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# INFORMATION SYSTEM OF EXCAVATIONS
# IN THE WIELICZKA SALT MINE

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**Abstract**

The "Wieliczka" Salt Mine has specific characteristics, related to the geological structure of the deposit, geomechanical properties of the rock mass, mine operation methods, the impact of the excavations on the surface and on the rock mass and the role of the mine as a cultural monument and tourist attraction. In order for an IT system to manage the mine, the system has to be prepared with consideration of the above-mentioned characteristics, which precludes the implementation of other systems for the Wieliczka mine. The article discusses the methods of creating a part of such a system in the form of a database about the excavations, which may be the basis of the entire system. The database uses the software available at the mine. The article indicates the practical applications of the database in the resolution of engineering and mining issues.

# SYSTEM INFORMACJI O WYROBISKACH GÓRNICZYCH
# W KOPALNI SOLI „WIELICZKA"

**Słowa kluczowe:** systemy informatyczne, bazy danych, inteligentne górnictwo, Kopalnia Soli „Wieliczka"

**Abstrakt**

Kopalnia Soli „Wieliczka" ma specyficzne cechy, związane zarówno z budową geologiczną złoża, geomechanicznymi właściwościami górotworu, sposobami eksploatacji, wpływem wyrobisk na powierzchnię i górotwór, jak również z rolą, jaką odgrywa w kulturze i turystyce. Oparcie zarządzania kopalnią o system informatyczny wymaga uwzględnienia w nim wspomnianej specyfiki, co eliminuje możliwość implementacji innych systemów do potrzeb Wieliczki. W artykule omówiono metodykę tworzenia części takiego systemu w postaci bazy danych o wyrobiskach górniczych, która stanowić może podstawę całego systemu. Bazę oparto na oprogramowaniu dostępnym w kopalni. Podano możliwości praktycznych zastosowań bazy do rozwiązywania zagadnień inżynieryjno-górniczych.

## 1. INTRODUCTION

Mining operations and the preservation or decommissioning of mines require efficient management, which should consider not only the profitable extraction of useful minerals but also the safety of work, environmental impact of mineral mining and the preservation and future use (if any) of the voids left in the rock mass. The development of IT technology enables the resolution of the above problems. Mine management after the end of extraction can be made considerably more efficient using the principles of "*intelligent mining*", based

on IT systems, with respect to the geological properties of the deposit, mine operation, hazards and methods of protection against those hazards. It should be expected that the development of intelligent mining is the future (which has already started) of the management of natural resources in the world.

The Wieliczka Salt Mine is one of the most well-known and oldest mines in Poland. Salt extraction in that mine ended in 1993, although the mine continues to extract brine. However, the Wieliczka mine now has a more important role – it is a monument to the technical culture spanning from the middle ages to contemporary times. The mine was included in the UNESCO World Heritage List of Cultural and Natural Landmarks, and – by the order of the President of the Republic of Poland of 08/09/1994 – it was recognised as a Historic Monument. This made it necessary to efficiently manage a company that is both a mining enterprise and a tourist attraction.

The extraction from the deposit, ongoing for more than 700 years, yielded 25 millions of tonnes of salt and formed the current spatial arrangement of the excavations, located on 9 levels and 4 inter-levels. 2350 chambers have been driven. The estimated volume of post-mining voids is approximately 8.5 million m³ and more than 240 km of corridors (Kortas et all. 2004). The end of mining is not equivalent to the end of the operation of the mine because the existence of excavations in the saline rock mass that are subject to degradation and tightening creates specific hazards to the part of the mine used as a tourist attraction and to the surface of the town. Therefore, the primary objective of the current underground mining operations is the preservation of the heritage substance (Kortas et all. 2004).

The hazards to the mine are related primarily to the distribution of stresses and movements of the rock mass and to the hydrogeological patterns. The convergence of the excavations coincides with landslides on the surface, movements caused by suffosion and – to a limited extent – neotectonic movements. The penetrating action of water is particularly dangerous because water can dissolve halite. This led to repeated disasters in the mine – the last of these took place in 1992–1993 (water suffosion and water spill into the "Mina" corridor) (Badanie deformacji... 1998–2011). In order to maintain a heritage mine and make it available to tourists, it is necessary to recognise and control the harmful effects (Badanie deformacji... 1998–2010). The preservation works are performed continuously with insufficient investigation of geomechanical and hydrogeological conditions. The investigation of those conditions requires a series of observations and measurements and interpretation of their results by specialists. Measurements of rock mass properties are performed, complete with – particularly intensive – measurements of movements in the rock mass and on ground surface. Their results have been interpreted for many years, resulting in a series of reports, which, however, are scattered across many external institutions or mine departments. The diverse nature, form and scattering of those materials hinder the routine use of those resources. Therefore, it is necessary to integrate the measurement data and interpret them. This can be done by creating a unified database, combining test results and observations done during mining, geological, geophysical and geodetic activities. The creation of such a database also implies the need to construct a suitable IT system to enable the use of the database resources in the management of the mine and prevention of hazards. Consequently, it is necessary to create a model system of spatial information to be used for the assessment of the safety and functioning of the mine with consideration of the specific geodetic, geological, hydrological and mining data and the organisational structure of the mine.

## 2. CONCEPT OF THE INFORMATION SYSTEM OF EXCAVATIONS IN THE WIELICZKA SALT MINE

A concept of the construction of a spatial information system was prepared to meet that demand in order to assess the safety and functioning of the Wieliczka Salt Mine (Opracowanie... 2010). In accordance with that concept, the IT system should consider the specifics of the acquired geodetic, geological and hydrological data and the organisational structure of the mine. The core of the system should be a database containing spatial data. That task requires the resolution of multiple technical issues related to the transformation of archived materials into a form that can be recorded in the database, integration with the currently used software, specification of the options of visualisation and access to the data by the users and use of the acquired information for risk assessment and mine protection.

The concept of the database specifies the range of data collected in the system, including information from the following sources (fig. 1):

1) base map,
2) cadastral map,
3) control network,
4) survey of the excavations,
5) terminology,
6) geology,
7) hydrogeology, including spills (their composition, method of pumping, etc.),
8) backfilling and decommissioning of excavations,
9) deformation (rock mass convergence, surface and rock mass lowering, vertical deformation, observations of water dams),
10) ventilation and infrastructure.

Those data have to be standardised by transformation into a single system of coordinates, unification of the format in which they are recorded and specification of a set of attributes and relations for the individual objects.

