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# MULTI-CRITERIA LAND USE FUNCTION OPTIMIZATION

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**Abstract**

Space as a public good should be used in a way that is consistent with recognized social, cultural, aesthetic, economical and ecological values. The optimization of space is associated with its limitations, thus it should be subjected to rational management. Optimizing the function of city space involves identifying the most mismatched features of the area and a proposal to convert them into functions best suited with respect to the existing natural and anthropogenic, social, economic and ecological conditions. The selection criteria of the optimal use of land will be presented, as well as the parameters characterizing them and the possibility of using chosen multi-criteria methods of analysis. Social, economic and ecological criteria adopted for the analysis are the basis for the sustainable development of an area and coincide with factors which ought to be taken into account during the development of land-planning documents.

**Key words**: *multi-criteria analysis, optimization, land use.*

**JEL Classification**: R11, R14.

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## 1. Introduction

Space as a publicly used resource should be used in accordance with recognized social, cultural, esthetic, economic and ecological values. Spatial development is based on the principle of economy – the maximization of effects possessing the given spacial resources while minimizing expenditure in space to achieve the expected effects. Currently, the most proper method for the selection of spatial solutions would be to determine the Pareto optimality – an improvement in the situation of one specific spatial development entity would not negatively affect another entity. This approach should be concretely specified to find the golden mean between the studied quantities. Income from economic activity, obtained from space use, should be transferred for increasing its usefulness and restoring its quality to limit, to the maximum degree, the size of its use and create a reserve for new types of use (DOMAŃSKI 2006). Since space optimization is connected with its limitation, space should be developed rationally. An optimal solution with regard to only one criterion (e.g. cost) can rarely be found. The analyzed problems most often require the simultaneous consideration of many action

evaluation criteria in search of the optimal solution. One of the tools in determining the optimal land use function is multi-criteria analysis, which consists of supporting the decision-making process when several or a few dozen criteria are available. The aim of this analysis is the optimal selection of variants (obtaining one common result), taking into account different criteria with a crucial effect on the implementation and functioning of a given solution which, in this case, concerns the selection of the optimal land use function.

**2. Urban space optimization**

The need for sustainable development is the effect of man's innate will to maintain the natural order of the world, a certain "optimum" which enables the development of mankind and, above all, ensures their survival. The optimization of urban space functions aims to verify the most mismatched land functions and propose their replacement with functions best matched to the existing natural and anthropogenic features, as well as social, economic and ecological needs. Adaptation of problem areas – generating what are known as spatial conflicts, should be based on the opinion of the city's residents, reflecting their current needs, which can be called social optimization, and on so-called economic calculation – economic optimization, or assuming the minimization of environmental effects – ecological optimization (BIŁOZOR 2013).

Optimal spatial development is treated as a priority in modern land use planning. Every fragment of space has, or has the capacity to achieve, the optimal state of use at a given moment. However, every change in the use of the analyzed area should be preceded by determining the necessity and profitability of this transformation. It may turn out that the difference between the value of the future optimized land use and the value of the current use will be lower than the costs of transformation. Analysis and interpretation of social, spatial and economic information is the basis for the implementation of planning space optimization, as a tool facilitating the understanding of mutual relationships between all objects from the planning space, both in the scope of spatial development and economics, finance, management and demography.

The land use function change algorithm developed in an earlier study (BIŁOZOR 2012, 2013), as an instrument for optimizing planning space is, in this case, an element facilitating the making of the proper – optimal decision on the use of the analyzed area. This ordered set of operations, from which we will obtain the solution of a specific problem, i.e. the determination of the optimal land use function, has been modified and adapted to the specificity of spatial development. The procedure for conducting the decision-making process for the selection of the optimal land use function should be carried out in the following stages:

1. spatial monitoring – selection of an area where the change of function is possible or necessary;
2. setting the principles of social optimization – the development of principles and manners of conducting surveys concerning the state of space management, and interpretation of the obtained results;
3. determination of economic conditions for the optimality of the land function – an analysis of the land transformation process in regard to functionality, costs and profits:
   1) development of the principles of economic income optimization - analysis of real estate property transaction prices from the local real estate market, identification and analysis of the effect of elements of economic calculations in land transformation, determination of the optimal function generating the highest possible profit,
   2) development of the principles of economic cost optimization - identification of the anthropogenic and natural space features indicating the current state of land development, conducting an analysis of geoinformation necessary in the spatial optimization process, determination of the optimal function using the developed matrix of features producing the optimal land use;
4. analysis of the social, economic and ecological circumstances of the studied area – multi-criteria analysis of the appropriateness of changing the land function;
5. optimization of land use.

