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Invitation Paper

OPTIMIZATION OF LAND DISTRIBUTION IN URBAN LAND CONSOLIDATION

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***Abstract**: This paper describes the legal framework and the problems of urban planning in the Republic of Serbia. Basic principles of urban land consolidation whose application would improve the urban land development are discussed. The possibility for defining the redistribution of land mass as an optimization mathematical model, which can be solved using the single criteria or multi criteria methods of operational researches in urban land consolidation is presented. The requirements of land redistribution are mathematically modeled so that when combined can form single criteria or multi criteria optimization models adapted to the characteristics of the land consolidation area. Two models are defined: linear single criteria optimization model adapted to solving with simplex method and multi criteria model adapted to solving with weight coefficients method. The case study Ovča confirmed the applicability and advantage of using these optimization models.*

***Keywords**: urban land consolidation, optimization, land mass, mathematical model, redistribution, weight coefficient model.*

1. INTRODUCTION

The spatial and urban planning depends on the historical and cultural heritage, ideology, politics, socio-economic development and the way of life. Land development largely depends on the state and legislation at various levels, from national to local. Land development is influenced by size of investments, investors, experts, various interest groups, organizations and individuals.

The purpose of the spatial and urban plans is their implementation in a given period on a specific area and must be balanced with the real interests of both land and buildings owners and the urban community in terms of development and meeting public needs, protection and sustainable development. The successful implementation of urban plan demands resolving the conflicts of interests, especially when the properties over real estates are in question.

The main objective of urban land development includes preparation of the land for construction (preparation of urban plans, resolving property issues, etc.), as well as the construction of utility infrastructure, public facilities and traffic areas. Local government, through a system of urban design, ensures complete management and protection of land. Recently in Serbia, this segment of spatial development was significantly damaged by inadequate planning and disregard for regulations and the emergence of illegal building that has degraded the area of urban settlements. Providing area for building lots did not follow the demographic changes in urban areas, and where the urban plans were developed there wasn’t conditions for their consistent implementation. Positive method of urban land development (forming of building lots) that inevitably arises in Serbia is urban land consolidation. Implementation on urban development by urban land consolidation (land redistribution) is used in a number of mostly European and Asian countries, and the leaders in that area are Germany and Japan. Urban land consolidation procedures in individual countries are generally different in terms of relations and the role of local authorities, landowners, attitude to urban planning and attitude to the distribution of the costs and benefits of the procedure.

2. DOCUMENTS FOR SPATIAL AND URBAN PLANNING IN SERBIA

The spatial and urban planning in the republic of Serbia is regulated by the law [13] that defines the documents for spatial and urban planning such as: 1) planning documents which include spatial and urban plans; 2) documents for the implementation of spatial plans and 3) technical documents.

The defined spatial plans are: 1) Spatial plan of Republic of Serbia (national level); 2) Regional spatial plan (regional level); 3) Local spatial plan (municipal or city level) and 4) Spatial plan of special purpose area.
According to the law urban plans are: 1) General urban plan; 2) General regulation plan and 3) Detailed regulation plan.

The documents for the implementation of spatial plans [13] are: 1) Implementation program of spatial plan of Republic of Serbia; 2) Implementation program of regional spatial plan and 3) Implementation program of spatial plan of special purpose area.

The technical documents for implementation of planning documents are: 1) urban design and 2) redistribution and allotment design.

Documents for spatial and urban planning were changed in the past in terms of their definition and content in accordance with the changes of the social systems and perception of social needs.

Geodetic survey as the basis for urban designing (cadastral, topographic and utility maps) represent the property's and positional technical basis for dimensioning and shaping of building lots and spatial distribution of the items on the plan (buildings, infrastructure, etc.).

3. PROBLEMS OF URBAN PLANNING IN SERBIA

The Republic of Serbia through the change of social and political systems had different phases of urban land development. In the period of socialism property over land was not important, while on the other hand the urban plans that couldn't be implemented were designed. Migration of the population from rural to urban areas was intense and caused an increased need for space for housing. Lack of urban plans and inability to implement the existing ones, as well as violation of legal procedures in construction led to illegal construction of all types of buildings. De facto, today in Serbia, there is not enough formed building lots on the market, which directly slows construction industry and economic development of the country. At present it is rightful to say that the adequate solutions are only just noticeable. Those solutions should eliminate the irregularities of the past and define the right ways of effective planning and environmental protection. One such solution to the unsustainable position is the urban land consolidation which is prescribed by law (announced) in 2011 and its detailed elaboration is yet to come.