The mine maps have been prepared in the Wieliczka system of coordinates. The Wieliczka system is based on the former cadastral system of Lesser Poland. The parameters of that system are not fully known. The projection used to calculate the plane coordinates is unknown. According to previous analyses (Banasik, Szewczyk 1997), it is more similar to conformal projection than to Cassini projection. The conversion of the coordinates in the Wieliczka system into the 2000 coordinate system done in 2010 (in 4 variants: Helmert transformation – angle preserving – first- and second-order – and first- and second-order affine transformation) [6] demonstrated a high accuracy of all variants; the transformation error of a point was approximately 2–2.5 cm. The error values achieved for the transformed points were within the 1–10 mm range. The indicated transformation variants are essentially equivalent in terms of accuracy. In the end, the coordinates after the first-order Helmert transformation were kept because they met all accuracy requirements (the transformation errors did not exceed 1 cm).

The concept also concerned the relations between the individual users of the database and selection of optimum IT tools (fig. 2).

The purchase of licenses for commercial databases and IT maintenance for those databases generate high costs, which can be considerably reduced using the so-called free software. The implementation of a database based on free licenses such as PostgreSQL/PostGIS
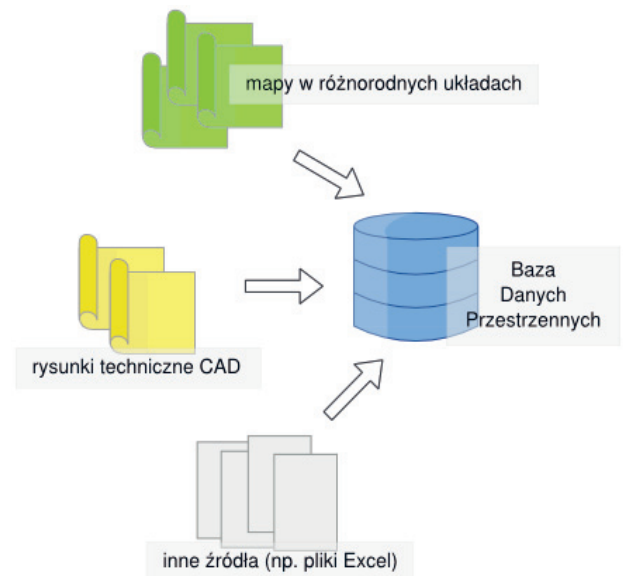


**Fig. 1.** Initial entering of the acquired data into the Mine information system (Opracowanie... 2010)
**Ryc. 1.** Wstępne zasilenie systemu informacji zgromadzonymi danymi (Opracowanie... 2010)

or MySQL/Spatial is economical. It also enables high scalability and cooperation and data exchange with entities external to the Mine, both with respect to the export and import of spatial data. The interface used to integrate the commercial AutoCAD applications used at the Wieliczka Salt Mine with the spatial databases
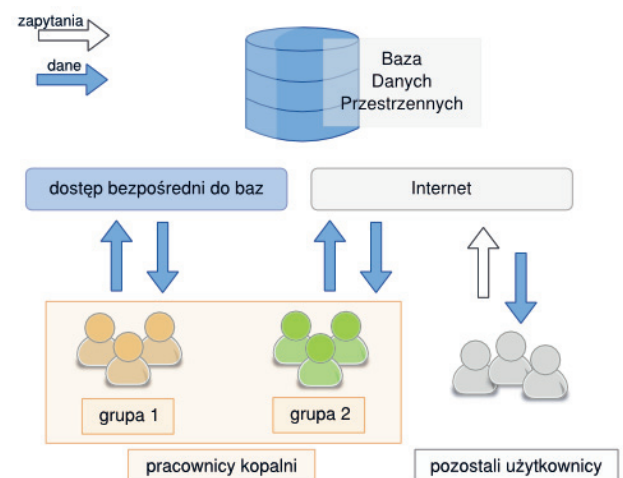


**Fig. 2.** User communication with the Mine information system (Opracowanie... 2010)
**Ryc. 2.** Komunikacja użytkowników z systemem informacji Kopalni (Opracowanie... 2010)

is the Feature Data Objects (FDO) technology, developed with a considerable contribution of the Autodesk company. The FDO is a free open source project, which makes it a more competitive solution.

The cited concept also provides for the possible applications of the designed system. In addition to tasks related to routine operation of the mine, the system also provides for functions related to hazard identification. These include the following (among other):

- spatial comparison of the distribution of deformation in the rock mass and on the surface and analysis of the results of preservation activities,
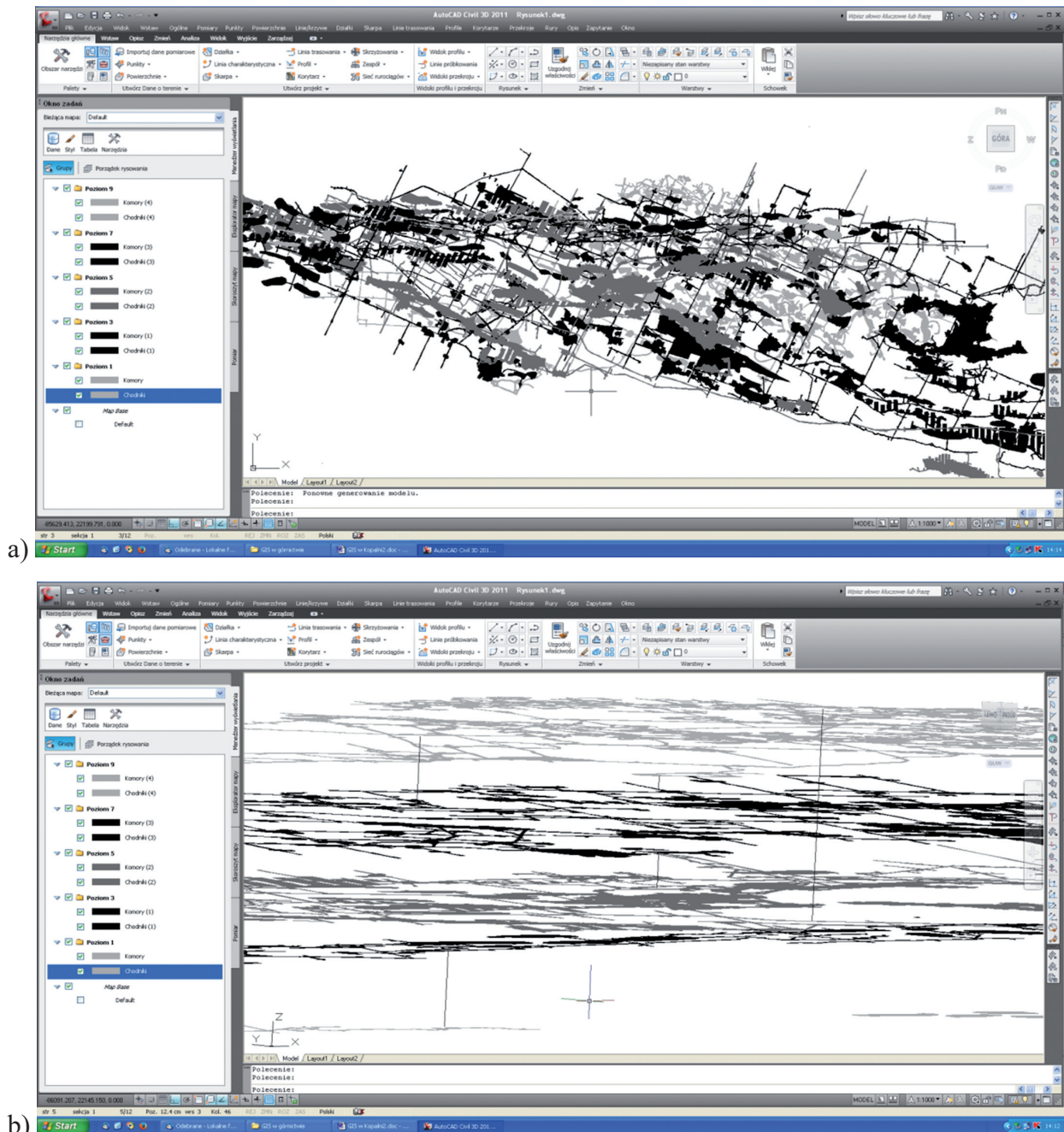


