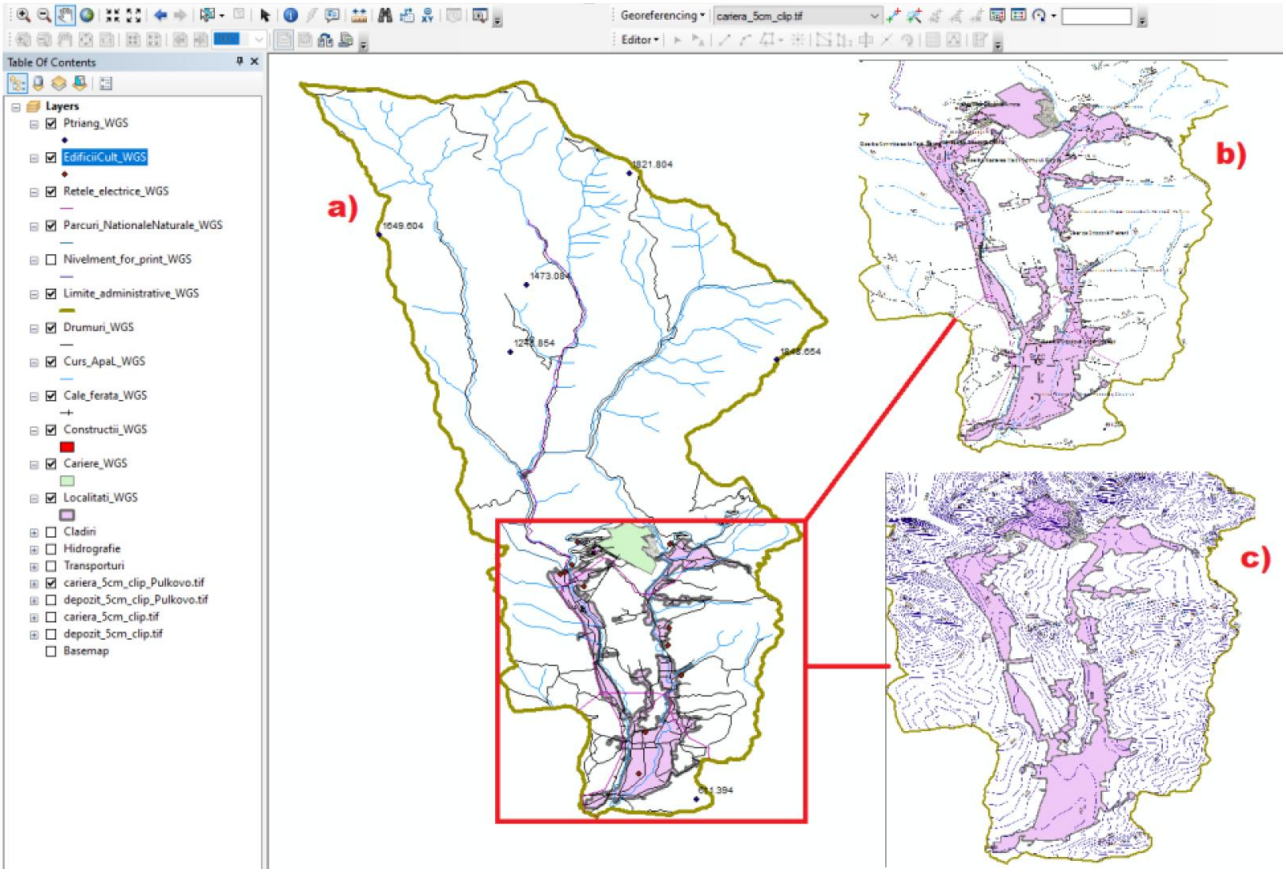


Figure 9. Data sets downloaded from the ANCPI geoportal:
a) visualization at the level of UAT Costești, b) visualization at the level of Bistrița locality – various thematic layers,
c) visualization at the level of Bistrița locality – level curves

- data sets that can be purchased from ANCPI through the online store system, by identifying the properties of interest (by cadastral number). In this way, the geometries and details of existing constructions, land and buildings can be obtained. This data is delivered in polyline and point format (each measured point from which the contour was generated). At the same time, for each cadastral number, the Cadastral Plan Extract and the Ensemble Plan on a scale of 1:2500 can be delivered.

- photogrammetric products (base maps) available online (provided by various providers);
- the photogrammetric products (orthophotoplans) obtained within the photogrammetric activities;
- graphic elements of the image type or quick access to files that present various information of interest;
- other existing data sources.

4. CONCLUSIONS

Effective management of surface mining operations requires the use of tools that have the ability to quickly process and analyze data, so that decision makers can adopt documented actions and decisions. These systems have different architectures and include various technical components, but they all depend on the way data is organized and stored, i.e., database structures.
Database design and implementation must meet user requirements and needs. The quality of the database (both in terms of design and stored data) has a direct influence on the exploitation capacity of the GIS type system. A properly designed and implemented database facilitates data retrieval, extraction, and presentation.

Mining databases should at least allow the management of the main activities in surface mining, such as: land management and exploration and exploitation perimeters, management of environmental and waste elements, monitoring of air and water quality, management of cartographic background, etc. At the same time, databases should allow the integration with the external systems and data sources, which increases both their usefulness and the analytical capacity of the systems (making direct measurements, filtering elements according to attributes or location, proximity analyses, simulations etc.).

References

Ali, S.H., Giurco, D., Arndt, N., Nickless, E., Brown, G., Demetriades, A., Durrheim, R., Enriquez, M.A., Kinnaird, J., Littleboy, A., Meinert, L.D., Oberhänsli, R., Salem, J., Schodde, R., Schneider, G., Vidal, O. i Yakovleva, N., 2017. Mineral supply for sustainable development requires resource governance. *Nature* 543, pp. 367–372.

