Automatic Calculation of 3D Characteristics of a Cadastral Parcel for the Purposes of Mass Valuation

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***Abstract**:Valuation of real estate is an important factor in the economic and political development of a modern state. Modern real estate valuation systems at national level are based on spatial data, both cadastral and topographic, which are maintained using advanced technologies -spatial databases in particular. Through adequate modelling, by combining data from the existing databases, it is possible to create a national system for real estate valuation. This paper first gives an elaboration of possible characteristics of a digital terrain model database, and continues to describe an approach to automatic calculation of 3D characteristics, i.e. the slope and the azimuth of a cadastral parcel. The system response time to queries for a single cadastral parcel was measured, as well as for a set of 5100 cadastral parcels, in an implementation based on the Oracle10g spatial database.*

***Key words**: mass valuation, cadastral database, DTM database, spatial databases*

1 Introduction

Each modern state needs to have a real estate valuation system for the purposes of fair ownership and real estate taxation, as a support to the real estate market, and for better management of rural or urban environment. 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), with emphasis on the building zones in the urbanized environment. Due to the years of data accumulation, these systems can rely to a degree on the methods that require spatially referenced data about the completed transactions. On the other hand, developing countries started to build such systems not before the early 1990's, when they adopted the market economy (UNECE 2001), so there are no data about the completed transactions, or these are unreliable and inconsistent. For that reason, these systems can, in the beginning, 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 are the first factor that determines its value. Another, equally

Automatsko računanje 3D obilježja katastarske čestice za potrebe masovnog vrednovanja

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Sažetak: *Vrednovanje nekretnina je važan čimbenik u gospodarskom i političkom razvoju moderne države. Moderni sustavi za vrednovanje nekretnina na nacionalnoj razini svugdje su temeljeni na prostornim podacima, kako katastarskog tako i topografskog podrijetla, koji su održavani korištenjem naprednih tehnologija ponajprije prostornih baza podataka. Uz pravilno modeliranje moguće je kombiniranjem podataka iz raspoloživih baza stvoriti i nacionalni sustav za vrednovanje nekretnina. U članku je, nakon obrazloženja mogućih postavki baze digitalnog modela reljefa, opisan pristup automatskom računanju 3D obilježja odnosno nagiba i azimuta pojedine katastarske čestice. Obavljena su i okvirna mjerenja vremena odaziva na upit za jednu katastarsku česticu i za skup od 5100 katastarskih čestica u sustavu ostvarenom na prostornoj bazi podataka Oracle10g.*

Ključne riječi: *masovno vrednovanje nekretnina, baza katastarskih podataka, baza podataka DMR-a, prostorne baze podataka*

1. Uvod

Svaka moderna država treba sustav za vrednovanje nekretnina, bilo u svrhu pravednog oporezivanja vlasništva ili posjeda na nekretninama, pomaganja djelovanja tržišta nekretninama ili općenito upravljanju ruralnim odnosno urbanim okružjem. Države s dugom tradicijom tržišnoga gospodarstva već dugo imaju neki oblik sustava za vrednovanje nekretnina (Färnkvist 2002, Kertscher 2004, Manthorpe 1998). Slijedeći prirodni korak u razvoju postojećih sustava za vrednovanje nekretnina, a koje trenutačno poduzimaju spomenute države, njegovo je usavršavanje u pogledu uvođenja novih objekata vrednovanja i novih skupina podataka temeljem kojih se ona obavlja (Roos 2006) i, općenito, uvođenje većeg broja prostorno određenih podataka u postupak vrednovanja (Peltola 2006), i to s naglaskom na građevinsko zemljište u urbaniziranim područjima. Zbog dugogodišnje akumulacije podataka ti se sustavi mogu osloniti, barem u određenoj mjeri, i na metode koje zahtijevaju prostorno referencirane podatke o obavljenim transakcijama. S druge strane, države s gospodarstvom u razvoju takve su sustave tek počele razvijati početkom 1990-ih kroz prelazak na tržišno gospodarstvo (UNECE 2001), pa nemaju podatke o transakcijama, ili su oni nesigurni i nesustavno prikupljani. Ti se sustavi zato moraju u početku osloniti isključivo na objektivne podatke o obilježjima nekretnina koji se mogu prikupiti za svaku nekretninu za koju se pokaže potreba za vrednovanjem (Cichociński i Parzych 2006).

Prema (UNECE 2001) masovno vrednovanje nekretnina (engl. *mass valuation*) sustavno je vrednovanje skupina nekretnina koje se obavlja na određeni datum pomoću standardnih procedura i statističkih analiza. Kako bi takav sustavni pristup bio moguć, potrebno je raspolagati dovoljnim brojem objektivnih podataka o svakoj zahvaćenoj nekretnini. Prostorni podaci oduvijek čine osnovu svakog sustava za vrednovanje nekretnina već i zato što su nekretnine znatno određene svojim prostornim obilježjima (Yomralioglu i Nisanci 2004). U Katastru zemljišta vrednovanje je obavljeno određivanjem kulture i klase za svaku katastarsku česticu (Roić i dr. 1999), no takav pristup više ne može dovoljno učinkovito odgovoriti potrebama suvremene uprave i gospodarstva. Granice protezanja nekog (stvarnog) prava na nekretninama prvi 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.