The correctness of the space use optimization procedure aims to minimize uncertainty in land use planning. The proposed system can be used on different scales (for a gmina - commune, poviat - district) and with diverse degrees of detail regarding spatial analyses. The final decision on a change in land use should take into account a number of social, economic and ecological factors, for the analysis of which it is necessary to apply multivariant analysis of the justifiability of the change in the

area's function. The basic principles of decision theory in land use planning have been successfully used by Polish and foreign research centers, with examples found, among others, in the following recent publications: BOWMAN et al. (2012); CHEN et al. (2012); FAN et al. (2006); KIRAN, JOSHI (2012); FRIEDMANN (2011); MINNERY et al. (2012).

### 3. Urban space optimization on the example of the town of Olsztynek

The procedure of selecting optimal land development was conducted in the town of Olsztynek. The central part of the town is intensively used. The housing and service function and the service function are dominant. The northern part is dominated by green areas – a forest, and non-cultivated green areas. The single-family housing function, non-cultivated green areas and Lake Jemiołowo are found in areas situated in the southern part of Olsztynek. The eastern part is dominated by industrial land and allotment garden areas, while the west contains single-family residential housing areas and green areas.

Ten areas where function change is possible or necessary were selected during so-called spatial monitoring. The choice was based, above all, on the opinion of the residents, who had indicated the least attractive places in Olsztynek in a survey. These are areas located mainly in the northern and southern part of the town, improperly developed and used, and causing a number of spatial conflicts. The location of the areas to be optimized is shown in Fig. 1.


**Fig.1.** The areas selected for conducting the optimization process. *Source*: own study based on www.geoportal.gov.pl.

These are areas where the dominant forms of development are: 1, 2 – forests, 3 – agricultural land, 4 – allotment garden areas, 5, 8, 9, 10 – non-cultivated green areas, 6, 7 – service areas. The local zoning plan, which has covered the whole town since 2006, provides for the function of forest parks and semi-open recreational areas for areas 1, 2, 3, 8 and 9, multi-family housing function for area 4, the service function for areas 5 and 7, the housing and service function for area 6, and finally the sports and recreation function for area 10.

The optimization of Olsztynek's urban space was planned taking into consideration three diametrically different approaches:

- social optimization,
- economic optimization,
- ecological optimization.

Each of the prepared analyses consisted of finding the best possible (optimal) form of land development, taking into account the type of approach used to tackle the analyzed problem.

Social optimization is directly related to the residents' expectations regarding the manner of land development in the city or town. This part of the work aims to examine the residents' preferences, needs and requirements regarding: the most and least attractive places in Olsztynek, the availability of social and commercial services, sports and recreation infrastructure and any lack of facilities and forms of development. A questionnaire survey conducted on a randomly selected group of 50 town residents indicated that:

- the most attractive places in the town are the square in front of the Olsztynek Town Hall, the Teutonic Knights' Castle and the Ethnographic Park (Skansen),
- the least attractive places in the town are the railway station, the town market, areas adjacent to Lake Jemiołowo, and the area behind Ratuszowa St.,
- the respondents evaluated the availability of social and commercial/service infrastructure as being at a quite good level as to the number of schools, kindergartens, grocery and general stores, and service outlets; only the availability of means of communication was evaluated as bad,
- the availability of sports and recreation infrastructure was evaluated far worse by the respondents. There is a lack of town beaches and life-guarded swimming areas, cycling routes, public recreation areas and facilities, playgrounds for children and meeting places for the residents.

