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Method for Cartographic Symbols Creation in Connection with Map Series Digitization

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Abstract: The article addresses the issue of the unification of cartographic symbols in terms of graphics (visual) and interpretation in an international context. The motivation is the ongoing digitization of processes in the conditions of Industry 4.0, especially Construction 4.0, where geodesy and cartography have their irreplaceable share. The aim was both to design uniform cartographic symbols for the description of geographical objects on the map and to design a general method for the description of unified cartographic symbols so that it is independent of specific applications. The authors compared the symbols used in the map works of the Czech Republic and neighboring countries that are members of the EU and proposed a formal description of the graphics properties of the symbols, which is based on a general mathematical model. The description takes the form of a text string, and a Python algorithm was built to render the symbol and implemented in the QGIS environment. The article also presents a comparison of some cartographic symbols used in the Czech Republic and in selected EU countries and a proposal for their unification. The motivation is the effort to unify the cartographic language within the EU. The problem is in accordance with the INSPIRE directive (seamless map of Europe) at the international level and with the Digital Czechia 2018+ strategy at the national level.

Keywords: cartographic symbol; maps digitization; automated drawing of cartographic symbols; design of cartographic symbols; formal description of cartographic symbols

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1. Introduction

The present time is characteristic of extensive digitization in almost all fields of human activities. In the Czech Republic (CR) a strategy for coordinated and comprehensive digitization of the Czech Republic 2018+, in short, "Digital Czechia", was accepted. One of the sub-targets of this strategy is an item called GeoInfoStrategy. It is about the effective use of spatial information in the state administration and in the public interest. This category also includes the digitization of national map series and relevant cartographic products. World map products differ in their content, various coordinates, vertical systems, projections, and cartographic languages used. One of the many projects that have been in this area is the research and development of software for state map series generalization addressed in [1]. Within this project was the modification of the symbol key also solved, the aim of which were:

- Enrichment of the brand key with new elements or attributes from other databases,
- Unification of the brand key across all scales,
- Bringing the brand key closer to the form of other brand keys for better usability of the transmitted data,
- Brand key to an automated mapping process adapting and avoiding the need for manual adjustments (resizing or color).

Part of this project was the study of cartographic symbols, the possibility of unifying the set of symbols in an international context, and their use in digitized map products. Currently, the standardization of symbol sets for printed maps is not still satisfactorily resolved at national levels. In the case of map production using information technologies, the standardization is only reflected in metadata structure and used system formats. Currently used cartographic symbol sets are stored in different software (ArcGIS, MicroStation, etc.) in libraries that are not fully compatible among particular application software [2–5]. Methods for users to create new symbols or to modify existing symbols are not unified across the software. This situation limits the process of map product digitization across all platforms and their common use on a national and international scale. In connection with the massive advent of digitization, the solution to these problems is very urgent.

A considerable number of projects, works, and studies have been devoted to the issue of the digitization of maps. Projects at the European level include the European Interoperability Framework (EIF) [6], which aims:

- To promote and support the delivery of European public services by fostering cross-border and cross-sectoral interoperability;
- To guide public administrations in their work to provide European public services to businesses and citizens;
- To complement and tie together the various National Interoperability Frameworks (NIFs) at the European level. Interoperability of data, services, and technologies is enabled by international technical norms and standards (ISO, OGC, etc.). The initiators of these activities are the INSPIRE directive, Euro-Geographics, etc.

In the Czech Republic (CR), the issue of unification and creation of cartographic symbols is addressed in several follow-up projects with the support of the Technology Agency of the Czech Republic, for example [1].

The aim of this article is to propose a suitable methodology for the creation, formal description, unification, and automatic drawing of cartographic symbols in the digital map series.

The paper is organized as follows. In Section 2, we mention some related work concerning cartographic symbols. In Section 3, we describe problems regarding cartographic symbol creation and propose the method of a possible solution. Section 4 demonstrates the experiments. Section 5 contains a discussion of the given topic. Section 6 addresses the conclusions.

2. Related Works

The topics selected in this section are directly related to the goal defined in the previous chapter. The methods of formal description of cartographic symbols are described in [7–9]. The aim was to find out existing ways (methods) of finding common descriptions of cartographic symbols that are platform-independent (desktop, web application, etc.).

A proposal for a new cartographic language paradigm that would suit the map series of various states and thus make international collaboration in this field possible is presented in [7]. Authors do not propose the creation of individual cartographic symbols, but a cartographic language as a whole. They solve language style issues in various state map series, specific national conventions, and problems with cartographic symbol standardization. Authors propose a completely new cartographic language alphabet based on GIS templates that are more usable than conventional pixels or symbols. Templates of variable GIS icons support additional graphic elements including length/width/shape/angle/orientation. Numerals, alphabetical characters, and iconographic symbols can be used as variables. The benefit is the possibility of visualization of multidimensional data relationships. Problems with the proportional size of cartographic symbols are solved in the work [8] by programming language R. This method is general and allows for both mathematical and perceptual scaling in the process of displaying the symbols. There is no solution for the complex description of cartographic symbols graphics including attributes (color, thickness, line type, etc. The article [9] deals with linear cartographic language creation in the programming language C++. The creation of linear cartographic language creation in the programming language C++ is a topic in [9]. The algorithm concept primarily presents symbol visualization on digital maps with respect to cartographic rules and valid standards. The formal symbol description is very similar (including rendering) at the expense of complexity and generality.

The design of cartographic symbols including special symbols (user symbols) with regard to currently used symbols in EU states and their compatibility with applications for map production (GIS SW) is shown in [3,5,10–15].

Methods of cartographic symbol creation in a GIS environment (ArcGIS) and on the website (Web Map Services) are discussed in paper [3]. Cartographic symbols were created in the application CorelDraw and imported into the ArcGIS library via Font editor. National and international standards were respected during symbol creation. The advantage of this concept is the possibility of using symbols in both GIS environments and web applications. The disadvantage is a partial dependence on specific platforms (CorelDraw, ArcGIS).

The use of random variable configurations and boundaries for the creation of cartographic symbols is a topic in [11]. These generating algorithms are limited by shape elements, cartographic standards, and many other conditions. The method is based on fractal geometry, namely the iterated function system (IFS). This method was implemented into a digital mapping system for practical use. The essence of symbol generation is inspiring, but the limited use of symbols with randomly planar patterns is a disadvantage. A cognitive geometry model for cartographic symbols realization is proposed in [12]. Its advantage is usability not only on two-dimensional maps but also on digital maps, maps animation, and cartography for blind users. Another advantage of this model is precise data source representation and an intuitive understanding of the phenomena that symbols represent on the map. However, the article does not indicate the methodology of symbol creation, their inclusion in applications, and binding to valid standards. The paper [5] describes cartographic symbol creation for geological maps. Symbols are defined with the aid of XML language and stored in the library. However, the library is dependent on the application and was specially developed for GIS Manifold®. Symbol definitions are simple and sufficiently common, so after some modifications, they can be used in other GIS programs. Special standardized cartographic symbols set for planetary mapping based on the American standards for geological exploration are presented in [13]. Symbol sets are implemented into the GIS system, namely ArcGIS. This is a contribution to space research presentation and subsequent interplanetary space mapping.

A new methodology for creating two-dimensional cartographic symbols and diagrams for application in thematic maps is described in [14].

The proposed method extends two construction theories of Bertin [10] and Wilkinson [15]. The benefit is improved visualization of statistical data on thematic maps.

Problems of map product digitization are the topic of [16–23]. The aim was to discover problems that result from a transfer of classic analog to digital form maps.

A method for creating map legends in a dynamic environment is introduced in [16]. These legends were developed for static media with respect to optimal map visualization. The main criteria for the design of legends are element selection, symbols layout and their position, representation dynamics, and other factors. Cartographic symbols appear here only as legend components without further context. A multi-level hierarchic spatial model is designed in work [17]. Objects with increasing detail are stored in levels and can be used in the composition of maps at some scale. The method can also be applied to a specific display of cartographic symbols on a definite map at some scale. The problem of symbol creation is not solved in this paper. Geologic maps are characterized by very extensive and complicated legends. A new flexible legend that offers a lot of diverse geomorphological information and possibilities of many information combinations is proposed by the authors of [18]. The result is a scientific data-rich map that is more informative than most maps used until now but is based on a simple legend. The developed system uses GIS applications as a base. Information based on geomorphological map symbols can be stored digitally and can be used as an efficient database with thematic levels and attribute tables. The advantage of this method is the simplification of the legend, but this does not address the concept of cartographic symbols creation in the legend. Graphics, numbers, and optimal distribution of buttons with inserted functions in applications for mobile mapping and maps presented in a web environment are described in [19]. The problem of symbols creation and standardization is not solved in this work. With the integration of cartographic symbols that come from different sources into united map output deals [20]. The research results were primarily for mobile devices for LBS (Location Based Services) and intended to accept spatial data from various providers. The conception is based on ontology and has general utilization. The article does not resolve the symbol creation issue, only their selection in a common map. Several selection rules ensure the avoidance of symbol duplication. A hierarchical classification system for thematic cartography is proposed in paper [21]. The system was applied to atlases in the Czech Republic and the Slovak Republic from 1935 until now. The contribution of the work is a method for the time series analysis of cartographic products and their subsequent classification in terms of topics and logic. The article [22] proposes the method for the automatic selection of point height positions that represent natural features as peaks, saddles, or depressions. The algorithm and data structure are designed for a continuous scale. The contribution is a result comparable with manually created reference compilations. This research does not solve the cartographic symbol creation issue but introduces an interesting method for other use of these symbols. The algorithm for automatic contour line generation according to cartographic lines is proposed in the article [23]. This algorithm deals with supplementary contours selection and automated methods for their placement on topographic maps. Results of this method are similar to manually placed supplementary contours. The method is suitable for digital terrain model creation and is a rewarding contribution to map digitization.