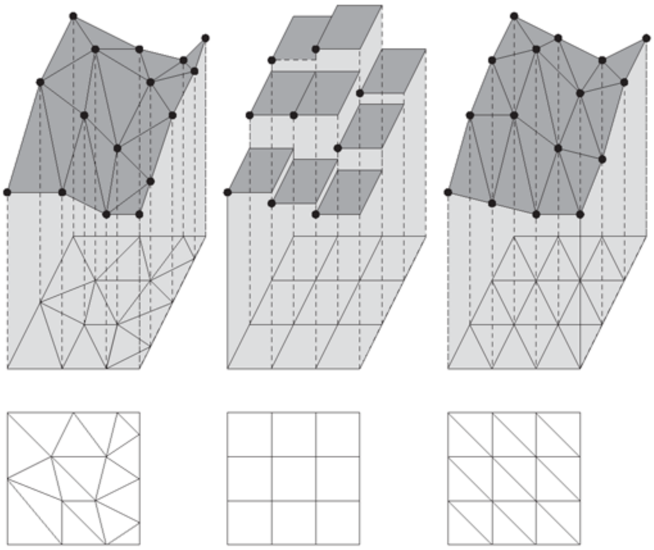

Fig. 1. TIN, stepped RSG and triangulated RSG (De Floriani and Magillo 2003)

Slika 1. TIN, stepenasti RSG i triangulirani RSG (De Floriani i Magillo 2003)

2 Real Estate Valuation

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. However, a good information system, which provides those experts with relevant information quickly and efficiently, will make their job much easier. 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). It is important to recognize dependence of all these 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). Those are the main sources of possibly incorrect valuation with these approaches. Furthermore, 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 that 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. For building zones and buildings already built, important features are for example:

- Traffic connectivity,
- Level of noise,
- Distance from the institutions (school).

For agricultural land, the most important feature is its productivity. Furthermore, two fundamental components influencing productivity are:

- Size, shape and position of the cadastral parcel and
- Quality of soil (texture, water supply, current vegetation).

It is obvious that the size, shape and the position of a piece of land are uniquely defined by two sets of data, je od čimbenika koji određuju vrijednost nekretnine. Drugi, jednako važan, čimbenik njezina su prostorna obilježja (položaj, veličina, orijentacija, ...) (Faber 1991). Upravo te dvije vrste prostornih podataka državne razine, katastarski i topografski, uz ostale čimbenike tvore osnovu za vrednovanje nekretnine.

U našim prethodnim radovima o informacijskim sustavima za potporu vrednovanja nekretnina (Matijević i dr. 2005) dan je pregled općih postavki za ostvarivanje jednog takvoga jednostavnog i učinkovitog sustava u slučaju da su katastarska i topografska baza podataka raspoložive i temeljene na tehnologiji prostornih baza podataka (SDBMS). Veliko zanimanje koje je izazvalo predstavljanje nastavka nekih ideja iz izvornog rada na Kongresu FIG-a održanom 2006. godine u Münchenu (Tomić i dr. 2006) potaknulo nas je na daljnju razradu početne ideje. Kako su tehnološka osnova za to prostorne baze podataka koje upravljaju katastarskim i topografskim podacima na razini države, u ovom radu daje se detaljniji opis metoda i tehnika korištenih za njihovu pripremu, obradu i uporabu u svrhu potpore masovnom vrednovanju nekretnina. Neka preliminarna ispitivanja u pogledu učinkovitosti sustava za upite o pojedinoj katastarskoj čestici odnosno o skupu od 5100 katastarskih čestica također su obavljena tijekom istraživanja.

2. Vrednovanje nekretnina

Procjena vrijednosti nekretnine može se opisati kao pažljivo predviđanje njezine vrijednosti temeljem iskustva i uzimanjem u obzir svih njezinih u prvom redu prostornih, ali i drugih obilježja. Postoje mnogi tipovi vrijednosti koja se procjenjuje:

- tržišna vrijednost,
- vrijednost osiguranja,
- likvidna vrijednost,
- prodajna vrijednost,
- zamjenska vrijednost,
- knjižna vrijednost,
- gotovinska vrijednost,
- otkupna vrijednost.

Vrlo često postoji dvojba između procjene “as is” ili “subject to”. Vrijednosti se odnose na stanje vlasništva. “Subject to” – nekretnina se uređuje, a stranka želi vrijednost nekretnine kao da su uređenja završena. Drugi je pristup “as is” – stranka želi vrijednost nekretnine kakva je u trenutku procjene. Općenito su poznate tri glavne metode procjene nekretnina:

- troškovna metoda
- metoda tržišnog uspoređivanja i
- dohodovna metoda.

