SPATIAL DATA ACQUISITION, MANAGEMENT AND VISUALIZATION IN GEOGRAPHIC INFORMATION SYSTEMS

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Lucrarea discută despre funcţionalităţile software grupate în achiziţie de date, management şi vizualizare pe hartă specifice sistemelor informatice geografice. Instrumentele de dezvoltare software din acest domeniu pot fi utilizate eficient pentru a rezolva probleme de timp, cost sau erori umane. Scopul acestui studiu este proiectarea şi implementarea unei aplicatii bazate pe aceste instrumente pentru a fi utilizată în departamentele de management urban. Lucrarea contribuie la analiza problematicii dezvoltării aplicaţiilor software pentru mamagementul urban ce integrează funcţionalităţile specifice sistemelor informatice geografice.

The paper discusses about a developer viewpoint regarding a geographic information system (GIS) software used in geographic data acquisition, management and visualization in a map document. GIS tools can be used effectively to overcome problems such as time consuming, costs or human errors. The purpose of this study is to design and implement a GIS-based application to be used in urban management departments. Our experience contributes to the integration of spatial data models into GIS. Also it contributes to the building of a domain knowledge base which will be used further in the software development of applications for urban management.

Keywords: information systems, software development, GIS, database, georeferencing, map documents

1. Introduction

A geographic information system (GIS) is defined as a system for capturing, storing, checking, manipulating, analyzing and displaying data which are spatially referenced to the Earth [3]. GIS are now well established as a technology and they have become a relevant field of focus in information systems

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due to the increasing need of managing spatial information. The development of GIS technologies has been rapid over the last decades and driven by broader developments in information technology. Faster and cheaper computer systems, the development of the Internet, and the many other hardware and software developments have made it easier to capture, store and process geographic information in digital form.

The majority of GIS application domains are found in utilities companies, defense and security agencies and governmental organizations [8][7]. The recent development of spatial data management related to GIS has created the new era of city modeling [9]. Considering the integration of various data models into the GIS, the scope and scale of urban areas problems make the GIS a powerful tool for management of spatial data, complex analyses and visualization [10]. Due to the ability to manage a number of spatial data formats, data structures created in GIS open the ways to building urban management information systems that synthesize geospatial city data to support spatial analysis. There is also a growing amount of the digital maps in the GIS community, which are used to support decision-making processes of the urban authorities (data sets for land cover and climatic variables, digital elevation models, which are extended by blocks of buildings and trees, road and railway networks) [13]. While much progress has been made with the mapping and creation of city data sets, many challenges remain.

GIS represent a significant and growing field of both fundamental and applied research. A specific domain of applied research is database which defines GIS and distinguishes it from other information systems. The main concerns are spatial data structure, acquisition, management, analysis and visualization. One of the key factors in the success of GIS usage in various application domains is the software development method. The application is designed according to the principles of Object Oriented Analysis and Design [1], where the design procedure is accomplished in four different stages. The first stage concentrates on capturing the user requirements in a specification. In the second stage, the user requirements are analyzed to build a conceptual model and in the third stage, a design model is built based on specific GIS software. In the final stage, the design model is implemented in an application with a database management system (DBMS).

In this paper we discuss about our experience with a GIS software from the developer viewpoint to integrate GIS functionality in applications that need spatial data acquisition, management and visualization in map documents. Furthermore, we discuss only about the use of Esri ArcGIS. There are many commercial offerings from companies such as Manifold System, Intergraph, or Mapinfo with similar functionalities. Moreover, many free and open source components following OGC specifications are available on Internet. ArcGIS

Desktop 9.2 [6] is chosen as the target GIS software for the current study. While similar in some respects to data created and stored in a database program or graphics software, GIS data have some unique characteristics. In the sections of the paper we introduce the structure of GIS data and discusses about data acquisition and georeferencing that allows displaying on a single map various datasets from different sources. Geodatabases technologies are discussed and various geodatabases and datatypes sets are analysed for to be used in a database design model. Finally, visualization features that are provided by this tool are presented. This study contributes to the building of a domain knowledge base which will be used further in the database design model based on specific GIS software and implementation of applications for urban management domain.