Methods for automated visualization of cartographic symbols are the topic of several works [4,24–28]. This part deals with symbol selection from a suitable database, their positioning and plotting in a map face using automated tools. A method for the visualization of proportional cartographic symbols on a map is presented in [24]. The algorithm is based on a decomposition of an original symbol to components and their hierarchical synthesis and contains tools for display optimization. With respect to the concept, this approach is similar to ours. The study [4] presents possibilities of cartographic symbols' dynamic visualization on digital static maps. The proposed methods were based on a series of visual tests, parameters of dynamic symbols visualization (intensity and frequency of blink, size, etc.), and their optimization in relation to the current scale was evaluated. The publication [25] presents a proposal of a method for the improvement of visualization of cartographic symbols stored in the GIS applications library. The symbols' proposal is based on the aliasing repression and solves mutual relations between particular symbols. The proposed method is also inspirational for the topic solved in this article. An effective method for linear cartographic symbols depiction in 3D is described in the paper [26]. It is about an acceleration algorithm for GPU (Graphics Processing Unit). Due to this, symbol depiction can be in almost real-time executed. The authors of [27] deal with perceptional aspects of graphic variables (namely shape and size), the problem of chosen and map background during cartographic visualization. The benefit of this study is understanding map users' reactions to various cartographic symbols in different cultural conditions. These experiments were accomplished in the Czech Republic and China. The proposal and implementation of variable POI (Points Of Interest) symbol models is the topic of [28]. The benefit is improved symbol visualization on digital maps in a web environment based on principles of cognitive psychology.

It is clear from relevant literature that problems of creation, formal description and visualization on digital map products are solved from many perspectives and in various contexts. All the presented methods are inspiring, and include original ideas, but none of them solve this problem comprehensively. Cartographic symbols creation is application-dependent in many cases. The methods proposed for the description of cartographic symbols are, in many cases, based on Cascading Style Sheets for Maps—CartoCSS [29] or OGC (Open GeoSpatial Consortium) Symbology Encoding [30]. The advantage of these tools is their versatility and flexibility, the disadvantage is the relative complexity of the description and the need to know the syntax of these languages, which requires good knowledge of information technology. The method proposed in this article tries to remove the previously mentioned problems.

3. Materials and Methods

The aim, described in Section 1 (to propose a suitable methodology for the creation, formal description, unification, and automatic drawing of cartographic symbols in the digital map series) was delivered in two parts:

1. Analysis of cartographic symbols in map series in CR and related EU states in order to design a uniform symbol set.
2. Proposal of a suitable method for the description of cartographic symbols.

3.1. Analysis of Cartographic Symbols in Map Series in CR and Selected EU States in Order to Design a Uniform Symbol Set

This topic was in [31] and [32], basic results are presented in Section 4.1. Project [1] was solved under the cooperation of the Czech Office for Surveying, Mapping and Cadaster and Institute of Geodesy, Faculty of Civil Engineering, Brno University of Technology (both Czech Republic).

Given the significant historical development of the features used in the national map series of the EU, it would not be right to reject these features and design completely new ones. On the contrary, it is more advantageous to support this development and thus use these symbols for the new uniform symbol set. The biggest advantages lie in the experienced features of both map users and makers, but also in the fact that they are tested for use in practice. As the features in each country have evolved, it can be assumed and even desirable that the newly created single set will undergo evolution with the necessary changes and adjustments.

However, it is not possible to take a set of symbols from one country and declare it the best that should be used throughout the European Union. A single symbol set should be created by comparing and evaluating matching symbols. Considerations on a uniform symbol set should thus begin with the selection of countries whose symbol sets will form the so-called basic symbol selection group. The used selective method with predetermined conditions thus determines the symbol sets that will enter the analytical part of the work. Reducing the number of countries for comparison will make the comparison analysis more efficient.

One of the main selection criteria should be the number of people who are already related to the field. Because the more inhabitants the state has, the more users are already used to its state symbol set. If the symbol sets of the most populous countries are combined, fewer users will have to learn new symbols. This condition mainly concerns users, but we must not forget the map creator either. It can be assumed that the larger the area, the more people must participate in the creation of the state map. These two considerations combine the criterion of population and area of states to select a basic group for comparing features. At the same time, the selected countries should represent the majority of the European Union in both area and population.

The number of states was reduced during the project processing on the basis of cooperation with the Embassy and it needs further reduction. In the end, the work is primarily aimed at the countries of Central Europe, that is, the Czech Republic and neighboring countries.

Next, comparisons and detailed analysis of the graphical variables of the corresponding features helped to reveal the trends of contemporary national cartographic languages and their similarity or, conversely, diversity. The manual visual comparison of graphic variables was performed by the research team and subsequently evaluated by the authors in a quantitative and qualitative comparison.

A similar comparison was made due to the history of the symbols used on the maps of Czech state map works in order to reveal the trends in the development of cartographic language in CR. This analysis was also performed by the visual comparison of graphical variables and resulted in quantitative and qualitative outputs.

3.1.1. The Process of Accepting New Symbols

The design of the new features then took place on the basis of a discussion among experts from the cartographic section of the Embassy, their experience with problematic situations in cartographic interpretation and, last but not least, with the inclusion of comments from users of state map productions. These proposals had to go through several trial publications with departmental and interdepartmental comments. All cartographic activities are subject to the Surveying Act, which, after approval by the Parliament of the Czech Republic on 30 September 1994, entered into force on January 1st 1995.

Only then were they admitted to the press for public distribution. All symbols were drawn in ArcGIS and used for the automatic creation of state map series. The symbols are at the same time supplemented with detailed specifications and published in a comprehensive symbol key.

3.1.2. Factors Influencing the Comparison of Symbols

The biggest obstacle for comparing symbols is the translation of their meanings because one word in a foreign language can have several Czech equivalents and vice versa. The differences between the names of the symbols are difficult to distinguish, especially when it comes to specialized objects, such as electrical or mining elements. The use of multilingual regulations and a terminological dictionary partially addresses this issue [33]. Another significant complication is the absence of dimensions. This makes it impossible to compare the symbols in detail and draw other conclusions, such as the importance of the phenomenon, etc. The comparison is thus limited to the appearance of the symbols. The biggest problem is the different ways and details of the division of elements and their hierarchical division.

3.2. Method for Description of Cartographic Symbols

Afterward, we can formulate basic requirements for the method for cartographic symbols creation:

There is a possibility to generate own symbols besides established standards, for example, for thematic maps.

- Depiction for any scales (proportional change of symbol geometric proportions).
- Possibility to modify symbols according to requirements.
- Possibility to combine symbols.
- Application independence.
- Optimization of symbols location to map face in case of possible symbols overlap.

Proposed solution concept**.**

The authors chose the following working procedure for automated cartographic symbols generation:

- Creation of a mathematical model of cartographic symbols based on graphic variables.
- Proposal of a formal language for graphics description (syntax).

- Choice of a scripting language to symbols depictions for variable scale maps.
- Proposal of an algorithm and the realization of the process in a suitable application (e.g., ArcGIS, QGIS).

The proposed method is shown in Figure 1.

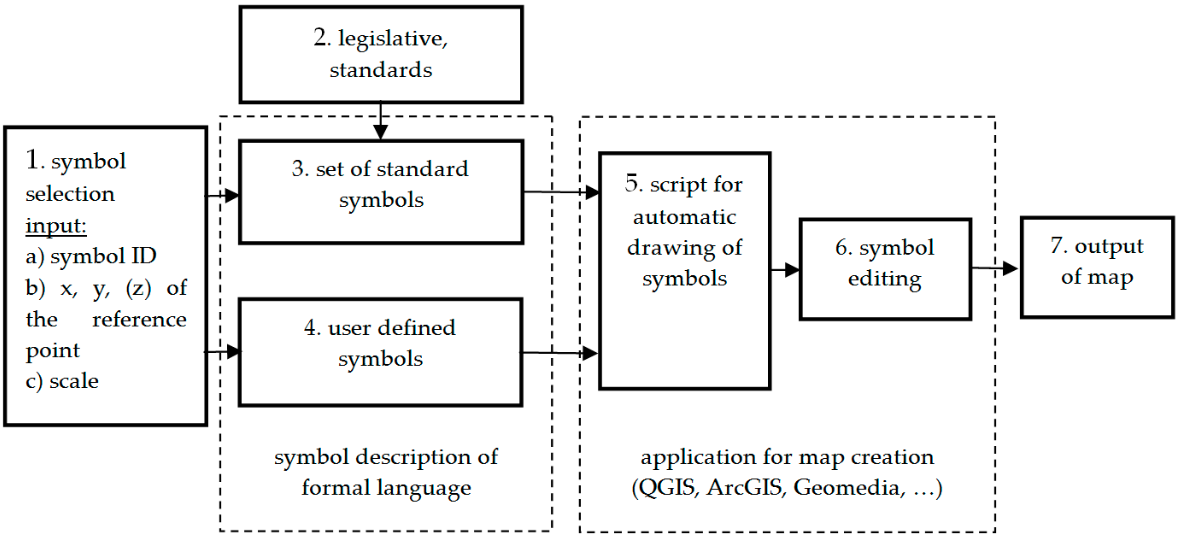


Figure 1. Concept of automated creation and usage of cartographic symbols.

