Mass Valuation Using Quantified Spatial Characteristics of Cadastral Parcels

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Summary
Each modern state needs to have a real estate valuation system for purposes of: fair real estate taxation, as a support to the real estate market, for better management of rural or urban environment or any other purpose. This enables a mass valuation system by systematic valuation of groups of real estate units performed on a certain date with the help of standard procedures and statistical analysis.
In order to be able to valuate real property its size and value-per-size factor are required. The product of the two multiplied by, for instance, the tax rate yields the amount of tax to be paid, but can also be used for other purposes. As opposed to the tax rate which is defined by legislative acts and the size which can be explicitly quantified (calculated) from its geometry, the value-per-size of real property must be determined based on a predefined set of rules and criteria. Generally, the more rules and criteria included, the more fairly the value can determined. Furthermore, for this value to be as fair as possible, the rules and criteria need to be defined and tested for the entire jurisdiction affected.
Real property can generally be seen as land, buildings, and whatever is attached or affixed to the land. In this research we limit ourselves to land i.e. a part of it defined by a cadastral parcel. Besides the size which is defined by its area, there are other characteristics of a cadastral parcel which explicitly and unambiguously define it. No matter what its purpose may be, the three spatial characteristics which directly influence the value of a piece of land are its azimuth, slope and shape compactness.
In this paper we first give a theoretical background for the method for automatic quantification of the mentioned three characteristics, provided cadastral and DTM databases are available in digital form and managed using spatial database management systems (SDBMS) technology. The shape compactness of cadastral parcel is calculated using its area and perimeter. Slope and azimuth are calculated by spatially intersecting triangles from the DTM with the shape of cadastral parcel. Since we wanted a distinct value for the slope and azimuth of each parcel, 'per parcel' averages are calculated using the weighted mean of 'per intersection' values of slope and azimuth. The area of intersection was used as weight. Finally, a description of a test system based on presented method and implemented on top of Oracle10g SDBMS is given. Within the research a sample DTM and cadastral database have been loaded into the system, and response times to queries for a single cadastral parcel and for a set of 5100 parcels indicate that such a system should be able to function in real world conditions.

1. INTRODUCTION

Each modern state needs to have a real estate valuation system for the purposes of fair real estate taxation, as a support to the real estate market, for better management of rural or urban environment or any other purposes. The states with a long tradition of market economy have had a form of real estate valuation system for quite some time (Färnkvist 2002, Kertscher 2004, Manthorpe 1998). The next logical step in the development of the existing real estate valuation systems, which these states are currently undertaking, is the improvement, i.e. specifying new objects of valuation and new sets of data on which the valuation is based (Roos 2006), as well as including a larger number of spatial data in the valuation process (Peltola 2006). The basis of the real estate valuation system should rely only on the objective data about the real estate properties, which can be obtained for each object of real estate that needs valuation (Cichociński and Parzych 2006).

Mass real estate valuation is, according to (UNECE 2001), a systematic valuation of groups of real estate units performed on a certain date with the help of standard procedures and statistical analysis. To enable such a systematic approach, it is necessary to have enough objective data about each piece of real estate involved. Spatial data have always presented the basis of each real estate valuation system, the real estate being significantly determined by its spatial properties (Yomralioglu and Nisanci 2004). In the Land Cadastre, the valuation was executed by assigning the type of soil coverage and its class to each cadastral parcel (Roić et al. 1999), but such an approach can no longer efficiently respond to the needs of the modern administration and economy. The limits of a specific right to real estate is the first factor which determines its value. Another, equally important factor, is its spatial properties (position, size, orientation...) (Faber 1991). These two kinds of national-level spatial data, i.e. cadastral and topographic, along with other factors, compose a basis for real estate valuation.

Our previous papers on the information systems as support for real estate valuation (Matijević et al. 2005) give an overview of general requirements for establishing such a simple and efficient system, provided the cadastral and topographic databases are available and based on the spatial database technology (SDBMS). Great interest provoked by the further development of some ideas from the original paper at the Congress FIG 2006 in Munich (Tomić et al. 2006) has stimulated us to further develop the original idea. With the national-level spatial databases which manage the cadastral and topographic data as the technological basis, this paper gives a detailed description of methods and techniques used in their developing, processing and usage as a support for mass real estate valuation. Some preliminary measurements of the efficiency of response to queries about a cadastral parcel or a set of 5100 cadastral parcels were carried out as well in the course of research.