2. Background

2.1. Methods of integration spatial data models into GIS

A few scenarios can be established to integrate various data models into the GIS. The basic level is represented by the standalone software application for simulation of models, which is accompanied by data inputs and outputs [13].

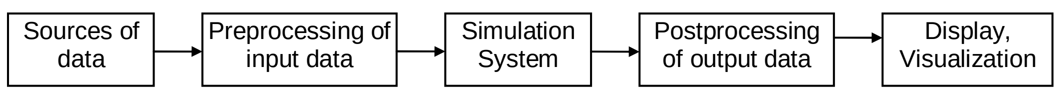

Fig. 1. The standalone simulation of data models with extended pre/post processing software systems

All data can be used independently by other software systems (WWW applications, GIS, database management systems). The individual programs form heterogeneous data structures that require the conversion of data into various data formats. Fig. 1 illustrates an example of steps carried out during the simulation of data models that have been acquired from various sources of data.

On the other side, a number of software applications have been developed to integrate specific functions of the GIS, modeling and graphic systems. Mostly, they are determined to perform operations on data without links to other software applications. The GIS based software applications are mostly based on spatial software libraries. The missing functions (modeling, visualization tools) can be complemented through the dynamic–link libraries. The integrated specific data analysis systems, which offer alternative ways of using the specific data models together with selected functionality of the GISs, are described by [13]. A number of software applications are focused on design of geodatabases and their interconnection with standard modelling systems. The structure of the applications developed with spatial software libraries is presented in Fig. 2.

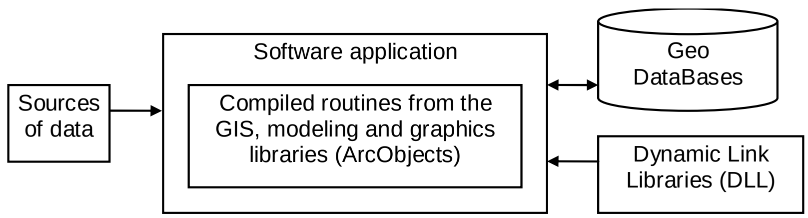

Fig. 2. A standalone software application for integrated spatial data

2.2. GIS data management and functionality analysis framework

2.2.1. Geographic data structure

Nowadays, there are standards for representing geometry information using database data types (OGC SFS, SQL/MM), and GIS systems store geometry values together with other attributes. Geographic objects may be represented by polygons, lines, points in a vector form or by pixels in a raster form. Generally the object is described by one or more co-ordinates which constitute the basic geographic data describing the object uniquely. The hybrid data model is the most common approach to store geographic data together with attributes data of a standard DBMS [11]. In this model, the geographic objects are stored separately and are characterized by a unique identifier which serves as a link to the attribute database. The co-ordinate files may be stored in a number of ways depending on particular application requirements. In all applications, essential requirements are speed and ease of updating of the geographic objects.

The integration of geographic objects and alpha-numeric databases in one spatial database management system allows for new ways of formulating data queries. The structured query languages (SQL) for standard databases make it possible to retrieve data according to alpha-numeric conditions of the type: *ID > 7*. An extension to a spatial structured query language permits a combination of standard queries with queries such as *All parks contained in city x*.

The simpler spatial queries include relational joins, sub-queries, and grouping factions and it is thus possible to form very complex queries. However, queries like data layer intersection (overlay) can not be performed in this way. It is possible to implement such non-standard SQLs by breaking them up in smaller components and applying one or more special geographic operations. The object oriented DBMS offers an alternative approach to implementing spatial queries.

2.2.2. Functionalities of GIS

GIS provides data acquisition, database integration, geographic data manipulation and visualisation. [4][2].