3.2.1. Mathematical Model

Authors Pravda [34] and Bertin [10] mention these basic graphic variables of a symbol:

Shape—given by symbol contour line.

Size—represents the quantitative value of phenomenon and this quantity is proportional to symbol size.

Filling or texture—using colors or raster to express phenomenon quality, quantity can be expressed by different intensities of color or raster.

Orientation—is important if symbols express some phenomenon's position in relation to coordinate grid (or another object) or phenomenon development along some route.

Color—characteristics used are hue, saturation, and brightness [35].

Hojovec [36] and Voženílek [37] extend these graphic variables by two more:

Structure—internal graphic segmentation of symbol. It can express quantitative relations among components that form the whole phenomenon. The structure can have only esthetic sense.

Position (georeferencing)—symbol location on the map using coordinates.

Digital forms of cartography provide another means of expression, such as movement, blinking, or color change, etc. Problems of these variables are not explored in this work.

On basis of the above-mentioned variables, cartographic symbol $s \in S$ is given by depiction of f

$$f: P \times G \times M \times O \to S, \text{ e.g.,: } s = f(p, g, m, o) \quad (1)$$

where

S is collection of cartographic symbols. The collection means that symbols may repeat in the set. This enables the creation of composed (also hierarchical) cartographic symbols and their repeated use, for example, basic symbol pattern placing on a linear element.

P is the set of symbol fixed points in a map space with coordinates *x*, *y*, *(z)*, *G* is a set of geometrical and descriptive elements with attributes of which a symbol is composed (symbol graphical variables); the set is influenced by standardization and valid legislation. They can be standard or created for a given purpose. They depend on a geographical object $o \in O$ that is represented by the given symbol.

M is map scale—it also influences symbol representation on a map. It influences the size of the symbol that is to be displayed.

O is the set of geographic objects on a map, which are represented by the symbol (symbol semantics).

When designing symbols, taking existing symbol forms in the CR and the EU into consideration is necessary. It is also important to select suitable representative symbols that would be appropriate in a wider context of use. This is a method of compromise between the modern approach to digitalization and the symbol forms used so far within the European and world cartographic communities.

3.2.2. Proposal of a Formal Language for Symbol Graphic Description (Syntax)

The language for a cartographic symbol description was proposed on the basis of graphical variables and Equation (1)—see the previous subchapter. The basic idea was a description of graphic variables set by simple elements (primitives), from which it would be possible to create more complex elements using composition (e.g., a circle replaced by a sequence of line segments).

The basic attributes of the symbols were classified within the information analysis in the previous subchapter. Symbolic equivalents that serve as commands for drawing were assigned to these attributes :

1. Global symbol parameters (valid for the whole map sheet or slice):
   - symbol **ID**,
   - **x, y, (z),** coordinates of symbol fixed point,
   - **M**—map scale-value **M** = 0 means that the symbol will not be drawing in a given scale.
2. Local symbol parameters:
   a) Commands for geometric elements drawing (drawing of points, lines, arcs, circles, or polygons. Coordinates relative in relation with symbol fixed point).
   - **L** = line x_1, y_1, x_2, y_2
   - **A** = arc—add parameters
   - **R** = ring x_s, y_s, r (circle with center and radius)
   - **P** = polygon x_i, y_i (vertexes on polygon boundary)

   b) Commands for geometry design—color, type, and weight of the line (drawing attributes).
   - **C** = color <color ID> (color code, same as filling color code)
   - **F** = color <color ID for filling>—last defined entity (circle or polygon) will be filled with given color. Colors (C, F) will be from color table chosen. F = N means without filling
   - **Y** = type <type line number>
   - **W** = weight <weight line number>
   - **T** = text <font number>—other attributes (C, Y, W) will be adopted from geometry definition
   - **H** = hypertext—link to another object (file) in case of dynamic visualization (animation) or symbol with multimedia components.
   - Separators of commands are semicolons ';' (alternative TAB or space).
   - Decimal points will be represented by dots '.'.

The previously mentioned formal language of symbols description will be saved in a text file in this format:

(line structure for 1 cartographic symbol):

<ID, commands sequence, EOL (End of Line)>.

Symbols are currently saved in application libraries in graphic formats (raster or vector). The disadvantage is a necessity for the symbol transformation for a given scale while putting symbols into the map sheet. The transformation works automatically in this method.

For the proposed method, a special algorithm for drawing cartographic symbols was developed. The input of the algorithm were global data (symbol ID, coordinates of the reference point x_0, y_0, scale M) and a text file containing a formal description of cartographic symbols. The flowchart of the algorithm is in Figure 2.

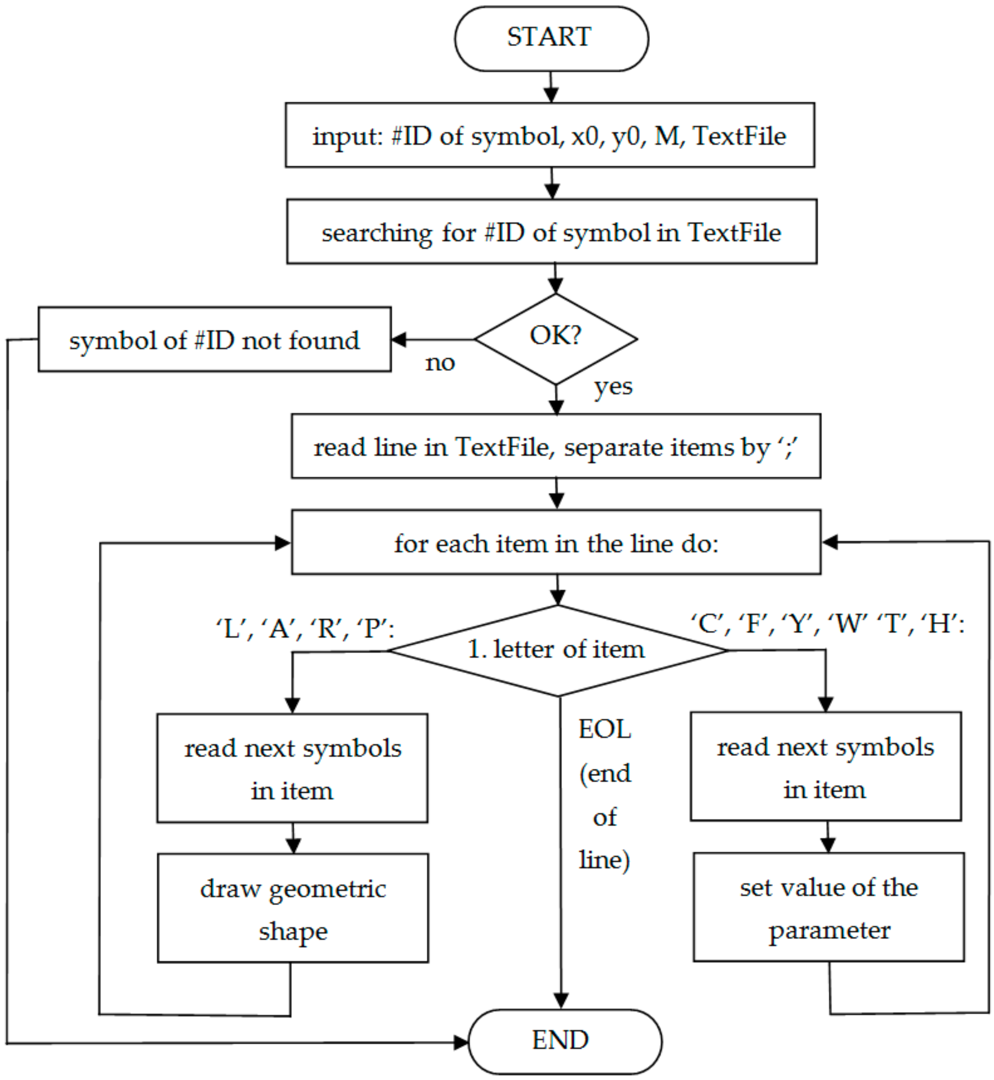


Figure 2. Algorithm for drawing cartographic symbols.

4. Experimental Results

The verification of the proposed methodology consisted of three phases:

1. Processing of analysis of used cartographic symbols in map works of neighboring states with relation to the Czech Republic and the EU.
2. Design of new cartographic symbols.
3. Design and implementation of an algorithm for drawing the cartographic symbols based on the formal description.

4.1. Analysis of Used Cartographic Symbols in Map Works of Neighboring States with Relation to the Czech Republic and the EU

This part is a proposal for new symbols that would unify the cartographic language in the Czech Republic with neighboring states or with EU countries. This issue was addressed in a project supervised by the Surveying and Mapping Authority of the Czech Republic.

