International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:6, No:9, 2012

Possibilities of Delimitation of City Centers using GIS

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Abstract**—**The article describes problems of city centers with regard to possibilities of their delimitation in a GIS environment. First the definitions and delimitations of a city centre which are in use are mentioned, furthermore a chosen case study (the historical centre of Olomouc city in the Czech Republic) is employed to describe the methods of delimitation in use. In addition to describing the current state, the article also deals with possibilities of delimitation of a city centre in GIS environment by means of several chosen approaches. The authors describe, compare and discuss the chosen methods and assess the achieved results and also applicability of the designed methods for other cities.

Keywords**—**analysis, city center, GIS, spatial structures

I. Introduction

CITY centre is a commonly used term which, however, can have more meanings. A person living right in the centre has a different idea about a city centre and especially its delimitation than someone living in an adjacent residential district, a trading area, a periphery or in a nearby village. Number of authors, some of which are mentioned in the article, were trying to devise a method for delimitation of cities or their centers. Each of the methods, naturally, has its advantages but also many disadvantages and limitations. The most common problem lies in the applicability of a specific method on cities other than the one it was devised for (or a structurally similar ones). Ideally, one would establish a tool which would, reliably and objectively, delimitate a city and its centre even without any knowledge of local environment (how is a city and its structure currently delimitated) solely on the basis of defined parameters and data. An objective delimitation of a city centre is important e.g. for a statistical comparison of parameters and data from different cities (number of inhabitants, migration between peripheries and the centre, suburbanization, population density, commutation) in different parts of a country. Research of various approaches to delimitation of a city centre, their comparison, evaluation and their application on the city of Olomouc is the main subject of this work.

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II. City Centre

Research of an inner structure of a city is one of the priorities of the current city geography. The term spatial structure refers primarily to the individual parts of a city – centre, suburbs, city districts, functional zones etc. There are three basic parts of the inner spatial structure of a city – physical, functional and social. The physical spatial structure refers to a morphological spatial structure of a city, the functional spatial structure refers to a division of specific parts of a city according to their function and subsequent differences in utilization of buildings, land and areas. The social spatial structure is a part of the functional spatial structure (residential function-bound). It is usually evaluated by means of the basic demographic characteristics of residents.

According to General Encyclopedia [19] a center is defined as a core district of a city with the most intensive commercial occupancy of an area in which shops, financial and cultural institutions and branch offices of big companies are concentrated. The most expensive land is to be found here; most of the area is used as office and commercial spaces; the residential function is suppressed.

Mayeh [10] in connection with city centers describes a so called “central business district” (CBD). He considers it to be a heart of a city, often located in a place a city transportation is directed to and which contains the highest percentage of shops and offices. Due to high accessibility the prices of land are high and therefore the area is utilized most intensively.

Both the definitions stated above agree on the fact that a city centre is a place in which there is the highest concentration of services and business and the most expensive land. However, in the conditions of the Czech Republic one can not agree with the statement that due to high prices of land there is a high density of tall buildings in city centers. The centers of Czech cities consist mostly of historical core in which both redevelopments and new developments are highly restricted.

A. Delimitation of City Centre

A universally applicable method of delimitation of a city centre was dealt with e.g. by Murphy and Vance [11]. In their work the authors were aiming for an objective comparison of centers (or more precisely CBDs) of cities of the same size. However, they found out that individual municipalities have different ways of delimitating CBDs which are usually based rather on knowledge of local environment than on the basis of measurable factors. Within the frame of the research nine American cities were selected. They were roughly the same size (population of 150–250 thousand inhabitants) but had different functions.

Furthermore, Delimitation was carried out on the basis of two indexes – CBHI (Central Business Height Index) and CBII (Central Business Intensity Index).

These were applied to blocks of houses. The authors admit that this delimitation of CBD is not ideal because the resulting border of a city centre is in principle fuzzy and should be expressed rather by a zone than by a line. However, they were followed by a number of other authors.