Data acquisition. A suitable GIS is required as a platform for the various types of data acquisition which are imposed by a particular application [12]. If vector data are needed, then existing paper maps may be used as sources for digitalization. This may be done either using a digitizer tablet or with on-screen digitizing of scanned maps. Scanned images may be sufficient if only background maps are needed or if they are to be processed as raster data. In that case, it may be more convenient to work directly with digital data acquired by remote sensing such as aerial photography of satellite observation. For urban applications of GIS it is often necessary to integrate the location of buildings or, more precisely, postal addresses. The data for these may be acquired by digitizing of cadastral maps or through the use of Global Positioning Systems. Once such address locations have been acquired, other georeferenced data may be geocoded.

Database integration. The modern approach to effective database management involves an integration of relevant databases which preserves their initial structure and allows for their use in different contexts. These objectives are realized through the use of Open Database Connectivity and other network protocols which offer a set of special commands for retrieving data in a client/server mode. An essential element in preserving data integrity is to have consistent data structures with common keys and procedures for maintaining and updating the databases. In a multi-user environment, it is important that these structures and procedures may scale smoothly with increasing user numbers.

Geographical operations. The basic geographic data manipulation for a GIS based on raster data is map algebra. It involves the operations of addition, subtraction, multiplication and division acting on individual pixel elements. Different raster data layers may be transformed and combined in a variety of ways to suit a particular application. Some operations use pixel proximity to create derived datasets. For example, by a buffering operation a zone is created around pixels which have specific characteristics. For vector data, the geographical operations involve transformation and combination of the basic geographic objects, polygons, lines and points. Distance operations, such as buffering, are widely used in environmental applications to create derived data layers with attributes in specific ranges.

Geographic queries and selection criteria may be formulated and applied easily for both raster and vector data. They are most often based on the relations "*within*", "*outside*", and "*intersects*", eventually in combinations with inequalities between the numerical attributes of the geographic objects. Most GIS provide for an easy use of SQL which embody geographic and alpha-numeric characteristics and may effect sophisticated queries.

Visualization. Thematic mapping is one of the most effective ways of visualization raster as well as vector data on 2 dimensional maps. Different pixels or vector objects are simply represented by different colors or patterns according the value of attributes corresponding to specific themes. The thematic maps may be combined with other data layers (e.g. point locations) so as to produce an appealing output which illustrates concisely a particular GIS application. Most GIS now offer the possibility of representing data in 3 dimensions. This is of course not only possible for real 3 dimensional data involving a height dimension (i.e. elevation data) but also for an abstract third dimension like a pollution concentration. This type of visualization of the distribution in 2 dimensional space of a certain attribute is a very effective tool for illustrating the presence of problem areas.

3. Analysis of GIS software

Nowadays, all the mentioned properties can accomplish a few of the GISs. In the presented study, the ArcGIS distributed by the Environmental Systems Research Institute [5] has been used for an evaluation of the data management and functionalities from a software developer viewpoint. The purpose is to use it in a GIS-based component for an urban management information system.

3.1. GIS data entities and models

GIS data is a digital representation of features or phenomena that occur on or near the earth's surface. Many types of geographic features and phenomena can be modeled with ArcGIS and stored as GIS data, including: (1) a physical object, either natural or man-made, such as a stream or a light pole. These objects may be stationary or mobile, such as a delivery truck with a radio transmitter. (2) a defined object that isn't necessarily visible on the ground, but that can be displayed on a map. Areas defined by boundaries, such as a county boundary, are an example. Many boundaries are legally defined, such as parcel boundaries, while some are formed by physical features, such as the boundary of a watershed. (3) an event that occurs for some relatively short period of time, such as a burglary, or an earthquake. While the event itself is ephemeral, the location, the date and the time of the occurrence can be captured and stored. (4) a locator, such as a street address, which doesn't represent a physical object, but a location that is important and useful to identify. Locators are often used to fix the location of events or mobile objects. For example, a street address is often used to identify the location of a burglary or to identify the location of students. (5) a spatial network representing linkage between objects or events. A network is defined on top of other geographic objects, such as a bus route which is a geographic feature defined from a set of streets and stops, themselves geographic features. (6) a phenomenon that can be measured at a location, such as elevation above sea level, soil moisture in the ground, or the concentration of ozone in the air.