Banerjee, T.K., Roy, S. and Dey, S., 2014. A GIS Solution for an Integrated Underground Coal Mine Management: A Conceptual Framework. *Journal of Management Policies and Practices* 2 (2), pp. 129–143.

Botín, J.A. and Palacios, M., 2010. Sustainable management: a strategic challenge for a global minerals and metals industry.

Proceedings of Copper 2010. https://www.researchgate.net/publication/266525055 (view at 12 Mar. 2023).

Bringezu, S., Potocnik, J., Schandl, H., Lu, Y., Ramaswami, A., Swilling, M. and Suh, S., 2016. Multi-scale governance of sustainable natural resource use-challenges and opportunities for monitoring and institutional development at the national and global level. *Sustainability* 778 (8), pp. 1–25. https://doi.org/10.3390/su8080778.

Buczyńska, A., 2020, Remote sensing and GIS technologies in land reclamation and landscape planning processes on post-mining areas in the Polish and world literature, *AIP Conference Proceedings 2209, 040002 (2020)*; https://doi.org/10.1063/5.0000009.

Călina, J., Călina, A., Bădescu, G., Vangu, G.M., Ionică, C.E., 2018, Research on the use of aerial scanning for completing a gis database, *AgroLife Scientific Journal – Volume 7, Number 1*, pp. 25-32, ISSN 2285-5718.

Călina, J., Călina, A., Iancu, T., Vangu, G.M., 2022, Research on the Use of Aerial Scanning and Gis in the Design of Sustainable Agricultural Production ExtensionWorks in an Agritourist Farm in Romania, *Sustainability – Volume 14*, 14219, https://doi.org/10.3390/su142114219.

Choi, Y., Baek, J. and Park, S., 2020. Review of GIS-Based Applications for Mining: Planning, Operation, and Environmental Management, *Applied Sciences* 10, https://doi.org/10.3390/app10072266.

Craynon, J.R., Sarver, E.A., Ripepi, N.S. and Karmis, M.E., 2016. A GIS-based methodology for identifying sustainability conflict areas in mine design – a case study from a surface coal mine in the USA. *International Journal of Mining, Reclamation and Environment* 30(3), pp. 197–208, https://doi.org/10.1080/17480930.2015.1035872.

Gankhuyag U. and Fabrice Gregoire, F., 2018. Managing mining for sustainable development. *Bangkok: United Nations Development Programme,* ISBN: 978-974-680-421-9.

Guvernul României – Ministerul Economiei, 2017, Strategia minieră a României 2017-2035 (Mining strategy of Romania 2017-2035), https://economie.gov.ro/images/resurse-minerale/STRATEGIE%20MINIERA%20draft%20final%2024%20OCT%202016.pdf (view at 14 Dec. 2022).

Kim, S.M., Choi, Y., Suh, J., Oh, S., Park, H.D., Yoon, S.H. and Go, W.R., 2012. ArcMine: A GIS extension to support mine reclamation planning. *Computers & Geosciences 46*, pp. 84–95, https://doi.org/10.1016/j.cageo.2012.04.007.

Kostetska, K., Marius Laurinaitis, M., Savenko, I., Sedikova, I. and Sylenko, S., 2020. Mining management based on inclusive economic approach. *E3S Web of Conferences 201*, 01009 Ukrainian School of Mining Engineering – 2020, https://doi.org/10.1051/e3sconf/202020101009.

Li, S., Dowd, P.A. and Birch, W.J., 2000. Application of a knowledge and geographical information based system to the environmental impact assessment of an opencast coal mining project. *International Journal of Surface Mining Reclamation and Environment* 14(4), pp. 277–294, https://doi.org/10.1080/13895260008953336.

Li, X. and Zhong, S., 2010. Digital mine design based on Data Warehouse and GIS. *Proceedings of the 2nd International Conference on Information Science and Engineering*, Hangzhou, China, 4–6 December 2010; IEEE: New York, NY, USA, pp. 3653–3656.

Maryati, S., Shimada, H., Sasaoka, T., Hamanaka, A., Matsui, K. and Nagawa, H., 2012. GIS Database Template for Environmental Management of Mining in Indonesia. *Journal of Geographic Information System* 4(1), pp. 62–70, http://dx.doi.org/10.4236/jgis.2012.41009.

Radulescu, C. and Radulescu, V.M.G., 2011. Approaches of the management informational systems regarding the implementation of the geographic information systems (GIS) in the mining basins of Romania. *In Proceedings of the 11th International Multidisciplinary Scientific Geoconference and EXPO*, Albena Seaside & Spa Resort, Bulgaria; pp. 215–222.

Ren, H., Zhao, Y., Xiao, W., Hu, Z., 2019, A review of UAV monitoring in mining areas: current status and future perspectives, *International Journal of Coal Science & Technology*, pp. 320-333. https://doi.org/10.1007/s40789-019-00264-5.

Suh, J., Kim, S.-M., Yi, H., Choi, Y., 2017. An Overview of GIS Based Modeling and Assessment of Mining Induced Hazards: Soil, Water, and Forest. *International Journal of Environmental Research and Public Health* 14(12), 1463. https://doi.org/10.3390/ijerph14121463.

Tsangaratos, P., Koumantakis, I. and Rozos, D., 2010. GIS based application for geotechnical data managing. *Bulletin of the Geological Society of Greece, 43(3),* pp.1656-1666. https://doi.org/10.12681/bgsg.11340.