The analysis of the answers given by the respondents, as well as technical and formal/legal conditions resulting from provisions in existing planning documents enabled the development of social optimization for the 10 areas of conflict indicated at the earlier stage of the study. The areas selected based on the performed analyses with the proposed optimal development function have been shown in Fig. 2. Taking into account the opinions of Olsztynek's residents, ten proposals for spatial development in the town have been created:

1. urban forest
2. northern park
3. commercial building
4. railway and bus station
5. recreational building
6. retail/service facility
7. urban marketplace
8. „Jemiołowo" park
9. watersport equipment rental
10. town beach

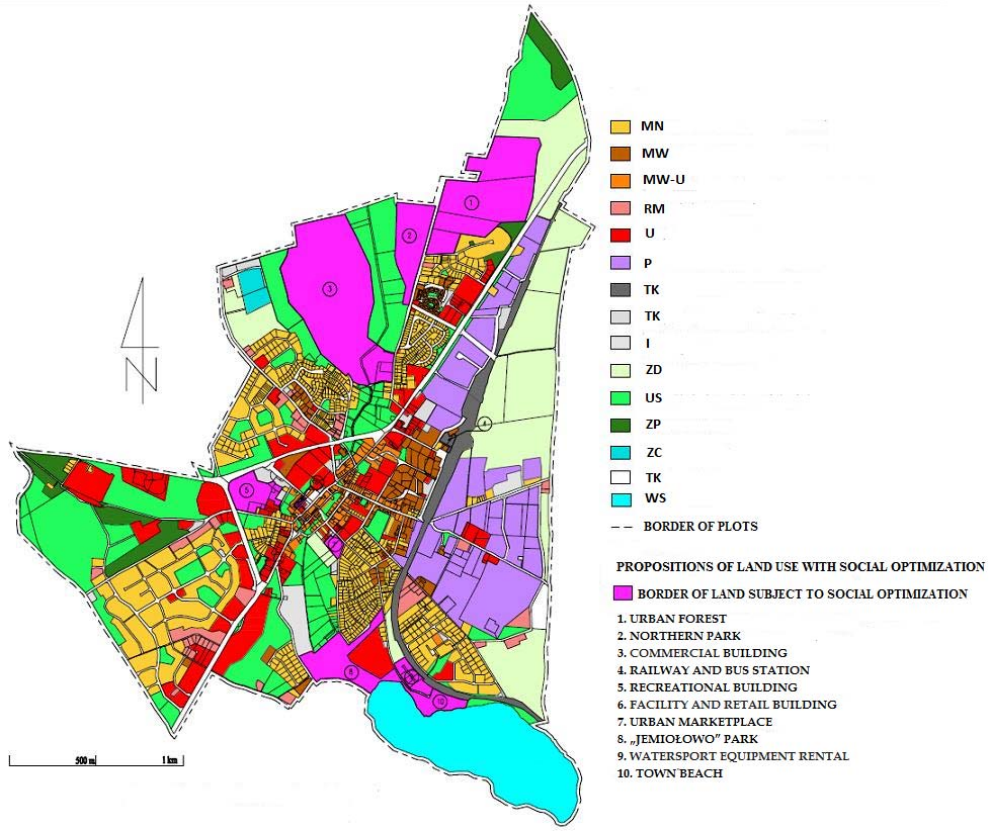
Such socially-optimized space meets the requirements declared by Olsztynek's residents.

Economic optimization focuses on a financial approach to land use planning. It consists of using the economic potential of space in the city or town to the maximum degree. In this case, the focus was on economic income optimization, where the optimal function – generating the highest possible profit – was determined for the 10 areas of conflict indicated at an earlier stage of study following the analysis of real estate transaction prices from the local real estate market and the analysis of the technical and formal/legal conditions of the change in the function of the area. According to data obtained from the Olsztynek Commune Office, only 22 transactions were recorded in the years 2012-2013 for the service, industrial, recreational and single-family housing functions. The low number of transactions and minimal differences in the recorded prices for individual functions allowed the average value to be adopted as a reliable statistical measure. Transaction price data for the functions which have been the object of trade in the last 2 years have been presented as averages below:

- 162 zł/m² in the case of land with the service function - location: central zone,
- 97 zł/m² in the case of land with the industrial function - location: peripheral zone,
- 64 zł/m² in the case of land with the single-family housing function - location: peripheral zone,
- 25 zł/m² in the case of land with the recreation function - location: peripheral zone.