From a GIS point of view, all these geographic entities have in common, that they have a location that can be captured and stored, and they have attributes. The attributes might be descriptions such as the zoning code of a parcel, or they might be measurements such as the population of a city. Linking the location with attributes it is possible to create highly customized maps, to perform spatial queries, and to perform analyses that take into account the spatial relationships between objects.

There are several models for representing this variety of geographic entities, however two of them are the most common. One represents geographic entities as geographic shapes (feature classes); the others represent them as cell values (raster data). Typical representations of feature classes are points, lines and polygons. Feature classes are stored as coordinate pairs that reference locations on the earth surface. A point in a feature class has specific coordinates. A line or polygon can be represented as a series of coordinate pairs that can be connected to draw the feature. This approach views features as discrete objects on the earth's surface and the representation is referred to as vector data.

In contrast rasters represent geographic features by dividing the world into discrete square or rectangular cells laid out in a grid. Each cell describes the phenomenon being observed. For example, the cell values in a vegetation raster represent the dominant vegetation type in each particular cell. Cell values can also be any measured or calculated value, such as elevation, slope, rainfall, vegetation type or temperature.

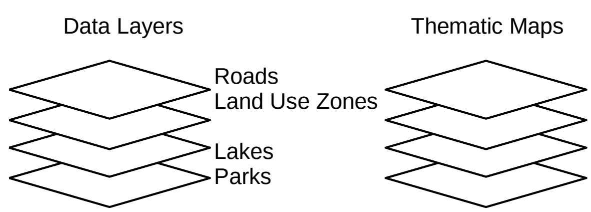

Fig. 3. Datasets displayed as layers

While most geographic features can be represented using either of these approaches, using one or the other is often more appropriate. For example linear features, such as roads, are often represented using feature classes. Phenomena that occur everywhere and are measured as continuous numeric scale are usually represented as raster data. Quite often both types of data are simultaneously used when creating a map or when performing analysis. If necessary there are tools to convert data between feature classes and raster data. Features of a similar type within a designed area are stored in a single dataset. Data sets are homogeneous collections of geographic elements. Roads in a town are stored in one dataset, land use zones in another, census tract boundaries in a third, buildings in a forth and so on. The various data sets are often thought of and portrayed as layers of information for that place. During mapping datasets are symbolized and displayed as map layers (Fig. 3).

3.2. Geographical data acquisition using georeferencing

A key concept of GIS data is that the geographic data sets represent a location on or near the Earth's surface. Because the data are tied to actual locations on the surface of the earth they are stored using coordinates that correspond to positions on the Earth's surface. The coordinates represent these positions to ensure that the feature shapes and their relationships to other features reflect actual conditions on the ground. Describing the correct location of features requires a framework for defining real-world locations. This process is called georeferencing and is accomplished by specifying a coordinate system for the dataset. Georeferencing allows displaying on a single map various datasets from different sources and have them register correctly. Once georeferenced, the datasets refer to the same location on the ground and register correctly. Each GIS dataset has a set of properties that define the specific details about the coordinate system. Once specified, the coordinate system definition is maintained with the dataset. Many standard coordinate systems are established for the globe or for various regions. The UTM (Universal Transverse Mercator) system is used worldwide. Other countries or regions often have their own local systems that use a local set of geographic controls.

