THE SPATIOTEMPORAL DATABASE OF THE TERRITORY - A TOOL FOR STUDYING CHANGES IN THE LANDSCAPE

Michal Kepka, Jiří Belinger, Josef Huml, Martina Kepka Vichrová

Ing. Michal Kepka, Ph.D., Tel: +420 377 639 212, mkepka@kgm.zcu.cz
Bc. Jiří Belinger, belinger@students.zcu.cz
Department of Geomatics, University of West Bohemia, Pilsen, Czech Republic
Ing. Josef Huml, jsf.huml@gmail.com
Cadastral Branch Office Rokycany, Czech Office for Surveying, Mapping and Cadastre, Prague, Czech Republic
Ing. Martina Kepka Vichrová, Ph.D., vichrova@kgm.zcu.cz
Department of Geomatics, University of West Bohemia, Pilsen, Czech Republic

Abstract
Maps and datasets provide information about the landscape at the moment of data acquisition. An archive of old maps offers a unique collection of snapshots of landscape appearance and phenomena in particular moments of history. Nevertheless, the landscape - features and phenomena - can be represented in each map by different methods and means of map representation, given by the date of origin of each map. Therefore, a complex landscape analysis needs complex data source processing, often focused on selected features or phenomena. The article describes the design and development of a digital landscape model implemented as a database with spatial and temporal dimensions. The spatiotemporal database is focused on landscape change monitoring in selected territories in available time snapshots. The spatiotemporal database of the territory was designed to integrate geographical data originating from different maps and datasets into the data model and with harmonised object classification. The article describes the results of integrating several large- and medium-scale datasets covering the first half of the 19th century up to the present day in a pilot locality in the Czech Republic. The analytical potential of the database is presented by a set of typical analyses utilising temporal views of datasets. The possibility of analysing spatial and attribute changes of features and phenomena in the territory in different periods of time provides a valuable tool for landscape change analyses.

Keywords: *spatiotemporal database, digital landscape model, old maps, spatial dataset, spatial analysis*

INTRODUCTION

Nowadays, there is an increasing need for knowledge about the historical form and development of the territory in terms of landscape structure, urban area and infrastructure development, forestry or agriculture. Maps and thematic geographical datasets provide important information about the territory they portray. The content of the map or dataset represents reality at the moment of data registration, and it can be considered as a snapshot of reality at a specific time and with a corresponding level of detail. When we have available datasets from different years or epochs with similar scope and level of detail covering the same territory, we can compare content and detect changes between available time snapshots. Features recorded in the reality snapshot are defined by the original purpose of the dataset or map - what were the subjects of mapping and the level of the dataset or map scale. For effective management and maintenance of these types of data, it is important to create databases that integrate individual data sources in terms of their original purpose, time, and space. The standalone task is to prepare a harmonised classification of processed data to ensure coherence in the meaning of feature representations across many original datasets and decades between different publications. Harmonised classification allows for the comparison of datasets. Integrating different map products and map series brings the challenge of comparing datasets as the legislation and regulations for surveying subjects or map content have changed many times.

The article presents an initial design and development of the Spatiotemporal database of the territory (STDB of Territory). The STDB of Territory is a digital model of the territory that is currently integrating both present and old datasets on the level of large-scale maps. Integrating present and old datasets adds the time dimension to the spatial database. The study was tested on large-scale datasets of a selected pilot locality - a cadastral territory of a small village in the Czech Republic - covering a time period between 1839 and 2023. Selected datasets are different types of cadastral maps and orthophotos from the historical period. Examples of three types of analyses are presented. These analyses cover simple summarising and attribute queries using harmonised classification and investigation of selected object changes.

MATERIALS AND METHODS

A digital landscape model is a common approach to modelling reality in a defined level of detail and a defined level of thematic content. The digital landscape model can be designed as a spatial database in general [1, 2, 3]. We can define key elements that characterise the model. One of the characteristics is how objects are categorised – thematically, geometrically, combined or other [2, 3, 4].

The idea of the STDB of Territory corresponds to the approach of many national products of large-scale digital landscape models produced by different National Mapping, Cadastre or Land Registry authorities in Europe. We can mention several examples from European countries and how they categorise objects. Detailed descriptions can be found in [5].