In this part, only the essential results of research related to the topic of the article are presented. The study compared the cartographic symbols of these selected countries: the Czech Republic (CZE), the Federal Republic of Germany (DEU), the Polish Republic (POL), the Republic of Austria (AUT), and the Slovak Republic (SVK). The symbols were compared in the scale series of 1:10,000, 1:25,000, 1:50,000, 1:100,000, and 1:200,000. From the Czech Republic, the comparison symbols for civil-based maps (BM) and for military topographic maps (MTM) were included. An overview of the available scales in each is given in Table 1. The character "X" means that a map in the given scale is missing.

Table 1. Overview of scale series included in comparison tables.

CZE—BM	CZE—MTM	AUT	DEU	POL	SVK
1:10,000	X	X	1:10,000	1:10,000	1:10,000
1:25,000	1:25,000	1:25,000	1:25,000	1:25,000	1:25,000
1:50,000	1:50,000	1:50,000	1: 50,000	1:50,000	1: 50,000
1:100,000	1:100,000	X	1:100,000	1:100,000	1:100,000
1:200,000	1:250,000	1:250,000	1:250,000	X	1:250,000

A comparison of the features of map works in the selected countries was performed by analyzing the map works on a scale of 1:50,000. Map works in all selected countries are published on this scale. The comparison was made from two points of view:

1. Quantitative, where the number of identical symbols was determined absolutely—see Table 2 and relatively—see Table 3. Table 2 shows how many identical symbols the individual combinations of the six states have (character "X" means coincidence), Table 3 shows the number of identical symbols found when comparing all pairs of selected states. The most important symbols are the symbols that are the same in all countries (Table 2), these can be used without major changes. However, even symbols identical in a smaller number of states are usable for the resulting set of symbols. It is from them that the characteristics of the new symbols can be derived, which are then easier for a larger number of users to accept. The second comparison (Table 3) evaluates the consistency only between individual pairs of states, regardless of the others. The number in the cell means, how many symbols are in the pair of countries identical or similar. Table 4 shows the colors for road symbols on maps in selected countries and on different scales. The character "X" means, that roads on a map of the given scale are missing. Detailed analysis results are available in [32].

Table 2. Comparison maps of selected countries (scale 1:50,000).

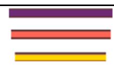
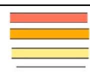
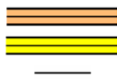
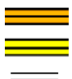
Number of Countries	Number of Identical Symbols	CZE—BM	CZE—MTM	AUT	DEU	POL	SVK
6 countries	13	X	X	X	X	X	X
	13	X	X	X	X	X	
5	4	X	X		X	X	X
countries	1	X	X	X	X		X

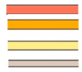
4 countries	10		X	X	X	X	
	9	X	X	X		X	X
	7	X	X	X	X		
	3	X	X		X	X	
	3	X	X	X			X
	3	X		X	X	X	
	3	X			X	X	X
3 country	18	X	X	X			
	7		X		X	X	
	5	X			X	X	
	5		X	X		X	
	4	X				X	X
	4		X	X	X		
	3	X	X			X	
	2			X	X	X	
	1	X		X	X		
	1				X	X	X
2 country	76		X		X		
	37	X			X		
	15		X		X		
	13		X			X	
	11	X		X			
	8				X	X	
	7			X	X		
	5			X		X	
	4	X				X	
	4	X					X
	3	X	X				
	2				X		X
	1					X	X

Table 3. Comparison of pair of map series, scale 1:50,000.

	CZE—MTM	DEU	POL	AUT	SVK
CZE—BM	77	90	64	79	32
CZE—MTM		77	80	159	21
BAV			72	61	24
POL				60	26
AUT					17

Table 4. Demonstration of the colors of the road network—all scales.

	CZE—BM	CZE—MTM	AUT	DEU	POL	SVK
1:10,000		X	X			
1:25,000						
1:50,000						

1:100,000			X			
1:200,000 (1:250,000)					X	

2. Qualitative, where the features were compared in terms of graphic variables (shape, color, types of lines) or uniqueness. Different symbol shapes for the same object (gas station, hospital, and greenhouse) in individual countries and map series are in Table 5. Table 6 shows symbols that only appear on several maps (cadastral boundary—CR BM, weather station—CR MTM, underground metro station—CR MTM, product pipeline pumping station—CR MTM, stop station—AUT, and well—AUT). In these cases, the unification of symbols was proposed.

Table 5. Different shapes of symbols—scale 1:50,000 [38–42].

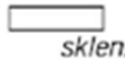
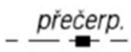
Gas Station		Hospital		Green House			
CR-MTM	POL	DEU	AUT	CR-ZM	CR-MTM	BAV	POL
							

Table 6. Objects displayed on only one map part—scale 1:50,000, [39,40,43].

Cadastral Boundary	Weather Station	Underground Metro Section	Product Pipeline Pumping Station	Stop Station	Well
CR—BM	CR—MTM	CR—MTM	CR—MTM	AUT	AUT
					

4.2. Design of New Cartographic Symbols

The Czech Office for Surveying and Cadaster approached the revision and creation of a new symbol key, primarily in order to unify the symbols across all the standards published in its diction. At the same time, it was decided to bring the symbols closer to the form of their respective equivalents on the maps of neighboring states. The technologies used for the creation and printing of map works, especially their possibilities and limits, also play an important role in designing new features. By adapting the symbols to these processes, more manual adjustments can be avoided and automated creation can be supported. With the use of suitable digital means, the drawing can also be refined, smaller symbol sizes and thinner lines can be used, thus preventing multiple elements from overlapping.

One of the technical limits that need to be set and harmonized at the same time are the values of graphical variables—see the mathematical model. Within the physiological capabilities of the human body, the minimum line thickness can be used. Based on many years of experience, a thickness of 0.13 mm was determined for ZTM5 and ZTM10, a thickness of 0.10 mm for ZTM25 and ZTM50, and 0.075 mm for ZTM100 and 0.10 mm for ZTM250.

In addition to unifying the geometry of the symbols, a uniform color palette and a table of the fonts used and comprehensive rules for their use at all scales are also needed. The color palette contains the names and visualizations of the colors themselves, their specifications using CMYK components, and usage examples. An example of a color chart is shown in the cut-out in Table 7, the whole is then part of the new symbol key.

The extensive analysis presented in [32] was followed by the design and construction of new cartographic symbols. Given the need to harmonize symbol interpretation on map products on a wide scale from 1:5000 to 1:250,000, it was necessary to make several compromise decisions and establish certain rules for their design at the beginning of symbol processing. It was the alignment of color and geometric shape and other parameters. A major problem was the unification of requirements for symbols and their form between scales of 1:5000 and 1:10,000. Collisions in needs occurred mainly due to the fully automated creation of ZTM5 and the amount of information and space on Base Map 1:5000 (BM5). In BM5, it is preferred to display objects using point symbols without description, while BM10 prefers symbols with accompanying descriptions. Especially for BM5, multiple symbols often overlap because the objects are close to each other (less than 5 m), hence, the so-called double symbols were created. Examples of double symbols for the same object and their classic equivalents are shown in Table 8.

Table 7. Color range of new symbols (zoom).

		C	M	Y	K	
Green		6	0	22	0	Filling areas of hop gardens, vineyards, orchards, parks, gardens, cemeteries, recreational buildings, open-air museum, ZOO
Yellow		0	0	85	0	Road filling II. and III. class
Light yellow		0	0	20	0	Permanent grassland–meadow, pasture
Purple		0	70	0	0	Administrative boundaries

Table 8. Examples of double symbols for the scale 1:5000.

Factory Chimney	Poppet-Head in Operating	Monument, Memorial, Headstone	Fountain, Spa Spring	Lonely Rock, Lonely Boulder	Group of Boulders
2,6 1,5	2,5 1,3	1,4 1,3	0,9 1,7	2,3 2,2	1,9 2,0

For several symbols, it was required to distinguish more types from an original model. The current symbol was mostly preserved while a new symbol has been added or modified for the newly recognized category. A typical example is a symbol for a church, which existed in the original BM only once. For the new state map series, a distinction was made between a church with a tower and without a tower, as well as the creation of a new symbol for the synagogue. Similarly, newly distinguishers between two types of fuel filling stations, in particular, LPG or CNG and others were created. Furthermore, instead of one symbol for the fortress and the bunker, the heavy object and the others were distinguished. An example of the symbols is shown in Table 9.

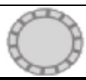
In terms of categorization, there were relatively large changes for area fillings and point symbols for vegetation and soil surface (garden, orchard, forest soil, etc.). At the same time, the colors across the scales were unified.

Table 9. Distinguish multiple types of the same object.

	Church			Fuel Station		Bunker, Blockhouse	
original symbol							
new symbol	with tower	without tower	syna-gogue	LPG or CNG	other	heavy object	other
							

New symbols were also created based on the requirement to eliminate existing descriptions. In the original CZE-BM, some symbols were identical for several objects and for clarification were supplemented by a description. Thanks to the newly designed specific symbols for particular elements, such descriptions are not required and thus the map becomes more transparent. These specific symbols were created, for example, for a cooling tower (formerly used building emblem with a description), for a cylindrical tank and reservoir (displayed on the BM using the emblem for a tower on a building, tower, or building with a description), for a museum and theater (displayed by a building cultural object), for a cooling tower (originally displayed as a building with a description). Some of the newly created symbols are shown in Table 10.