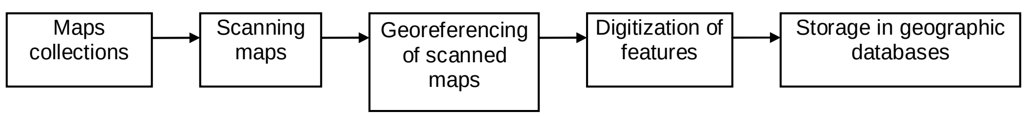

Fig. 4. Geographical data acquisition and georeferencing

Fig. 4 describes the georeferencing process. Raster data is obtained by scanning maps or collecting aerial photographs and satellite images. Scanned maps don't usually contain information as to where the area represented on the map fits on the surface of the earth. The location information delivered with aerial photos and satellite imaginary is often inadequate to perform analysis or display in proper alignment with other data. To establish the relationship between an image (row, column) coordinate system and a map (x, y) coordinate system it is necessary to align or georeference the raster data (image). Digitizing is the process of encoding geographic features in digital form as x, y coordinates. It is carried out in order to create spatial data from existing hardcopy maps and documents.
In our work the geo-referenced raster images of Constanta city are digitized using ArcMap 9.2, which is included in ArcGIS (Fig. 5).

Fig. 5. Georeferencing result of a .jpg image

We have performed on-line digitization. Streets network of the study area is digitized as line features. Lakes and parks are digitized as polygon features. Bus stations, railway stations, hospitals, places of touristy interest, offices, educational institutions and stadiums are digitized as point features. The above spatial data is organized in layers in the current project.

3.3. Geodatabases integration

In ArcGIS a geodatabase is both a format for storing datasets and a way of organizing related datasets. A geodatabase is a collection of geographic datasets of various types used for representing features, images and tabular and other data types. Creating a geodatabase for storing and organizing GIS data has several advantages: (1) there are tools for specifying rules and creating specialized datasets that are more closely to the behavior of geographic entities. Thus the creation of a geometric network models a flow of water through a system of pipes and valves. (2) A geodatabase set up a structure that ensures relationships between datasets are made explicit and are maintained. (3) There are instruments to set up rules to ensure data integrity. For example, a rule might state that parcel boundaries cannot cross. (4) Storing data in a geodatabase is an efficient way to manage related datasets as a single unit.

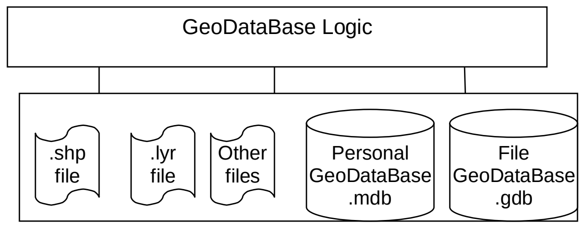

Fig. 6. Geographical data files

ArcGIS provides several types of geodatabases (Fig. 6). Two of them are file (the .gdb file) and personal (the .mdb file) geodatabases that are designed for use by one or few people. They can be edited by one person at a time – they do not support having multiple versions of a geodatabase that can be worked on by different people simultaneously. The information model of the database includes topologies, raster catalogs, network datasets, address locators, etc. Personal geodatabase uses the Microsoft Access data file structure and the other is a new geodatabase type released in ArcGIS 9.2. Other geodatabases are designed to be accessed and edited simultaneously by many users, they can handle transactions that occur over a long period (such as continuous updating), can track the changes in the database over time through versioning.

4. Application development with integration of GIS software

ArcGIS can be customized for particular applications of GIS or independent applications can be developed using specially designed data models and functionality. The ArcGIS functionality is expanded by the COM, Java, .NET and C++ technologies, which uses various programming languages (Fig. 7). Application development with integration of GIS software uses the services provided ArcObjects, which are ArcGIS software components. The software architecture consists of three layers that are associated to user interface, ArcGIS Components and Geodatabase. The application required functionality is accomplished by customizing the behavior of the ArcGIS objects.

All data are stored in the geodatabases, which can be represented on the basic level by the personal geodatabase (Microsoft Access), or by the RDBMS (Oracle, Microsoft SQL Server). So, the data transfer among other standalone software applications can be realized directly through the implemented database connections. In case of the ArcGIS's geodatabase, all the data are loaded into the relational database, so that the geospatial coordinate data of the GIS data layers are stored in the relational data tables. Since the relational database supports relationships between its tables, feature-to-feature spatial connections can be set up among the GIS data layers together with linking and joining of external data tables.