All prices refer to land situated in the town of Olsztynek, serviced with technical infrastructure such as: electricity, gas, sewerage and water. The level of the average land prices for the individual functions outlines the general picture of the profitability of performing economic optimization in a

given area with respect to the change in the manner of development. The analysis of the obtained information showed that using land for service purposes is most profitable for economic reasons. This manner of optimization is also recommended due to a lack of such forms of use in the town. The location of interesting service facilities, which are lacking in the town, will significantly contribute to increased spatial value. Economic analysis, technical and formal/legal conditions, enabled the development of economic optimization for the 10 conflict areas indicated at an earlier stage of work. The areas of conflict that had been selected based on the performed analyses, along with the proposed optimal manner of development, have been shown in Fig. 3. Taking into account the results of economic optimization, ten proposals for spatial development were made:



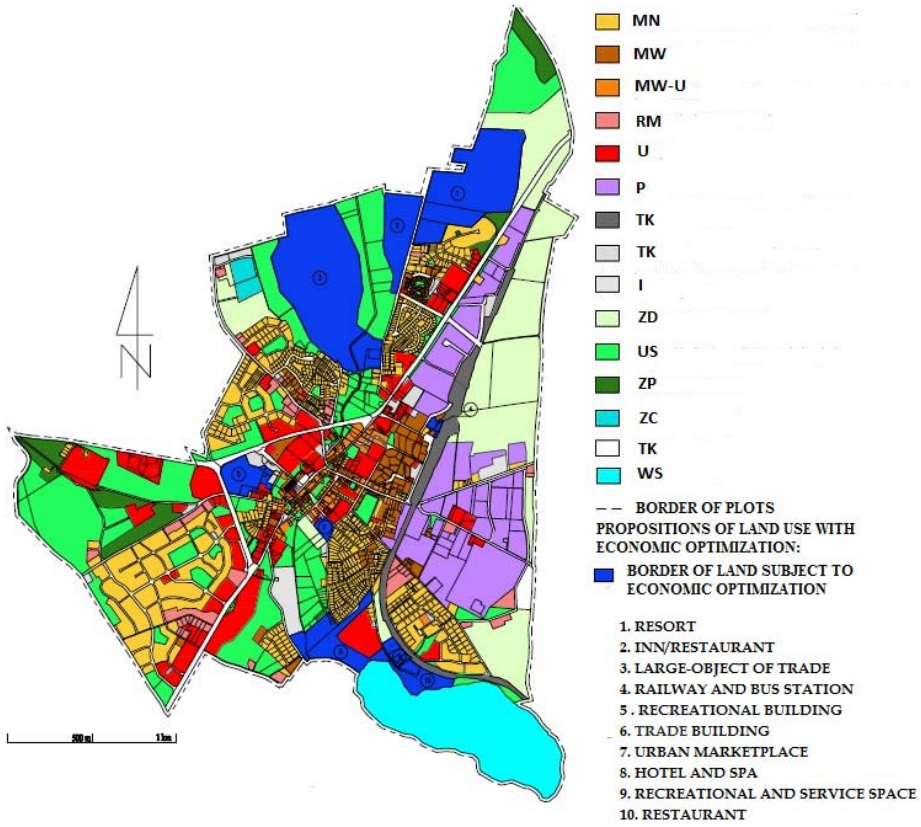

MN - Residential areas with single-family homes, MW- Residential areas with multi-family homes, MW-U - Residential and service areas, RM - Areas of farm buildings, U - Areas of retail-service buildings, P - Areas of productive facilities, depots and stores, TK - Areas of transport and technical infrastructure, TK- Areas with parking lots and garages , I – Areas of utilities , ZD - Areas of allotments, US - Sport and recreation areas, ZP - Natural green areas, ZC – Cemeteries, WS - Areas of inland surface water.

**Fig.2.** Social optimization. *Source*: own calculations based on – http://planowanie.olsztynek.pl/plan_miasta.html.

1. resort,
2. inn/restaurant,
3. large-object of trade,
4. railway and bus station,
5. recreational building,
6. trade building,
7. urban marketplace,
8. hotel and spa,
9. recreational and service space,
10. restaurants.

Performing economic optimization in Olsztynek would increase the attractiveness of the town in the eyes of residents, tourists and potential investors. This process would largely contribute to a change of the town's image and promote the economic development of the whole gmina.

Ecological optimization is focused primarily on environmental protection and its preservation in the best possible condition. A number of available documents concerning this sphere of urban space were analyzed to perform ecological optimization. The Study of Land Use Conditions and Directions of Olsztynek Gmina specifies the ecological priorities for individual areas, in which the following examples of aims were included.




MN - Areas with residential single-family homes, MW- Areas with residential multi-family homes, MW-U - Residential and service areas, RM - Areas of farm buildings, U - Areas of retail-service buildings, P - Areas of productive facilities, depots and stores, TK - Areas of transport and technical infrastructure, TK- Areas with parking lots and garages , I – Areas of utilities , ZD - Areas of allotments, US - Sport and recreation areas, ZP - Areas of natural greenery, ZC – Cemeteries, WS - Areas of inland surface waters.

