Concept of Evaluation and Optimization of Spatial Structures

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Abstract. Start Human striving for perfection is reflected in the optimisation. The adjustment of problem areas, i.e. those generating so-called 'spatial conflicts' should be based on inhabitants’ opinions, in order to reflect their current needs and on the so-called economic calculation. The optimisation of spatial processes makes sense when the adopted criteria reflect the actual preferences of space users. Most often, the problems under analysis require that numerous criteria for the assessment of conduct while searching for an optimum solution be considered and that a decision on a change to its use be taken. It is the tasks in the field of optimisation and poly-optimisation that are widely used for the selection and modification of the space. Additionally, the process of optimisation is described as a task aimed at finding the best variant of a solution to a particular problem, while the process of poly-optimisation is described as a task aimed at finding a set of compromise variants. The application of optimisation and poly-optimisation procedures in the process of spatial design offers a number of advantages, for example supporting the decision-making process in an effective manner, formulating detailed principles of choice, discovering new areas of a solution, building a platform for discussions while negotiating and visualising multi-faceted situations. The optimisation and poly-optimisation of spatial processes primarily refers to the reasonableness and cost-effectiveness of a change to functions of an area. This comes down to taking decisions on a change to land use, which results in specific development status and spatial structures making optimum use of spatial potential. The main aim of the study was to develop the concept and the rules of optimisation and poly-optimisation of spatial structures. As demonstrated in the study, the combination of methods of optimisation and poly-optimisation of spatial structures with a comprehensive analysis and classification not only enables an increase in the effectiveness and reliability of spatial analyses and an assessment of property market but also, in combination with appropriate tools, allows one to determine the potential of the space along with the prospects of development, which serve an extremely important role in the spatial economy.

1. Introduction
A specific feature of current human spatial activity is the planned appropriation of space, which is mainly associated with socio-economic development. Administration of space is based on the principle of economy, i.e. the maximisation of effects while having specific space resources at one’s disposal and, at the same time, minimisation of expenditures in order to achieve the expected results. The need for optimum use of space results from its limited nature, from the existence of certain
boundaries, and from a specific size, shape and capacity which must not be exceeded. Due to the limited nature of space, it is also required that it be administered in a reasonable and, most often, in terms of economy, effective manner. Human striving for perfection is reflected in the optimisation. The adjustment of problem areas, i.e. those generating so-called 'spatial conflicts' should be based on inhabitants’ opinions, in order to reflect their current needs and on the so-called economic calculation. The optimisation of spatial processes makes sense when the adopted criteria reflect the actual preferences of space users. An optimum solution based only on a single criterion (e.g. cost) can rarely be found. Most often, the problems under analysis require that numerous criteria for the assessment of conduct while searching for an optimum solution be considered and that a decision on a change to its use be taken. It is the tasks in the field of optimisation and poly-optimisation that are widely used for the selection and modification of the space. Additionally, the process of optimisation is described as a task aimed at finding the best variant of a solution to a particular problem, while the process of poly-optimisation is described as a task aimed at finding a set of compromise variants. The application of optimisation and poly-optimisation procedures in the process of spatial design offers a number of advantages, for example supporting the decision-making process in an effective manner, formulating detailed principles of choice, discovering new areas of a solution, building a platform for discussions while negotiating and visualising multi-faceted situations. The optimisation and poly-optimisation of spatial processes primarily refers to the reasonableness and cost-effectiveness of a change to functions of an area. This comes down to taking decisions on a change to land use, which results in specific development status and spatial structures making optimum use of spatial potential.