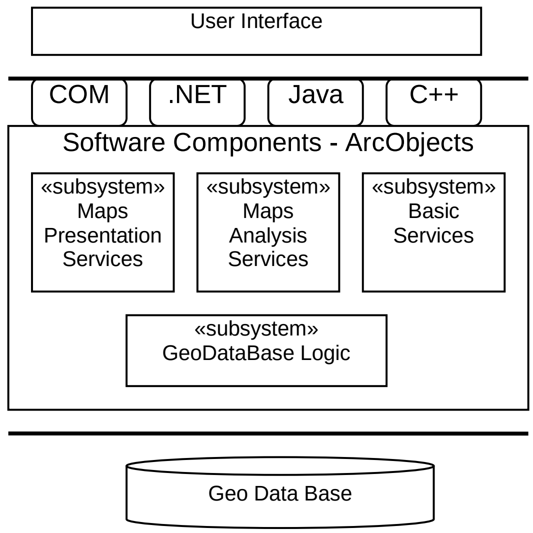

Fig. 7. GIS-based applications development

In the following we describe the frequently used entities in a GIS information model for software applications development. Also the map visualisation functionality provided by an application user interface.

4.1. Data types in GIS information model

Currently, a general data model has been published in for e-government domain [6]. Data models for urban management applications can be customized based on this general model. Information model consists of GIS specific entities for representing the most common dataset types and other specialized ones. The data types that can be viewed and analyzed are: (1) data stored using different data models: vector or raster; (2) data in different file formats: feature classes, shape files or coverages; (3) data sets imported from various sources including images (.bmp, .jpg files, etc.), CAD files, other geographic data formats; (4) tables in Excel. The main mechanism for organizing geographic data in a GIS software application is to define a workspace, which is any folder containing the GIS data. Workspaces also contain other files and documents that are collected or created during data processing.

Basic geodatabase datasets are feature classes, raster datasets and tables. Feature classes are homogenous collections of common features, each having the same spatial representation, such as points, lines or polygons and a common set of attribute columns. Raster datasets are used for representing and managing imagery, digital models and other spatially continuous phenomena. Attribute tables store all the properties of geographic objects. These include holding and managing feature geometry in a Shape column of the table.

Basic geodatabase datasets are extended and specialized with other datasets to ensure data integrity, manage the relationships between geographic features and between tables. Spatial data integrity is achieved with feature datasets and topologies. A feature dataset is a specific element in a geodatabase that holds one or more feature classes. A coordinate system is specified when a feature dataset is defined. Any feature classes must have the same coordinate system to ensure a correct registration. A topology is a set of rules that defines spatial relationships between adjacent or connected features in a feature class or between feature classes. Topologies are created within feature datasets. Attribute data integrity is achieved with domains and subtypes. Specialized datasets are included in a geodatabase, too. These may be used in specific applications such as surface modeling or network analysis. We have identified: (1) network dataset, which is used for modeling connectivity and flow for a transportation network, such as roads or rail; (2) geometric network – used for modeling outage and flows for a utilities network such as electrical, water and telecommunications; (3) address locator – used for assigning locations to a set of street addresses; (4) linear referencing – used for locating events along linear features with measurements, such as highway with kilometres markers.

4.2. Map visualization integrated a GIS application

A map document is composed of data frames, layers, symbols, labels and graphic objects. This is a .mxd file stored on disk. A data frame is a container in a map document that holds data. Usually there is only one data frame named Layers in map document.

Each data frame contains one or more layers that are created by adding datasets to a map document. Each dataset, and hence each layer, contains geographic features of the same type, streets in one layer, parks in another, and so on. A layer contains information about how to display the dataset, but not the data itself. Rather a layer references the underlying dataset wherever it is stored on disk so it is not necessary to store a copy of data in each map document the dataset is added to. Layers are created from a dataset and any changes to the dataset automatically appear in any of the layers created from the dataset. Thus from the same dataset it can be created as many layers as are needed in a single map document. Also there are layers that contain a subset of geographic features from a dataset. For example from a layer of city streets it can be selected just the principal streets and create a layer showing these. Layers have an associated attribute table that contains descriptive information (obtained from the underlying dataset) about the features in the layer – for example, the name of each park, its size, and which agency maintains it.