Up to now implementations of urban plans consisted on shaping and determining the borders of building plots where, in most cases, the existing allotment didn't suit the new parcel borders, or the necessary rules for construction and public needs. The new building lot is usually composed of parts of existing cadastral parcels belonging to different owners and in practice, very often, it represents the insurmountable obstacle to resolving the property issues. The end result is that the building plot belonged to one subject, who would gain the right of construction on it. Conflict between designed and actual situation is encouraged also by the difference between the actual and the cadastral borders.

Because of the existing problems every urban plan requires its specificity and appropriate legal and technical approach for its implementation. Because of that it is necessary to anticipate through legislation and practice, all possibilities of urban plans production taking into consideration all types of situations in all parts of Serbia. Adequate legal mechanisms of urban land consolidation protect owners' interests, take care of public interest and contribute to the conductive concept in real time. The experiences of many countries in the world (Germany, Japan, France, Thailand, Indonesia, South Korea etc.) [1], [2], [3], [4], [5], [8], clearly show that it is true.

4. BASIC PRINCIPLES OF URBAN LAND CONSOLIDATION

Urban land consolidation is applied in urban land development of areas on the outskirts of the settlements that are spread on adjacent land, and can be applied to smaller partially taken areas inside the settlements. Urban land consolidation is used for shaping or creation of conditions for shaping building lots, providing land for streets, parks and public areas, at the same time with regulation of property rights (figure 1). New allotment gives the land owners the plots with the area and shape adapted to the criteria defined by urban planning, with the required access from the street.

Common needs reduction coefficient is higher than in land consolidation of agricultural land and ranges from 20 to 30%, because providing land for streets, parks and public areas. However, on the other hand, the value of new lots is significantly increased because of providing the legal and urban prerequisites for construction, leaving both the land owners and the local government the benefits.

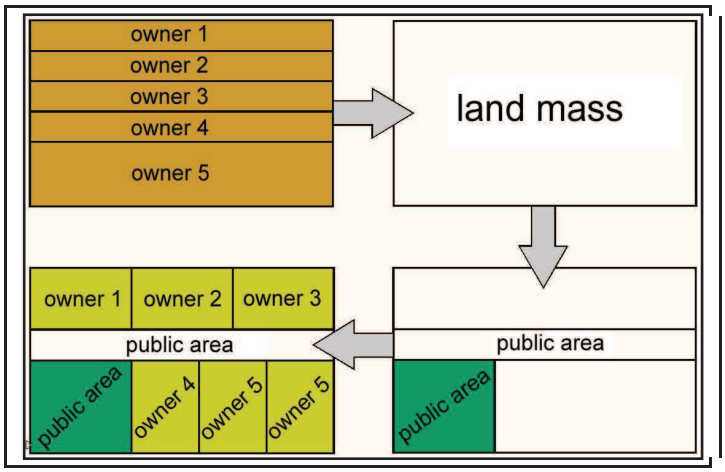

Figure 1. Schematic of urban land consolidation

The implementation of the procedure of urban land consolidation and the definition of the area must be regulated in accordance with the urban plan. The subject of urban land consolidation is land inside the defined area except the building lots which are defined or built in accordance with current urban plan, parcels that have the shape and area defined by current urban plan and parcels with built objects on them whose shape and area can be changed so the parcel coincide the current urban plan.

Figure 2. An example of a small area where urban land consolidation is performed

Valuation in urban land consolidation is based on market value of land. An example of a small area where urban land consolidation is performed (allotment) is shown in Figure 2. For planning of phases of urban land consolidation foreign experiences can be used, while taking into account domestic legislation.

Indubitably, one of the most sensitive phases in urban land consolidation is the redistribution of land mass, or distribution, shape and size of the new building lots. According to research presented in the paper [6], analogous to the application of optimization methods for redistribution of land mass in land consolidation of agricultural land could also be applied in urban land consolidation.