Scott [14], with the help of their method, delimitated the CBDs of six Australian cities and consequently studied their development and structure. Another application of this method is described in Bonhert and Mattingly[1].

The authors aimed at delimitation of CBD by means of a method applicable to CBD in the past, the present and near future. The resulting index value was determined on the basis of a research in five relatively small cities in the state of Illinois with a similar structure. It is therefore possible that to delimitate CBDs in bigger or differently structured cities another limit value would have to be used.

Another research which could be mentioned is e.g. Bowden [2], in which the same method (with two minor modifications) is used to study the development of a CBD in time or the Carters and Rowleys work [3], in which the application of the method on the city of Cardiff is described. With respect to the fact that cities in Great Britain (or in Europe) had been developing in a different way than those in the United States, the method had to be considerably simplified and generalized to yield an objective result.

Some of the European institutions which could be mentioned are e.g. Centre for Advanced Spatial Analysis – University College London which worked on the project "Definition of City Centers" aimed at determining conditions for delimitation of centers of British cities Bowden [2].

The pilot study was carried out in London [17]. The Statistical data related to ZIP codes were used as input data. Thus an irregular network of points was established in which some of the points had zero value. To process this data a method of Kernel Density Estimation – KDE was used.

Central European authors deal with delimitation of city centers mostly on a theoretical level and if they do delimitate it, they base it on a historical development of a city. Ouředníček [12] divides a city into a historical centre, an inner city and an outer city. Nevertheless, it does not define any factors which would differentiate these parts.

Matlovič [9] in Ptáček et. al. [13] defines five basic zones for the needs of the research of the transformation processes of the communistic cities. A City centre (old town) is, according to this research, usually represented by a medieval core of a city and its immediate surroundings. Sýkora [15] divides Prague into five concentric zones: (1) historical centre, (2) inner city, (3) garden city belt, (4) belt of prefabricated apartment complexes and (5) countryside. A historical centre is usually delimitated by its surroundings, which is a belt of blocks of houses built since the mid 19th century till the Second World War.

Kotus [7] defines four parts of a socialist city, one of them being a historical centre which is characterized as a medieval core with a pre-war building development.

B. Delimitation of Olomouc City Centre Currently in Use

There are several delimitations of the city centre in Olomouc: The city district Olomouc – centre; the cadastral district Olomouc – city; the basic settlement unit – historical centre; historical town reserve; in the municipal plan the functional area of the inner city is defined; Szczyrba [16] delimitated the economic subcentre core. All the delimitations are displayed in Fig. 1.

The City district, the cadastral district and the basic settlement unit are component elements of the structure of communities. They were delimitated mainly on account of administrative reasons. A Historical town reserve is, according to the Czech-Austrian-Slovak handbook of urban planning terminology [5], a coherent part of historical cities, area of which has a homogenous historical value and represents the highest level of conservation.

In Fig. 1a the city district Olomouc – centre is delimitated. It contains the historical centre (delimitated by city parks), surrounding parks and in the east also the areas surrounding these parks. In Fig. 1b the cadastral district of Olomouc – city is delimitated. It mostly corresponds with the delimitation of the city district but includes also the Olomouc train station, Nova street and its surroundings and in the east also the Senimo supermarket. Fig. 1c depicts the delimitation of the economic subcentre core. This delimitation is significantly smaller than the previous two and includes the historical centre of the city and the adjacent parks. In Fig. 1d one can see the delimitation of the basic settlement unit called historical centre. Fig. 1e shows the functional area of the inner city taken from the municipal plan of Olomouc from the year 1999 and in Fig. 1f one can observe the delimitation of the historical town reserve. The last three delimitations do not differ significantly. The differences consist mainly in whether they include the area of Bezruc Gardens and the residential blocks between the Hrdinu square and Cech and Smetana Gardens.