Ti postupci, detaljnije opisani u (Mastelić Ivić 2004), odnose se uglavnom na izgrađeno ili građevinsko zemljište, prvenstveno su okrenuti na informacije s tržišta nekretnina i u svima je stručni procjenitelj još uvijek nezamjenjiva središnja sastavnica. Ipak, dobar informacijski sustav koji mu pomaže brzim i učinkovitim priskrbljivanjem relevantnih podataka uvelike će mu olakšati posao. Uzimajući u obzir raspoložive podatke moguće je statističkim metodama, s određenom sigurnošću, predvidjeti vrijednost nekog čimbenika dalje korištenog u postupku izračunavanja konačne vrijednosti (Barańska 2004). Važno je ipak u svim tim pristupima prepoznati njihovu ovisnost ili o subjektivnom dojmu procjenitelja ili o raspoloživoj količini vjerodostojnih podataka o prethodno obavljenim transakcijama na usporedivim lokacijama. I planovi vrijednosti (engl. *value maps*) kao nadolazeći trend u masovnoj procjeni stvaraju se uz određeno uopćenje (Gall 2006). Upravo to su glavni izvori moguće pogrešne procjene kod takvih metoda. Nadalje, ti se postupci koriste za procjenu pojedinačne nekretnine, a za masovnu procjenu nisu pogodni.

Objektivne metode vrednovanja nekretnina temelje se na jednoznačno definiranim prirodnim obilježjima koja su za određeno područje izabrana kao relevantna i ona mogu i trebaju poslužiti kao polazna osnova za metode procjene vrijednosti nekretnine. Za građevinsko zemljište odnosno već izgrađene građevine važna obilježja su na primjer:

- prometna povezanost,
- jačina buke,
- udaljenosti od ustanova (škola).

Za poljoprivredno zemljište osnovno je obilježje njegova proizvodna sposobnost. Ovdje se mogu prepoznati dvije osnovne sastavnice koje utječu na proizvodnu sposobnost:

- veličina, oblik i položaj katastarske čestice i
- kvaliteta tla (sastav, navodnjenost, trenutačni pokrov).

Jasno je da su veličina, oblik i položaj dijela zemljišta jednoznačno određeni dvama skupovima podataka kojima se upravlja na državnoj razini i to katastarskima i topografskima. Katastarska čestica pritom određuje oblik i veličinu te položaj u ravnini, a topografska baza određuje prostorni položaj (nagib i azimut). Osim toga iz topografske baze podataka mogu se preuzeti i podaci o vrsti pokrova koji također utječu na proizvodnu sposobnost zemljišta. U daljnjem razmatranju ograničit ćemo se na obilježja katastarske čestice određena reljefom.

3. Digitalni model reljefa

Digitalni model reljefa (DMR) koristi se na različitim razinama i u različite svrhe. Može se koristiti za određivanje vidljivosti (De Floriani i Magillo 2003), za vizualizaciju (Lindstrom i Pascucci 2001), hidrološke analize (Gajski 2004) i drugo. Sukladno zahtjevima prilagođeni su i modeli pohrane podataka DMR-a, pa tako postoje nepravilna mreža trokuta (engl. *triangulated irregular network* – TIN) i pravilna mreža kvadrata (engl. *regular square grid* – RSG). Kvadrati u modelu RSG mogu biti podijeljeni na dva trokuta, što se naziva triangulirani (engl. *triangulated* RSG – TRSG), ili jednaka visina može biti dodijeljena cijelom kvadratu pa nastaje tzv. stepenasti model RSG (engl. *stepped* RSG – SRSG) (Slika 1).

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). Also, the topographic database contains data on the types of vegetation, which bears influence on the productivity of the land. Our further analysis will focus on the relief-based properties of a cadastral parcel.

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 (Fig. 1).

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 that 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 that are to be met in the process of triangulation. Such an approach is suitable for a static database that 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 that 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 Calculation of 3D Characteristics of a Cadastral Parcel

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 pre-processed 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 that is adapted to the actual needs. It is to be assumed that, at the national level, the necessary accuracy of all measurements that 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 modelled as a network of triangles, and pre-processed and optimised, to meet all the official requirements for measurement accuracy. Now, we are interested in data