2. REAL ESTATE MASS VALUATION AND APPRAISAL

Real estate appraisal (or assessment) can be described as a detailed estimation of real estate value, based on experience and all its primarily spatial, but also other characteristics. Numerous types of value are appraised:

- market value,
- insurance value,
- quick sale value,
- exchange value,
- book value,
- cash value,
- buy-off value.

Often there is a dilemma between the appraisal 'as is' and 'subject to'. These refer to the ownership. 'Subject to' – the real estate is under development, and the client wants the appraisal of the completed development.

The other approach 'as is' - the client wants the appraisal of the real estate the way it is at the moment of valuation. In general, there are three main approaches to real estate appraisal:

- cost approach,
- sales comparison approach and
- income capitalization approach.

These approaches, as described in more detail in (Mastelić Ivić 2004), relate mostly to developed or developing building zones, are oriented to real estate market information and require an expert in appraisal as the crucial component. Taking into account the existing data, it is possible to, use the statistical methods and with a degree of certainty assess the value of a component later to be used in assessment of the final value (Barańska 2004). However, a good information system, which provides those experts with relevant information quickly and efficiently, will make their job much easier. It is important to recognize dependence of all the appraisal approaches on the subjective impression of the appraiser, or the available amount of reliable data about the completed transactions on comparable locations. The value plans, as a new trend in mass valuation are also created with a degree of generalization (Gall 2006). The mentioned approaches are used for assessment of a single piece of real estate and are not suitable for mass valuation.

Objective approaches to valuation are based on uniquely defined natural features which are chosen as relevant for a certain area, and they can and should be used as a starting point for all the methods of real estate appraisal.

Real estate can generally be seen as land, buildings, and whatever is attached or affixed to the land. In this research we limit ourselves to land i.e. a part of it defined by a cadastral parcel. This is important because, be the purpose of the real estate agricultural production or building of residential or any other kind of buildings some common important spatial characteristics can be recognized.

Besides the size which is defined by its area and which is the most obvious one, there are other characteristics of a cadastral parcel which explicitly and unambiguously define it. No matter what its purpose may be, the three spatial characteristics which directly influence the value of a piece of land are its azimuth, slope and shape compactness. To summarize, the basic spatial characteristics which explicitly determine the value of a cadastral parcel are:

- size,
- azimuth,
- slope and
- shape compactness.

For building zones and buildings already built, those can be accompanied by other important features as:

- traffic connectivity,
- level of noise,
- distance from the institutions (school).

For agricultural land, the most important feature is its productivity.

Some of the mentioned basic characteristics influence productivity. For instance the azimuth determines the amount of the exposure to the sunlight, and the slope can influence its humidity. Productivity of land is additionally influenced by:

- chemical composition of soil,
- structure of soil,
- current vegetation and so on.

These additional characteristics must be chosen for different types of real estate based on the requirements or available data sets, but the basic ones apply for the cadastral parcels in general.

It is obvious that the size, shape and the position of a piece of land are uniquely defined by two sets of data, cadastral and topographic, which are managed at the national level.

The cadastral parcel defines the shape, the size and the planar position, while the topographic data defines the spatial position (slope and azimuth).

3. DIGITAL TERRAIN MODEL

Digital terrain model (DTM) is used at different levels and for different purposes.

It is used for determining visibility (De Floriani and Magillo 2003), for visualization (Lindstrom and Pascucci 2001), hydrological analyses (Gajski 2004), and other. According to the requirements, models of DTM data storage are adapted so as to form a triangulated irregular network – TIN, and a regular square grid – RSG. Squares in the RSG model can be divided into two triangles, which is called the triangulated RSG – TRSG, or the same height can be applied to the whole square, forming the so-called stepped RSG - SRSG (Figure 1).