**Fig. 3.** Excavations in the database – 2.5D model: a) horizontal and b) axonometric projection
**Ryc. 3.** Wyrobiska w bazie danych – model 2.5D (rzut poziomy i aksonometryczny)

- indication of regions and objects at risk of deformation, including their classification into a suitable mining area category,
- comparison of the changes in the nature of the spill with the values of surface and rock mass deformation,
- optimisation of the ventilation system of the excavations.

## 3. CREATION OF THE DATABASE OF THE EXCAVATIONS

### 3.1. Assumptions

The preparation of the presented concept involved the creation of a database of the excavations that would be the basis for the development of the system. That area was related to environmental information. Consequently, the database should be created in accordance with the INSPIRE directive. This will enable future integration of information with the County Land Records Office (PODGiK) and creation of zoning plans for mining and post-mining areas. By definition, the database to be created has to be a data warehouse, i.e., integrate the spatial and descriptive data concerning the excavations. The object model of data organisation was chosen because it enabled full integration of all attributes. The system was created using the AutodeskCivil 3D software that was used in the mine at the time.

The excavations are three-dimensional. During the analysis of the source material, it was decided to use a pseudo-plane model 2.5D (Opracowanie... 2010). In that model, the excavations of each level are described as plane figures – orthogonal projections of the floor located at the average height of the given level (fig. 3). That model was adopted primarily due to the low amount of information about elevations in the source materials. The flattening of the objects has the following consequences:

- high simplicity of the model,
- overlapping of parts of the objects located at the same level but at different height,
- possibility of verifying topological consistency only for objects located at the same height.

The excavations in the database are plane objects, but they are distinguished by a set of descriptive attributes. Consequently, the following classes have been defined in the object model (fig. 4):

- corridors,
- chambers,
- use,
- fills,
- lining.

The database of the excavations was created in accordance with the following procedure:

- preparation of spatial data from various sources,
- object vectorisation,
- definition of the classes of objects (corridors, chambers, etc.) in the .sdf file,
- object creation,
- unification of descriptive data contained in the .xls file and creation of a database with descriptive data,
- assignment of the descriptive data in the external database to the objects in the drawing,
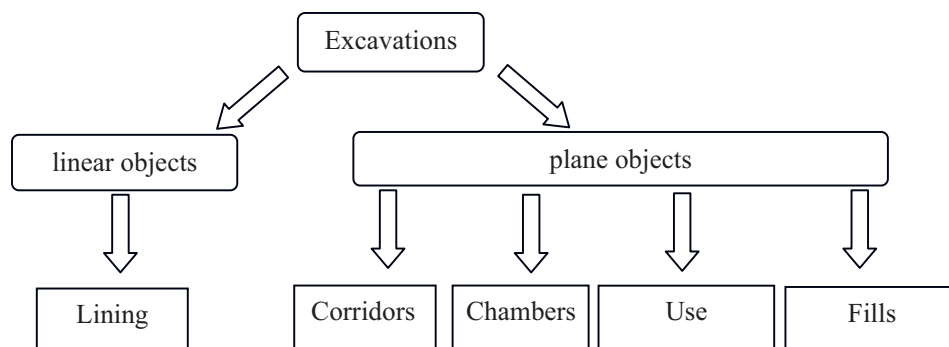- data verification.



**Fig. 4.** Diagram of the database of the excavations
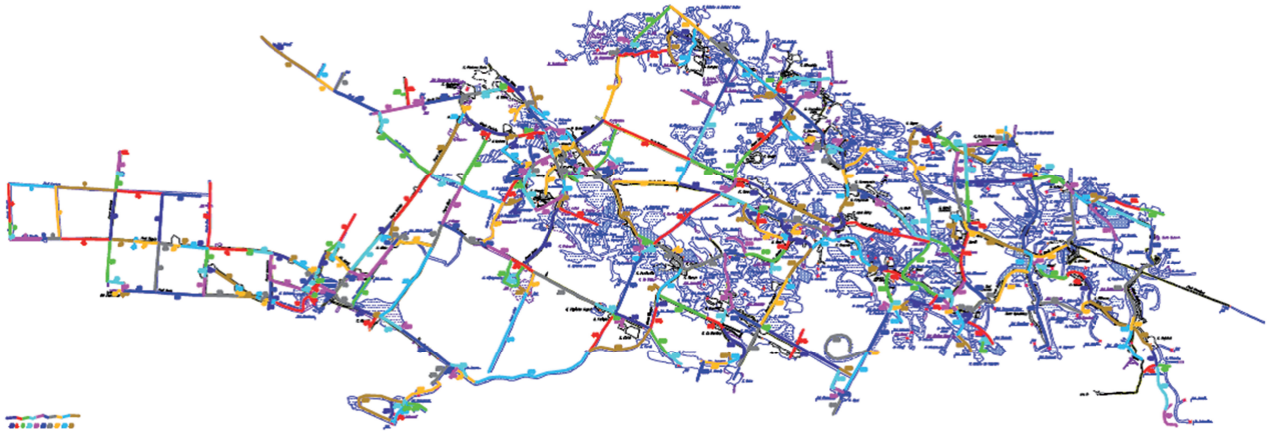**Ryc. 4.** Schemat bazy danych wyrobisk górniczych

**Fig. 5.** Vectorised first level of the mine
**Ryc. 5.** Zwektoryzowany I poziom kopalni

## 3.2. Preparation of spatial data

The spatial data were acquired in the form of raster maps and vector maps of the excavations. 3 maps were available for each level:

- vector inventory map,
- scan of the 1:2000 reference map,
- vector survey map.

The activities were performed using the vector inventory maps. Although the same coordinate system was used in the individual maps, there were differences ranging up to 7 m, and the axes of the workings were shifted to the south-east in relation to the surveyed excavations. Since the system was to be based on the vector survey map, the indicated contours of the excavations in the raster maps and the symbols of excavation axes were regarded as supplementary information, useful in the preparation of excavation contours and excavation symbols.