5. APPLICATION OF OPTIMIZATION TO CREATING REALLOTMENT PROJECT

For defining applicable methods of land mass distribution in this paper we rely on the mathematical model presented in the paper [6]. Optimization mathematical models that can be used for the land mass distribution in urban land consolidation can be defined as single criterion or multi-criteria.

5.1. Single criterion optimization model

Considering the general formulation of linear programming mathematical model [6] adapted to solving with simplex method and mathematically modelled requirements for grouping lots and land mass redistribution, the following mathematical model could be set as:

Objective function

$$\min F = \sum_{i=1}^{n} \sum_{j=1}^{m} w_{ij} x_{ij} \tag{5.1}$$

with constraints

$$\begin{aligned} &\sum_{j=1}^{m} x_{ij} = VT_i, \quad i = 1,2,...,n, \ \sum_{i=1}^{n} x_{ij} = VP_j, \quad j = 1,2,...,m \\ &DL \le x_{ij} \le GL, \quad i = 1,2,...,n; \quad j = 1,2,...,m. \end{aligned} \tag{5.2}$$

Therefore, we seek the maximum value of objective function F which is the product of distribution coefficients w_{ij} and the unknown value of new parcels x_{ij}. The first group of constraints (5.2) means that the sum of new plots in a block be equal to the value of that block (VTI). The second group of constraints (5.2) means that the sum of new plots of each participant is equal to the values of parcels (VP_j), entered into the land mass. Instead of equality signs we could include inequality signs. Then we could allow a defined percentage smaller or greater value of new parcels to be assign to the block, and the compensation could be given in money. The third and fourth group are the minimum (5.2) (DL) and maximum (GL) value of new parcels.

Coefficient w_{ij} and unknowns x_{ij} in the objective function can represent the following properties:

1. the sum of the old lots of redistribution participants that fall into the newly designed blocks $w_{ij} = c_{ij}$,
2. the reciprocal of distance between land consolidation blocks and holders' yards $w_{ij} = d_{ij}^{-1}$,
3. the reciprocal of the absolute difference between the ratio of lots (holdings) values and area which participants entered the land consolidation process with and ratio of reallocation blocks values and area $w_{ij} = | KP_j - KT_i |^{-1}$, and
4. wishes of land consolidation participants in percent (points) according to priorities ($w_{ij} = z_{ij}$); for instance: z_{ij} could take 100 for the primary desire, 80 for the first alternative, 60 for the second alternative, etc.

The system of inequality constraints can be extended to new groups of equations or inequations. The first group of equations constraints can be replaced with two new groups of constraints if we want to respect certain tolerance assigned parcel areas.

$$\sum_{i=1}^{n} x_{ij} \ge VP_j(0.9 + k), \quad (j = 1,2,...,m), \quad \sum_{i=1}^{n} x_{ij} \ge VP_j(1.1 - k), \quad (j = 1,2,...,m). \tag{5.3}$$

The second group of constraints can also be replaced with two new groups of equations which provides tolerance to the sum of new plot by blocks.

$$\sum_{j=1}^{m} x_{ij} \ge 0.9 * VT_i, \qquad (i = 1,2,....,n), \quad \sum_{j=1}^{m} x_{ij} \le 1.1 * VT_i, \qquad (i = 1,2,....,n), \tag{5.4}$$

5.2. Multi-criteria optimization model

Multi-criteria programming allows introducing more objective criteria functions. Considering mathematical modeling of the land mass redistribution that is presented in (Mihajlović, 2010), it is evident that the multi-criteria programming can include a greater number of defined requirements simultaneously, thus allowing objective optimization of land mass redistribution. This is certainly another step closer to actual implementation of operations research in the land mass redistribution practice.

The forming of a mathematical model starts from the fact that the distribution coefficients in criteria function (5.2) ($w_{ij} = c_{ij}$, $w_{ij}=d_{ij}^{-1}$, $w_{ij} = |KP_j - KT_i|^{-1}$ ili $w_{ij}=z_{ij}$) are not in the same measurement units, thus must be normalized. Single criterion objective function (see [6]) are:

$$\begin{aligned} &\max F_1 = \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}x_{ij}, \quad \max F_2 = \sum_{i=1}^{n}\sum_{j=1}^{m} d_{ij}^{-1}x_{ij}, \\ &\max F_3 = \sum_{i=1}^{n}\sum_{j=1}^{m} \left|KP_j - KT_i\right|^{-1} x_{ij}, \quad \max F_4 = \sum_{i=1}^{n}\sum_{j=1}^{m} z_{ij}x_{ij} \end{aligned} \tag{5.5}$$

and they are normalized so that for each of them we calculate new values of coefficient:

$$g_{kij} = \frac{w_{kij}}{\sum_{j=1}^{m} w_{kij}}, \quad i=1\ldots n, \quad k=1\ldots p. \tag{5.6}$$