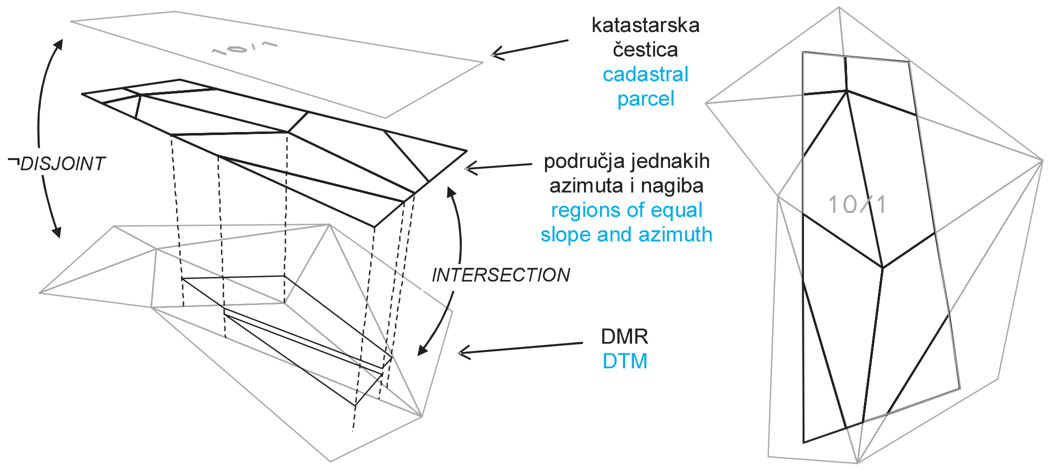

Fig. 2. Identifying regions with equal slope and azimuth

Slika 2. Određivanje područja s jednakim nagibom i azimutom

Ako opisane modele želimo razvrstati, logična je podjela na kontinuirane (TIN i TRSG) i stepenaste ili rasterske (SRSG). Rasterski DMR zauzima manje prostora u sustavu za pohranu, jednostavniji je za indeksiranje i pretraživanje. No ako se koristi u izvornom obliku, zbog jednostavnosti odnosno pridruživanja podatka o visini cijelom kvadratu čime se uvodi značajan stupanj uopćenja, općenito daje rezultate koji znatnije odstupaju od stvarnosti u odnosu na kontinuirane modele. Hibridni modeli temelje se na preuzimanju najboljeg iz oba pristupa odnosno kombiniranjem kontinuiranih i stepenastih modela prema zahtjevima pojedinog područja (Kraus i Otepka 2005).

Jedan od mogućih modela podataka za pohranu DMR-a je i tzv. implicitni (engl. *implicit*) TIN opisan u (Jones i dr. 1994). Ideja je da se uz visinske podatke DMR-a ne pohranjuje pravi TIN, već samo ograničenja odnosno uvjeti koji moraju biti poštovani pri obavljanju triangulacije. Takav je pristup pogodan za statičku bazu podataka pred koju se mogu postaviti složeni zadaci za koje se očekuje vrlo dugo vrijeme odaziva kao stvaranje različitih skupova podataka TIN-a primjereno različitim potrebama. Za bazu s neposrednim pristupom implicitni TIN nije pogodan. Ona mora čuvati većinu podataka u unaprijed ostvarenom (geometrijskom) obliku kako bi omogućila višestruki istodobni pristup i analize.

Jednostavan pristup pohrani, s topološkim pokazivačima i dijeljenom geometrijom opisan u (Stoter i Gorte 2003) osigurava minimalnu količinu redundancije, ali i dodatno opterećivanje sustava zbog on-line ostvarivanje trokuta. Ako je potrebno obavljati prostorne upite na podacima to je ostvarivo uspostavljanjem funkcijskog (engl. f*unction based*) prostornog indeksa na stupcu u kojem su pohranjeni pokazivači na geometrijske podatke. Razmatranje korištenja funkcijskog indeksa na prostornim podacima dano je u (Matijević 2006). Opterećenje neće predstavljati problem samo ako se ne očekuju upiti koji kao rezultat vraćaju velike količine trokuta. Pohrana s dijeljenom geometrijom odnosno topološkim pokazivačima posebno je pogodna za prostorne podatke kod kojih je nekad potrebno manipulirati geometrijom bez mijenjanja topologije odnosno za one koji zahtijevaju vrlo visoku sigurnost za održavanje konzistentnosti pod transakcijama (kao katastarske). Podaci DMR-a neće se mijenjati često, a kada se promijene, ako su pohranjeni u obliku TIN-a, može se očekivati da je potrebno za zahvaćeno područje obnoviti postupak triangulacije. Konačno najjednostavnija i najučinkovitija podatkovna struktura koja se može upotrijebiti za pohranu TIN-a čisti je geometrijski model korištene SDBMS. Iako je ovdje stupanj redundancije najveći, zbog izostanka bilo kakovog pripremnog računanja u trenutku postavljanja upita, performanse će biti bolje u odnosu na ostale pristupe. Znatno povećanje količine podataka ovdje nije opasno jer će promjene biti rijetke, a suvremeni hardversko-softverski sustavi jednostavno upravljaju vrlo velikim bazama podataka.

Zbog svega navedenoga logično je očekivati kako će baza podataka DMR-a nacionalne razine, s mogućnošću višestrukog pristupa unutar ili izvan institucija državne uprave, koristiti jednostavnu ostvarenu strukturu prostornog podatka temeljenu na nekom kontinuiranom modelu. Daljnja razmatranja temelje se na toj pretpostavci.

4. Računanje 3D obilježja katastarske čestice

Jedno istraživanje pristupa rješavanju problema određivanja pravoga prostornog položaja i oblika katastarske čestice dano je u (Stoter i Gorte 2003). Autori opisuju način kojim se rješava problem određivanja položaja objekata određenih 3D koordinatama s obzirom na površinu katastarske čestice. Predloženi pristup temelji se na pronalaženju svih točaka (položaja) DMR-a s podatkom o visini koje se nalaze unutar katastarske čestice te na formiranju ograničenog (engl. *constrained*) TIN-a s granicama katastarske čestice kao ograničenjima. Iako autori navode kako bi se ubuduće triangulacija mogla obavljati on-line, u svojem su primjeru koristili softverska rješenja izvan SDBMS-a kako bi obavili triangulaciju. Osim toga autori navode kako je golema 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 (Fig. 2).

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 $\{t_1, t_2, ..., t_n\}$ is defined as:

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

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.