The inventory vector map of the excavations contained the contours of mine chambers, corridors, shafts, fore-shafts, names and survey numbers. The map contains symbols indicating the status of use of the excavations: (useful, inaccessible and museum workings) and the method of their preservation or decommissioning (lining, cribs, backfill, fall, etc.).

For corridors, the survey maps were very useful because they indicated the routes of the tunnels and their survey numbers. These were important because the range of the individual corridors could be determined only based on the axes. For the chambers, the survey

maps were less useful because they only presented the useful fragments of the chambers. Some elements have only been identified on the raster maps, which had to be vectorised. Every object on the numerical map was assigned attributes specifying the properties of the object (number, fill, etc.).

The plane elements of the excavations differing by their survey number, status and fill type were included in the system (fig. 5).

The following contour criteria were used:

- all contents were vectorised at the average height of the given level,
- on relevant levels, the outer contour of the corridors and chambers was vectorised regardless of the method of their use (used, decommissioned, museum areas) or fill (cribs, backfill, fall, etc.),
- if a corridor passed through a chamber, it was separated from the chamber, but the chamber always included the corridor that passed through it. In that situation, all fills were included in the chamber,
- on the *used excavations* layer, the areas in use, museum areas and decommissioned areas were vectorised without differentiation between corridors and chambers,
- the contours of all fills (cribs, backfills, etc.) were vectorised independently,
- they were transferred to relevant layers of excavation lining and classified at the same time,
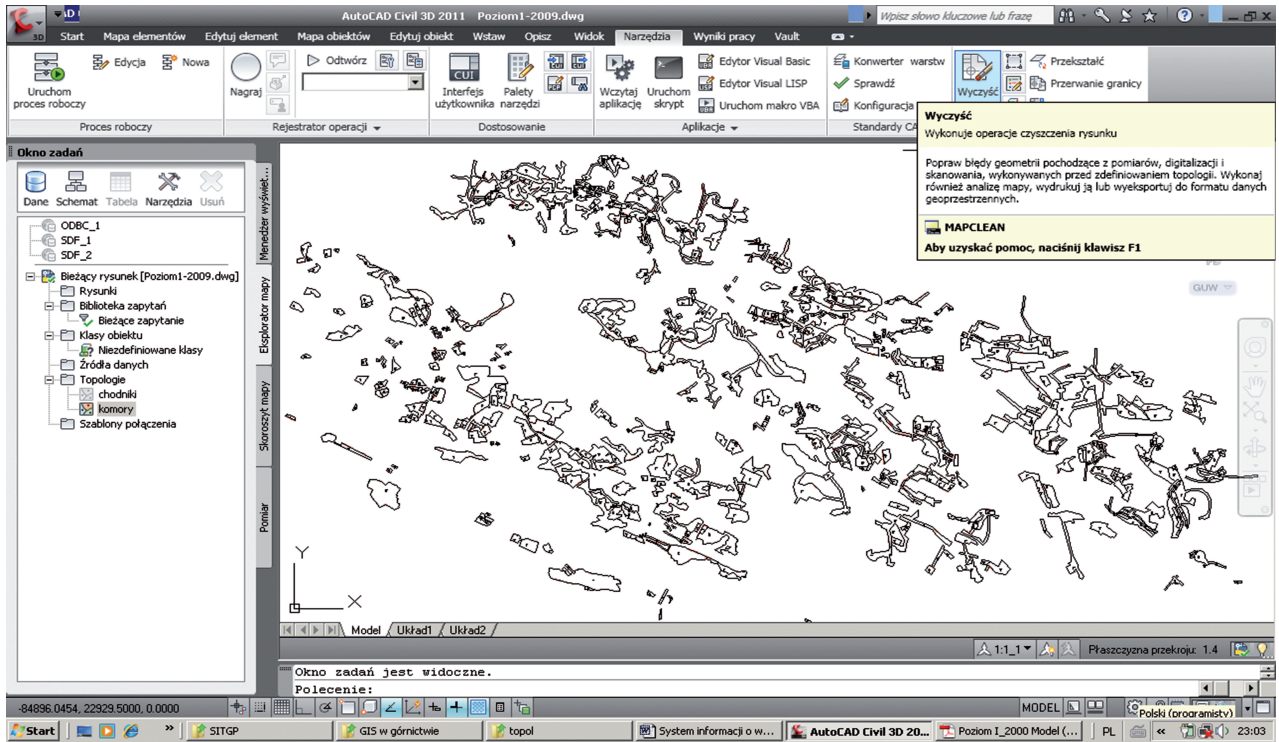- the topological consistency was verified for objects located at the same height (fig. 6).

**Fig. 6.** Drawing clean-up regarding the topological consistency of the objects
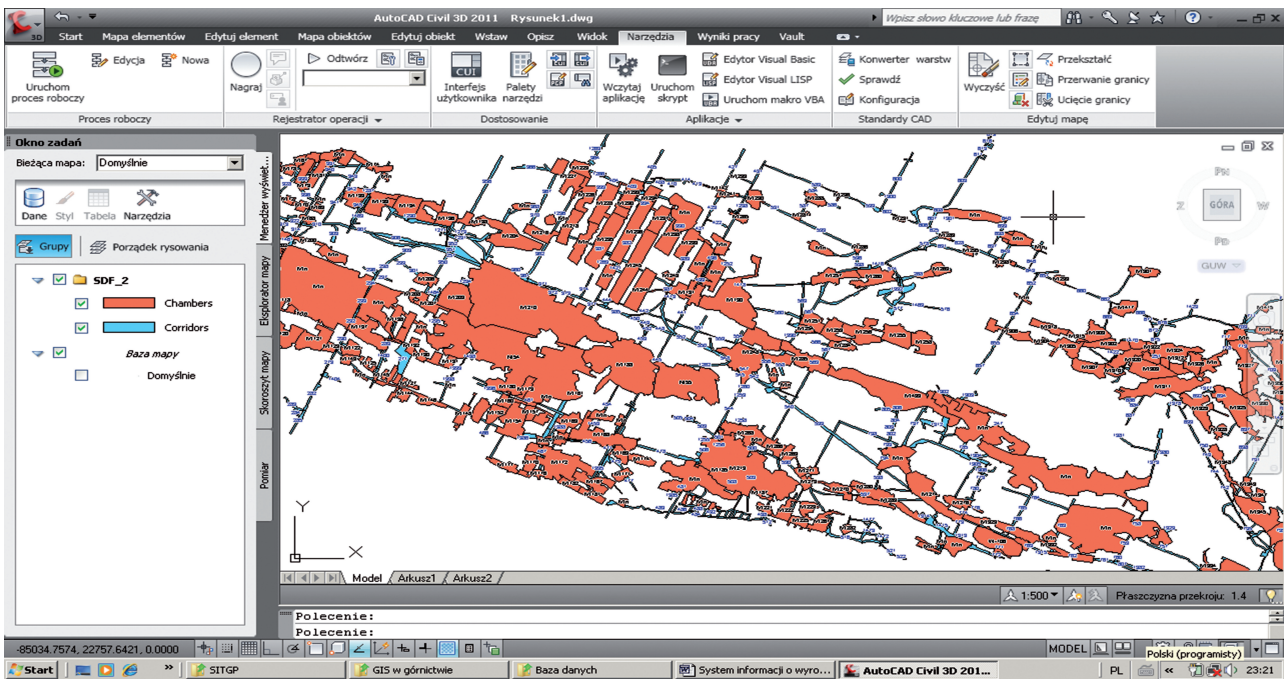**Rys. 6.** Czyszczenie rysunku pod względem spójności topologicznej obiektów