Normalized objective function has the following form:

$$\max F_k = \sum_{i=1}^{n}\sum_{j=1}^{m} g_{kij}x_{ij}, \quad \text{za} \quad k=1,2,\ldots,p=4; \tag{5.7}$$

Constraints, with such defined objective functions, can be made by combining the equations defined in [6]. For instance, they may be:

$$\begin{aligned} &\sum_{i=1}^{n} x_{ij} = VP_j, \ \text{za} \ i=1,2,...,n; \ \sum_{j=1}^{m} x_{ij} \geq VT_i * P1_i, \ \text{za} \ i=1,2,...,n \\ &\sum_{j=1}^{m} x_{ij} \leq VT_i * P2_i, \ \text{za} \ i=1,2,...,n, \\ &x_{ij} \leq GL, \ \text{za} \ i=1,2,...,n; j=1,2,...,m, \ x_{ij} \geq DL, \ \text{za} \ i=1,2,...,n; j=1,2,...,m \end{aligned} \tag{5.8}$$

where

$VT_i \cdot P1_i$ is the upper limit of the sum of new lots that fall in the block i (building blocks),
$VT_i \cdot P2_i$ is the lower limit of the sum of new lots that fall in block i.

For the coefficients P1 and P2 deviations percentage (e.g. 2%) could be taken to the discretion of (the designers) but their value does not exceed ±10%. Upper and lower limit for the value of new parcels can be determined in the phase of calculating according to values and shapes of land consolidation blocks that are designed according to the rules of urban land development.
Thus a mathematical model can further customized to specificity of the methods defined to solve multi-criteria optimization problems such as interactive methods for solving like the STEM (STEP Method) method, weight coefficients method, the criteria functions space bound methods or the goal programming [6].

5.3. Urban land consolidation area OVČA

An example of the application of optimization models for the land mass redistribution in land consolidation model for urban design (urban land consolidation) is considered in the land consolidation area OVČA, whose basic parameters are shown in Table 1. The land consolidation area was included in the General Plan of Belgrade (Figure 3), in which the land purpose is set for housing (yellow coloured land). Land consolidation area is defined within the limits of defined purpose for the south part of settlement Ovča.

CHARACTERISTICS OF LAND CONSOLIDATION AREA OVČA	
LAND CONSOLIDATION SITE AREA	118.6775 ha
NUMBER OF PARTICIPANTS	205
NUMBER OF PARCELS	446
AVERAGE AREA OF PARCELS	0.3927 ha
AVERAGE VALUE OF PARCELS	0.3590
RATIO VALUE : AREA	0.91

Table 1. Characteristics of land consolidation area OVČA

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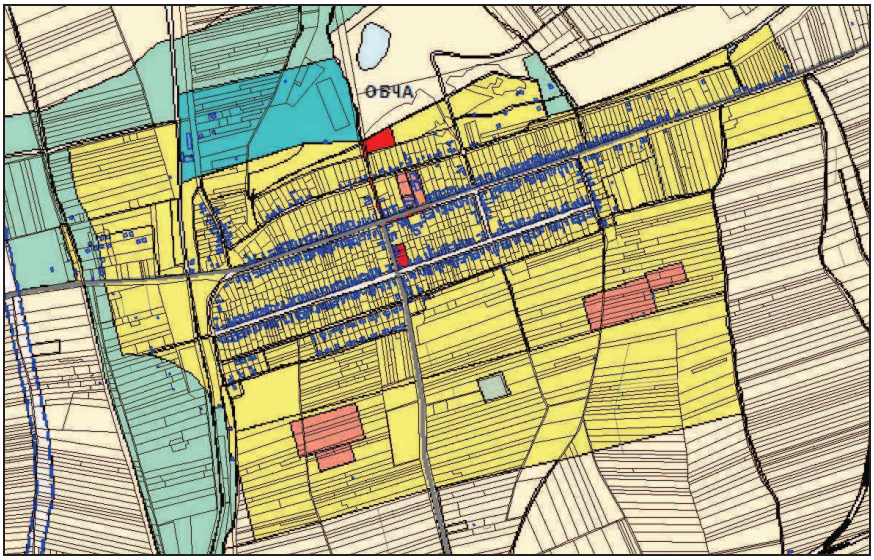

