

Registering the underground objects in the 3D cadastre: a case study of wine cellar located in the vineyard area Tokaj

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The paper explores the way in which the underground objects can be measured, modelled, stored in spatial database and visualised for purposes of the 3D cadastre. The underground objects can be represented as 3D consolidated parcels representing an independent property that is not related to the surface parcel boundaries. The proposed solution is demonstrated for the wine cellar located in the vineyard area Tokaj. Since the international standard ISO 19152 Land Administration Domain Model exists and allows for the registration of 3D parcels, it is important that the used data model for storage of 3D underground parcels is based upon this standard. To model the 3D underground parcels the LADM boundary face concept with topological encoding is used. To visualise the 3D underground cadastral map, a new visualisation tool has been developed. The tool enables the visualisation of spatial data directly from the spatial database. When working with a huge amount of spatial data, it is necessary to optimise the way the data in the database are queried. To optimise the loading of data from the spatial database the vector tiles were created.

Keywords: 3D cadastre, underground objects, wine cellar, LADM, 3D visualisation.

Introduction

The main purpose of the cadastral system is to support the registration of a title with a legally binding digital cadastral map (Falzon and Williamson, 2001). People want to have the legal status of their property clearly defined in the cadastre. That gives a clear and serious responsibility to cadastre to define the boundaries of the property in all dimensions. Also, the third dimension is a source of income and a criterion which increases the land value (Aydin, 2008). The current 2D cadastral systems cannot support the description of underground parcels (Sandberg, 2001). Kim and Heo (2017) argue that an advanced cadastral system is required for management of the physical and legal statuses of underground parcels. 3D cadastre then registers and gives insight into rights and restrictions not only on 2D parcels but also on 3D property units (Stoter and Oosterom, 2006).

In 2012 an international standard ISO 19152:2012 Land Administration Domain Model (LADM) was accepted. Domain-specific standardisation is needed to capture the semantics of the land administration domain on top of the agreed foundation of basic standards for geometry, temporal aspects, metadata and also observations and measurements from the field (Lemmen et al., 2015). LADM supports cadastral data exchange with and from the distributed land administration, for example, legal data related to cadastral objects with data from other sources describing physical objects as utilities (Janečka and Souček, 2017). It means that the concepts presented in LADM can be used in the building of Spatial Data Infrastructure (Čada and Janečka, 2016).

LADM also allows for the registration of 3D parcels and therefore has to be considered for establishing of the 3D cadastre including the registration of underground objects. The registration of underground objects has been recently studied. A volume of papers discuss the registration of underground utilities in the 3D cadastre (Cevdet (2008), Ghawana et al. (2013), Spirou-Sioula et al. (2013), Shojai et al. (2013), Pouliot et al. (2015), Hashim et al. (2016)). In some countries (for example Serbia) the utilities are considered to be separate subjects of law which can be sold or bought and therefore there is a reason for their future registration using 3D spatial units (Radulović et al., 2018). This paper is more about the underground objects characterised by separate special-purpose use (typically wine cellars). Karabin et al. (2018) and Kitsakis et al. (2018) explored that in many countries around the world such underground objects (like wine cellars, metros, underground buildings) are considered to be real estates. However, they are not registered nor displayed on a cadastral map. Also, the legal and organisational aspects need to be considered, however, these are out of the scope of this paper.

Regarding the current manners in which the underground constructions are nowadays displayed on the 2D cadastral map, an example is illustrated in Figure 1. This approach is also applicable to the wine cellars (Janečka and Souček, 2017). Aydin (2008) argues that it is anticipated that without planning of underground spaces for supporting surface life city in the years and generations to come, there will be serious and unavoidable problems with growing populations and emphasizes the need to register the underground objects, but the wine cellars, metros or mining objects are not mentioned. However, it is obvious that also such objects need to be registered in the cadastre. Kim et al. (2015) introduced a concept of a 3D underground cadastral system based on data