1. Základní báze geografických dat (ZABAGED) from the Czech Republic, [6, 7]
2. Amtliches Topographisch-Kartographisches Informationsystem (ATKIS) from Germany, [8]
3. Digitales Landschaftsmodell (DLM) from Austria, [9]
4. Maastotietokanta (MTK) from Finland, [10]
5. OS Master Map from the UK, [11]
6. Basisregistratie Grootschalige Topografie (BGT) from the Netherlands, [12]

These examples of digital landscape models, topography databases or national geographical information systems are maintained and published by the national authorities mainly to present the current status of the landscape by a wide range of corresponding map scales, but primarily on the level of medium or large-scale maps. National digital models and databases mainly categorise objects by themes, with individual attributes for each category. The crucial point is maintaining the abovementioned databases as products based predominantly on primary data sources - land surveys, mappings, aerial surveys, LIDAR data, etc. The previous state of the database then represents primarily the time dimension.

An example of a geographical database whose primary purpose is to create a database as a source for different map products is OpenStreetMap [13]. The OpenStreetMap is the community geographical database integrating data from other sources. It can involve primary or secondary data sources with various map scale ranges. The important difference from previously mentioned national databases is that OSM data are categorised based on geometry types and attributes and serve as identificators of object categories. The database is published under the open licence and maintained by a large community of contributors.

Valuable spatial data sources are old medium- and large-scale maps, which can cover historical periods for the last two or three centuries. We have found several projects processing the content of old maps and developing visualisations or digital datasets [14, 15, 16, 17]. A significant publication project of old topographic maps is the project Arcanum, which is outstanding in its seamless coverage of Europe [18, 19]. The members of the authors' team were already involved in developing the Database of settlements [20]. An important step in processing old maps is comparing changes in the map content [21].

A digital landscape model based on a spatiotemporal database is a valuable data source for further analytical processes, especially with a higher potential for integration with other thematic datasets (e.g. [22]) or visualisation in 3D (e.g. [23]) with the extension of the time dimension.

We have identified several data sources suitable for building a digital landscape model on the level of large-scale maps in the area of the Czech Republic. These data sources can be divided into several types, where detailed descriptions are available in [5]:

- **Old cadastral maps** – from 1826 to 1993 – are mainly available in scanned map sheets; some datasets are already georeferenced, but georeferencing is necessary in the case of the oldest maps.
- **Current cadastral maps** – from 1993 to the present – are already in the form of digital or digitised datasets that can be directly used.

- **Aerial surveys photos or orthophotos** – rarely from the 30s, systematically from 1953 to the present – some periods are already available as digitised orthophotos or digital datasets, and some periods are still in the form of analogue aerial photographs and scanned of demand.
- **Old large-scale maps** – from the first half of the 20th century to the present – are available as non-georeferenced or georeferenced scans.
- **ZABAGED** – mainly up-to-date data – is available as a digital dataset and can be directly used.

Most of the mentioned datasets are available as old maps, and thus, we need to preprocess these data sources by georeferencing and vectorisation. The process of georeferencing and vectorisation of old maps of the Stable cadaster to be used in the STDB of Territory is described in detail in [24].

The STDB of Territory aims to integrate the most detailed datasets available for the target territory for defined time periods. For the pilot study, we have decided to limit the datasets to cadastral data and orthophotos for one small locality with potential conflicts of map content and the ground truth because of the presence of military objects and knowledge of administrative boundary changes.

The pilot locality and available datasets

The selected pilot locality was defined by the boundary of the basic cadastral territory involving a small village – Strašice – 30 km to the east of the city of Pilsen in the Czech Republic. Two main phenomena influenced this village and the landscape during the last two centuries. First is the metallurgical industry's growth in the second half of the 19th century and its reduction at the beginning of the 20th century. Second, the neighbourhood of the former military area, Brdy. The establishment of the military area in 1926 and its cancellation after 90 years significantly influenced the change of the landscape and the village's growth when military quarters and residences were built. Even the municipality's boundary was significantly changed two times during the observed timespan.

We have identified and processed seven datasets available for the pilot locality. The following datasets were used for the pilot locality with the corresponding year of publication and available form of the data:

- Maps of Stable Cadastre (1839) – scanned map sheets, georeferencing and vectorisation were applied.
- Maps of revision survey of Stable Cadastre (1879) – scanned map sheets, georeferencing and vectorisation were applied.
- Maps of cadastre of lands (1929) – scanned map sheets, georeferencing and vectorisation were applied.
- Maps of real estate registry (1966) – scanned map sheets, georeferencing and vectorisation were applied.
- Maps of Cadastre of real estate of the Czech Republic (2023) – digital dataset
- Greyscale orthophoto (1953) – scanned sheets of orthophoto, vectorisation was applied.
- Modern full-colour orthophoto (2001) – raster image, vectorisation was applied.