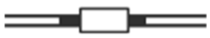
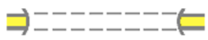
Table 10. Newly created symbols to eliminate the description.

Cooling Tower	Cylindrical Tank, Reservoir	Silo	Museum	Theatre
 				

There were also fundamental changes in the roads/railways category, especially for roads. The colors were changed and all contour lines were thinned. For registered roads, road numbers were added. The symbol for the bridge, which was newly designed, underwent a major change with several stages of creation. In the category of Railways, the color was changed to a darker gray. The original intention to implement symbols for trails and tracks from the military maps did not take place. The main reason was the frequent collision of the transverse lines of the symbol with other drawings, often requiring manual adjustments.

Other symbols from this category underwent similar modifications as in the Road category. Examples of some changed symbols from the roads/railways category can be seen in Table 11.

Table 11. Change of symbols in the roads and railways category.

	Railway Stop	Park or Ceme-teryPath	Tunnel of the I. Class Road	Tunnel of the II. Class Road
Original symbol				
New symbol				

Several completely new symbols had to be created. This mainly concerns the 1:5000 scale, but some information and features were also shifted to smaller scales. The newly distinguished elements include, for example, a rest area, a heliport, public administration offices, an underground reservoir, or a tribune—see Table 12.

Table 12. Symbols for newly distinguished elements.

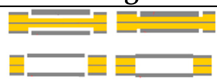
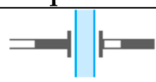
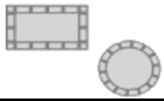
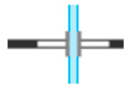
Heliport	Rest Area	Municipal Authority
		

The design of new symbols and changes of existing symbols has undergone gradual development. Often, innovative designs had to be abandoned in the end because the changes were not very favorable when tested on printed examples. Examples of the development of some symbols are shown in Table 13 (silo, cooling tower, bridge, and aqueduct).

The final list of symbols contains the symbols for all scales, including dimensions. Some dimensions are not listed for symbols that display objects in BM 1:5000 depending on the actual dimensions. Above all, these are the symbols of roads and watercourses, which are drawn according to the actual width. The complex catalog of symbols for basic topographic maps in the whole scale range can be found in [32].

According to the authors, the procedure presented in this section is one of the effective methods that suit the extensive digitization of map works and their harmonization from a transnational point of view.

Table 13. The development of new symbols.

	Silo	Cooling Tower	Bridge	Aqueduct
Working proposals				
Final proposals				

4.3. Implementation of an Algorithm for Drawing the Cartographic Symbols Based on Formal Description

The principle of the proposal formal language is clear from the example of the point symbol depiction (chapel) on a map and the relevant formal notation of drawing—see Figure 3.

Coordinate system: Datum of Uniform Trigonometric Cadastral Network (in Czech: SJTSK).

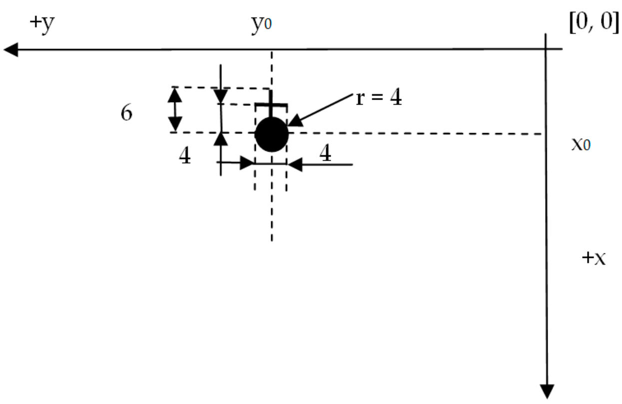


Figure 3. Example of point symbol depiction (chapel) from the formal description.

Formal notation

Global parameters:

Fixed point coordinates:

$x_0 = [x_{SJTSK}]$

$y_0 = [y_{SJTSK}]$
scale M = 100 (1:100)
ID = <chapel>
Symbol geometry description:
It is assumed that $x_0 = 0$ and $y_0 = 0$ (relative coordinates):
Line in Text File:
ID; F = 255; R0,0,2; C = black; Y = solid; W = 1.5; L0,0,−6,0; L−4,2,−4−2; <EOL>
Algorithm input parameters for symbols depiction:
ID, x_0, y_0, M.
The symbol representing the church in the environment QGIS is shown in Figure 4.

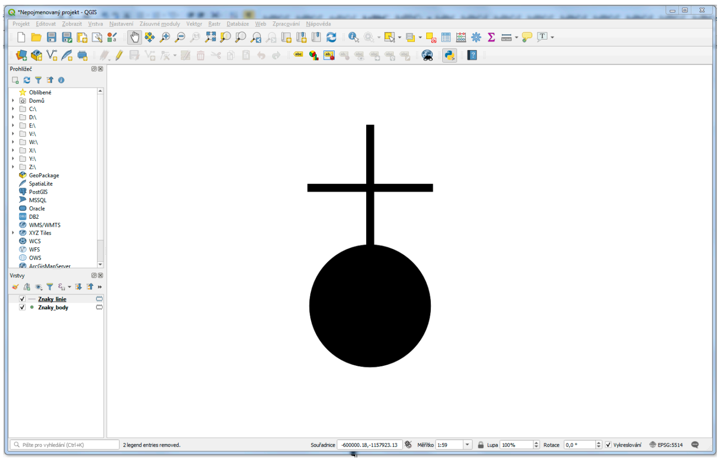


Figure 4. The symbol representing the chapel in the QGIS environment.

Another demonstration example of a linear symbol is shown in Figure 5. This symbol represents the difficulty of the route in maps of cycling paths [2]. This basic segment is repeated on the whole route.

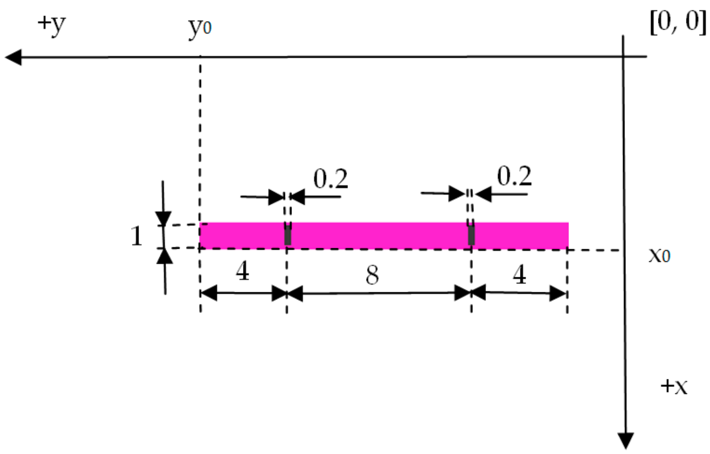


Figure 5. Example of linear symbol depiction (road) from the formal description.

Symbol geometry description:
It is assumed that $x_0 = 0$ a $y_0 = 0$ (relative coordinates), ID = <road with type of surface>
Line in Text File:
ID; F = violet; P0,0,−1,0,−1,−12,0,−12; F = black; P0,−4,−1,−4,−1,−4.2,0,−4.2;
P0,−12,−1,−12,−1,−12.2,0−12.2;<EOL>
The proposed method is able to describe also composed symbol. An example of an area symbol is shown in Figure 6, symbol geometry description is in the next text.

Symbol geometry description:

It is assumed that $x_0 = 0$ a $y_0 = 0$ (relative coordinates), ID = <area symbol: garden>

Line in Text File:

ID; F = green; P0,0,-8,0,-8,-12,0,-12; F = N; Y = solid; R−2.5,−3,1;R−5.5,−3,1;R−2.5,−9,1;R−5.5,−9,1;

F = black; R0,0,0.8;R−2,0,0.8; R−4,0,0.8; R−6,0,0.8; R−8,0,0.8; R−8,−2,0.8; R−8,−4,0.8; R−8,−6,0.8; R−8,−8,0.8; R−8.−10.8; R−8,−12,0.8;

R−12,−6,0.8; R−12,−4,0.8; R−12,−2,0.8; R−12,0,0.8;

R−10,0,0.8; R-8,0,0.8; R−6,0,0.8; R−4,0,0.8; R−2,0,0.8; <EOL>

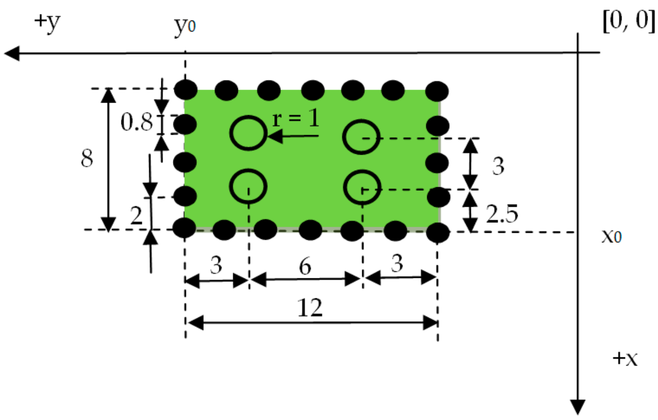


Figure 6. Example of area symbol depiction (garden) from the formal description.

A demonstration example of a special user-defined symbol is shown in Figure 7. This symbol represents a pub in purpose maps of cycling paths [2]—see Figure 8.