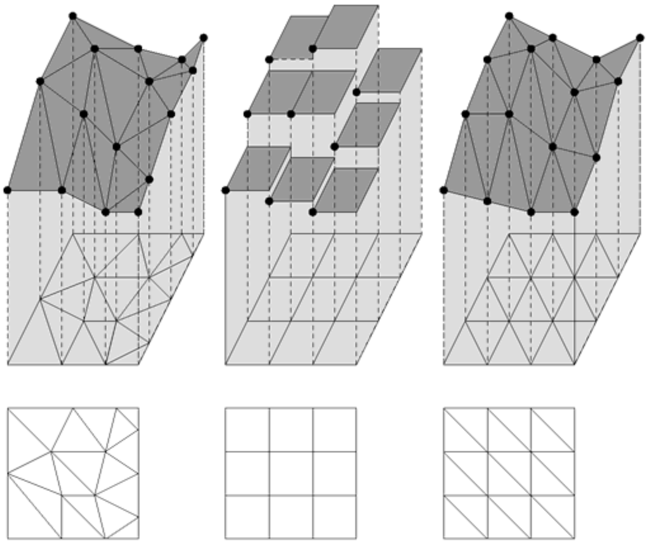


Figure 1. *TIN, stepped RSG and triangulated RSG (De Floriani and Magillo 2003)*

If we want to group the described models, it is logical to divide them into continuous (TIN and TRSG) and stepped or raster ones (SRSG). The raster DTM takes up less space in the storage system, and is simpler for indexing and searching. But, if it is used in its original form, due to simplicity, i.e. assigning the data on height to the whole square, which leads to generalization, it gives results which are not as accurate as with the continuous models. Hybrid models take the best from both approaches, i.e. combine the continuous and the stepped models, according to the requirements of an area (Kraus and Otepka 2005).

One of the possible models of DTM storage is the so-called implicit TIN described in (Jones et al. 1994). The idea is, along with the DTM data on height, not to store the actual TIN but only constraints, or conditions which are to be met in the process of triangulation. Such an approach is suitable for a static database which is supposed to respond to complicated tasks in a longer time period like by creating different TIN data sets according to different needs. The implicit TIN is not suitable for a database with direct access. This database has to keep spatial information in a realized (geometric) form to enable multiple simultaneous access and analyses.

A simple approach to the storage with topological pointers to shared geometry described in (Stoter and Gorte 2003) has the minimal redundancy, but adds an additional load on the system due to the on-line realization of the triangles. If spatial queries are to be performed, it is done through a function-based spatial index on the column where the topological pointers to geometric data are stored. Examination of the use of the function-based spatial index is provided in (Matijević 2006). The load will not be a problem only if there are no queries resulting in a large number of triangles. The storage with shared geometry, i.e. topological pointers, is applicable to spatial data the geometry of which sometimes has to be used without changing the topology, i.e. to those which require secure consistency keeping in the process of transactions (like cadastral). The DTM should not change frequently, and when it does, and if stored in the form of TIN, for the segment involved it is usually necessary to redo the triangulation. The simplest and the most efficient data structure to be used here is the plain geometric model of the used SDBMS. Although the level of redundancy is the largest here, since no preliminary calculations in the query time are required, the performance will be better in comparison to other approaches. A significant increase of data does not present a danger here because a relatively small number of changes can be expected, and the contemporary hardware-software systems efficiently manage very large databases.

Due to everything above-mentioned, it is only natural to expect that the DTM database at national level, with multiple access capability inside or outside the government institutions, will use a simple, realized database structure, based on a continuous model. The following considerations are based upon this premise.

4. QUANTIFYING SPATIAL CHARACTERISTICS OF CADASTRAL PARCELS

Besides its size and position which can be easily quantified from its geometric representation there are two groups of spatial characteristic of cadastral parcels. Slope and azimuth are related to relief i.e. to the DTM, and can be calculated and explicitly averaged for the entire parcel and classified yielding a slope-value factor (Fs) and a azimuth-value factor (Fa). Now slope and azimuth designated value of cadastral parcel can be calculated by multiplying its area with the two factors. The shape of cadastral parcel is also defined by its geometry however its application is not as straight forward as that of the slope and azimuth. Nevertheless, another factor called relative compactness can be calculated and used to produce the value of cadastral parcel.