Most available datasets were vectorised manually, except the present Cadastre of real estate. Regarding maps of Stable Cadastre, map sheets were georeferenced to the national coordinate referenced system (S-JTSK) according to the methodical instructions [25]. Objects were vectorised from original datasets to shapefiles with defined attributes and values based on original map keys. In the case of vectorisation of orthophotos, the set of objects and their attributes were reduced. However, the main reason for incorporating orthophotos into the database was to have the ground truth about the landscape. While acts and specifications define the content of cadastral maps, and it can be reduced by, for example, the strategical objects (in the case of the pilot locality, this issue was applicable), orthophotos contain the reality of the landscape appearance.

Design of the Spatiotemporal Database of Territory

The data model of the STDB of Territory was designed based on several requirements, which were defined by the target purpose of the database and the types of datasets which will be integrated. The basic requirements were as follows and are described in detail in [5]:

1. unified integration of datasets with initially variable structure,
2. harmonised classification of features,
3. preserving all original attributes of features, including geometry,

4. definition of the geometry of features by 2D geometric primitives, including multitype geometry,
5. definition of feature validity based on original datasets' dates (validity, publication date),
6. division of features by a set of themes,
7. clustering of features by administrative units.

The harmonised classification was designed and developed to ensure the comparability of objects and their attributes' values across different map series. It combines current topographical object attributes used in the ZABAGED data model but extends it by the coded values from the INSPIRE Land Use classification (HILUCS). More details about the harmonised classification can be found in [5].

The basic schema of the data model contains only six objects, see Figure 1. The core is an "Object" representing a map feature with geometrical and non-geometrical attributes originating from a map or dataset "DataSource". The "object" is located in an "AdminUnitArea" defined by national authorities. An "Object" is classified by the harmonised classification "CommonClassification" and linked to the "Terminology" of the land cover types. The correspondence between the present classification and original classifications of datasets is harmonised by the "ConversionClassification".

Definition of types of objects

We have defined seven types of objects that could be recognised on large-scale maps and represent the core structure of the landscape. The types of objects are the following, and the categories are inspired by the INSPIRE themes:

- Buildings
- Transport
- Hydrography
- Land cover
- Point objects
- Geodetic control
- Hypsography

In the case of the cadastral maps, the information on the hypsography is minimal. In the case of orthophoto datasets, we are limited to Buildings, Transport, Hydrography and Land cover. Different geometries can represent the same thematic types of objects, and one object type can have more than one geometry type – typically, a road can be represented by the polyline of the road's centerline or by a polygon representing the area of the road or the cadastral parcel. A similar schema is for a watercourse.