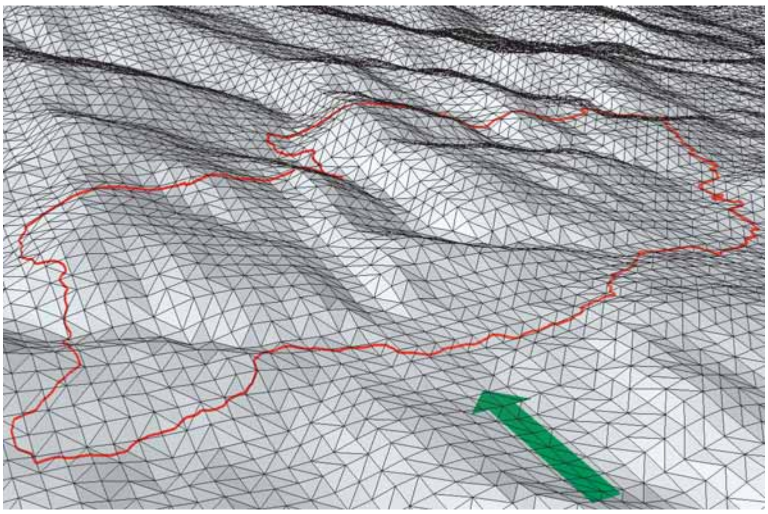

Fig. 3. Boundaries of a set of parcels projected onto the DTM (the arrow points the direction az=0)

Slika 3. Granice skupa čestica projicirane na DMR (strelica označava smjer az=0)

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 (2×3.4GHz, 2GB, 2×136GB 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 that can be expected, i.e. as a relative measure of difference between performances on different types of queries.

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 3×3" 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 60×90 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 količina točaka DMR-a, koju je danas vrlo lako prikupiti, neprikladna za održavanje i korištenje ako nije prethodno obrađena ponajprije izradom TIN-a. Već iz toga se može zaključiti kako će u slučaju dobro organiziranoga nacionalnog sustava za upravljanje topografskim podacima DMR biti pohranjen u obliku TIN-a, prilagođenoga konkretnim potrebama. Može se pretpostaviti da će na nacionalnoj razini biti određena potrebna preciznost kojom se moraju obavljati sva računanja za koja je potrebno koristiti službenu visinski prikaz površine države te da će i DMR biti prilagođen tim zahtjevima. Iz tog razloga u okviru ovog istraživanja uzeto je kao činjenica postojanje nacionalnog DMR-a, i to pohranjenog kao TIN.

Prema obrazloženju iz prethodnog poglavlja naše istraživanje polazi od pretpostavke da postoji baza podataka DMR-a modelirana kao mreža trokuta, te prethodno obrađena i optimizirana tako da zadovoljava sve službene potrebe za preciznošću računanja. Sada nas za svaku odnosno za pojedinu katastarsku česticu zanimaju podaci o njezinu azimutu odnosno nagibu jer te dvije značajke određuju među ostalim njezinu proizvodnu sposobnost, a time i vrijednost. Na raspolaganju je DMR s trokutima s unaprijed (off-line) izračunanim ili on-line dostupnim podacima o azimutu i nagibu svakog trokuta te njegovo prostorno protezanje u 2D ili 3D obliku. Te su opcije podrobnije opisane u poglavlju o izvedbi sustava. Korištenjem standardnog skupa prostornih operatora (ISO 2004) moguće je za svaku katastarsku česticu prema bazi podataka postaviti SQL upit koji vraća njezinu vrijednost (Slika 2).

Rezultat jednog upita za katastarsku česticu bit će skup prostornih objekata određenih presjecima katastarske čestice i pojedinog trokuta. Konačni rezultat može se dobiti izborom klasa za pojedine raspone vrijednosti azimuta odnosno nagiba te zbrajanjem površina presjeka u skladu s tim klasama. Isto je tako moguće odrediti jedinstvenu numeričku vrijednost koja bi bila rezultat postupka, a ta može biti na primjer težinska aritmetička sredina. Težinska sredina diskretnog skupa brojeva $\{x_1, x_2, ..., x_n\}$ s težinama $\{t_1, t_2, ..., t_n\}$ dana je izrazom:

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

Dakle, ako površine presjeka smatramo težinama pojedinih vrijednost azimuta i nagiba za jednu katastarsku česticu, onda se težinska sredina dobiva dijeljenjem umnožaka svake površine presjeka s njezinom vrijednošću azimuta (ili nagiba) sa zbrojem svih površina. Prikazano kao algoritam, to je:

- pronaći skup presjeka tražene k.č. i svih trokuta koji su u prostornom odnosu s njom,
- za svaki presjek
  - izračunati površinu,
  - prikupiti podatke o azimutu i nagibu,
  - obaviti potrebna zbrajanja i množenja
- sljedeći presjek,
- vratiti srednji azimut i nagib.

5. Izvedba i djelovanje sustava

Prema zahtjevima navedenima u prethodnom poglavlju osnovane su dvije baze prostornih podataka, i to katastarska i topografska na poslužitelju Katedre za upravljanje prostornim informacijama. Svi su radovi obavljeni na Oracle10g instanci pokrenutoj na HP Proliant ML 370 (2×3.4GHz, 2GB, 2×136GB SCSI Raid 1) poslužitelju. Na poslužitelju je bio pokrenut i cijeli sustav Oracle Application Server pa rezultate treba uzeti samo kao pokazatelje reda veličine očekivanih performansi odnosno kao relativne odnose između performansi pojedinih vrsta upita.