2. The concept of evaluation and optimization of spatial structures

The proper selection and arrangement of urban areas to be used in a variety of ways is essential to meeting the economic, functional and planning needs of the city. The problem of assessment, valuation and classification is one of the fundamental issues in the research on all relationships between people and their environment. In this case, classification seeks to determine the order of the analysed phenomena in time and space and to understand the complexity of these phenomena and determine their structure and dynamics. An analysis of the structure and of the nature of the surrounding space helps determine as to whether attractive prospects exists and whether the growth potential is present in the area under analysis. This is why a procedure was proposed for assessment and classification of spatial structures, being part of a decision-making system, based on an analysis of the situation in the property market in the form of a rating. A rating is a process and a result of an assessment, classification of a particular phenomenon. Using the generalised and extended notion of a rating, and going beyond the capital market, the process of preparing ratings may concern not only the areas of investment but also other aspects associated with the classification of spatial phenomena and processes.

Since properties and their resources in specific markets play an increasingly important role in global economy and attract increasing numbers of international investors, the demand for reliable classification and scoring systems has become a significant tool in the process of investment planning. The carried out assessment and classification of spatial structures is the first step of an assessment of the reasonableness of going through the process of land or property optimisation. The low score achieved in the rating process means that there is a need to go through the process of optimisation or poly-optimisation of the space or particular components of the spatial structures under analysis.

An assessment and classification of spatial structures, as well as the optimisation of these structures or their particular components, is determined by having a resource of information at one’s disposal, which allows one to carry out regionalisation of the area under study. The starting point is to make an inventory of anthropogenic, natural, social, and economic information concerning the object being assessed, which can be a city as a whole, a district, a street or even a specific property.

The most commonly known definition of optimum land use is such a use which, from legal and physically possible forms of use that are “coherent with its purpose”, generates the highest land value. The optimum status of land use may be understood as a function of the needs of humans and nature,
i.e. as a sum of the values of natural and anthropogenic features, which results in the highest value of land. In addition, there is a conflict between the need to satisfy human needs and the need for changing the use along with a change to the conditions of the environment and the natural potential.

The optimisation of land use, particularly in urbanised areas, requires that a number of tasks raised at the stage of studies and task analyses be solved which minimize the possibility for the emergence of spatial conflicts. The optimisation method is otherwise referred to as the method for land valuation, and it has originated in Poland as the “Warsaw optimisation method” [1]. The method was developed in the years 1961–1963 as a tool supporting the planning of urban development after the Second World War. The purpose of the method was to find a reasonable location for investment projects in a city. The main adopted principles were the minimisation of costs of acquiring land as well as of investment and operating costs. When possible land uses were determined, and combinations of particular variants were developed, a model helped evaluate the investment and operating costs.

The concept of optimisation of spatial structures is based on an analysis of social, economic and ecological needs. Social optimisation, where the subject of research is the relationships between humans and the physical, architectural environment, provides a picture of social needs and expectations as regards architectural and urban solutions and results in the proper and diversified development and functioning of a city. Social optimisation is based either on surveys or, e.g. on the so-called mental maps drawn by respondents, which are prepared in order to identify social needs and preferences. Economic optimisation of spatial structures is based on the economic calculation as regards the maximisation of income or minimisation of transformation costs. Ecological optimisation involves the protection and preservation of the natural environment and ecological potential of the area under analysis in the best possible condition.

The concept of a procedure for carrying out an assessment and classification of spatial structures and the selection of the optimum land use which were developed and described in the real estate rating publications: [2], [3], [4], [5], optimisation of the urban space: [6], [7], [8], [9], [10] and on the basis [11], [12], [13], should proceed through the following stages (Figure 1).

The algorithm of land use assessment and change, being an instrument of optimisation of a planning space, will, in this case, be an element that facilitates making the right, i.e. optimum, decision concerning the use of the area under analysis. This ordered set of tasks, by which we will obtain a solution of a specific task, i.e. carrying out an assessment and the designation of the optimum land use. A modified algorithm of decision making, adjusted to the specificity of spatial economy, is presented and described in detail below.