TABLE I
THE DEFINED AREAS OF DELIMITATIONS OF CITY CENTRE IN USE

used delimitations of centre	**delimitated area [km^2]**
municipal plan – the functional area of the inner city	0.595
the basic settlement unit – Olomouc historical centre.	0.842
the historical town reserve	0.961
the economic subcentre core	1.389
the city district Olomouc – centre	2.279
the cadastral district Olomouc – city	2.708

III. POSSIBILITIES OF DELIMITATION OF CITY CENTRE USING GIS

A. Used Data

The data used to delimitate the centre of the Olomouc city were provided by the Department of Conception and Development of the Municipal Council of Olomouc.

It consisted of vector layers in dgn and shp formats in scales from 1:2 000 to 1:10 000. The data concerning services were created by means of GPS devices by students of the Department of Geoinformatics as a part of their training.

B. Used Software

All the map outputs and the spatial analyses were processed by the ArsGIS 10 software developed by the Esri company. Most of the calculations only required the default sets of tools. Some of the calculations were carried out by means of the Repeating Shapes tool for ArcGIS created by the Jennes Enterprise company. This tool enables creation of a regular network of points or polygons in a range specified by a user. The output can be saved in the shapefile format or exported to a personal geodatabase. The tool is available for download and installation on the company's webpage [6].

User can choose area of a newly generated layer in such a way it covers the selected objects within the scope of a particular layer, all layers in the map or in the displayed area. User can choose from several different shapes (points, circles, squares, triangles, hexagons) and layouts. Points and circles can be placed in a square or a triangular grid with arbitrary gaps. Squares, triangles and hexagons can have arbitrary sizes set either as a size of an area which should be covered by the individual polygons or as a length of an edge of a polygon. All the shapes can be oriented in whatever direction.

C. Delimitation of City Centre According to Price Map

The centre was delimitated by means of the price map of Olomouc on the basis of the most expensive pieces of land in the city centre. An average price of land in Olomouc is 1 109.5 CZK/m^2, excluding the land for which the price was not set (mostly pieces of land which are not for sale and owned by the city). A minimum price is 100 CZK/m^2, a maximum price is 9 9770 CZK/m^2. To delimitate the city centre, pieces of land with price higher than 2 600, 5 000 and 9 000 CZK/m^2 were selected. That represents approximately 5 %, 2 % and 1 % of estimated land.

In the historical centre of the city there are several pieces of land price of which has not been set (e.g. the land the city hall is on, churches and other historical monuments). In case these pieces of land were completely surrounded by the selected land they were also included in the selection. In this way three different city centers were delimitated. The delimitations of the city centre with price of land higher than 2 600 and 5 000 CZK/m^2 differ only slightly (see Fig. 2a).

The area with the price of land higher than 2 600 CZK/m^2 is roughly delineated by Hrdinu Square, Svoboda Avenue, marketplace, fortification walls running along Bezruc gardens, Jiri z Podebrad street, Vaclavske Square, Republiky Square, Dobrovskeho Street and the Slavonic House. To delimitate the city centre only the pieces of land which formed the biggest continuous area were selected (they were meeting the polygon by at least one edge).

The total area of the city centre delimitated in this way is 0.57 km^2. By selecting the pieces of land with price higher than 5 000 CZK/m^2 an almost identical area was created; it did not include the part of the city between Sokolska and Dobrovskeho streets. The total area of the city centre delimitated in this way is 0.48 km^2. The selection of the pieces of land with price higher than 9 000 CZK/m^2 includes the area of Horni and Dolni squares and the adjacent streets.

The total area of the city centre delimitated in this way is 0.2 km^2. The area of the individual delimitations is displayed in Table II.

TABLE II
THE AREA OF THE CITY CENTRE DELIMITATED BY MEANS OF THE PRICE MAP

price [CZK/m^2]	delimitated area [km^2]
more than 2 600	0.566
more than 5 000	0.81
more than 9 000	0.203

As one can observe in Fig. 2a, the resulting polygons of the delimitations of the city centre do not have smooth edges, on the contrary, they are very jagged. A possible solution to this would be a generalization of the polygons either by one of the tools used in ArcGIS or by setting up certain rules. These rules could include removal of protrusions smaller than a specific area or inclusion of polygons price of which was not set if at least 60% of its edges meet the selected polygons. At the same time one should consider housing because it is not desirable for the border to lead through buildings, which are the smallest indivisible unit of a price map. The area of the centre delimitated by means of the price map is the most similar to the functional area of the inner city from the municipal plan of Olomouc.