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acquisition with terrestrial laser scanning and proposed 3D underground property mapping with an indoor mapping method designed for as-built BIM. They defined the concepts of 3D underground parcels by the representation of survey measurements through the creation of new classes and attributes for the existing ISO 19152:2012 LA_SpatialUnit package and LA_Surveying and Representation package. The paper aims to demonstrate another suitable data acquisition method for the underground objects like wine cellars, the storage of the selected underground object in the LADM compliant data model and its visualisation using the own newly developed tool enabling basic visualisation directly from the Oracle Spatial database. This is in accordance with the general requirements for the establishment of 3D cadastre as defined (together with the need of 3D property registration laws) by Aien et al. (2013). The main advantage of the proposed solution is a possibility to model and store the existing 2D parcels and newly created 3D underground parcels in one environment. The newly created visualisation tool also enables to visualise such data directly from the spatial database without a necessity of their conversion into another data format.

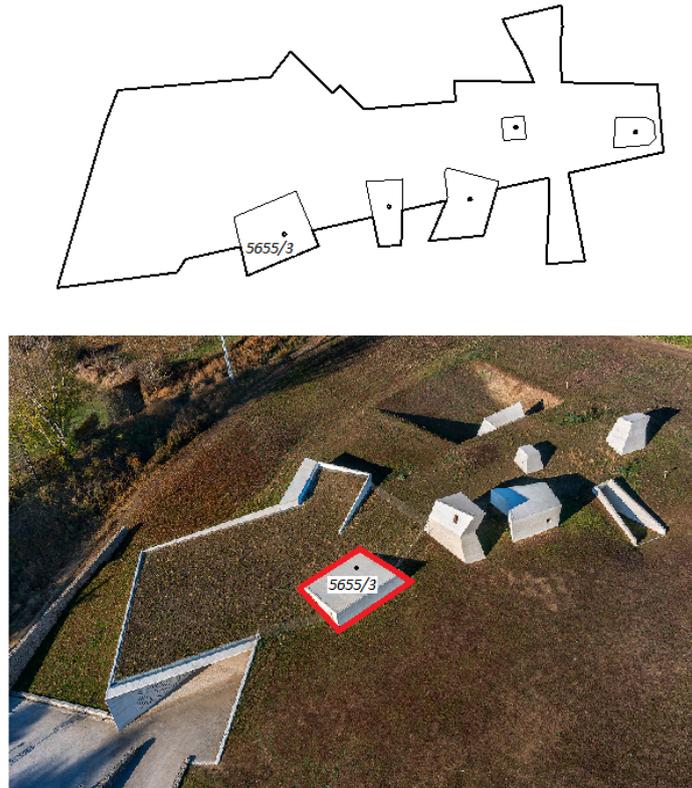


Fig. 1. (top) 2D visualisation of the boundaries of underground construction (Archeopark Pavlov, Czech Republic) on the cadastral map. Every component of the construction located above ground is displayed on a “separate” building parcel. However, in fact, only one building parcel is registered in the cadastre (here with parcel number 5665/3). (down) The photography of the underground object with components located above the ground. Highlighted in red is the part of the underground object corresponding to the building parcel 5655/3 (source of photography: <http://alesjungmann.cz/project/archeopark-pavlov>).

Due to the fact that the data model presented in the paper is based on LADM, it can serve as a base for extension of other LADM based models. In the last years, several LADM based country profiles have been proposed, i.e. for Poland (Bydłosz, 2015), Czech Republic (Janečka and Souček, 2017), Serbia (Radulović et al., 2017) or Croatia (Vučić et al., 2015). For example, the Czech LADM based country profile currently does not include the LADM class LA_BoundaryFace. The Czech cadastre still retains the 2D paradigm. The Czech LADM based country profile contains all of the classes and code lists required for Level 2 compliance. Moreover, it also contains some Level 3 classes. The Czech cadastre is based on the registration of 2D parcels, and therefore (for example), the Level 3 class LA_BoundaryFace is not integrated into the Czech profile. If the necessity for the further development of 3D systems arises within the Czech cadastre (e.g. advanced registration of underground objects), then the profile can be expanded precisely to support 3D parcels modelled using LA_BoundaryFace in the way as presented in this article.