Symbol geometry description:

It is assumed that $x_0 = 0$ a $y_0 = 0$ (relative coordinates), ID = <area symbol: pub>

Line in Text File:

ID; F = blue; P-1,-1,-2,0,-12,0,-13,-1,-14,-2,-14,-12,-13,-13,-14,-12,-14,-2,-13,-1,-12,0,-2,0;

F = white; A-10,-2.5,12,-6,-10,-9.5; L-10,-2.5,-10,-9.5; P-2,-2,-9,-2,-9,-9-9,-2;

F = blue; P-3,-3,-8,-3,-8,-4,-3,-4; P-3,-5,-8,-5,-8,-6,-3,-6P-3,-7,-8,-7,-8,-8,-3,-8;

C = white; W = 1; L-8,-10,-8,13;A-8,-13,-6.5,-12.5,-4.5,-10; <EOL>

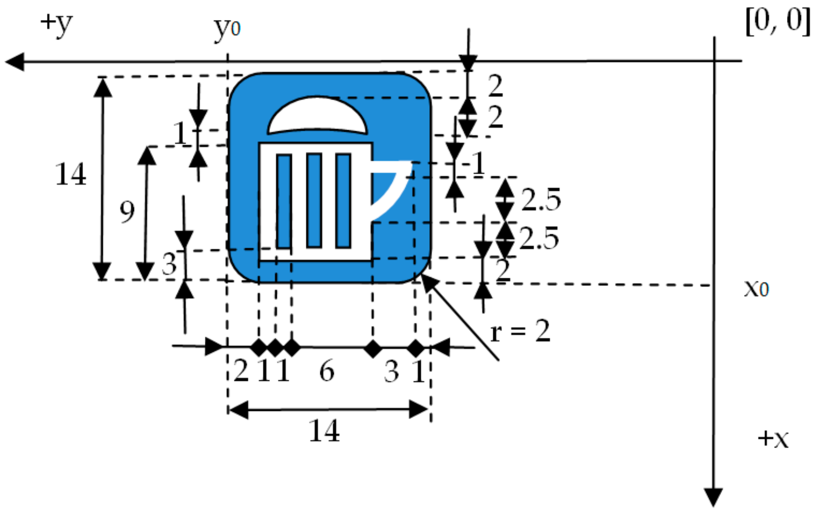


Figure 7. Example of user-defined symbol depiction (pub) from the formal description.

According to the symbol ID, the program searches for the appropriate line in the text file and performs parsing of the text. Commands for drawing a symbol (line points, polygons) are identified using separators (special characters). Within each command, the symbology of individual elements (color, strength and line type, etc.) is processed and written to the appropriate layer. Finally, optional operations such as merging layers, converting from vector to raster format, and the like are performed. The algorithm was debugged in the Python scripting language in the QGIS environment. Figure 4 shows a church symbol in QGIS. This emblem was designed as a common symbol for map works in the Czech Republic and neighboring countries [32]. The symbol description according to the methodology in chapter 3.3 is (the separator is a semicolon):

ID5; Fblack;R0,0,70; Cblack; Ysolid; W4.6; L0,0,−6,0; L−4,2,−4,−2; <EOL>

The algorithm is sufficiently universal and can be used in any CAD, GIS, etc. application.

The proposed method was verified when creating special maps for cycling. In this case, it was necessary to display the route map with additional information such as type of surface, difficulty of the road, type of road (1st, 2nd, or 3rd class road), etc. An example of these maps is shown in Figures 8 and 9. Maps for bike paths were also created for the web environment—the link is to [44].

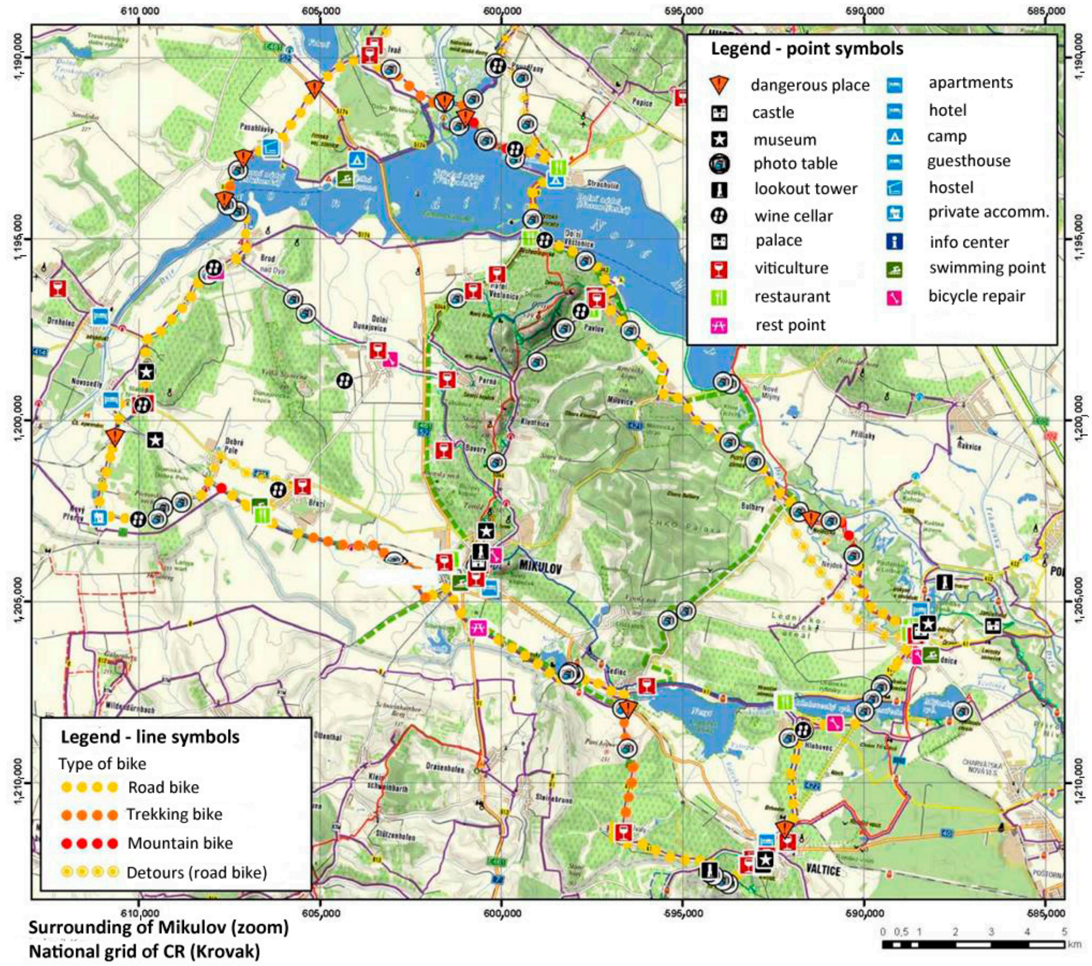


Figure 8. Point and line symbols in a special map for cycling paths.

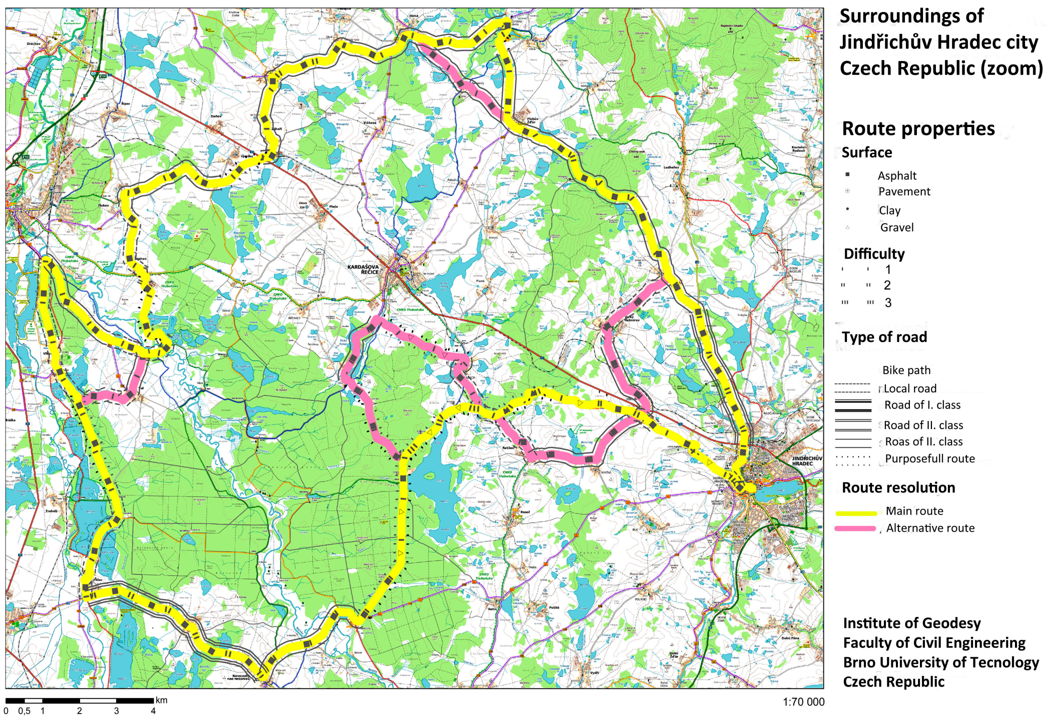


Figure 9. Combined line symbols in a special map for cycling paths.