The structure of the decision-making support system in the process of land use optimisation is primarily based on an assessment and classification of spatial structures and on so-called “spatial monitoring”. Spatial monitoring of urbanised areas is based on an analysis of the status of space development as well as identification, location, and selection of areas in which a change to functions is possible or necessary (this primarily concerns the functions of “non-urban” nature [5], [6], which are not explicitly associated with a city, i.e. agricultural areas, orchards, allotments, uncontrolled natural greenery areas, etc.).

The adaptation of problem areas which generate the so-called spatial conflicts and have an adverse effect on the image and quality of the land use should be based on city dwellers’ opinions and reflect their current needs, which can be defined as social optimisation, and on the so-called economic calculation, which can be referred to as economic optimisation.
Figure 1. A model of the decision-making support system in the process of land use optimisation. Source: own work based.

Survey-based social optimisation requires that a questionnaire be drawn up, and a survey be carried out in order to determine social preferences (for the entire population by means of e.g. a referendum, public consultation, or for selected units from a sample) as regards the development of a particular city or its part (a specific district).

Economic optimisation is focused on the financial approach to spatial planning, and involves the use, to the greatest extent possible, of the economic potential of the space. Economic optimisation can be implemented in two planes – through the minimisation of transformation costs, or through the maximisation of incomes. Minimisation of costs involves the optimum use of natural and anthropogenic features of the area under analysis through a matrix of natural features [4], resulting in the optimum use of the area – a matrix of relationships between the functions of the urban space with the characteristics of the area – Table 1.

| No. | Urban space function | MN | MW | U | US | UC | P | ZP | ZC | WS | K | IT |
|-----|----------------------|----|----|---|----|----|---|----|----|----|---|----|

Table 1. Matrix of connections of urban space functions (the land use function) with land features and with the present infrastructure
As for economic income optimisation, the focus was on an analysis of transactional prices of properties from the local property market, being objects of market trade over recent years, and an analysis of technical as well as formal and legal determinants of a change to the functions of the area.

Using linear programming and the mathematical notation of optimizing conditions for the land function, it can be determined whether a given area can be subjected to the transformation process while meeting two basic conditions:

- the sum of natural and anthropogenic values for the given function is higher than the natural and anthropogenic values of the current function;
- the economic value after the transformation is highest compared to the current one and relative to the other land functions.

If these basic conditions for the optimality of the land function are not met, the highest sum of natural, anthropogenic and economic values after the transformation of the land should be assumed as its solution [6]. Ecological optimisation was primarily focused on the protection and preservation of the natural environment in the best possible condition.
The correct land use optimization procedure allows the reduction of uncertainty in the spatial planning process. The proposed system can be used on a different scale and at different levels of spatial analyses detail, and for so-called "spatial monitoring", which is used to analyse and verify particular land development forms [6]. The basic criterion of optimization is the so-called objective function, so, in this case, minimisation of modification costs (where: $f(x) = x_{\text{cost}} \rightarrow \text{minimum}$) and maximisation of social expectations (where: $f(x) = x_{\text{social}} \rightarrow \text{maximum}$), economic incomes (where: $f(x) = x_{\text{economic}} \rightarrow \text{maximum}$) or ecological values (where: $f(x) = x_{\text{ecological}} \rightarrow \text{maximum}$).

3. Optimization for spatial processes – case study
The optimum land development selection procedure was carried out in the area of the Town of Toruń. An assessment and classification of the existing spatial structures, developed in the form of rating, carried out at the first stage of the optimisation process, specifies the reasonableness of the entire process. The specified condition and quality of the use of a space, and the proper location of new forms of development, are an extremely important issue as regards spatial administration.

According to the concept of evaluation and classification of spatial structures [2], [3], the real estate market in Toruń was assessed at the level: B (Moderate return on investments. Moderate market outlook. Certain threats to market growth potential (supply and demand on the real estate market). Moderate potential for economic and spatial growth. Lower self-regulatory capacity, less flexible response to economic changes. The situation on the real estate market fosters moderately positive social change. Greater discrepancies between the cost and prices of real estate. Less predictable behavior of real estate market actors. Moderate threats to the growth of the real estate market. The situation on the real estate market fosters moderately positive social change.)