The rest of the paper is structured as follows: The used research methodology is described in the section Methodology. The data acquisition method and creation of the 3D underground parcel is in detail described in the section Creation of a 3D model of the wine cellar. The paper intended that the proposed solution has to be in accordance with the ISO 19152:2012 (LADM) international standard. The section Registration of the

underground objects considering LADM introduces the data model and its fulfilling by the data. Furthermore, this section contains a description of the developed tool which enables the basic visualisation and first attempts towards the optimisation of the visualisation. The paper ends with the conclusions.

Methodology

The vineyard Tokaj is located to the southeast of Slovakia. This area, especially due to the high-quality and character of the land, is suitable for wine production. The storage of wine is one of the most important fact affecting its final quality. The wine cellars in this area are well-known for their macro- and microclimatic conditions. The wine cellars are located below the ground, only the entrance portals are located above the ground, as depicted in Figure 2. Nowadays, to register the wine cellars in the cadastre the survey sketch has to be created. The graphical part of the survey sketch is shown in Figure 3. To know the exact legal and physical extent of wine cellars in a given area is a necessary condition for the further 3D development of the area including the property rights. The paper assumes that the legal extent of the 3D underground parcel representing wine cellar is defined by its physical boundaries. If there is a necessity to store some protected area around the wine cellar, then the physical boundaries will be different from the legal boundaries including the protected area.

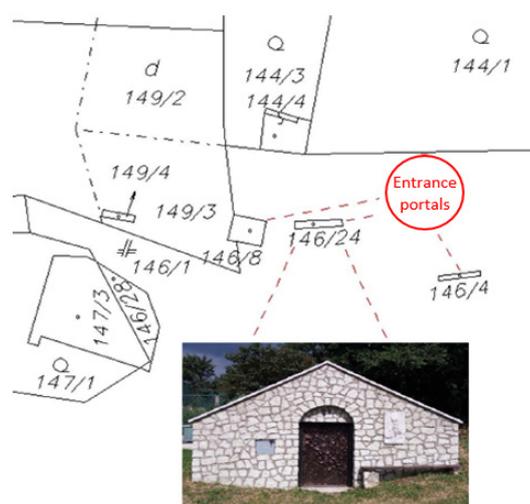


Fig. 2. The entrance portals of wine cellars (vineyard area Tokaj, cadastral unit Velká Trňa) and their displaying on the 2D cadastral map. In this case, every entrance portal is established on separate building parcel.