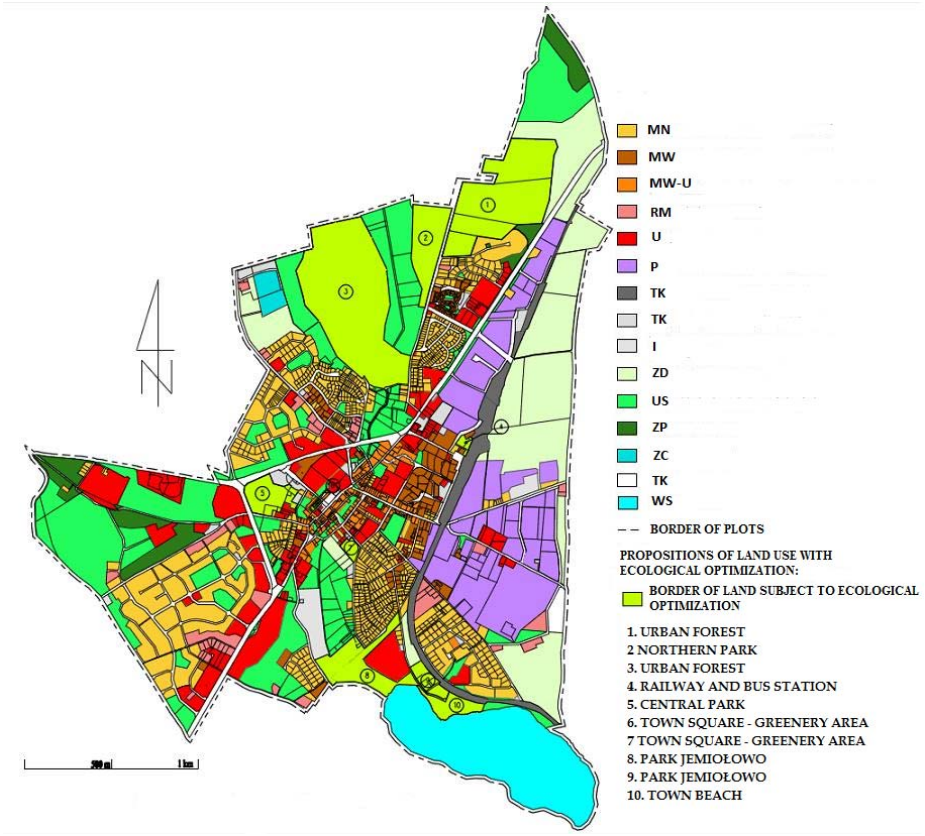
**Fig. 3.** Economic optimization. *Source*: own study based on http://planowanie.olsztynek.pl/plan_miasta.html.

- protection of the values and functioning conditions, as well as the spatial continuity of ecological systems,
- protection of the quality and resources of surface and ground waters,
- increasing the public's ecological awareness.

The analysis of the collected information served to develop ecological optimization, as well as indicate proposals for the manner in which the individual areas ought to be developed. Because there are no protected and valuable natural areas in the town, the indication of ten areas aimed at environmental preservation and protection against excessive human interference was proposed in the ecological optimization process. The areas of conflict selected based on the performed analysis, with the proposed optimal manner of development, have been shown in Fig. 4. The ten areas that are optimal from an ecological point of view along with their proposed manner of development can be found below:

1. urban forest,
2. northern park
3. urban forest
4. railway and bus station ,

5. central park,
6. town square - green area,
7. town square - green area,
8. park Jemiołowo,
9. park Jemiołowo,
10. town beach.




MN - Areas of the residential, single-family, MW- Areas of the residential, multi-family, MW-U - Residential and service areas, RM - Areas of farm buildings, U - Areas of retail-service buildings, P - Areas of productive facilities, depots and stores, TK - Areas of transport and technical infrastructure, TK- Areas of parking lots and garages , I – Areas of utilities , ZD - Areas of allotments, US - Sport and recreation areas, ZP - Areas of natural greenery, ZC – Cemeteries, WS - Areas of inland surface waters.