In the process of so-called “spatial management” 10 areas with possible or necessary change of function were selected. These are areas located in different parts of the town, developed and used in an improper way, and thus causing a number of spatial conflicts. The location of areas designated for optimization is presented in Figure 2.

Figure 2. The areas selected for conducting the optimization process, source: own study with the use of google maps and geoportal web page

Results of the survey indicate which functions, and to what extent, are most useful for social optimization. In the survey, the inhabitants’ needs and requirements were determined as regards the most and the least attractive places in the city, the availability of social, trade and services, and sports
and recreational infrastructure, missing objects, and forms of area development. In respect of land development forms, the residents lack the most:

- ZP – 57%
- US – 41%
- MN – 23%
- K – 23%
- U – 16%
- UC – 16%

The respondents also defined the manner of developing individual areas to be optimized. The income approach in economic optimization is aimed at the maximization of income, determined on the basis of an analysis of transaction prices for the functions being the object of trade in the last two years. Averaged prices for the functions being the object of trade in the last year, obtained from the Municipal Council in Toruń, are presented below:

- service function – 285 PLN/m²;
- single-family residential function – 210 PLN/m²;
- industrial function – 105 PLN/m²;
- recreational – 125 PLN/m².

In the process of economic cost optimization for all 10 areas, an optimum function was determined using a matrix of connections of urban space functions (land use). An example of such a matrix for the area No 4, 5 is presented in Tables 2, 3.

Table 2. Area 4 – matrix of connections of urban space functions (the land use function) with land features and with the present infrastructure, source: own elaboration

| No. | Urban space function | MN | MW | U | US | UC | P | ZP | ZC | WS | K | IT |
|-----|----------------------|----|----|---|----|----|---|----|----|----|---|----|
| 1   | Electricity          | 8  | 8  | 9 | 8  | 8  | 10| 0  | 5  | 3  | 4 | 10 |
| 2   | Telephone            | 7  | 7  | 6 | 4  | 8  | 7  | -8 | 3  | -7 | 0 | 8  |
| 3   | Waterworks           | 9  | 8  | 9 | 7  | 9  | 9  | 3  | 6  | 3  | 2 | 9  |
| 4   | Sewage system        | 7  | 8  | 6 | 3  | 5  | 9  | -6 | 1  | 3  | 3 | 8  |
| 5   | Gas                  | 7  | 8  | 4 | 2  | 4  | 8  | -8 | 2  | 3  | 4 | 9  |
| 6   | Easy access by road  | 7  | 7  | 8 | 2  | 6  | 7  | 1  | 5  | 4  | 6 | 4  |
| 12  | Single-family houses | 10 | -8 | -3 | -3 | -3 | -9 | 5  | -8 | -9 | -6 | -8 |
| 13  | Public buildings     | -3 | 1  | 8 | -9 | 2  | -4 | 4  | -7 | -8 | 0 | -5 |
| 16  | Neighborhood with same function | 3  | 2  | -8 | -6 | 1  | 8  | -9 | 3  | 2  | 4 | 3  |
| 17  | Access to education  | 4  | 5  | 2 | -6 | 1  | -2 | -9 | -7 | -9 | 3 | -1 |
| 20  | Large format stores  | -7 | -5 | 1 | -10| 10 | 4  | -10| -6 | -9 | 9 | 5  |
| 21  | Hard-surfaced roads  | 6  | 7  | 8 | 2  | 9  | 10 | -3 | 9  | -2 | 10 | 6  |
| 29  | Groups of trees, groves | 1 | -6 | -9 | 6  | -3 | -1 | 7  | 3  | 6  | -8 | -1 |
| 34  | Western exposure     | 3  | 2  | -4 | 5  | -6 | 5  | 3  | 3  | 3  | -10|-4  |
| 35  | No land slope        | 6  | 3  | -3 | -6 | 10 | 10 | -3 | 6  | -2 | 9 | 9  |
| Sum total |                  | 68 | 47 | 34| -1| 61 | 61 | -33| 14 | -19 | 22 | 52 |