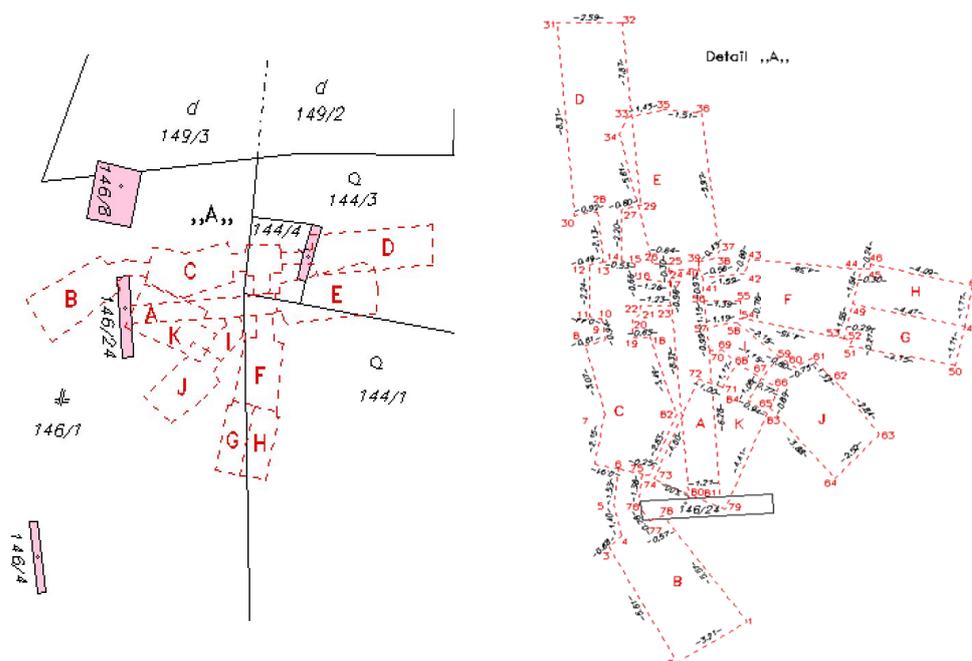


Fig. 3. Demonstration of the graphical part of the technical background (survey sketch – for measurement of the entrance portal, underground cellars and passages marked with letters A-K serving to register a legal act (from a letter - contract) into cadastre of real estates (Bobíková and Janečka, 2017).

Regarding the registration and modelling of 3D parcel representing the underground construction, there are in principle two main basic principles (which are also applicable for underground utilities). The 3D underground parcel can be split into several smaller 3D spatial units with respect to the surface parcel partition. Such an approach was demonstrated, for example, by Thompson et al. (2017). All these smaller 3D parcels then together form the whole 3D underground parcel which represents the underground construction. The conception of 3D underground parcel representing the wine cellar used in this paper is as given by Karki et al. (2013) and Van Oosterom (2013), i.e. the 3D underground consolidated parcel representing an independent property that is not related to the surface parcel boundaries. The latter approach still enables the user to ask the queries like finding all the surface parcels below which the 3D underground parcel is located and is quite independent on the situation (partition of parcels) on the surface. Döner et al. (2011) recommend using the absolute heights for geometries of 3D underground parcels. In such case, the geometry of the 3D underground parcel is not related to the surface. Therefore, to model the 3D underground parcel representing the underground wine cellar the consolidated parcel with absolute heights was used. Furthermore, Thompson et al. (2015) introduced a categorisation of 3D spatial units consisting of several categories. Among others, there is the category of general 3D spatial units, which can be potentially used also for representation of underground objects. The category of general 3D spatial units contains the spatial units whose geometries are formed by general faces. From the LADM perspective, such 3D spatial units can be modelled using the LADM boundary face concept. As recognised by Janečka et al. (2017), to store the geometries of such 3D spatial units into the spatial database management system, the freeform faces need to be appropriately approximated by planar faces. This is also the case of the 3D underground parcel representing the wine cellar which is described in the paper as in the reality the wine cellar's ceiling is shaped like an arc.

The used data model is based on the model proposed by Thompson (2013). The data model follows the LADM concepts and enables storing both 2D (using boundary face strings concept) and 3D (using boundary face concept) spatial units, i.e. the boundaries of 2D surface parcels above the wine cellar were stored in the same data model as the 3D underground parcel representing the wine cellar. Furthermore, a precise Digital Terrain Model (DTM) was available for the territory of the study area. The paper presents three types of underground cadastral mapping for the wine cellar, according to Kim et al. (2015):

1. An isometric view of the 3D underground cadastral map. This is used to describe the geometric information of a 3D underground parcel separately from the surface parcel.
2. A 2D surface parcel with footprints of the 3D underground cadastral map, which is used to represent the 3D underground property with corresponding surface parcels.
3. A 3D surface and 3D underground cadastral map, which are used to represent the location of 3D underground properties with regard to real-world situations. They are able to register and manage depth information, which represents the difference between 3D surface and 3D underground property.

In order to optimise the way in which data are retrieved for visualisation the data model was extended for the classes storing the vector tiles.