D. Delimitation of City Centre According to Density of Services

The second delimitation of the city centre was carried out on the basis of the density of services. By means of the Repeating Shapes tool several regular polygon grids of various shapes and sizes were created (see Table III). These were used to cover the area encompassing roughly the city of Olomouc without the annexed villages. Covering the whole area of the city would disproportionately increase the processing time of the individual analyses and would not contribute anything new to the results. For each individual polygon a number of services in it was counted (without dividing services according to qualitative criteria) and subsequently 5% of the polygons with the highest concentration were selected. Out of those the biggest continuous area of polygons comprising the city centre was selected. In the end the selections from the individual polygon grids were added up and only the area in which 100 % of input areas were added together was chosen.

Thus a final delimitation of the city centre according to the density of services was obtained.

To delimitate the city centre a triangular, a square and a hexagonal regular grids with the area of the individual polygons ranging from 5 to 25 thousands m^2 and a resolution of 5 000 m^2 were chosen. When using the polygon grid with the smallest polygon area the Horni Square was not delimitated as a part of the centre because the polygon covering the inner space of the square included only the city hall. When using the polygons with the biggest area, even parts of the city in which there were no services were delimitated (e.g. city parks).

The sizes of the individual delimitated areas are summed up in Table III. One can observe that the selected shapes of polygons did not change the results much; when using polygons of the same size, the resulting areas were almost identical. The most significant differences between the delimitated areas occur when using the biggest and the smallest polygons of different shapes. The best visual results were achieved by using the hexagonal grid.

When comparing polygons of the same shape but different areas, the smallest differences in size is exhibited by triangles; between the smallest and the biggest delimitated area there is a difference of only 0.05 km^2. With the square grid the difference is 0.12 km^2 and in case of the hexagonal grid it amounts to 0.115 km^2.

TABLE III
SIZES OF THE DELIMITATED AREAS OF THE CITY CENTRE

	Area of delimitated centre [km^2]		
Areas of polygons [km^2]	**Triangles**	**Squares**	**Hexagons**
0.005	0.250	0.180	0.260
0.01	0.280	0.290	0.300
0.015	0.285	0.270	0.270
0.02	0.300	0.280	0.300
0.025	0.275	0.300	0.375

Furthermore, a polygon representing the overlapping area of all the delimitations stated above was created. This polygon was not compact (this was caused by the gaps which occurred when delimitating the city centre by the polygon grid with the smallest area of polygon; in this case the surroundings of the city hall were not included in the city), therefore it was modified into a compact shape. Subsequently it was generalized in the ArcGIS environment using the Simplify Polygons tool (the BEND_SIMPLIFY algorithm and a reference baseline of 50 m) in order to straighten the edges which were too complex.

The resulting polygon (see Fig. 2b) covers the area of 0.191 km^2, which is similar to the city centre delimitated by the pieces of land with the price higher than 9 000 CZK/m^2 (Fig. 2b).

As compared with the delimitation already in use, this area is significantly smaller. It only covers The Horni and The Dolni squares and partially also the adjacent streets. The area of this polygon is the most similar to the delimitation of the centre by the square grid with the polygon area of 5 000 m^2, however its shape does not correspond. The shape is most similar to the delimitation by the hexagonal grid with the polygon size of 15 000 m^2 (see Fig. 2c).

E. Delimitation of City Centre According to Density of Public Transportation Stops

The city of Olomouc basically corresponds with a monocentric model of a city and most of its main roads lead to its centre.

This tendency is also observed by the public transportation system which carries passengers towards the centre. This fact became an impulse to attempt to delimitate the city centre according to the density of lines and stops of the public transportation system.