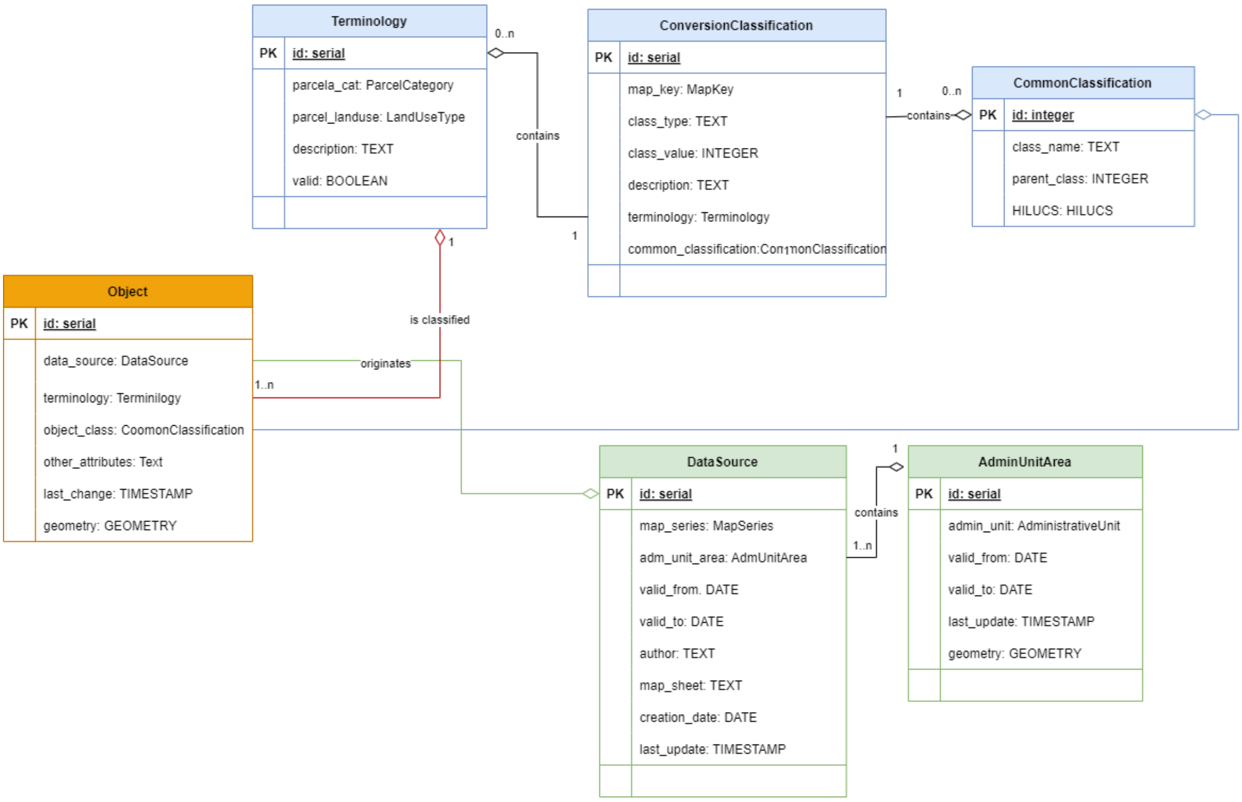

Figure 1 – The UML model of the core schema of STDB of Territory, source [5]

RESULTS OF DEVELOPMENT AND ANALYSES

The data model implementation for the STDB of Territory was realised in the open-source database system PostgreSQL (version 14) with spatial extension PostGIS (version 3.2). The individual types of objects were implemented as separate database tables. A set of coded value lists was implemented to ensure the database model's normal form and tables' one-to-many relations. The non-primitive datatype for geometry was used to implement the geometry of objects – GEOMETRY from PostGIS extension, and the JSON datatype for storing all attributes of features recognised during the vectorisation. Utilising non-primitive datatypes for attributes is an advantage for data storage, but it needs to be considered when SQL queries are designed.

We will present examples of three types of analyses to show the capabilities of the STDB of Territory. The first is the analysis of the number of recognised buildings. The number of buildings was analysed to investigate the change in the number of buildings observed in each original dataset. The analysis was performed using attribute query directly on data in the database system.

Table 1 – Analysis of the number of recognised buildings in different datasets, source [5]

Dataset	**Valid from**	**Valid to**	**Number of buildings**
Stable Cadaster	1839	1877	443
Revision survey of Stable Cadastre	1878	1882	501
Cadastre of Lands	1928	1956	567
Orthophoto 1953	1953	1953	661
Real Estate Registry	1967	1992	797
Orthophoto 2001	2001	2001	922
Cadastre of real estate of the Czech Republic	2023	2023	1572

The analysis in Table 1 shows an increasing number of buildings during the observed period. The significant change in the number between datasets of 2001 and 2023 was investigated in detail. The result can be explained by including a block of row garages as one building in orthophoto vectorisation but as a separate building with individual land parcel numbers in cadastral data. A similar issue is row flat houses, vectorised as one building from orthophoto but represented as individual buildings in cadastral data. Both types of row buildings were built during the 70s and 80s in the area.

The second type of analysis evaluates the area change of the selected land cover type, which is harmonised across all cadastral datasets. We have chosen the type "grassland" according to the present definition in cadastral data, which covers formerly used categories "pasture", "municipal pasture", "hayfield", or "meadow".

Table 2 – Analysis of the area size of features of the category grassland, source [5]

Dataset	Valid from	Valid to	Absolute area size [ha]	Absolute area of the municipality [ha]	The ratio of grassland to municipality area [%]
Stable Cadaster	1839	1877	337	3075	11
Revision survey of Stable Cadastre	1878	1882	285	3075	9
Cadastre of Lands	1928	1956	287	3075	9
Real Estate Registry	1967	1992	229	790	29
Cadastre of real estate of the Czech Republic	2023	2023	166	3484	5

Table 2 shows two changes in the "grassland" category area. The first decrease was at the end of the 19th century, when further investigation was needed to determine what land cover categories were increasing. The second change was visible mainly in the relative percentage of the area, which was caused by the decrease in the total municipality area by removing the part belonging to the military area in the 50s of the 20th century.