**Fig. 4.** Ecological optimization. *Source*: own study based on - http://planowanie.olsztynek.pl/plan_miasta.html.

Ecological optimization would significantly affect the condition of the natural environment in Olsztynek. The implementation of the aims specified during ecological optimization would greatly change the town's appearance and emphasize the esthetic values of the surrounding nature.

## 4. Multi-criteria land use function optimization

The proper location of new forms of development is an extremely important issue in spatial development. A number of important factors should be taken into account when seeking the optimal solution to the decision-making problem regarding land use function change. Each optimization performed by the authors concerns only one variant – social, economic or ecological. Therefore, a taking the three variants into consideration, the best solution for the given time and place should be sought. The final result of the conducted work is the combination of all three aspects to obtain an optimally-developed urban space. Using the basic principles of multi-criteria analysis, decision-making in regards to city planning can be supported, thus avoiding conflict situations. According to KALISZEWSKI (2008), multi-criteria decision-making consists of the selection of the most preferred variant, to which the decision-maker comes to as a result of "wandering" among the examined

variants, guided by evaluations of individual variants based on the adopted criteria, thus maximizing decision efficiency.

Multi-criteria analysis consists of supporting the decision-making process when several or even around a dozen criteria are available. Its aim is to obtain one common result (HEJMANOWSKA and HNAT 2009). The criteria used in multi-criteria analysis can be hard (barriers, limitations) or soft (parameters, factors). Using hard analysis criteria, an image representing the areas meeting and not meeting the set conditions is obtained. When applying soft criteria, the degree in which the given areas are suitable for meeting the goal specified during the analysis is acquired (the result is not as clear as in the case of hard criteria). This can also be called the degree of membership of a given criterion to the adopted goal. In this analysis, criteria are treated as members of fuzzy sets with specific degrees of membership to the goal function. Fuzzy decision systems are successfully used in very many fields of science, among others in medicine, pharmacology, economics, banking, chemistry, sociology, neuroengineering and, in recent years, also in land use planning (among others, in publications: ZHANG (2012); NOWICKI (2009); TAY, HO (1992); RENIGIER-BIŁOZOR, BIŁOZOR (2008)).

The criteria adopted for multi-criteria land use function optimization concern the need of meeting specific social, economic or ecological conditions by a given function. In the hard method applied by the authors – overlaying, they are defined as barriers and result in a so-called land suitability map (map [image] of optimal functions), which is the simple conjunction of individual suitability maps. An analysis performed based on hard criteria, determined during social, economic and ecological optimization, taking into account the minimization of possible spatial conflicts, allowed the optimal states of development (Table 1) to be identified and a map of land suitability for specific functions to be created (Fig. 5).