4.1 Slope-Value and Azimuth-Value Factors

In order to be able to quantify it 3D characteristics a cadastral parcel needs to be positioned in the thre dimensional space. An approach to problems of specifying the actual spatial position and the shape of a cadastral parcel is given in (Stoter and Gorte 2003). These authors describe a method to determine the position of objects defined by 3D coordinates related to the cadastral parcel. The approach is based on acquiring all the data (positions) of the DTM with data on height, which are spatially located within the cadastral parcel, and on forming a constrained TIN with boundaries of the cadastral parcel as constraints. Although the authors state that, in the future, the triangulation could be done on-line, they used software solutions apart from SDBMS to execute triangulation. Furthermore, the authors state that a huge amount of the DTM data, which can be easily obtained today, is inappropriate for maintenance and use, if not preprocessed through development of the TIN. This leads to conclusion that in a well-organized national system for topographic data management, the DTM will be stored in a TIN form which is adapted to the actual needs. It is to be assumed that, at the national level, the necessary accuracy of all measurements which involve the official height presentation of the state area will be determined, and that the DTM will be adapted to that accuracy. For that reason, within the scope of this research, the existence of a national DTM stored as the TIN was taken as a premise.

As explained in the previous chapter, our research is based upon the premise that there is a DTM database modeled as a network of triangles, and pre-processed and optimized, to meet all the official requirements for measurement accuracy. Now, we are interested in data of each single cadastral parcel on its azimuth and slope, since these two features determine its productivity, i.e. its value. A triangular DTM with already (off-line) calculated or on-line accessible data on the azimuth and slope of each triangle, and its spatial coverage in 2D or 3D form can be used. These options are described in more detail in the chapter on system implementation. Using the standard set of spatial operators (ISO 2004), it is now possible for each cadastral parcel to make a SQL query to the database, which gives its value (Figure 2).

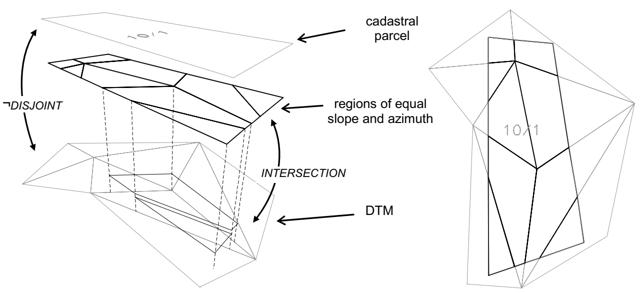


Figure 2. *Identifying regions with equal slope and azimuth*

The result of a query about a cadastral parcel will be a set of spatial objects defined by intersections of the cadastral parcel and each triangle. The final result can be obtained choosing classes for different scopes of the azimuth or the slope values, and adding up the intersecting areas, according to the classes. It is also possible to calculate a distinct numerical value as the result of the process, and which can be, for example, the weighted mean. The weighted mean of a discrete set of numbers $\{x_1, x_2, ..., x_n\}$ with weights $\{w_1, wt_2, ..., w_n\}$ is defined as:

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}$$

If the intersecting areas are considered to be the weights of specific azimuth and slope values of a cadastral parcel, then the weighted mean is calculated dividing the sum of products of multiplying each intersecting area with its azimuth (or slope) value, with the sum of all areas involved. Presented as algorithm, this is as follows:

- *find the set of intersections of the particular cadastral parcel and all triangles spatially related to it*
- *for each intersection:*
  * *calculate the area,*
  * *gather data on the azimuth and slope,*
  * *do the necessary additions and multiplications*
- *next intersection,*
- *return the calculated azimuth and slope values.*

Once the mean slope and azimuth are calculated and in order to be applicable for calculation of value of cadastral parcel, a criteria for slope-value and azimuth-value needs to be determined. This can be done by simply classifying the ranges of both characteristics according to the purpose of specific parcel and merging them into a single factor with or without assigning weights. This factor multiplied by the area of the parcel yields the slope/azimuth valuated area of the cadastral parcel.

4.1 Relative Compactness as a Shape-Value Factor

The measure of shape compactness is its area perimeter ratio. Although different formulations are possible, compactness C(X) of shape X with area A(X) and perimeter P(X) is usually given by

$$C(X) = \frac{4\pi A(X)}{P(X)^2}$$

yielding the dimensionless value of 1 for a planar disk (circle) and approximately 0.785 for a square. Planar polygons with circle-like shape have compactness values greater than that of a square, however the value of 1 can never be reached due to the polygonal nature of shape of cadastral parcels. Two characteristics of shape compactness are worth noticing here.