The last analysis example is focused on monitoring the change of selected objects. We have chosen two objects. The first is the church recognised in each dataset up to the present. The second is the pond, which ceased to exist at the beginning of the 20th century and was recognised only in the first two datasets. The geometric shape presents the objects' change in the following figures (Figure 2, Figure 3).

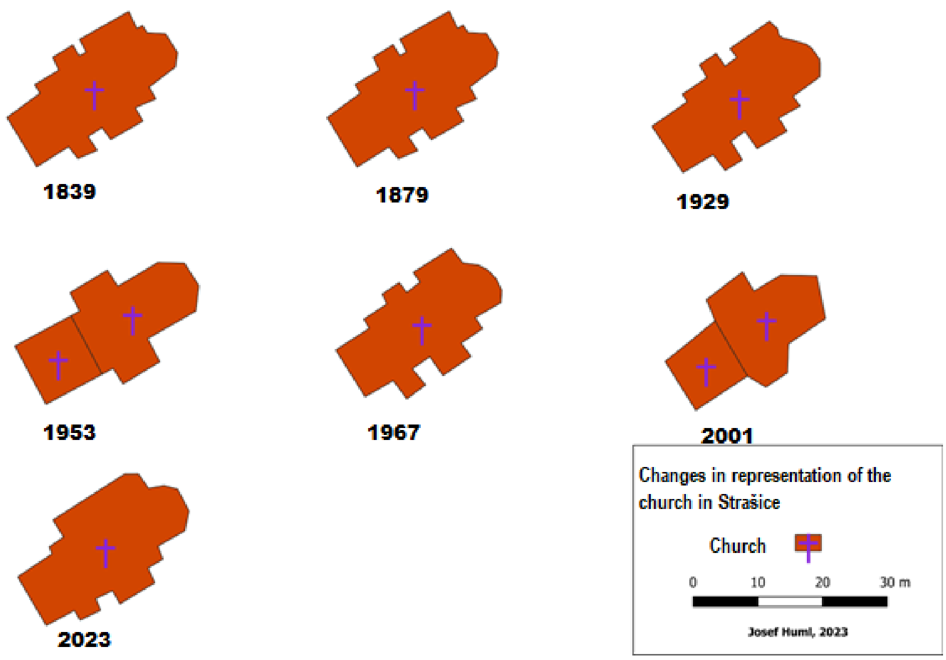

Figure 2 – Change of the geometry shape of the church in Strašice in seven datasets, source [5]

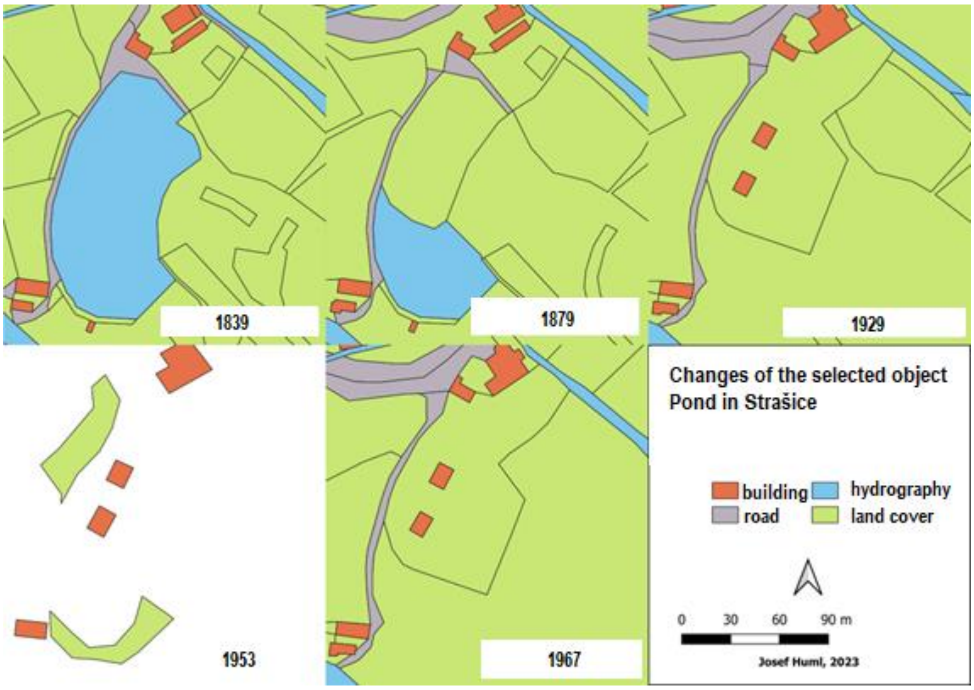

Figure 3 – Change of the pond in Strašice in five datasets, source [5]