Creation of a 3D model of the wine cellar

Data acquisition

A geometrical model of the 3D parcel is required for registration of 3D properties (Kim et al., 2015). To create the model of the wine cellar the data with appropriate accuracy are needed. Nowadays, there are a lot of different methods that are suitable for surveying 3D objects. However, they are effective for 3D above-ground cadastral systems and are not well suitable to 3D underground cadastral systems.

The used method to capture the detail data for creation of the 3D model of wine cellar was tacheometry. Using tacheometry, one can determine the position and height of the point (X, Y, and Z point coordinates) in the defined coordinate system. Principle lies in measurements of oblique length, horizontal and height (zenith) angle simultaneously by one instrument – universal measuring station (UMS) (Blišťan and Kovanič, 2012). The accuracy of tacheometry using UMS is sufficient also for the needs of precise documentation of various underground geo-objects (for example wine cellars).

Creation of the 3D wire-frame model

Upon the measured points, the 3D wire-frame model was created. The creation of the 3D wire-frame model of wine cellar was done in MicroStation Descartes software and stored in DGN file format. For the visualisation purposes (see Figure 4) the “faces” were classified (floors, walls, ceilings).

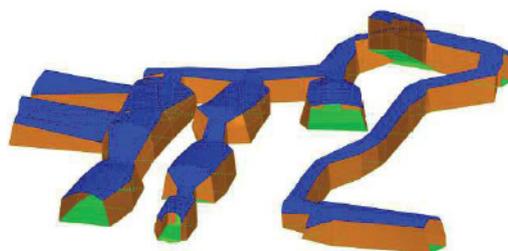


Fig. 4. The 3D model of the wine cellar. The floors are highlighted in green, walls are brown, and ceilings are blue (Janičková et al., 2016).

Registration of the underground objects considering LADM

The data model

To store the 3D model representing the wine cellar in the spatial database the data model based on the model by Thompson (2013) was proposed. The used data model is based on the LADM and is able to accommodate full 3D parcels. It also supports all level of encodings defined in ISO 19152:2012 (ISO-TC211, 2012). In case of wine cellar topology based encoding was used, i.e. adjacency is directly encoded in the database. Another advantage of the data model is that is also able to combine 2D and 3D spatial data seamlessly. To model the 3D boundaries of underground objects the boundary face concept presented in ISO 19152:2012 is used. The principle of the concept is captured in Figure 5. The corresponding class for modelling boundary faces is `LA_BoundaryFace`. An instance of class `LA_BoundaryFace` is a boundary face. Another LADM class used in the research is `LA_BoundaryFaceString` to model 2D parcels (which could be theoretically interpreted as unbounded volumes). The principle of the boundary face string concept is demonstrated in Figure 6. The physical data model for storing the 2D and 3D spatial units is captured in Figure 7.

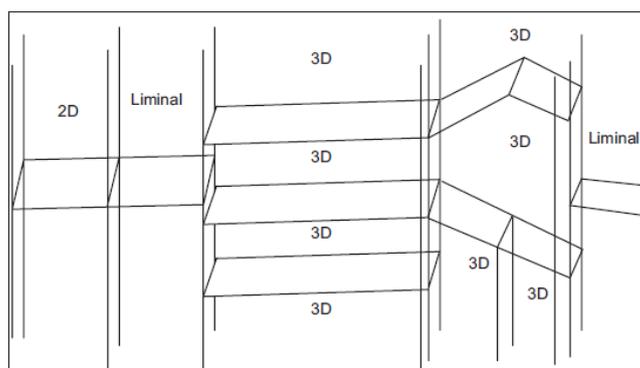


Fig. 5. The side view showing the mixed use of boundary face strings and boundary faces to define both bounded and unbounded 3D volumes (according to ISO-TC211 (2012)).