First, it is invariant to change of size, i.e. it is the absolute measure of shape compactness. Any square has a value of approximately 0.785, regardless of the length of its sides. Furthermore, it can be calculated for both convex and non-convex polygons but the value does not give any indication on the type of the polygon. A comparison of the polygon compactness with other methods for determining its complexity is given in (Edison 2003). Because it is simple enough and because it gives a good measure of the complexity of a polygon, shape compactness has been chosen to be tested for applicability in quantification of shape-value ratio of cadastral parcels.

For simple shapes of cadastral parcels compactness values can with little practice be well assessed from visual inspection only. Square like parcels will have values near and above 0.7 and the elongated ones 0.1 and less (figure 3).

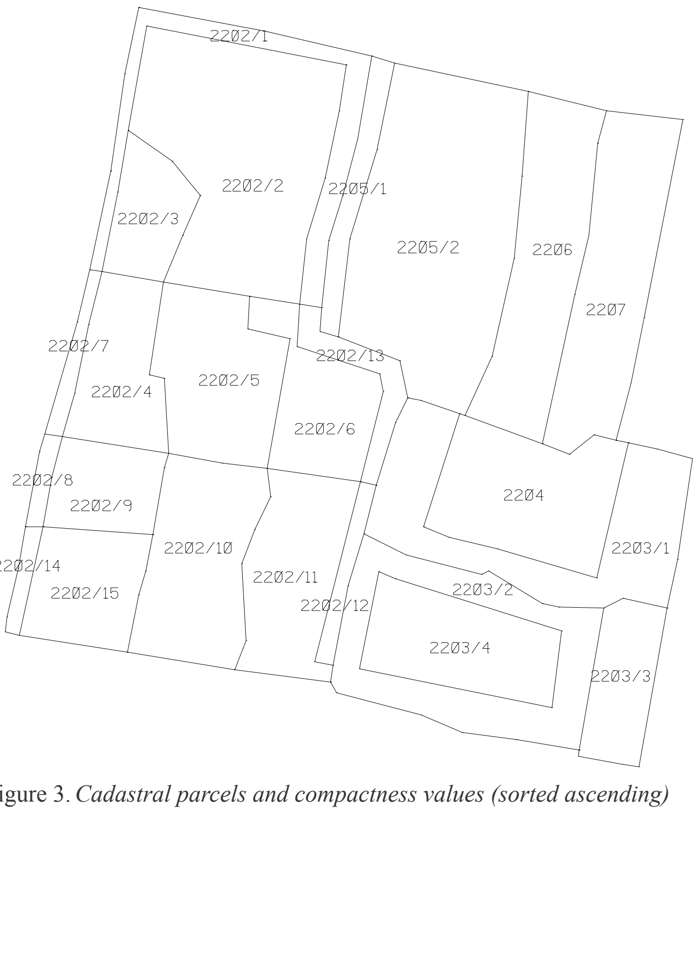
Of course, it must be clear that the shape compactness of cadastral parcels is by it self not a measure of value. The difference in the potential value of parcels with id of 2202/8 and of 2206 is huge while the corresponding compactness values differ in mere 0.01. This indicates that, should compactness be chosen for a measure of value of a cadastral parcel, it can not be used as an independent indicator of value, but only as a factor for multiplication i.e. weighting of another characteristic, like area. Introduction of another factor which we call the Relative Compactness, given by

$$Cr(X)=C(X)*A(X)$$

can simplify the situation. Now, when considering the relative compactness, differentiation of the before mentioned parcels appears as a more adequate measure of value (figure 3). Of course, such simplification is applicable only if the compactness-value ratio is chosen to be constantly proportional for the whole range of possible compactness (0-1), otherwise additional criteria need to be introduced. This was not researched within this project.