The method of delimitation was similar to the one used for delimitation according to the density of services. The input layer consisted of representations of the routes of all the regular daily lines of the public transportation system. For each polygon a density of bus and tram lines per square kilometer was calculated. Then the polygons with the highest density were selected. Lengths of lines in the individual polygons were calculated by the means of the Hawt's Analysis Tool.

This method of delimitating the city centre proved to be unsuitable for three reasons. The first one being the fact that the historical centre of Olomouc is a pedestrian zone surrounded by parks.

Therefore the transportation system does not access the city centre itself but only its outskirts; the highest density of lines can be found on the southeastern edge (between the Hrdinu Square and the city marketplace). The remaining parts of the city centre are, due to the parks, bypassed by the lines and therefore can not be used to delimitate it.

The second reason lies in the low density of the lines of the public transportation system which is sufficient for transporting passengers but not for the delimitation of the city centre. When a polygonal grid with an area smaller than 200 000 m^2 was used, too many polygons returned a zero value of density of lines. When a larger area of polygons was used, it was not possible to delimitate the city centre; the area of polygons was too big.

The last reason is that even though Olomouc has a monocentric character, the public transportation is directed not only towards the city centre but also towards the train station which serves as an interchange station for trains and city busses bound both for the villages annexed to Olomouc and other surrounding villages (these depart both from the front of the train station and from the nearby bus station). The highest density of the public transportation lines can therefore be found rather in the vicinity of the train station than near the centre.

In Fig. 2d one can see an attempt to delimitate the city centre using the density of the public transportation lines in a hexagonal grid, polygons of which have the area of 50 000m^2 and 250 000 m^2. Neither of these grids succeeded in delimitating the centre; they only included its western part through which most of the lines run.

It is also apparent that the small polygons delimitate only the parts of the city in close proximity to the routes of the public transportation lines whereas the large polygons delimitate even the parts of the city which do not belong to its centre – for instance a quarter of family houses north of Dobrovskeho street. The figure also shows that the public transportation system basically bypasses the centre.

F. Delimitation of City Centre According to Mental Maps

A mental map is a graphic (cartographic or schematic) interpretation of a person's mental image of a geographical space, mostly concerning its quality or structure [4]. Voženílek [18] distinguish between two basic types of mental maps – these are so called Gould's and Lynch's types of maps. The Gould's type (named after P.d Gould) presents a mental map as an image of attractiveness of spatial preferences (or rather defferences) obtained usually by a person's choice of an ideal place in an arbitrary area. The Lynch's type (named after K. Lynch) sees a mental map as a depiction of space expressing one's perception of dimension, location or shape of elements in a chosen environment, his spatial orientation, topology etc. Mental maps (of Lynch's type) of inhabitants of Olomouc tend to differ significantly with respect to the borders of the city centre. Therefore in this diploma thesis the mental maps of inhabitants of the Olomouc city were not only compared with each other but also with the other results achieved in this work. The group of respondents consisted of total of 40 students of Palacky University whose task was to draw the city centre in an aerial photograph of the city according to their individual perception. The data were subsequently summed up using the tools of map algebra in the ArcGIS environment. The result was divided into 5 categories; each of these represents an accordance of a given percentage of the students on a particular delimitation. The category on which most of the students agreed (more than 80%) is the smallest one. It includes the Horni and the Dolni squares and the adjacent streets and has an area of 0.27 km^2. The second smallest delimitation on which more than 60% of students agreed is only slightly bigger – it has an area of 0.3 km^2. The biggest delimitation of the city centre has an area of 1.47 km^2. The results can be seen in Fig. 2e, a comparison of the individual delimitations is in Table IV.