Figure 3. Purpose according to city development plan in settlement Ovča (a suburb of Belgrade), where there are conditions for the realization of urban land consolidation

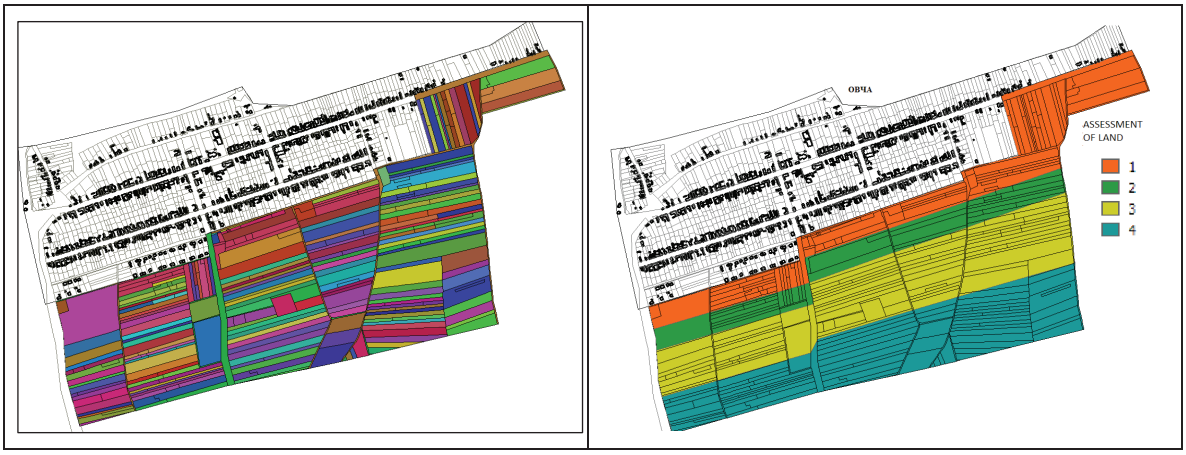

Figure 4. Borders of parcels before land consolidation coloured by owners and general map of land consolidation assessment

Figure 4 shows the parcels of defined land consolidation site in cadastral municipalities Ovča in the borders prior to consolidation, coloured according to holders (land consolidation participants) and general map of land consolidation assessments, and Figure 5 shows the design of field roads (new streets) which form 33 land consolidation blocks (blocks for building purpose).

In the assessment land consolidation site is divided into four zones (Figure 4 i 5). Basic criterion for determining the land value was the distance from settlement Ovča. The coefficients of assessment classes are determined in that manner and their values are: q_1=1.000, q_2=0.900, q_3=0.800 and q_4=0.700.
Optimization of the land mass redistribution included the use of single criterion Simplex method and weights for three different coefficients in the objective function are:

1) the total value of the old plots by land consolidation blocks ($w_{ij} = c_{ij}$),
2) distance of land consolidation blocks from the Ovča settlement centre, ($w_{ij} = d_{ij}^{-1}$)
3) the wishes of land consolidation participants expressed as primary (100 points), secondary (80 points) and tertiary (60 points) ($w_{ij} = z_{ij}$) .

As constraints for single criterion optimization inequality systems are taken (5.3) and (5.4), for multi-criteria optimization inequalities system of (5.8), with no upper limit.