**Fig. 7.** Third-level chambers and corridors as objects defined in the *.sdf file
**Ryc. 7.** Komory i chodniki poziomu trzeciego jako obiekty zdefiniowane w pliku *.sdf

### 3.3. Definition of classes in the *.sdf file and creation of objects

The diagram of the database was created in accordance with fig. 1. Each class contained a dedicated set of attributes. The types of attributes are collected in table 1. The previously prepared contours were used to create objects defined in the *.sdf files independently for each level of the mine (fig. 7).

### 3.4. Assignment of descriptive data to the objects

The descriptive attributes have been collected in the form of Excel tables describing all excavations. The verification of the tables involved the removal of record repetitions and unification of the format for the recording of the individual data. In the end, a single chamber or corridor corresponded to a single record of the table with accordingly selected sets of attributes. For instance, a single chamber is described in the system by a set of 39 attributes concerning the mining of the chamber, status and planned decommissioning. Similar sets of 23 attributes were prepared for the corridors. The descriptive data in the table was assigned to the drawn objects based on the survey number of the excavation. Thus, all objects acquired a complete set of data. The system acquired its final form after the verification of the data, leading to the preparation of a report about in-

**Table 1.** Types of attributes in the individual classes
**Tabela 1.** Rodzaje atrybutów w poszczególnych klasach

| Class | Attribute | Type | Description |
|---|---|---|---|
| Chambers | ID | Integer | identification number of record |
| | Nr | String | inwentory number |
| | Level | String | name of level or inter-level |
| Corridors | ID | Integer | identification number of record |
| | Nr | String | inwentory number |
| | Level | String | name of level or inter-level |
| Fills | ID | Integer | identification number of record |
| | Level | String | name of level or inter-level |
| | Type | Char | b – unfilled<br>k – wooden cribs<br>z – fall<br>m – reinforcement wall<br>p – backfill<br>h – hydraulic backfill<br>s – dry rock fill |
| Use | ID | Integer | identification number of record |
| | Level | String | name of level or inter-level |
| | Type | Char | u – in use<br>z – liquidated<br>m – museum |
| Lining | ID | Integer | identification number of record |
| | Level | String | name of level or inter-level |
| | Type | Char | d – wooden reinforcing<br>k – bedrock anchoring<br>m – steel reinforcing<br>c – brick reinforcing<br>b – concrete reinforcing |

consistencies. The verification also involved checking if all objects had the complete set of attributes and if all records of the database with descriptive data were assigned to the objects.

# 4. SAMPLE APPLICATIONS OF THE MINE EXCAVATION DATABASE

The created database enables the generation of multiple maps, charts, calculations, etc. – i.e., it enables the resolution of mining and geodetic issues related to the operation of the mine. Several examples of such uses are presented below.

The data in the database can, most importantly, be used – through a suitable stylisation of layers – to prepare a map of excavations that conforms to the standards. An example of a map generated as indicated above is presented in figure 8. The database also makes it possible to rapidly locate the excavation we are looking for using a suitable query.

In the Wieliczka mine, the excavations have a target status related to the need to preserve them. Some of the excavations are to be decommissioned or have already

been decommissioned, some are to be preserved (e.g., to be made available to tourists, for ventilation purposes, etc.). The current and target statuses assigned to the objects enables the visualisation of the progress of decommissioning activities. Figure 9 presents the axes of the corridors, differentiated by colour depending on their current status. The data can also be used to prepare a dedicated map of the target status of all excavations (Fig. 10).

The database of the excavations makes it possible to search for workings with specific attributes, including the differentiation of the values of those attributes. Fig. 11 presents a level map created in the system with indication of large excavations with a floor area of at least 1000 m$^2$.

The primary method of the preservation and decommissioning of the excavations is backfilling. The maps of the target status of the excavations are used to determine the volume of the workings to be backfilled and – based on that volume – the volume of the required backfill. Sample map (for one of the mine levels, fig. 12) and a suitable chart specifying the volume of backfill already introduced into the excavations and the volume
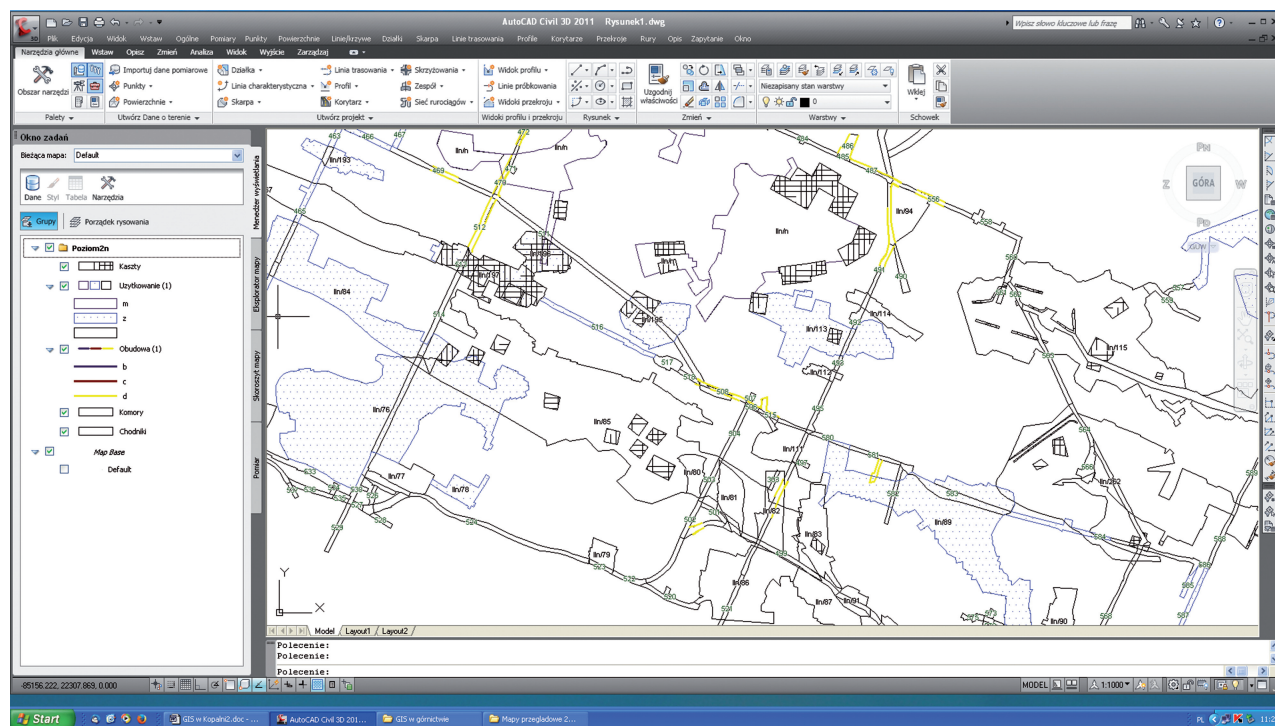