TABLE IV
THE AREA OF THE CITY CENTRE ACCORDING TO THE MENTAL MAPS

Accordance [%]	Area [km^2]
0 - 20	1.473
21 - 40	0.880
41 - 60	0.540
61 - 80	0.301
81 - 100	0.273

Both the appearance and the area of the two smallest delimitations is similar to the delimitations according to the price map and the density of services (Fig. 2e and Fig. 2f) The differences between those are caused mainly by the fact that the borders of delimited mental maps consist mostly of streets whereas the delimitation from the price map uses edges of allotments and the delimitation according to the density of services uses edges of polygons. In comparison with the delimitation of the city centre which is currently being used, this delimitation is considerably smaller.

IV. DISCUSSION

Three different approaches were used to delimitate the city centre. The delimitation of the city centre according to the density of the public transportation network unfortunately did not prove to be functional. However, the result of the other two methods were highly similar and, moreover, they correspond with the delimitation of the city centre according to the mental maps of the students. As exemplified by the city of Olomouc the methods proposed in this thesis proved to be reliable in delimitating the city centre. When delimitating according to the price map the 1% of the most expensive pieces of land proved to be the most accurate selection. To achieve an accurate delimitation of borders it would be necessary to apply this method to more cities.

When delimitating the centre according to the density of services, a relatively accurate result was achieved with the polygon grid in which the size of the polygons was set to 15 000 m^2. The best result was achieved by combining all the polygon grids of different sizes. However, this method of analysis is relatively time consuming and impractical. The method of analysis of the density of services or the public transportation system on a regular polygon grid proved to be, in its current form, inapplicable.

The delimitation according to the lines is not ideal because it does not reflect intensity of transportation, frequency of stops, vehicle capacity etc. Utilization of this information requires relatively detailed data and would not solve the shortcomings caused by the fact that the transportation bypasses the centre.

Besides the methods tested and described by the authors, there are several different ways of delimitating a city centre. Unfortunately, gathering the input data for these analyses is rather problematic. One of the possible methods is delimitation according to the density of commercial areas or the ratio between commercial and dwelling areas. Unfortunately this data is only accessible for the areas of basic settlement units which are too big to enable delimitation of a centre. Data from statistical areas or, ideally, from address points would be more suitable. In case there would be accessible data from address points it would be possible to apply them to a regular polygon grid and not only to arbitrarily created statistical units.

Another possible way is delimitation according to age of houses. According to Ptacek et. al. [13] more than a half of the houses (54,4 %) in the city centre were built before 1919.

Data about the age of houses can be obtained from the results of the Population and Housing Census.In a city centre there is the largest number of public facilities and many companies or shops reside there. This draws a large number of people to it during daytime. At the same time the number of inhabitants with permanent residence decreases in a centre. Therefore, it should be possible to delimitate a city centre on the basis of changes of daytime and night time inhabitants. In a similar way a centre could be delimitated as an area with the highest density of pedestrians. Both methods could use for example data from mobile network operators (BTS stations), however accessibility of this data is rather restricted.