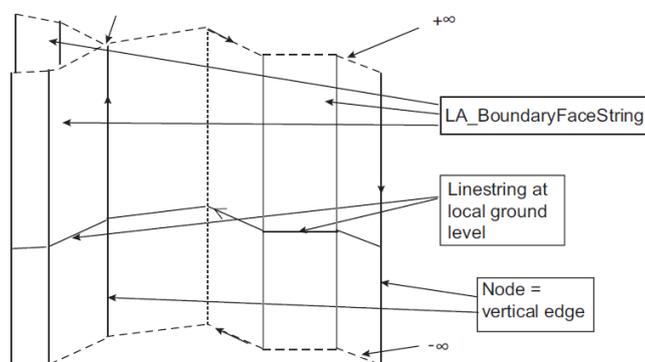


Fig. 6. Boundary face string concept (according to ISO-TC211 (2012)).

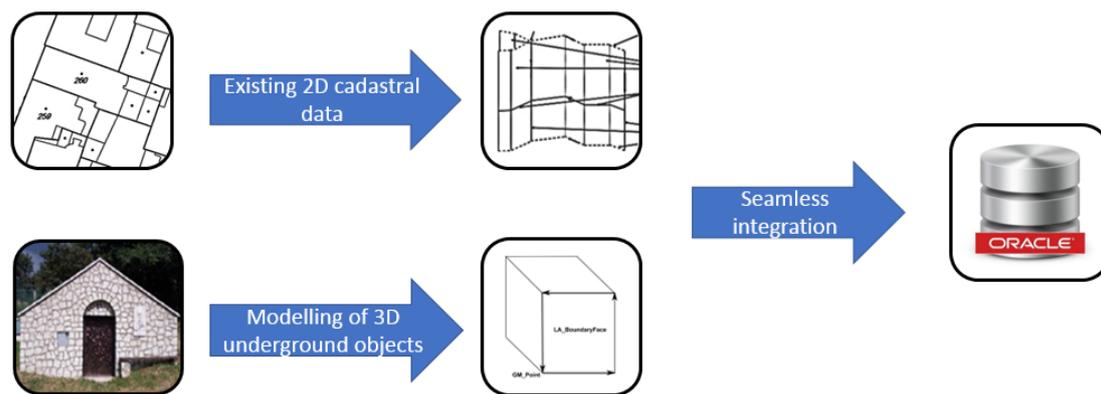


Fig. 8. Existing 2D cadastral data were imported into the data model according to the boundary face string concept. The 3D model of the wine cellar was stored using a boundary face concept.

Visualisation

After the data had been loaded into the database, the remaining task was to visualise the integrated 2D parcels (2,5D respectively) and 3D underground parcel. The intention was to make a program that would load the data directly from the database from the implemented data model, without the need of any middleware or transformation into another data format. To create the visualisation tool, C# has been used instead of previously intended Java, since it offers better performance and seemingly better engines, although it is not as portable. In particular, a 3D game engine called Unity (Agugiario et al., 2011; Ruzinoor et al., 2015) has been used, which comes with its own programming environment. So instead of writing a complete program, the solution was to write scripts that create and manipulate elements in this environment. This proved to be useful as extensions such as camera movement, or object colouring can be added easily.

The trouble was encountered when trying to load the cadastral data from the database because Unity engine does not support the .NET version needed for the usage of ODBC (Open database connectivity). To solve this issue, an executable programme ParcelLoader.exe was created in C# using Oracle.ManagedDataAccess library. The created executable programme then runs with specific parameters within the Unity environment to retrieve the requested data (parcels) from the database as depicted in Figure 9. The developed tool for visualisation is currently able to load and visualise 2D and 3D parcels directly from the Oracle Spatial database.

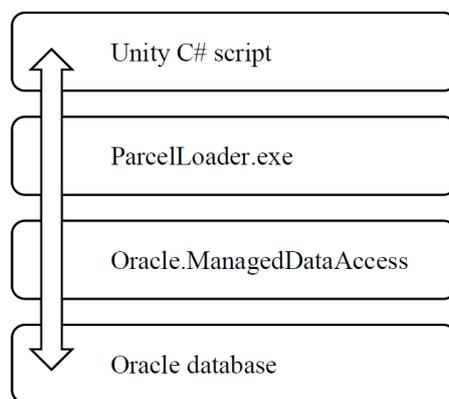


Fig. 9. The principle of using Unity C# script to receive the data from Oracle database.