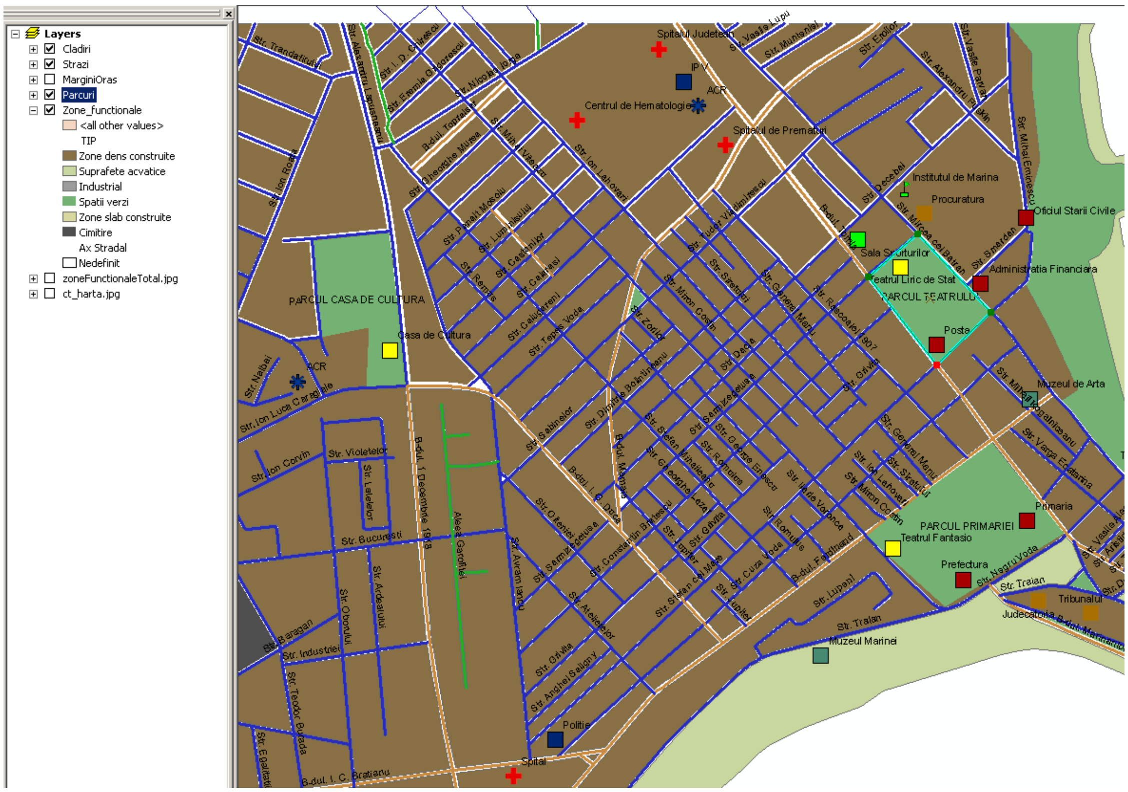

Fig. 8. Visualization of a map with table of contents, symbols, labels and graphic objects

Fig. 8 presents a table of contents of a map document that contains several layers in a data frame named Layers. It includes layers such as Buildings, Streets, CityBorders, FunctionalAreas, etc.. A map control allows to specify symbols to display various GIS data. GIS database contains tables with fields used to distinguish between various categories of data. These the values stored in these fields are used to set different symbols for each data category.