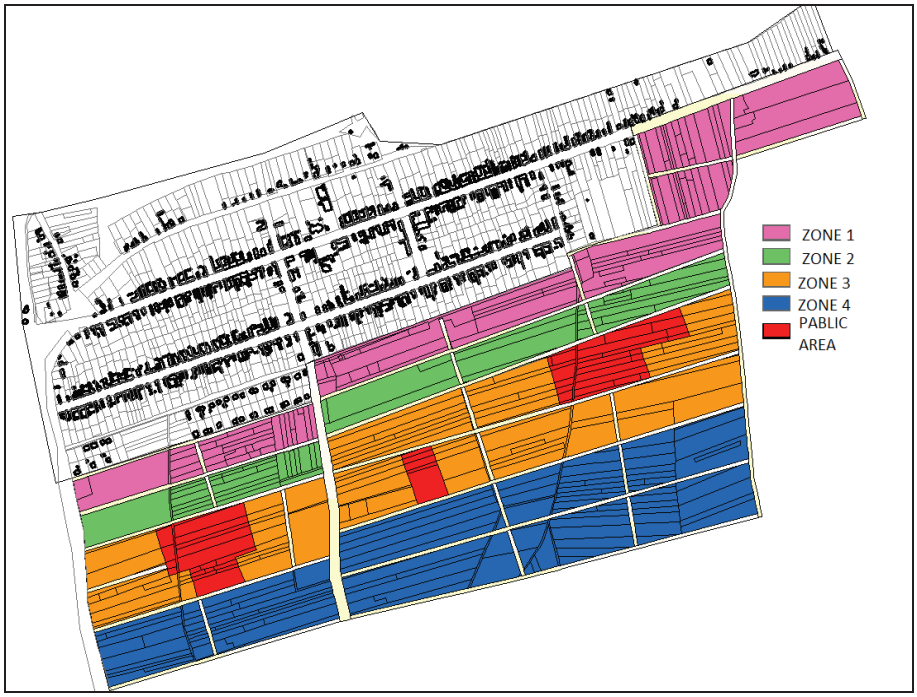

Figure 5. Project field roads (streets), of land consolidation blocks by zones and blocks of land for construction of public facility

Criteria 1 and 2 restrict the distribution of new parcels only to tables where there are old parcels, or for which there are participants wishes expressed, while the criterion 3 includes the entire area of defined zone (all blocks).

Formation and resolution of optimization models for land distribution was done by defined zones. For calculation of the new parcel values by land consolidation blocks, MATLAB scripts were used:

1. JKRaspodelaS for simplex method, and
2. VKRaspodelaTK for weight coefficient method.

Comparative results of calculations of new plots for the four optimization models are presented in Table 2. As the cheapest option for the land mass redistribution optimization multi-criteria optimization number 4 was selected - The method weights with three different coefficients in the objective function. w_{ij}=c_{ij}. $w_{ij} = z_{ij}$ and w_{ij}=d_{ij}^{-1}, for which the distribution of parcels by blocks was done using a Matlab script Nadela (Figure 5). This way obtained agricultural parcels would in the future be brought to purpose by forming building parcels in accordance with the rules of urban design plan. In this example, obtained parcels are not definitively dimensioned according to the rules of urban design, but they provide a good basis for the development of individual redistribution projects, which is a significant improvement comparing to the existing forms of parcels and illegal construction. Also on the basis of this

optimization building parcels could be designed instead of agricultural and using that design as the basis participants could be introduced to the property.

No.	OPTIMIZATION MODEL	PARCEL COUNT		AVERAGE PARCEL VALUE		ENLARGEMENT COEFFICIENT
		BEFORE LC	AFTER LC	BEFORE LC	AFTER LC	
ZONE 1						
1	SIMPLEX MODEL $w_{ij} = c_{ij}$	129	47	2286.2	4872.6	2.74
2	SIMPLEX MODEL $w_{ij} = z_{ij}$		49		4673.8	2.63
3	SIMPLEX MODEL $w_{ij}=d_{ij}^{-1}$		48		4771.1	2.69
4	WCM MODEL with 3 obj. functions		47		4872.6	2.74
ZONE 2						
1	SIMPLEX MODEL $w_{ij} = c_{ij}$	96	36	2478.5	3381.2	2.67
2	SIMPLEX MODEL $w_{ij} = z_{ij}$		41		2968.9	2.34
3	SIMPLEX MODEL $w_{ij}=d_{ij}^{-1}$		34		3580.1	2.82
4	WCM MODEL with 3 obj. functions		34		3580.1	2.82
ZONE 3						
1	SIMPLEX MODEL $w_{ij} = c_{ij}$	125	85	2898.6	2850.6	1.47
2	SIMPLEX MODEL $w_{ij} = z_{ij}$		80		3028.8	1.56
3	SIMPLEX MODEL $w_{ij}=d_{ij}^{-1}$		73		3319.2	1.71
4	WCM MODEL with 3 obj. functions		73		3319.2	1.71
ZONE 4						
1	SIMPLEX MODEL $w_{ij} = c_{ij}$	96	53	2584.9	2936.2	1.81
2	SIMPLEX MODEL $w_{ij} = z_{ij}$		56		2778.9	1.71
3	SIMPLEX MODEL $w_{ij}=d_{ij}^{-1}$		57		2730.2	1.68
4	WCM MODEL with 3 obj. functions		55		2829.44	1.75
LAND CONSOLIDATION SITE IN TOTAL						
1	SIMPLEX MODEL $w_{ij} = c_{ij}$	446	221	3590.1	3387.6	2.02
2	SIMPLEX MODEL $w_{ij} = z_{ij}$		226		3312.7	1.97
3	SIMPLEX MODEL $w_{ij}=d_{ij}^{-1}$		212		3531.4	2.10
4	WCM MODEL with 3 obj. functions		209		3582.1	2.13