**Fig. 8.** Layer stylization according to the instructions – mining map
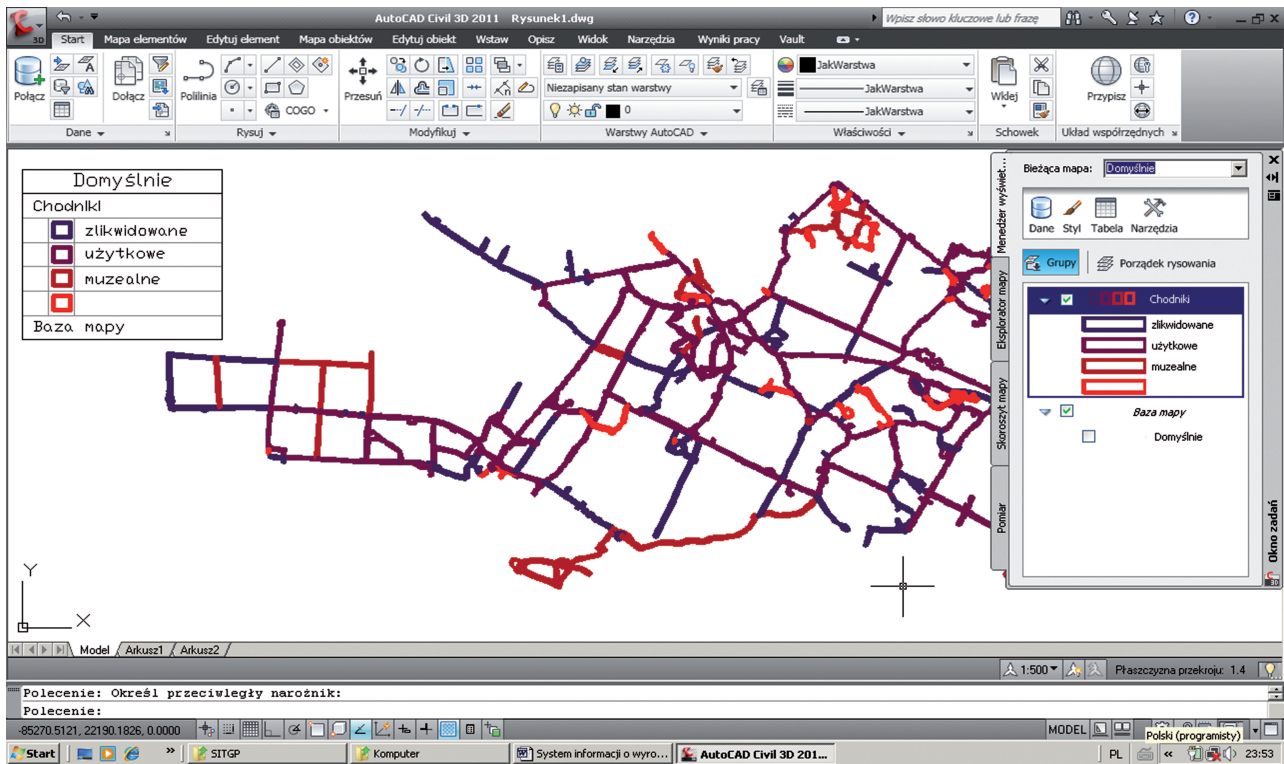**Ryc. 8.** Stylizacja warstw wg instrukcji – mapa górnicza

**Fig. 9.** List of corridors depending on their status
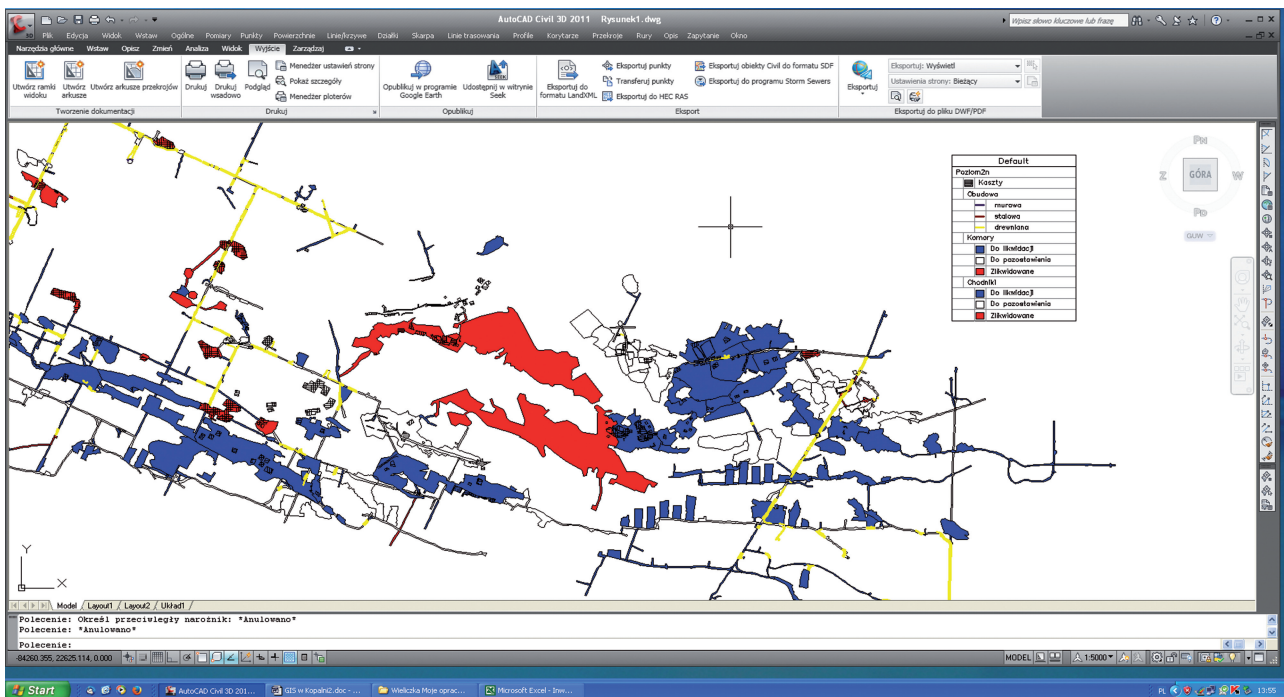**Ryc. 9.** Zestawienie chodników ze względu na ich status