5.1. Priprema baze podataka DMR-a i katastra

Za potrebe projekta ostvarena je baza DMR-a za područje jedne manje županije (površine oko 640 km^2). Podaci su preuzeti s interneta (URL1), gdje se za cijelu Europu slobodno može preuzeti DMR 3×3" nastao kroz SRTM (engl. *Shuttle Radar Topography Mission*) položajno referenciran u prostornom referentnom sustavu WGS84. Korištenjem podataka prethodno pohranjenih u bazu i vanjske aplikacije za obradu DMR-a (Microstation Geoterrain) stvoren je TRSG za željeno područje. Prethodno su položajni podaci transformirani u pravokutni državni koordinatni sustav, čime je na izabranom području dobiven raster točaka razmaka otprilike 60×90 metara. Od ulaznih oko 100 000 podataka (točaka) SRSG nastalo je oko 200 000 trokuta TRSG. Tablica je nazvana *tin2d*, a stupac tipa *sdo_geometry* nazvan je *geometrija* i na njemu je uspostavljen 2D prostorni r-tree indeks.

Iako je u korištenom SDBMS-u u okviru prostornog tipa objekta moguće pohraniti prave 3D podatke te uspostaviti 3D prostorni indeks (Oracle 2003), što intuitivno izgleda kao pogodno za implementaciju modela podataka DMR-a, ovdje je potreban drugačiji pristup. Naime, ako se na 3D modeliranim podacima uspostavi 2D prostorni indeks, moguće je koristiti i svu 2D analitičku funkcionalnost jer sustav prilikom izvođenja funkcija jednostavno zanemaruje *Z* koordinatu. Nadalje je važno opisati način upravljanja podacima o azimutu i nagibu. Te je podatke moguće unaprijed (off-line) izračunati i pohraniti zajedno s geometrijom trokuta. Ipak, zbog očekivanja vrlo velikih količina podataka, ovdje smo htjeli isprobati djelovanje sustava korištenjem funkcije za računanje nagiba i azimuta u trenutku pristupa, pa su za to pripremljene dvije zasebne funkcije nazvane *nagib* i *azimut* te kodirane u PL/SQL-u. Funkcije za proslijeđeni objekt tipa *sdo_geometry* korištenjem koordinata triju točaka, računaju vektor normale i iz njega nagib odnosno azimut ravnine u kojoj se trokut nalazi. Podaci jednog skupa katastarskih čestica (5100 k.č. i površine oko 5 km^2) smještenog na blago brežuljkasti dio testnog područja pokrivenog DMR-om (Slika 3), pohranjeni su u tablicu *katastarska_cestica*.

Stupac s prostornim podacima nazvan je *geometry1,* koji je također indeksiran 2D prostornim r-tree indeksom. Za potrebe te razine isprobavanja implementacije sve su tablice pohranjene u okviru iste sheme u bazi.

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

Tablica 1. Vremena obavljanja upita za različite vrste katastarskih čestica

Number of parcels Broj k. č.	**Number of points** Broj točaka	**Number of triangles** Broj trokuta	**Time of response (sec)** Vrijeme obavljanja (sek)
1933/3	4	1	0.02
3317/3	96	20	0.20
3231	189	75	0.87
3318	401	98	1.91
1117/1	187	132	1.39

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 3), were stored in the table *katastarska_cestica*.

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 first simple query returns the data on the slope (azimuth) of a particular cadastral parcel as the weighted mean of the slope (azimuth) of all triangles which are spatially related to it (¬DISJOINT is implemented as *anyinteract* in the Oracle) (Oracle 2003). The simple SQL query, which calculates for the particular cadastral parcel (number 3200/1) the mean azimuth and slope, is now:

```
SQL> select
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,0.01),0.01))
srednjiazimut, 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))
srednjinagib from katastarska_cestica c,
tin2d t where SDO_ANYINTERACT(t.geometrija,
c.geometry1) = 'TRUE' and c.broj='3200/1';

SREDNJIAZIMUT SREDNJINAGIB
------------- ------------
   110.959577   17.4386812
```


To test the speed of response to such a query, depending on the number of points that make up the cadastral parcel and the triangles involved, the one with the biggest number of points was selected. This can be done using a SQL query such as:

```
SQL> select * from(select g.broj
broj_cestice,SDO_UTIL.GETNUMVERTICES(g.geometry1)
z from katastarska_cestica g order by z desc)
where rownum=1;

BROJ_CESTICE                                  Z
---------------------------------- ----------
3318                                        401
```

The same query with the reverse sorting of results gives the cadastral parcel with the minimal number of points. The cadastral parcel that is spatially related to the largest number of triangles can be determined with:

```
SQL> select * from (select c.broj
broj_cestice, count(t.rowid) z from
katastarska_cestica c, tin2d t,
table(sdo_join('katastarska_cestica',
'geometry1', 'tin2d', 'geometrija',
'mask=ANYINTERACT')) j where j.rowid1=c.rowid
and j.rowid2=t.rowid  group by c.broj order
by z desc) where rownum=1;

BROJ_CESTICE                                  Z
---------------------------------- ----------
1117/1                                      132
```

Again, the reverse sorting gives the cadastral parcel that is spatially related to the smallest number of triangles. Before timing, the server was restarted, and both tables were analysed. 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).