**Table 1**

List of the optimal forms of land use

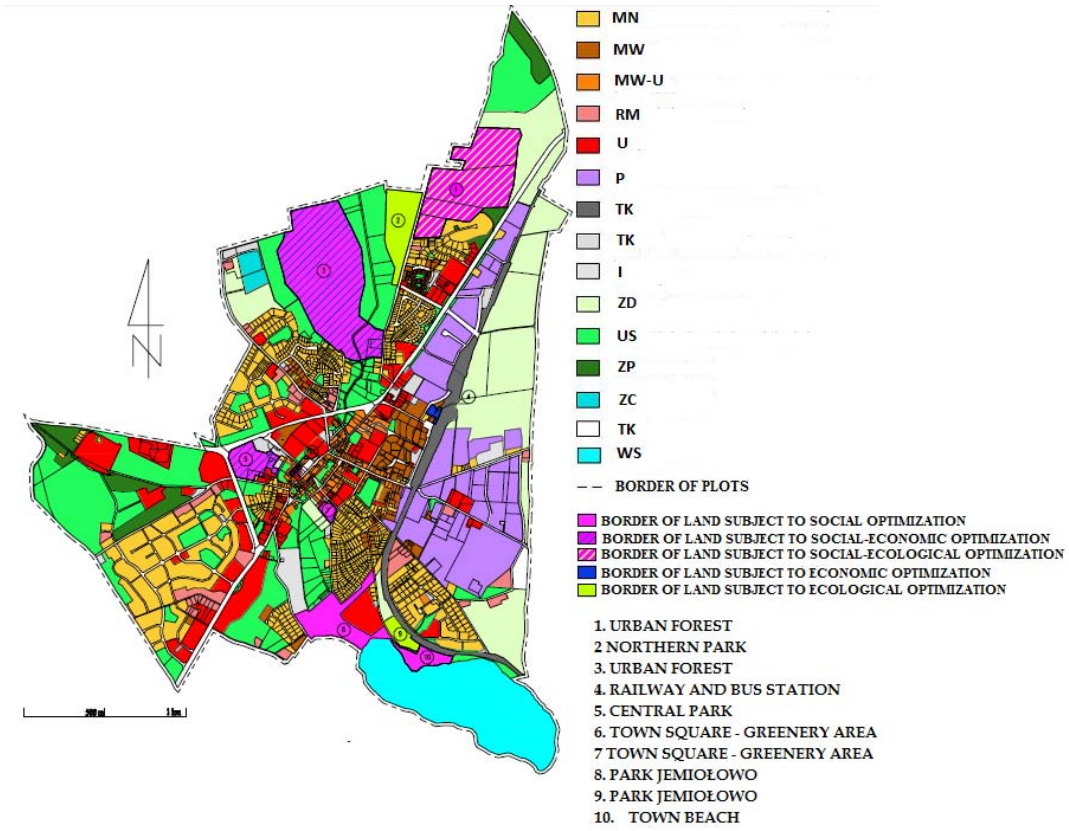
| No area | Optimization of space – function | | | The optimal form of land use (function / form of land use) |
|---|---|---|---|---|
| | Social | Economics | Ecological | |
| 1 | ZL | U | ZL | |
| 2 | ZP | U | ZP | ZP/ Northern park |
| 3 | U | U | ZL | U/ Commercial building |
| 4 | K | K | K-ZP | K/ Railway and bus station |
| 5 | US | US | ZP | US/ Recreational building – water park |
| 6 | U | U | ZP | U/Cafe |
| 7 | U | U | ZP | U/ Urban marketplace |
| 8 | ZP | U | ZP | ZP/ Park Jemiołowo " |
| 9 | US | U | ZP | US-ZP/Park Jemiołowo II with watersport equipment rental |
| 10 | US | U | US | US/Town beach |

*Source*: Own study.

The applied overlaying method shows that social expectations often coincide with proposals for ecological and economic optimization. In accordance with the theory of multi-criteria analysis, the dominant function, i.e. the one found most frequent in individual optimizations, was adopted as the optimal function in a given area in all of the analyzed cases. When the performed analysis did not clearly indicate the optimal function, selection was made by combining the least conflicting functions. Finally, the option resulting from social optimization was selected in 7 out of the 10 areas. For 4 out of the 10 cases, the selected optimal form of development coincided with economic optimization. Only in the case of 2 areas did the selected function result from ecological optimization. Once, the optimal land use function was the function formed from combining the 2 least-conflicting functions.

In the next method applied by the authors, that is the linear weighting method, soft criteria (parameters) are not converted into barriers, belonging to hard criteria. A fuzzy concept of defining suitable areas and boundaries between suitable and unsuitable areas is applied for the criteria which are parameters, while limitations, just as in the previous method, retain the character of hard criteria (HEJMANOWSKA and HNAT 2009). Proper degrees of membership to the goal function can be assigned to individual forms of optimization, depending on the model. In this method, parameters are standardized to a continuous suitability scale, ranging from, e.g. 0 (least suitable) to 1 (most suitable).

This scaling allows us, just as in the overlaying method, to combine and compare the criteria. Analyzing the results of the conducted research after the application of the above method, the degree of membership to (suitability for) a specific manner of optimization – for the goal function - should be determined for individual functions in social, economic and ecological optimization. The results of the conducted survey show which functions are most suitable for social optimization, and to what degree they belong to it. Because of a lack of studies on environmental protection in the gmina, the selection and determination of suitability and membership for the designed areas during ecological optimization largely depends on the natural environment, the character of the area and the possibilities of introducing individual natural forms.




MN - Areas with residential single-family homes, MW- Areas with residential multi-family homes, MW-U - Residential and service areas, RM - Areas of farm buildings, U - Areas of retail-service buildings, P - Areas of productive facilities, depots and stores, TK - Areas of transport and technical infrastructure, TK- Areas of parking lots and garages , I – Areas of utilities , ZD - Areas of allotments, US - Sport and recreation areas, ZP - Areas of natural greenery, ZC – Cemeteries, WS - Areas of inland surface waters.

**Fig. 5.** Optimization of the city of Olsztynek. *Source*: own study based on - http://planowanie.olsztynek.pl/plan_miasta.html.