**Fig. 10.** Target status of chambers and corridors
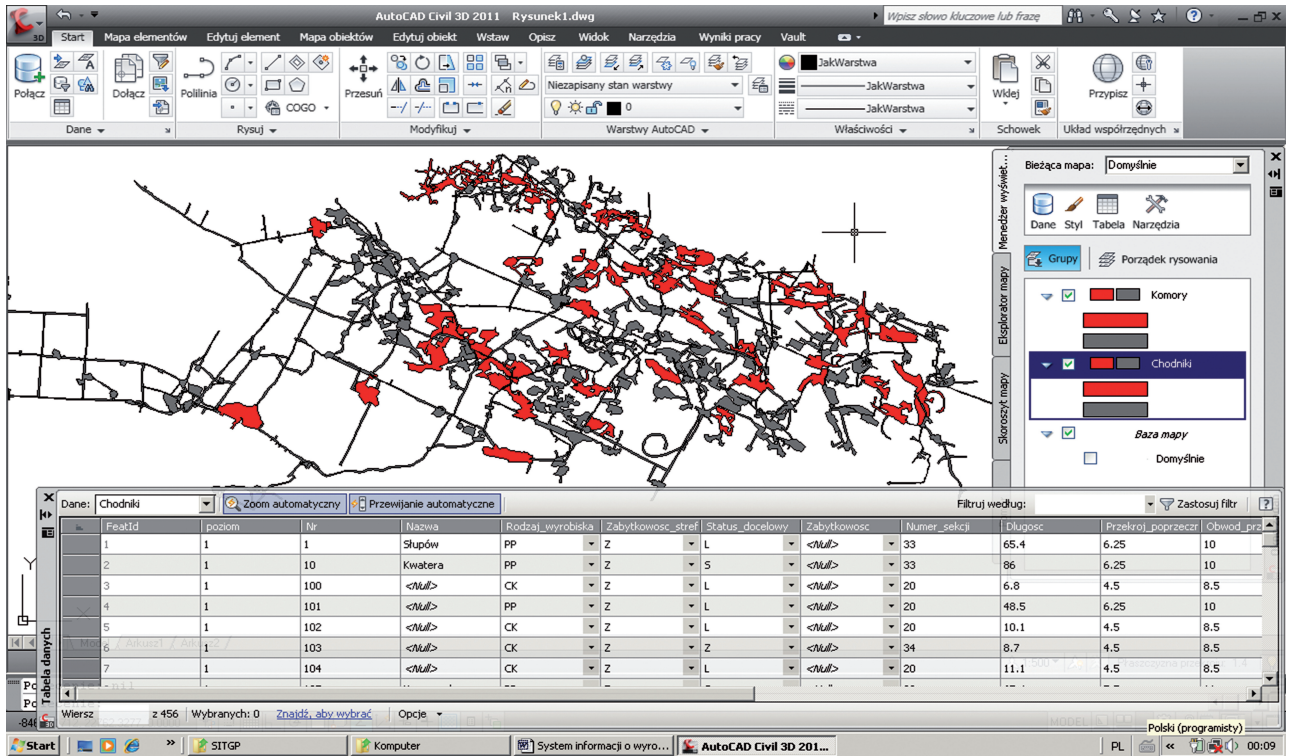**Ryc. 10.** Status docelowy komór i chodników

**Fig. 11.** Excavations with floor area > 1000 m²
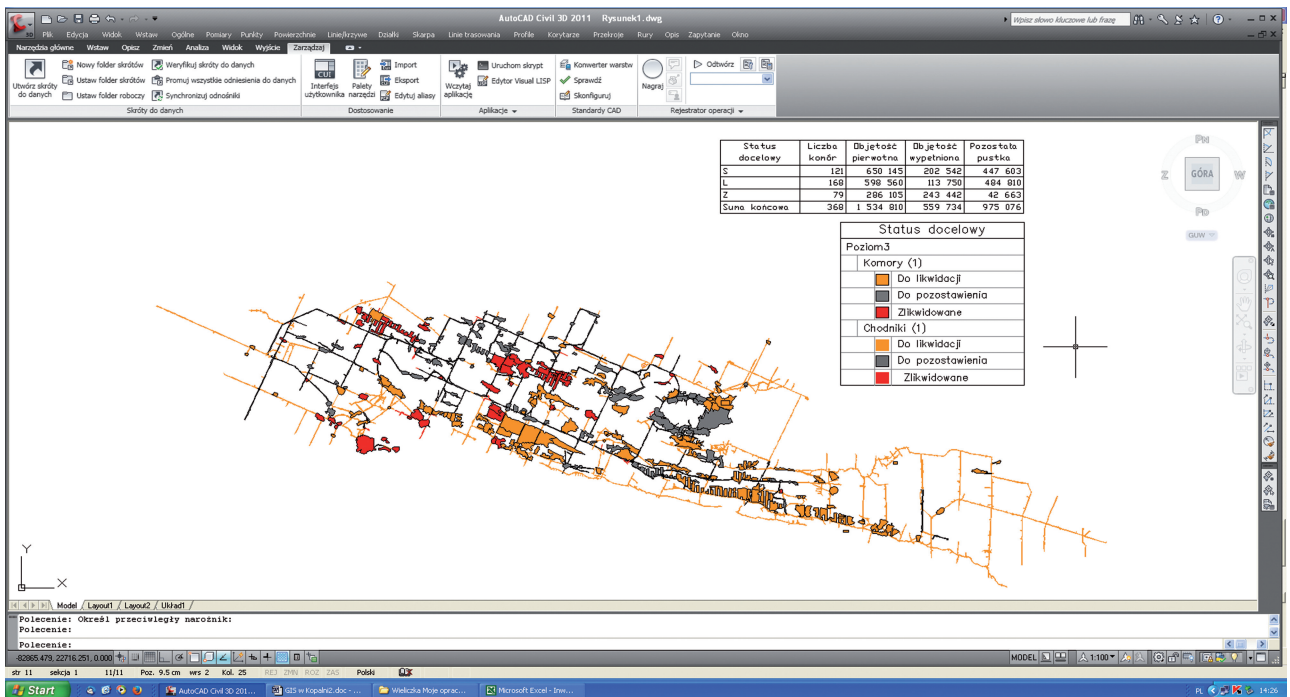**Ryc. 11.** Wyrobiska o powierzchni spągu > 1000 m²



**Fig. 12.** Excavations of the mine according to their target status
**Ryc. 12.** Wyrobiska kopalni według ich statusu docelowego

of backfill that has to be introduced for the entire mine (fig. 13) are presented below.