5. SYSTEM IMPLEMENTATION AND OPERATION

According to the requirements specified in the previous chapter, two spatial databases were created, a cadastral and a topographic one, on the server of the Chair of Spatial Information Management. All the research was performed on the Oracle10g instance, installed on the HP Proliant ML 370 (2x3.4GHz, 2GB, 2x136GB SCSI Raid 1) server. The full Oracle Application Server system was also installed on the server, so the results have to be seen as an indicator of performance which can be expected, i.e. as a relative measure of difference between performances on different types of queries.



parcel id	C(X)	Cr(X)
2202/1	.070	68.9
2203/2	.141	242.4
2205/1	.203	95.9
2202/12	.229	55.2
2202/7	.229	45.9
2203/1	.230	468.7
2202/13	.235	93.9
2202/14	.344	46.6
2202/8	.420	55.2
2206	.431	827.8
2207	.455	900.1
2202/6	.473	499.7
2202/11	.572	807.4
2202/4	.613	657.2
2203/3	.650	520.0
2202/2	.651	2114.4
2203/4	.662	892.3
2202/10	.685	1152.9
2204	.693	1186.2
2205/2	.704	2635.8
2202/3	.715	518.2
2202/5	.719	1102.0
2202/9	.770	580.7
2202/15	.779	786.5

Figure 3. *Cadastral parcels and compactness values (sorted ascending)*

5.1. Preparing DTM and Cadastral Databases

For the purposes of the project, a DTM database for the area of a smaller county (640 km^2) was created. The data were taken from the Internet (URL1), where the DTM 3x3″ is available for the whole Europe, created within the SRTM (*Shuttle Radar Topography Mission),* and spatially referenced in the WGS84 reference system. Using the data already stored in the database, and an external application for processing the DTM (Microstation Geoterrain), the TRSG was created for the chosen area. The data on position had been previously transformed into a rectangular national coordinate system, which resulted in a raster of data with spacing of 60x90 meters. Out of the input of 100 000 data points of SRSG, approximately 200 000 TRSG triangles were created. The name of the table is *tin2d*, and of the column of a *sdo_geometry* type is *geometrija,* on which a 2D spatial r-tree index was established.

Although, in the used SDBMS within a spatial-type object, it is possible to store the actual 3D data and set up a 3D spatial index (Oracle 2003), which could seem to be suitable for implementation of the DTM database, a different approach had to be taken. If a 2D spatial index is built on the 3D-modelled data, all the 2D analytical functioning can be used, since the system in the process of completing the functions disregards the *Z* coordinate. Now, it is also important to describe the management of data on azimuth and slope. These data can be calculated in advance (off-line) and stored together with the geometry of triangles. However, due to the expected very large amount of data, we tested the system efficiency using the functions for azimuth and slope calculation at the access time (on-line). Therefore, two separate functions, *nagib* and *azimut*, encoded in the PL/SQL, were prepared. Given the input object of a *sdo_geometry* type, the functions calculate the normal vector and the slope and the azimuth of the plane in which the triangle is positioned. The data of a set of cadastral parcels (5100 parcels covering around 5 km^2), located in a hilly part of the test area covered by the DTM (Figure 4), were stored in the table *katastarska_cestica*.

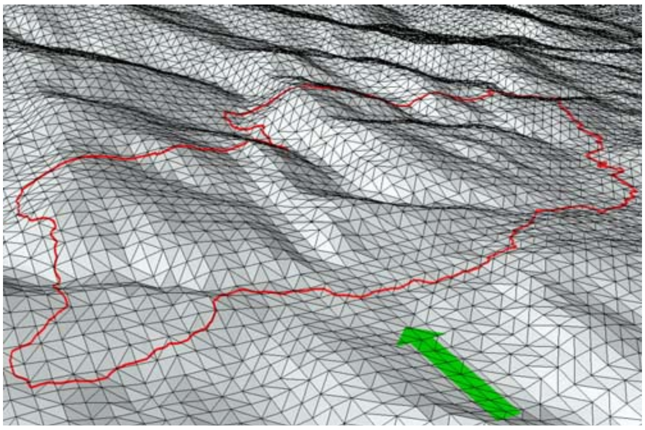


Figure 4. *Boundaries of a set of parcels projected onto the DTM (the arrow points the direction az=0)*

The name of the column with spatial data is *geometry1,* and it is also indexed using the 2D spatial r-tree index. For the purposes at this level of implementation, all the tables were stored within the same scheme in the database.