**Table 2**

Summary of membership degrees for optimal forms of land use

| | Optimization | | |
|---|---|---|---|
| Function | Social - the degree of membership | Economic - the degree of membership | Ecological - the degree of membership |
| MN | 0.20 | 0.40 | 0.00 |
| U | 0.25 | 1.00 | 0.00 |
| US | 0.85 | 0.15 | 0.20 |
| P | 0.00 | 0.60 | 0.00 |
| IT | 0.00 | 0.00 | 0.00 |
| ZP | 0.60 | 0.00 | 0.60 |
| ZL | 0.40 | 0.00 | 0.80 |

*Source*: Own study.

According to the theory of fuzzy sets and the above criteria, the degrees of membership were determined for individual functions (Table 2) which are found in the town of Olsztynek and were taken into account in the land optimization process. Individual degrees of membership for social and ecological optimization were determined based on the results of the conducted survey, where the respondents indicated, on a scale from 0 to 1, whether a given function fit the optimal image of the town. The degrees of membership for economic optimization were determined proportionally to the possibility of maximizing income from a space.

The criteria adopted for the analysis concern the need of meeting specific social, economic or ecological and technical conditions by a given function. Suitability analysis performed based on the criteria determined during social, economic and ecological optimization allowed the optimal states of development (Table 3) to be identified for the space within the town of Olsztynek.

**Table 3**

List of the optimal forms of land use

| Function | Optimization | | | Optimal forms of land use (total points ) |
|---|---|---|---|---|
| | Social - degree of membership | Economic - degree of membership | Ecological - degree of membership | |
| 1 | ZL/0.4 | U/1.0 | ZL/0.8 | ZL (1.2) |
| 2 | ZP/0.6 | U/1.0 | ZP/0.6 | ZP (1.2) |
| 3 | U/0.25 | U/1.0 | ZL/0.8 | U (1.25) |
| 4 | K/0.10 | K/0.0 | K-ZP/0-0.6 | K (0.7) |
| 5 | US/0.85 | US/0.15 | ZP/0.6 | US (1.0) |
| 6 | U/0.25 | U/1.0 | ZP/0.6 | U (1.25) |
| 7 | U/0.25 | U/1.0 | ZP/0.6 | U (1.25) |
| 8 | ZP/0.6 | U/1.0 | ZP/0.6 | ZP (1.2) |
| 9 | US/0.85 | U/1.0 | ZP/0.6 | U (1.0) |
| 10 | US/0.85 | U/1.0 | US/0.2 | US (1.05) |

*Source*: Own study.

The multi-criteria analysis performed above shows that social expectations most often coincide with proposals for ecological optimization. The function with the dominant sum of degrees of membership was adopted as the optimal function for a given area in all the analyzed cases. When the performed analysis did not clearly indicate the optimal function, the selection was made by combining the least conflicting functions. The option resulting from social optimization was selected for 9 areas. In 6 out of the 10 cases, the optimal manner of development coincides with economic optimization. Only in the case of 4 areas did the selected form of development coincide with the result of ecological optimization.

## 5. Conclusions

A developing city or town, organizing itself according to the adopted laws of a specific system of mutual connections and relationships, cannot remain in an unchanging state and undergoes a process of constant transformations. It changes as a whole, and its elements as well as the relationships between them go through changes. The development of a city or town is a continuous process and there is no "target state" which a city strives to attain. Every attained state is transitional and forms the basis for the next stage. For urban spatial development, every change is connected with the erection of a new building (structure or facility) or with the development of a part of the area. The search for solutions which are optimal for a given area should be one of the priority tasks in modern urban spatial development.

Performing multi-criteria analysis when selecting the optimal land use function showed the possibilities of its application as a tool supporting decision-making in city planning. The criteria adopted for the analysis: social, economic and ecological, are the basis for the sustainable development of a given area and should be taken into account in optimal land development planning.

Optimization of Olsztynek's urban space functions was intended to verify the most mismatched land functions and propose their replacement with functions best matched to the existing social, economic and ecological demands. The resulting spatial picture is neither extremely risky nor devoid of risk. Although Olsztynek is a town with great potential, it is not optimally used. The reconciliation

of social, economic and ecological interests is an extremely complicated task. Application of multi-criteria analysis in the optimization of urban space functions will help to eliminate conflict areas from the town and determine the hierarchy of proposals for function changes.

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