To display geographic data and to better communicate the information on the map, graphic symbols are used – lines, colors, patterns and so on. Symbols are a set of properties that get applied to a particular features or graphic object. Features in a layer have assigned symbols, such as blue lines for rivers and green color fill for parks. Parcels are symbolized by assigning a color to each land use type: all residential parcels are yellow, all unused parcels are grey. When data are added to create a layer, or when a graphic object is drawn default symbols are used. Predefined symbols are grouped in styles. Styles are used in predefined domains.

Labels identify geographic features on a map, such as labeling streets with their name (Fig. 9). There are several ways to create labels: (1) by specifying a field in a layer attribute table. These are placed automatically and can't be moved or edited individually. (2) by creating annotations. Annotations are associated with individual features and can be placed and edited individually. (3) by using graphic text that is placed and edited individually to label one feature or a few.

Fig. 9. Labels of geographic features

Graphic objects (circles, boxes, etc) are used to highlight the data that is displayed in a map document. Together with graphic text they are also used to create map elements such as titles, legends, north arrows that describe the information on a map.

5. Conclusions

This article represents an experience report for analysis of representation and display of spatial data in geographic information systems. In the beginning of our paper the focus is the definition of a GIS from the point of view of creating and populating a database that have to be used in an application for urban management. Then the paper describes how geographic entities are represented in a digital form, by layering various information that refers to the same place on Earth, georeferencing process that is used to align geographic references for different data sources. The paper also discusses about the visual elements of a map document based on geographic data stored in database tables. Our experience study creates the knowledge of the software applications development based on GIS. This knowledge is used to develop software applications that include various functionality required in urban management.

Our work evaluates a GIS tool from a software developer viewpoint. From a user viewpoint GIS tools are generally considered to be quite complex, not only in terms of understanding the interaction elements present in the user interface, but also the knowledge embedded in the tasks that can be accomplished by these systems. A novice user cannot explore maps without some assistance from an expert user or by studying books and manuals. Even an expert user usually faces significant difficulties using GIS tools. Also we found that GIS applications are hard to develop given the heterogeneity of GIS working groups involving several disciplines making difficult to assess the requirements of the final system. Better design methodologies in the requirements engineering field for the GIS specific domain are under development in our future research.

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R E F E R E N C E S

[1] *G. Booch*, Maksimchuk, R. et al., 2007, Object-Oriented Analysis and Design with Applications, Third Edition, Addison-Wesley Ed.
[2] *L.F.M. Cardona*, 2007, Using ethnographic techniques to describe requirements engineering processes in geographic information systems workgroups, in ICEIS 2007, INSTICC Press.
[3] *N. Chrisman*, 1997, Exploring Geographic Information Systems, NY: J. Wiley & Sons.
[4] *L. Dobrica* et al., 2008, Considerations regarding the usage of GIS technology in urban management, *IJCCC*, to appear, 12 pg.
[5] ESRI, 2006a, ArcGIS 9.2 Using ArcGIS Desktop.
[6] ESRI, 2006b, What is ArcGIS 9.2.
[7] ESRI, 2006c, GIS best practices for public work.
[8] Johnston R., 1999, Geography and GIS., in Geographical Information Systems: Principles and Technical Issues, **Vol. 1**, 2nd Edition. Wiley Ed..
[9] F. Lisboa, J. Iochpe, K. Borges, 2002, Analysis Patterns for GIS Data Schema Reuse on Urban Management Applications, CLEI Electronic Journal 5 (2).
[10] L. Matejicek, 2005, Spatial modelling of air pollution in urban areas with GIS: a case study on integrated database development, In DOAJ.
[11] D.R. Maidment, 2002, Arc Hydro: GIS for water resources, ESRI, California.

[12] *L.P. Maziero*, C.R. Slutter, L.S. Garcia, C.P. Ehlers, 2006, Evaluation of user interfaces for geographic information systems: A case study, in *ICEIS 2006*, INSTICC Press.
[13] D. *Rebolj, P.J. Sturm*, 1999, A GIS based component oriented integrated system for estimation, visualization and analysis of road traffic air pollution, Transport and air pollution, The 8th international symposium, 15-21.