Figure 10 presents the isometric view of wine cellar using the developed visualisation tool. This tool serves as a proof of concept of visualisation of the data directly from the Oracle Spatial database from the data model presented in Figure 7.

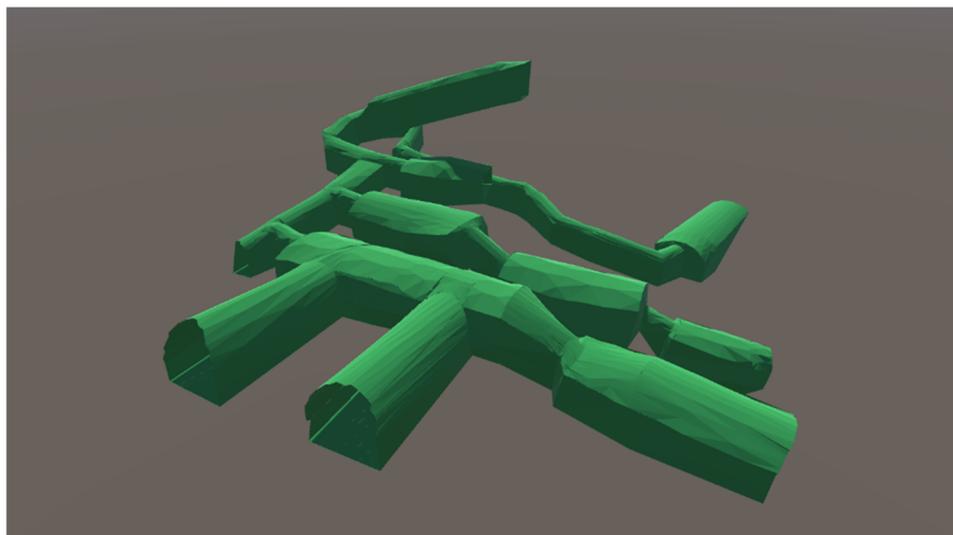


Fig. 10. Isometric view of a 3D underground cadastral map of wine cellar using the developed visualisation tool.

Figure 11 demonstrates the combination of 2D surface parcels with footprints of the wine cellar.

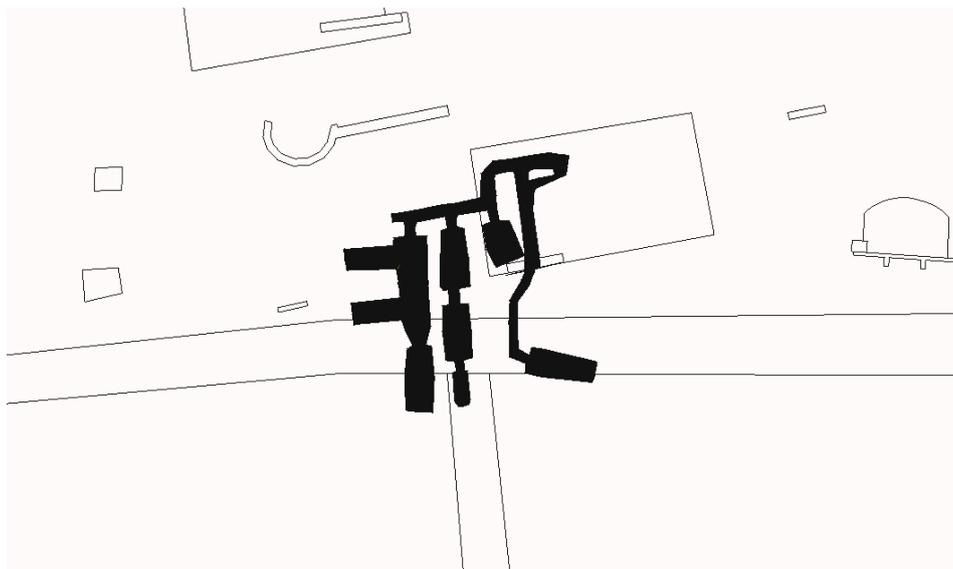


Fig. 11. 2D surface parcel with footprints of a 3D underground cadastral map of the wine cellar.