5.2. System Operation

Queries to the system are made using the standard SQL. The basic idea behind the queries is the same as in our previous work (Matijević et al. 2006), with the addition of shape compactness weighted area of cadastral parcel i.e. relative compactness. Furthermore, the returned values of mean slope and azimuth in the original query are now replaced by a conditional statement which converts the azimuth values ranging from 135 to 225 degrees to a value of 2 and the rest to 0.5. The azimuth range was selected to demonstrate a simple case of differentiating azimuth into two groups where the group of southern exposed land vas designated as twice as valuable as the rest. The slope values of 10 to 20 degrees were also arbitrarily chosen for the factor of 2 leaving the rest to return 0.5. The SQL query for a specific parcel (parcel_id=3200/1) can now be formulated as:

```
SELECT
case when (sum(sdo_geom.sdo_area(sdo_geom.sdo_intersection(c.geometry1,t.geometrija,0.01),0.01)*
azimut(t.geometrija))/sum(sdo_geom.sdo_area(sdo_geom.sdo_intersection(c.geometry1,t.geometrija,0.0
1),0.01))) between 135 and 225 then 2 else 0.5 end *
case when(sum(sdo_geom.sdo_area(sdo_geom.sdo_intersection(c.geometry1,t.geometrija,0.01),0.01) *
nagib(t.geometrija))/sum(sdo_geom.sdo_area(sdo_geom.sdo_intersection(c.geometry1,t.geometrija,0.01
),0.01))) between 10 and 20 then 2 else 0.5 end *
(select round(12.566*power(sdo_geom.sdo_area(z.geometry1,0.01),2) /
power(sdo_geom.sdo_length(z.geometry1,0.01),2),1) from katastarska_cestica z where z.broj=c.broj)
from katastarska_cestica c, tin2d t where SDO_ANYINTERACT(t.geometrija,c.geometry1)='TRUE' and
c.broj='3200/1' group by c.broj
```

Before timing, the server was restarted, and both tables were analyzed. The results are the arithmetic mean of time measurements of 6 series of repeated queries about all five cadastral parcels. The obtained results indicate that even in the case of the cadastral parcels containing several hundred points, and those spatially related to more than 100 triangles, the response time is within the scope of a few seconds (Table 1).

Table 1. *Time of response to queries for different types of cadastral parcels*

number of parcels	number of points	number of triangles	time of response (sec)
1933/3	4	1	0.07
3317/3	96	20	0.19
3231	189	75	0.91
3318	401	98	2.05
1117/1	187	132	1.44

Results compared to those from (Matijević et al. 2006) differ only due to different conditions on the server. This is caused by the fact that overhead from additional multiplications and divisions required for Cr are irrelevant in complexity when compared to spatial functions required for averaging slope and azimuth. We also timed response for the query which returns the sum of the value (Fa*Fs*Cr) fore the whole set of 5100 parcels, and the response times were around two minutes, again depending on the overall conditions of the system. More interesting than response time, because such complex queries will not often be required, is the result which shows the overall value of the set of cadastral parcels, and can be calculated using SQL aggregate *sum* operator.

6. CONCLUSION AND FURTHER WORK

After the analysis of a possible national-level DTM data model, the paper presents the method of calculating the characteristic slope and azimuth values of a cadastral parcel, through usage of the same model. The method is based on determining spatial intersections of related triangles in the DTM, and using their areas and slope and azimuth values, to calculate the weighted mean value for slope and azimuth. Shape compactness as a absolute measure of value of a parcel was found to be inappropriate, because small parcels with a good compactness can not be more valuable than larger ones with less good compactness. However, relative compactness i.e. product of compactness with the area can be used for determination of value of cadastral parcel.

The tests on the actual implementation gave the preliminary time of responses for queries about a single cadastral parcel, and about the group of 5100 parcels, which proves that the implementation would be purposeful and efficient enough.

Since the whole research was done on a both logically and physically identical database instance, further work can be based on establishing an environment with separate cadastral and topographic, i.e. DTM database systems, and on simulating multiple simultaneous access, which would enable insight into expected behavior in the real world conditions. Also, it is necessary to optimize the functions for calculating the azimuth and the slope of triangles. Using separate functions, some calculations are done redundantly, which may be avoided by using a single function for calculating both values.

This research leads to objective determinations of mentioned basic factors. In mass valuation system it will be possible to make quick recalculations if changes on real estate happen.

Usage of existing data (cadastral and topographic databases) will avoid a redundant data and multiusage will underpine development of national spatial data infrastructures.

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