It can be seen from the figures that the proposed description of the cartographic symbol is universal and allows the combination of all possible graphic elements within one symbol.

5. Discussion

The digitization of maps is not just about converting maps from analog to digital formats. It is mainly a unification of methods and processes in the creation, updating, and presentation of cartographic works.

Experience from practice confirms that digitization in the given field will be maximally effective, under the following conditions:

- All work procedures will be the same if possible.
- All processes will be as simple as possible.
- Data flows between subsystems will be in machine-readable format.
- Phenomena from legislation and standardization will be clearly implemented in the application software.
- The information infrastructure, that is., HW and SW, will be the same at all levels of organizational units.

In the field of cartographic works, the authors proposed to solve this problem on two levels:

- Analysis of the current state of map production in selected EU countries in order to unify the procedures for the creation, interpretation, and publication of map works at the national and international level.
- Unify the map key of the analyzed digital maps and design a method for the simple description of cartographic symbols.

Given the current solutions, the presented methodology is beneficial in the following points:

- Analyzes map works not only at the national but also at the international level.
- It seeks to unify the map key in an international context.

- Suggests a simple description of cartographic symbols, independent of application and national language.

The symbol description stored in the text file can be considered the simplest data structure that any user can create and interpret even without special information technology. In addition, each application has the means to process text files.

The paper contains examples of cartographic symbols and their description. These are just demonstration examples that prove that the proposed description is general enough to describe even complex features.

The methods published so far, which dealt with the design of symbols, were conceived mostly from a certain point of view without a broader context. For example, the method proposed in the article [3] is usable in a web environment but is application-dependent on ArcGIS and Corel Draw. The method of symbol creation described in the publication [5] is very general (description using XML), but also application-dependent. Another disadvantage is that the description of symbols using XML is extensive (of considerable size), complex, and confusing. The approach to symbol creation using fractal geometry proposed in another article has similar properties [11]. Other works focus more on cartographic language as a whole than on the creation of individual symbols. These are, for example, publications [7] where the benefit is a new paradigm of cartographic language, which would suit the map works of various states and thus enable international cooperation in this field. The authors [45] then propose a completely new alphabet of cartographic language based on templates. The benefit of the method is the possibility of visualizing the mutual relationship of multidimensional data.

One of the most important aspects of digitization is the unification of processes, procedures, and methods in a given field to the widest possible extent (region, state, …). To achieve this goal, it is necessary that all processes are simplified as much as possible and made understandable and easily accessible to all actors. These principles also apply to the digitization of cartographic symbols.

Currently, there is a growing need for digital maps for various and specific purposes. An example of this is, for example, a collection of maps for cycling, orienteering, etc. The authors encountered the issue of the requirement for special cartographic symbols in projects [46] (marking of areas on the map, where the optimal GNSS method is recommended) [47] (symbols representing selected properties for stakeholders) and [48] (creation of output maps for classification surfaces above underground gas pipelines). A similar problem was solved in the creation of maps for crisis management [49].

These maps use very specific map features for a given purpose. The advantage of the proposed solution is its simplicity, so the cartographic symbol can be described by the end-user, who is not an expert in the field of information technology. The proposed procedure can be considered as an alternative to the methods published so far. It is therefore a method that is accessible to the widest possible public using digital maps for its activities.

6. Conclusions and Future Work

This work is focused mainly on the possibility of converging cartographic symbol expression on state map works published in the Czech Republic and neighboring countries. The creation of a single symbol set is a very lengthy process involving several issued and tested sets, which can be gradually adapted to reflect the needs of the countries concerned. At the same time, it is necessary to use the experience from symbol sets that have already been published and used for several years. The gradual convergence of symbol sets between states depends primarily on the accessibility of individual state organizations. But given the involvement of countries in the European Union and in initiatives such as INSPIRE and EuroGeographics, interest in this development can be expected in at least some countries. Poland, Bavaria, and Spain, in particular, have already shown interest in this cooperation.

It is relatively clear from the results of the comparison of the symbols used in the countries concerned that creating a complete universal set of symbols for all countries would be a very demanding and probably time-consuming process. These are mainly categories of borders and communications, where each state applies a different division, hierarchy, and definition of individual elements. This cannot simply be unified, as administrative divisions are usually deeply rooted in the historical development of the state itself. Unification or at least approximation in this category would require longer negotiations and the involvement of relevant state organizations. In other categories, it would be possible, in agreement with the competent authorities of the individual states, to adjust the displayed objects and the detail of their differentiation and at least partially unify them. In these areas, even within the development of symbols in individual countries, there are often changes, as follows from the analysis of the development of symbol sets used historically in the Czech Republic.

The cartographic symbol key, which was created in this work in cooperation with the Czech Office for Surveying and Cadaster and Military Geographical and Hydrometeorological Office CZ, has so far been developed primarily for the needs of the Czech state map work. However, it is important that it was created precisely and with detailed additional information describing all the graphic variables of the symbols. At the beginning of 2020, trial production of ZTM5, ZTM10, and ZTM25 began, and further also ZTM50 and ZTM100. These pilot map sheets will gradually check the proposed features.

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References

1. Výzkum a Vývoj Programového Aparátu Pro Generalizaci Státního Mapového Díla. (Research and Development of Software for State Map Series Generalization). Applicant: Czech Office of Surveying and Cadaster with the Support of Technology Agency of the Czech Republic, 2018. (https://www.tacr.cz/dokums_raw/beta2/projekt_TACR_Beta2_v1.pdf Accessed on 25 January 2022).
2. Bartoněk, D.; Ježek, J.; Vacková, E. Design of the line symbols on the map of cycling paths by gis support. *Adv. Sci. Lett.* **2015**, *21*, 3515–3520.
3. Borisov, M.; Trifkovic, M.; Nestorovic, Z.; Marinkovic, G.; Pejicic, G. Creating the digital key of topographic-cartographic symbols in ArcGIS and web map server environments. *Tech. Technol. Educ. Manag.-TTEM* **2012**, *7*, 1575–1579. ISSN 1840-1503. https://www.researchgate.net/publication/291927178_Creating_the_digital_key_of_topographic-cartographic_symbols_in_arcGIS_and_web_map_server_environments Accessed on 25 January 2022).
4. Lai, P.-C.; Gar-On Yeh, A. Assessing the Effectiveness of Dynamic Symbols in Cartographic Communication. *Cartogr. J.* **2004**, *41*, 229–244. ISSN 1743-2774. https://doi.org/10.1179/000870404X13300.
5. Mihalynuk, M.G.; Mallory, S.M.S.; Grant, B. Geological symbol set for Manifolds Geographic Information System. *Comput. Geosci.* **2006**, *32*, 1228–1233. ISSN 0098-3004. https://doi.org/10.1016/j.cageo.2006.10.002.
6. ELF-The European Location Framework Project–One Source for Reference Geo-Information for Europe, 2013. (www.elfproject.eu Accessed on 25 January 2022).
7. Kent, A.J.; Vujakovic, P. Cartographic Language: Towards a New Paradigm for Understanding Stylistic Diversity in Topographic Maps. *Cartogr. J.* **2011**, *48*, 21–40. ISSN 0008-7041. https://doi.org/10.1179/1743277411Y.0000000004.