To be able to test the efficiency of mass calculation of the mean azimuth and slope values without the need to copy the data to the local database, a view was created which performs the calculations for all the records in the table with cadastral parcels.

```
CREATE OR REPLACE VIEW POGLED_SREDINE
("BROJ_KC","GEOMETRIJA","AZIMUT","NAGIB") AS
select c.broj,(select k.geometry1 from
katastarska_cestica k where k.broj=c.broj),
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,0.01),0.01))
srednjiazimut,
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))
```

5.2. Djelovanje sustava

Upiti se prema sustavu postavljaju korištenjem uobičajenog SQL-a. Prvi jednostavan upit vraća podatak o nagibu (azimutu) tražene katastarske čestice kao težinske sredine nagiba (azimuta) svih trokuta koji su s njom u prostornom odnosu (¬DISJOINT je u Oraclu implementirano kao *anyinteract*) (Oracle 2003). Jednostavan SQL-upit koji za konkretnu katastarsku česticu (broj 3200/1) računa srednji azimut i nagib je:

```
SQL> select
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,0.01),0.01))
srednjiazimut, 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))
srednjinagib from katastarska_cestica c,
tin2d t where SDO_ANYINTERACT(t.geometrija,
c.geometry1) = 'TRUE' and c.broj='3200/1';

SREDNJIAZIMUT SREDNJINAGIB
------------- ------------
   110.959577   17.4386812
```

Kako bi se ispitala brzina obavljanja takvog upita ovisno o broju točaka katastarske čestice i broju zahvaćenih trokuta, pronađena je ona s najviše točaka. To je ostvareno neposrednim SQL-upitom, npr.:

```
SQL> select * from(select g.broj
broj_cestice,SDO_UTIL.GETNUMVERTICES(g.geometry1)
z from katastarska_cestica g order by z desc)
where rownum=1;

BROJ_CESTICE                                    Z
--------------------------------------- ----------
3318                                          401
```

Isti upit uz obratno sortiranje rezultata daje katastarsku česticu s najmanjim brojem točaka. Katastarske čestice koje su u prostornom odnosu s najviše trokuta pronalazimo upitom:

```
SQL> select * from (select c.broj
broj_cestice, count(t.rowid) z from
katastarska_cestica c, tin2d t,
table(sdo_join('katastarska_cestica',
'geometry1', 'tin2d', 'geometrija',
'mask=ANYINTERACT')) j where j.rowid1=c.rowid
and j.rowid2=t.rowid  group by c.broj order
by z desc) where rownum=1;
BROJ_CESTICE                                    Z
--------------------------------------- ----------
1117/1                                        132
```

Obrnutim sortiranjem dobiva se katastarska čestica koja je u prostornom odnosu s najmanjim brojem trokuta. Prije ispitivanja obavljen je "restart" poslužitelja i obje tablice su analizirane. Rezultati su dobiveni kao aritmetička sredina mjerenja vremena iz 6 serija ponovljenih postavljanja upita za svih pet katastarskih čestica. Dobivena vremena pokazuju da se i kod katastarskih čestica reda veličine nekoliko stotina točaka odnosno onih koje su u prostornom odnosu s više od stotinu trokuta, dobivaju vremena odaziva reda veličine nekoliko sekunda (tablica 1).

Kako bi se mogla ispitati isplativost masovnog računanja srednjih vrijednosti azimuta i nagiba bez kopiranja podataka u lokalnu bazu, napravljen je "pogled" koji to obavlja za sve zapise u tablici s katastarskim česticama:

```
CREATE OR REPLACE VIEW POGLED_SREDINE
("BROJ_KC","GEOMETRIJA","AZIMUT","NAGIB") AS
select c.broj,(select k.geometry1 from
katastarska_cestica k where k.broj=c.broj),
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,0.01),0.01))
srednjiazimut,
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))
srednjinagib from katastarska_cestica c,tin2d
t, table(sdo_join('katastarska_cestica',
'geometry1','tin2d','geometrija','mask=
ANYINTERACT')) j where j.rowid1=c.rowid and
j.rowid2=t.rowid group by c.broj
```

Sada se mogu postavljati upiti i za cijeli skup katastarskih čestica:

```
SQL> set timing on;
SQL> select avg(azimut),avg(nagib) from
pogled_sredine;

AVG(AZIMUT) AVG(NAGIB)
----------- ----------
130.696266  17.7869134

Elapsed: 00:01:54.63
```

Očekivano vrijeme odaziva računanja statističkih funkcija za cijeli skup katastarskih čestica (5100 komada), reda veličine nekoliko minuta, prihvatljivo je jer će se takvi upiti postavljati rijetko. Time se otvara mogućnost pretraživanja skupa katastarskih čestica i prema kriterijima nagiba i azimuta. Na primjer, upit koje sve čestice imaju vrijednost srednjeg azimuta između 120 i 220 stupnjeva i srednji nagib veći od 20 stupnjeva sada glasi:

```
select count (*) from pogled_sredine where
azimut>120 and azimut<220 and nagib>20
```

Radi zornijeg uvida takvi se upiti mogu i vizualizirati korištenjem raspoloživog softvera. Prikaz prethodnog upita (slika 4) ostvaren je korištenjem jednostavnog i besplatnog preglednika (URL2) koji može uspostaviti vezu s korištenom SDBMS.