Table 2. Comparative review of two optimization models for all four zones using different distribution coefficients in objective function

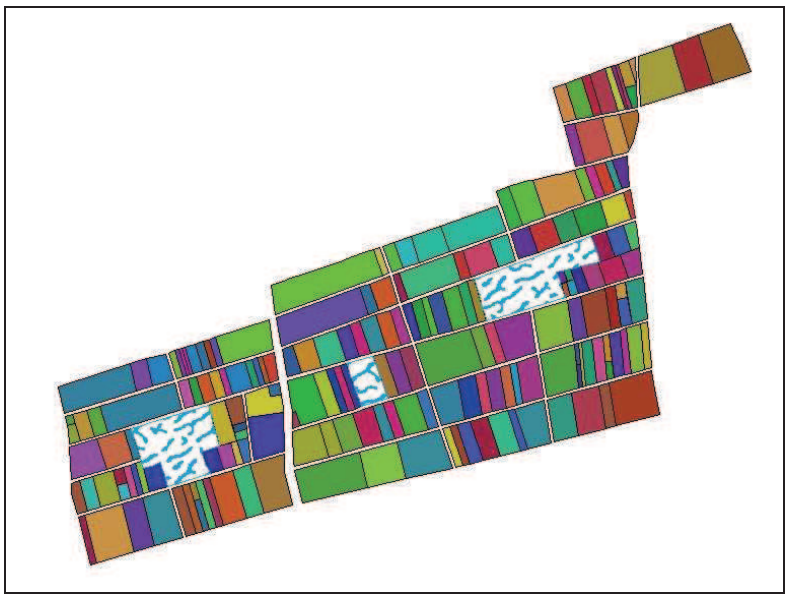

Figure 6. Showing boundaries of new parcels obtained with application of multi-criteria weight coefficient method with three objective functions (1, 3 and 4)

6. CONCLUSION REMARKS

Urban land consolidation as a method of building land redistribution provides real and very possible solutions in real time, allows the establishment of a new system of financing the acquisition of public land, provides the possibility of forming a large number of building parcels, which creates conditions for better trading, opens the perspective for development, adequate landscaping, and creates the basis for social welfare and sustainable development. Development of building land creates conditions for the free construction of housing, health, education, utilities, transport and other facilities.

Application of optimization of land mass redistribution is one of the segments to improve the technical possibilities of realization of urban consolidation, which creates a good basis for the design and layout of building parcels, especially on larger areas of land consolidation in which the land would be used as agricultural for many years until brought to purpose. In urban land redistribution it is quite irrelevant whether the individual owner will get his property in one or more pieces, which is not the case in redistribution of agricultural land. Instead of grouping properties, we set the requirement that any future cadastral (building) parcel is a separate building entity, i.e. that the form and size of the each parcel are adjusted to the building demands.

Application of urban land consolidation should be immediately launched in Serbia, especially in cities with intensive building and where the construction of buildings without the building approval took hold. Building land development with urban land consolidation would create an alternative to the illegal trade of land and illegal construction and enable the provision of land for public purposes, effectively resolve the property-legal relations and then saturating the market with a defined urban building land.

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