DISCUSSION AND FUTURE WORK

The advantage of the STDB of Territory approach is that all datasets, regardless of whether they were initially stored in different structures and heterogeneous classifications, are harmonised and stored in uniform objects and a harmonised classification. The harmonised structure of objects and attributes allows further processing and analysis. Limitations of the STDB of Territory are mainly defined by the original datasets used as data sources, which will often be secondary data sources. The information on the origin of each feature is important for any evaluation of the precision of geometry and the accuracy of attributes. The comparability of attributes across different map series is limited to the least common multiple of shared values, which are defined by the detail of each map series. A similar issue is defined by the specification of the subject of evidence, which can vary for each type of map series. A typical example of this issue is the definition of a building and the definition of the subject of adjudication in different kinds of cadastral maps.

The future work regarding the development of the STDB of Territory will focus primarily on two aspects. The first aspect is the extension of the data model to detect individual real objects throughout integrated original datasets. This goal is illustrated in the third type of analysis called "monitoring the change of selected objects". The idea is to develop a set of detection functions to identify presumably similar objects (evolving real objects) represented by map subjects in original datasets. For instance, a house with the description of house number 10 was built before 1830, extended in 1890, and reconstructed in 1953. For example, a brook where regulation was built in 1953, and impoundment was constructed in 2001. The detection process based on spatial join and geometry similarity is already under development. The second aspect is integrating datasets of different scales, especially old and current medium-scale topographic maps or thematic spatial datasets focused on the landscape's environmental aspects, e.g., soil or geological maps and biotopes.

CONCLUSION

This study presents the idea and design of the Spatiotemporal database of the territory (STDB of Territory). The STDB of Territory is designed to integrate both primary and secondary spatial data sources, primarily medium- and large-scale maps. Utilising present datasets in combination with old maps brings the time dimension to the typical spatial database approach. Using medium- or large-scale datasets brings detailed information about the landscape in the territory of interest and information about changes during the time period covered by available datasets. A combination of different types of maps can extend the database content by the amount of available attributes for each object. However, the challenge is to harmonise attributes and their values to be comparable because each historical mapping had different regulations and map keys. This study has presented examples of analyses testing the usability of the content of the STDB of Territory. However, analyses are currently limited to the layer-based approach, which we can compare among original datasets. Only manually selected objects can be compared individually. The user of the STDB of Territory should be aware that analyses are limited by the precision and accuracy of (1) original datasets as well as their content and subjects of survey, (2) georeferencing of map sheets and (3) vectorisation of content. The potential of the STDB of Territory lies predominantly in the field of landscape/territory development investigation and multidimensional visualisation of spatial data with additional thematic content.

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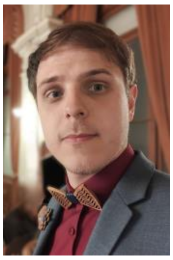
BIOGRAPHY

Michal Kepka is an academic staff member at the Department of Geomatics at the University of West Bohemia in Pilsen, Czechia. Michal’s research focuses on GIS, spatial databases, web technologies for GIS, and sensor data processing and publication. Michal has participated in several European and national research and technical projects.

Jiri Belinger is working as a researcher at the New Technologies for Information Society Centre and studying at the Department of Geomatics, Faculty of Applied Sciences, University of West Bohemia in Pilsen, Czechia. Jiri’s field of research includes geodesy and the application of GIS tools in analyses and visualisation. Jiri is currently involved in a project supported by the Czech Science Foundation.



Josef Huml is a graduate of the Department of Geomatics at the University of West Bohemia in Pilsen, Czechia. Josef is interested in geodesy, GIS, topographic mapping and the historical development of cadastre in Czechia. Josef is currently an employee of the State Administration of Land Surveying and Cadastre.

Martina Kepka Vichrova is an academic staff member at the Department of Geomatics at the University of West Bohemia in Pilsen, Czechia. Martina’s fields of expertise are geodesy, topography mapping, old maps analyses and cartography. Martina has participated in several European and national research projects and has coordinated a cross-border project focused on cultural heritage.