8. Tanimura, S.; Kuroiwa, C.; Mizota, T. Proportional Symbol Mapping in R. *J. Stat. Softw.* **2006**, *15*, 1–7. ISSN 1548-7660. (https://www.researchgate.net/publication/26469358_Proportional_Symbol_Mapping_in_R Accessed on 25 January 2022).
9. Yue, S.; Yang, J.; Chen, M.; Lu, G.; Zhu, A.-X.; Wen, Y. A function-based linear map symbol building and rendering method using shader language. *Int. J. Geogr. Inf. Sci.* **2016**, *30*, 143–167. ISSN 1326-3087. https://doi.org/10.1080/13658816.2015.1077964.
10. Bertin, J. *Semiology of Graphics: Diagrams Networks Maps*; University of Wisconsin: Madison, WI, USA; 1983; p. 415. ISBN 0299090604.
11. Chen, Q.; Liu, G.; Ma, X.; Li, X.; He, Z. Fractal generator for efficient production of random planar patterns and symbols in digital mapping. *Comput. Geosci.* **2017**, *105*, 91–102. ISSN 0098-3004. https://doi.org/10.1016/j.cageo.2017.04.009.
12. Comenetz, J. Cognitive Geometry for Cartography. *Cartogr. J.* **2002**, *39*, 65–75. ISSN 1743-2774. https://doi.org/10.1179/caj.2002.39.1.65.
13. Nass, A.; van Gasselt, S.; Jaumann, R.; Asche, H. Implementation of cartographic symbols for planetary mapping in geographic information systems. *Planet. Space Sci.* **2011**, *59*, 1255–1264. ISSN 0032-0633. https://doi.org/10.1016/j.pss.2010.08.022.
14. Schnabel, O.; Hurni, L. Primitive-based Construction Theory for Diagrams in Thematic Maps. *Cartogr. J.* **2009**, *46*, 136–145. ISSN 1743-2774. https://doi.org/10.1179/000870409X459851.
15. Wilkinson, L. *The Grammar of Graphics*; Springer: New York, NY, USA, 1999.
16. Dykes, J.; Wood, J.; Slingsby, A. Rethinking Map Legends with Visualization. *IEEE Trans. Vis. Comput. Graph.* **2010**, *16*, 890–899. ISSN 1941-0506. https://doi.org/10.1109/TVCG.2010.191.
17. Frank, A.U.; Timpf, S. Multiple representations for cartographic objects in a multiscale tree-an intelligent graphical zoom. *Comput. Graph.* **1994**, *18*, 823–829. ISSN 0097-8493. (https://www.researchgate.net/publication/223762201_Multiple_representations_for_cartographic_objects_in_a_multi-scale_tree-An_intelligent_graphical_zoom Accessed on 25 January 2022).
18. Gustavsson, M.; Kolstrup, E.; Seijmonsbergen, A.C. A new symbol-and-gis based detailed geomorphological mapping system: Renewal of a scientific discipline for understanding Landscape development. *Geomorphology* **2006**, *77*, 90–111. ISSN 0169-555X. (https://apps.webofknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=31&SID=D3QdFBtcg1xe9BXeXga&page=1&doc=1 Accessed on 25 January 2022).
19. Horbinski, T.; Cybulski, P.; Medynska-Gulij, B. Graphic Design and Button Placement for Mobile Map Applications. *Cartogr. J.* **2020**, *57*, 196–208. ISSN 1743-2774. https://doi.org/10.1080/00087041.2019.1631008.
20. Karam, R.; Favetta, F.; Kilany, R.; Laurini, R. Cartographic integration on mobile devices from several providers' LBS by means of map symbol ontology. In Proceedings of the WEBMGS 2010 1st International Workshop on Pervasive Web Mapping, Geoprocessing and Services, Como, Italy, 27 August 2010; pp. 38–44 (https://www.isprs.org/PROCEEDINGS/XXXVIII/4-W13/ID_30.pdf Accessed on 25 January 2022).
21. Miklin, J.; Dušek, R. Proposal for the hierarchical classification of thematic cartography methods and its application to evaluation of Czech and Slovak national atlases. *Inf. Vis.* **2019**, *18*, 211–229. ISSN 1473-8724. https://doi.org/10.1177/1473871618754344.
22. Rocca, L.; Jenny, B.; PUPPO, E. A continuous scale-space method for the automated placement of spot heights on maps. *Comput. Geosci.* **2017**, *109*, 216–227. ISSN 1873-7803. https://doi.org/10.1016/j.cageo.2017.09.003.
23. Samsonov, T.; Koshel, S.; Walther, D.; Jenny, B. Automated placement of supplementary contour lines. *Int. J. Geogr. Inf. Sci.* **2019**, *33*, 2072–2093. ISSN 1326-3087. https://doi.org/10.1080/13658816.2019.1610965.
24. Kunigami, G.; de Rezende, P.J.; de Souza, C.C.; Yunes, T. Optimizing the Layout of Proportional Symbol Maps. *Comput. Sci. Appl.-ICCSA* **2011**, *6784*, 1–16. ISSN 0302-9743. (https://www.researchgate.net/publication/221435569_Optimizing_the_Layout_of_Proportional_Symbol_Maps Accessed on 25 January 2022).
25. Yang Mei and Lin Li "Cartographic symbol library considering symbol relations based on anti-aliasing graphic library", Proc. SPIE 6751, Geoinformatics 2007: Cartographic Theory and Models, 67510P (1 August 2007); https://doi.org/10.1117/12.759674.
26. She, J.; Li, C.; Li, J.; Wei, Q. An efficient method for rendering linear symbols on 3D terrain using a shader language. *Int. J. Geogr. Inf. Sci.* **2018**, *32*, 476–497. ISSN 1326-3087. https://doi.org/10.1080/13658816.2017.1394463.
27. Stachoň, Z.; Šašinka, Č.; Čeněk, J.; Angsüsser, S.; Kubícek, P.; Sterba, Z.; Biliková, M. Effect of Size, Shape and Map Background in Cartographic Visualization: Experimental Study on Czech and Chinese Populations. *Isprs Int. J. Geo-Inf.* **2018**, *7*, 427. ISSN 2220-9964.(https://apps.webofknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=46&SID=D3QdFBtcg1xe9BXeXga&page=1&doc=1 Accessed on 25 January 2022).
28. Yu, C.; Ren, F.; Du, Q.; Zhao, Z.; Nie, K. Web map-based POI visualization for spatial decision support. *Cartogr. Geogr. Inf. Sci.* **2013**, *40*, 172–182. ISSN 1523 0406. https://doi.org/10.1080/15230406.2013.807030.
29. Cascading Style Sheets for Maps–CartoCSS. (https://carto.com/developers/styling/cartocss/ Accessed on 25 January 2022).
30. OGC (Open GeoSpatial Consortium) Symbology Encoding.(https://www.ogc.org/standards/se Accessed on 25 January 2022).
31. Andělová, P. Educational Database of Cartographic Symbols. 2014. (geo.niwi.cz Accessed on 25 January 2022).
32. Andělová, P. Tvorba a účelové využívání kartografických znakových sad (Creation and purpose usage of set of the cartographic symbols). Brno. Ph.D. Thesis. Brno University of Technology, Faculty of Civil Engineering, Institute of Geodesy, Brno, Czeh Republic; 2020; 142p. (In Czech)
33. Vúgtk. Terminologický Slovník Zeměměřictví a Katastru Nemovitostí (Terminological Dictionary of Land Surveying and Real Estate Cadaster). 2014. (accessed on http://www.vugtk.cz/slovnik/index.php. 10 July 2014) .(In Czech)

34. Pravda, J. Metódy mapového vyjadrovania: Klasifikacia a ukážky. In *Geographia Slovaca 21, 2006*; Slovenská akademie vied, Geodetický ústav Bratislava: Bratislava, Slovakia, 2006. 127p. ISSN: 1210-3519.
35. Maule, L. Mapové znaky (Cartographic symbols). In: Kartografické listy 10/2002. Geographical institute of Slovak Academy of Sciences: Bratislava, Slovakia, 2002; pp. 36–43. (In Czech)
36. Hojovec, V. *Kartografie. 1. Vyd*; Geodetický a kartografický podnik v Praze: Prague, Czech Republic, 1987; 660 p. (In Czech).
37. Voženílek, V. *Aplikovaná Kartografie I (Applied Cartography I)–Thematic maps. 1. Issue*; Palacký University in Olomouc, Olomouc, Czech Republic, 1999; 170 p. (In Czech)
38. Klíč smluvených značek (Key of agreed symbols). *Base Map of ČSSR 1:50,000. Base Map of ČSSR 1:200,000*; Czech Office of Surveying and Cadaster: Prague, Czech Republic 1971; 6p.
39. Čúzk. Geoportál ČÚZK. Base Map of the CR 1:50,000. Available online: http://geoportal.cuzk.cz/(S(cbucs0554zl0mx45omvd4snp))/Dokumenty/znacky50.pdf (accessed on 14 December 2012).
40. BEV. *Zeichenchlüssel für die Österreichische Karte 1:50 000 UTM dargestellt im Maßstab 1:25,000*;: Österreich, Austria, 2008.
41. Zeichenerklärung DTK50. Bayern (Bundesrepublik Deutschland): Landesamt für Vermessung und Geoinformation, 2011 – standard of Germany.
42. Objaśnienia Znaków i Skrótów *(Explanations of Symbols and Abbreviations) 1:50,000*; Główny Urząd Geodezji i Kartografii: Warszawa, Poland, 2011. Standard of Poland.
43. Ministry of Defence CR. *Topo 4–5 Mapové Značky pro Zpracování Topografických Map Měřítek (Map Symbols for Processing of Topographic Maps) 1:25,000, 1:50,000, 1:100,000*; Ministry of Defence CR: Prague, Czech Republic, 2008.
44. Projects of Institute of Geodesy, Faculty of Civil Engineering, Brno University of Technology, (http://geodesy.fce.vutbr.cz/vyuka/ukazky-studentskych-praci/2017-cykloturisticky-gis-moravskych-vinarskych-stezek/ Accessed on 25 January 2022).
45. Lafreniere, M.; Pazner, M.; Mateo, J. Iconizing the GIS image. In Proceeding of the GIS/LIS '96-Annual Conference and Exposition Proceedings, Denver, CO, USA, 19–21 November 1996; pp. 591–606.
46. Bartoněk, D.; Opatřilová, I. The Management of Global Navigation Satellite Systems Measurement via Geographic Information Systems. *Adv. Sci. Lett.* **2015**, *21*, 57–61. https://doi.org/10.1166/asl.2015.5745.
47. Bartoněk, D.; Dermeková, S. The Use of Decision Theory in the Business Geography. *Adv. Sci. Lett.* **2015**, *21*, 88–92. https://doi.org/10.1166/asl.2015.5746.
48. Bartoněk, D.; Bureš, J.; Opatřilová, I. Optimization of Pre-Processing of Extensive Projects in Geographic Information Systems. *Adv. Sci. Lett.* **2014**, *20*, 2026–2029. https://doi.org/10.1166/asl.2014.5664.
49. Konečný, M. *Dynamic Geo-Visualization in Crisis Management. Issue 1*; Masaryk University: Brno, Czech Republic, 2011; 380p. ISBN 9788021058583. (In Czech).