Na slici su zelenom bojom prikazana područja koja zadovoljavaju kriterije definirane u upitu.

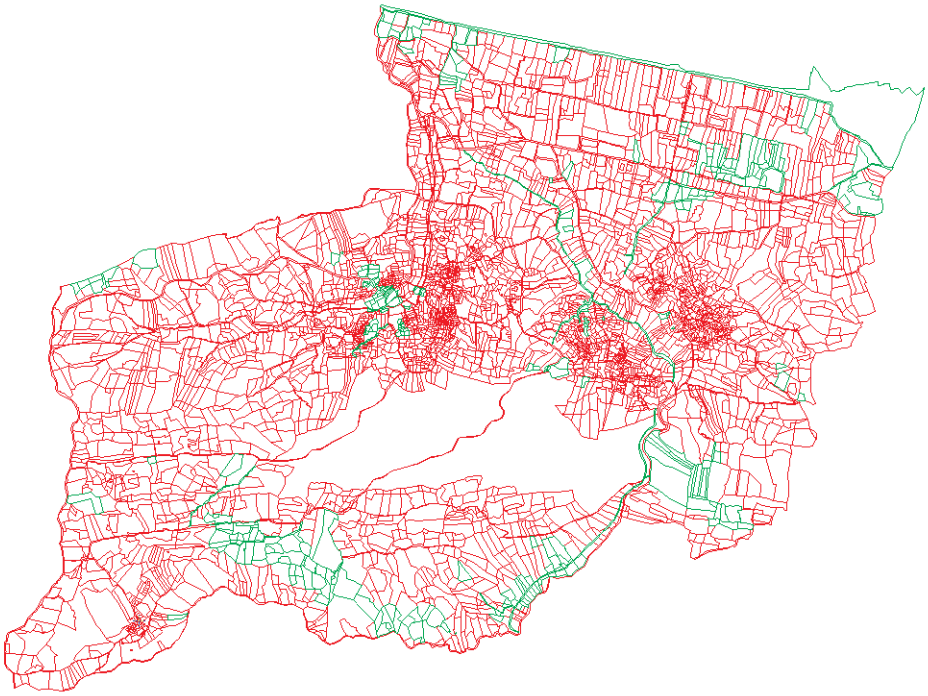

Fig. 4. Display of results of a query based on mean azimuth and slope

Slika 4. Prikaz rezultata upita prema srednjem azimutu i nagibu

```
srednjinagib from katastarska_cestica c,tin2d
t, table(sdo_join('katastarska_cestica',
'geometry1','tin2d','geometrija','mask=
ANYINTERACT')) j where j.rowid1=c.rowid and
j.rowid2=t.rowid group by c.broj
```

Now, queries can be made for the whole set of cadastral parcels:

```
SQL> set timing on;
SQL> select avg(azimut),avg(nagib) from
pogled_sredine;

AVG(AZIMUT) AVG(NAGIB)
----------- ----------
130.696266  17.7869134

Elapsed: 00:01:54.63
```

The expected time of response in the case of calculating statistical functions for the whole set of cadastral parcels (5100 parcels) within the scope of a few minutes is acceptable, since such queries will be rare. Furthermore, now it is a possible to search the set of cadastral parcels according to the criteria of slope and azimuth. For example, the query about which parcels have the mean azimuth between 120 and 220 degrees and the mean slope over 20 degrees, is as follows:

```
select count (*) from pogled_sredine where
azimut>120 and azimut<220 and nagib>20
```

For better insight, these queries can be visualized using the available software. A display of the previous query (Fig. 4) is possible in a simple and free viewer (URL 2), which can establish a connection to the used SDBMS.

The green areas in the figure are those that meet the criteria specified in the query.

6 Conclusions 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.

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 behaviour in the real world conditions. Also, it is necessary to optimise 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.

6. Zaključak i daljnji rad

U radu je nakon analize mogućeg modela podataka DMR-a državne razine prikazana metoda računanja karakterističnih vrijednosti nagiba i azimuta katastarske čestice. Navedena metoda temelji se na određivanju prostornih presjeka pojedinih trokuta iz DMR-a i upotrebom njihovih površina i vrijednosti nagiba i azimuta te računanjem težinske sredine.

Ispitivanjem konkretne implementacije dobiveni su preliminarni rezultati vremena odaziva na upite za jednu kao i za grupu od 5100 katastarskih čestica čime je pokazano kako bi implementacija bila svrsishodna i dovoljno učinkovita.

Kako su ispitivanja obavljena na logički i fizički istoj instanci baze podataka, daljnji rad može se temeljiti na uspostavljanju okruženja s odvojenim sustavima katastarske i topografske odnosno baze podataka DMR-a te simuliranju višestrukog istodobnog pristupa, čime bi se dobio uvid i u očekivanje ponašanja pod stvarnim uvjetima. Osim toga potrebno je obaviti i optimizaciju funkcija za računanje azimuta i nagiba pojedinog trokuta. Upotrebom odvojenih funkcija neka se računanja obavljaju redundantno, što se možda može ubrzati unificiranjem funkcije za računanje obiju vrijednosti.

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