The database may also be used for the optimisation of ventilation. This requires information about the cross-section area of the corridors and chambers determining the air flow rate. The automatic calculation of those areas for the excavations is not problematic because the database contains information about the height of the roof and width of the excavation. The result of such calculations can be presented graphically as in figure 14.
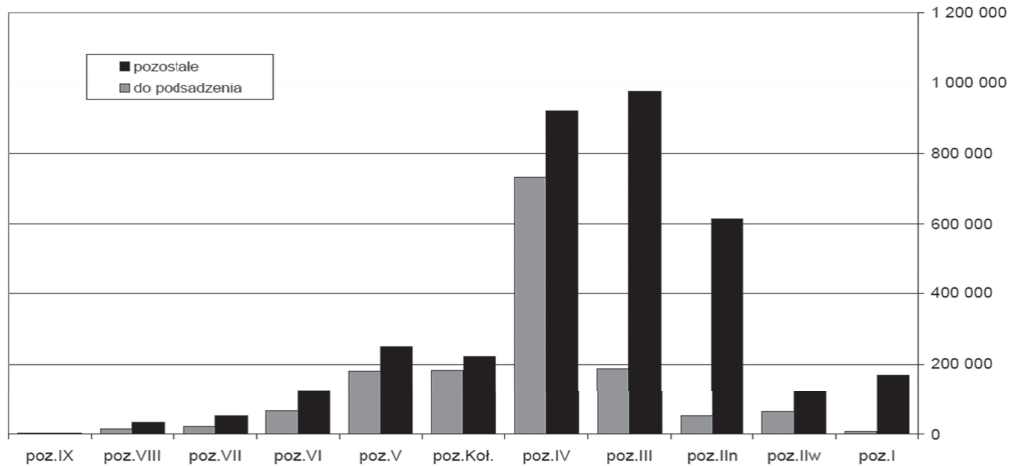


**Fig. 13.** Volume of introduced backfill and remaining voids for the mine
**Ryc. 13.** Objętości podsadzki wprowadzonej i pozostałych pustek dla kopalni
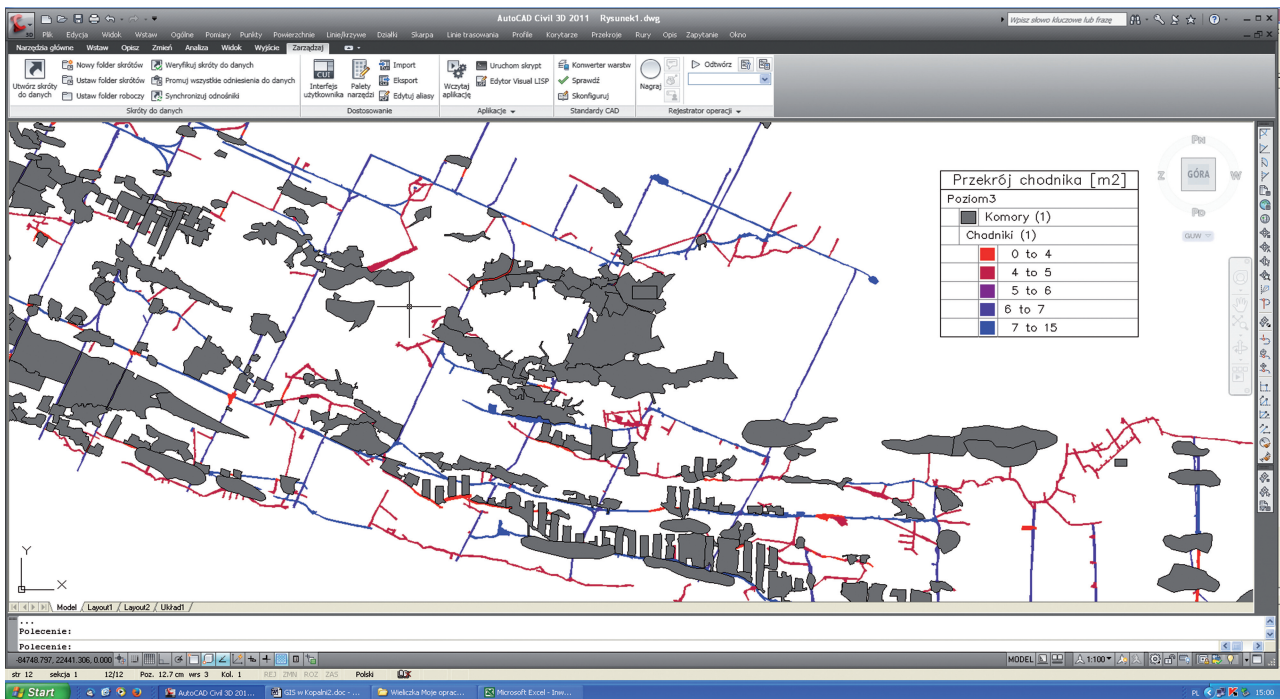


**Fig. 14.** Corridor cross-sections area – data for mine ventilation optimisation
**Ryc. 14.** Powierzchnie przekrojów chodników – dane do optymalizacji wentylacji kopalni

The examples presented above do not exhaust the potential uses of the database. However, they indicate that the above tool is very useful in the routine operation of the company and in the planning of further activities.

## 5. CONCLUSIONS

1. The characteristics of the mining process, geological structure, properties of the rock mass and the functions of the "Wieliczka" Salt Mine require a special approach to the construction of a suitable spatial information system. The IT systems used in other mines in Poland (and in the world) are not suitable for comprehensive implementation in those conditions.

2. The proposed concept of the IT system and databases in that system has been prepared with consideration of the characteristics of the mine. The concept provides for the creation of databases using free licenses (e.g., PostgreSQL/PostGIS or MySQL/Spatial), which reduces costs.

3. The article discusses the methods of creating the database for mine excavations providing for the integration of spatial data and descriptive data in the form of a data warehouse. The excavations are described as plane objects located at the average height of the given mine level (pseudo-spatial 2.5D model).

4. The object model involved the definition of five classes of attributes: corridors, chambers, use, fills and lining. The spatial data were acquired from raster maps and vector maps of the excavations. Each object was assigned spatial and non-spatial attributes. Overall, the chamber was described by a set of 39 attributes, the corridor – by 23 attributes; the descriptions were prepared in the form of Excel tables. The descriptive data were combined with the objects. The end result was verified to check for potential inconsistencies. The created database enables the systematic modification of the parameters of the excavations.

5. The completed database enables the resolution of a series of issues related to the practical operation of the mine. The article includes examples of such applications of the database.

6. The proposed model of data integration in the form of a database is universal, and it can be used for similar objects.

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