The developed visualisation tool does not allow for displaying DTM. Therefore, to visualise 3D surface (DTM) and 3D underground cadastral map ArcScene software was used (see Figure 12).

In case that one would like to visualise 2,5D parcels (2D parcels projected onto the DTM) using the developed visualisation tool, then the further development is needed. If the DTM is stored in the spatial database together with 2D and 3D parcels, then it would be theoretically possible to compute the projection of the boundaries of the 2D parcels onto the DTM directly at the side of a spatial database and then visualise them. Another approach could be to compute the projection at the side of the visualisation tool. To enable this computation, the capabilities of the tool has to be extended in the future also to support the loading (and visualisation) of DTM.

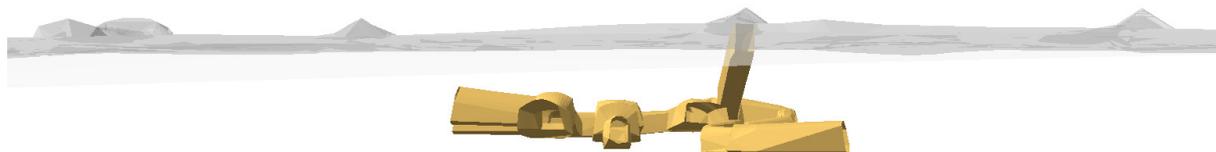


Fig. 12. 3D surface and 3D underground cadastral map.

Vector tiles for database query optimisation

The tool which has been developed aims to visualise the stored data from the spatial database. The main intention (from the paper's perspective) was to make a direct visualisation without conversion of the data into other format and to visualise the data from the LADM compliant data model containing both 2D and 3D topologically structured geometries. First, to retrieve the data from the database faster, the R-tree spatial indices were created upon the spatial attributes.

When working with a database with huge amount of spatial data it is necessary to optimise the way the data in the database are queried. Therefore the vector tiles (200x200 meters) related to spatial units were created. The indexing tables (TILE_2D_SU and TILE_3D_SU) store the identifier of the spatial unit and XY coordinates of the centre (s) of corresponding vector tile(s). This way only spatial units on nearby tiles are loaded while browsing the data. The principle of creation of vector tile is captured in Figure 13.



Fig. 13. The principle of how the vector tile is created. The grey highlighted parcels are associated with the particular tile.

Conclusions

The paper explored important aspects of the building of the 3D underground cadastre – the data acquisition, data modelling and 3D visualisation. The further work will also focus on the proposal of 3D property registration laws dealing with underground objects. The data model presented in figure 7 could be easily extended to support both the legal and physical boundaries of underground objects.

At the moment 2D and 3D parcels are stored in the spatial database in LADM based data model. The digital terrain model is stored outside the database in the DGN file format. In the further research, DTM will be stored in the spatial database; the first attempt is given for example in Janečka and Kára (2012).

The visualisation tool developed in this research is able to load and visualise 2D and 3D parcels directly from the Oracle Spatial database. Currently, the spatial database contains only a testing dataset consisting of

several tens of geometries. In the future work, the larger datasets will be imported into the database and performance analysis will be done.

The visualisation tool will be further developed in order to support also visualisation of DTM stored in the spatial database and 2,5D parcels in combination with 3D parcels.

The used approach for the 3D data acquisition, 3D modelling of the underground object and its 3D visualisation is applicable also on other types of underground objects, i.e. mining objects and is fully conformant with LADM.

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