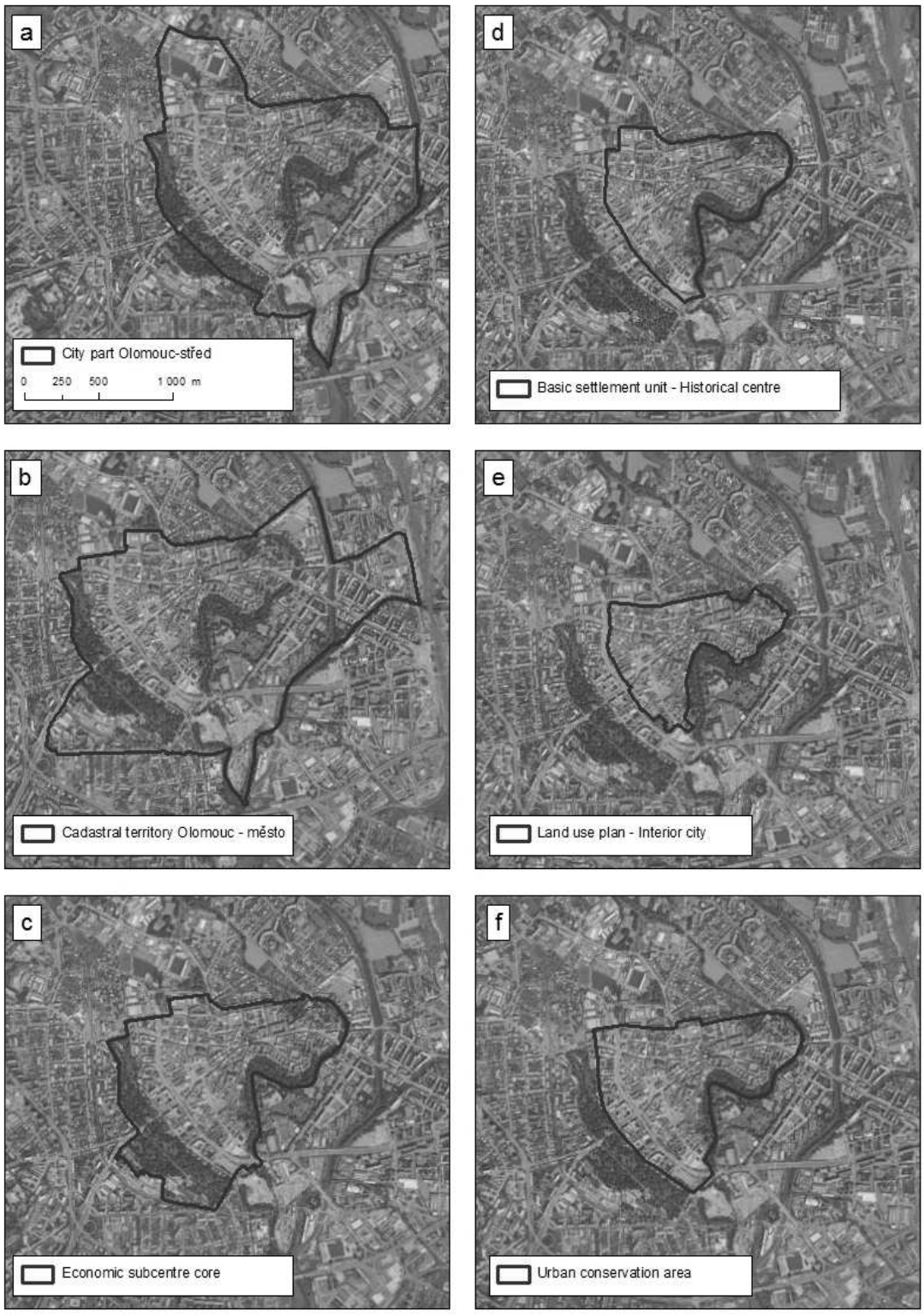

Fig. 1 Delimitations of the city center currently in use

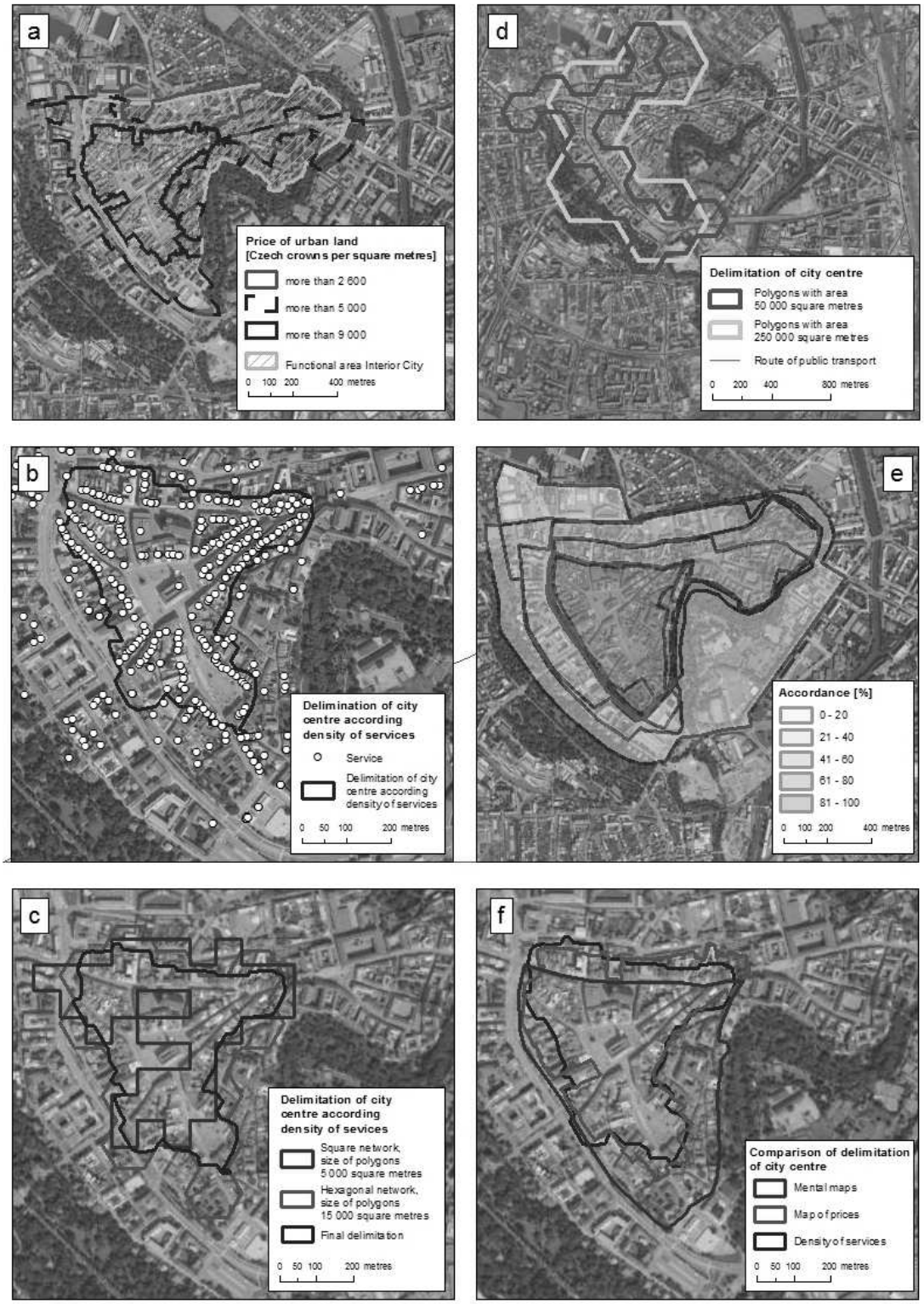

Fig. 2 Suggested delimitations of the city center

V. Conclusion

On the basis of the information gathered from the specialized literature several methods of delimitation of a city centre were designed. These were tested on the city of Olomouc. The parameters of the individual methods were set experimentally and were influenced by knowledge of the environment.

By selecting the most expensive pieces of land and areas in which services are accumulated (shops, national and municipal institutions, restaurants) very similar areas were delimitated. These areas also corresponded with the mental maps of the inhabitants of the city. Appropriate methods of delimitation of the city centre were found.

The best results were achieved when delimitating the centre according to the price map and the density of services. In comparison with the delimitations already in existence (the basic settlement unit, the cadastral district, the historical town reserve) the delimitations acquired in this thesis were significantly smaller. The delimitation of the city centre according to the density of the public transportation lines proved to be unsuitable because public transportation bypasses the centre of Olomouc.

However, none of the methods are universally applicable because they were tested only on the city of Olomouc; data from other cities were not accessible. The established methods might be applicable to cities of similar structure and/or size. To confirm this assumption a more detailed testing of the designed methods would be required.

Acknowledgment

The paper was supported by the Operational Program Education for Competitiveness - European Social Fund (CZ.1.07/2.2.00/15.0276 and project CZ.1.07/2.3.00/20.0170 of the Ministry of Education, Youth and Sports of the Czech Republic).

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