Ecological optimization which is primarily focused on the protection and preservation of the natural environment in the best possible condition. To this end, a number of available documents related to this sphere of urban space were analyzed, and ecological priorities for particular areas were determined. City Development Strategy 2020 [14] and The Environmental Protection Programme 2013-2016 [15] were the basis for ecological optimization.
Table 3. Area 5 – matrix of connections of urban space functions (the land use function) with land features and with the present infrastructure, source: own elaboration

| No. | Urban space function             | Land feature | MN | MW | U | US | UC | P | ZP | ZC | WS | K | IT |
|-----|---------------------------------|--------------|----|----|---|----|----|---|----|----|----|---|----|
| 1   | Electricity                     |              | 8  | 8  | 9 | 8  | 8  | 10| 0  | 5  | 3  | 4 | 10 |
| 2   | Telephone                       |              | 7  | 7  | 6 | 4  | 8  | 7  | -8 | 3  | -7 | 0 | 8  |
| 3   | Waterworks                      |              | 9  | 8  | 9 | 7  | 9  | 9  | 3  | 6  | 3  | 2 | 9  |
| 4   | Sewage system                   |              | 7  | 8  | 6 | 3  | 5  | 9  | -6 | 1  | 3  | 3 | 8  |
| 5   | Gas                             |              | 7  | 8  | 4 | 2  | 4  | 8  | -8 | -2 | 3  | 4 | 9  |
| 6   | Easy access by road             |              | 7  | 7  | 8 | 2  | 6  | 7  | 1  | 5  | 4  | 6 | 4  |
| 7   | Multi-family blocks of flats    |              | -7 | 10 | -2 | -6 | 5  | -4 | 2  | -9 | -8 | -3 | -7 |
| 8   | Public buildings                |              | -3 | 1  | 8 | -9 | 2  | -4 | 4  | -7 | -8 | 0 | -5 |
| 9   | Neighborhood with same function |              | 3  | 2  | -8 | -6 | 1  | 8  | -9 | 3  | 2  | -4 | 3  |
| 10  | Access to education             |              | 4  | 5  | 2 | -6 | 1  | -2 | -9 | -7 | -9 | 3 | -1 |
| 11  | Small floor space shops         |              | 4  | 4  | 10 | 3  | -7 | 1  | -4 | 2  | -3 | 4 | -1 |
| 12  | Hard-surfaced roads             |              | 6  | 7  | 8 | 2  | 9  | 10 | -3 | 9  | -2 | 10 | 6  |
| 13  | Southern exposure               |              | 5  | 4  | -3 | 6  | -5 | 5  | 6  | 3  | 3  | -10 | -8 |
| 14  | No land slope                   |              | 6  | 3  | -3 | -6 | 10 | 10 | -3 | 6  | -2 | 9 | 9  |
| Sum total |                          |              | 63 | 82 | 54 | 4  | 56 | 64 | -34 | 18 | -18 | 28 | 44 |

Results of the optimization indicate which functions, and to what extent, are most useful for social optimization. Analysis of the real estate market shows which functions are most useful for economic income optimization. In the economic cost optimization, we take advantage of the potential of space characteristics while minimizing the costs of transformation. The selection and determination of suitability and relevance for the designed areas during ecological optimization is determined, to a large extent, by the natural conditions, the nature of the area, and possibilities for the introduction of particular natural forms. When the overlaying method [16] is used, the optimum state of land development is obtained as the product of individual results of the optimization. The analysis performed on the basis of criteria determined during the process of social, economic, and ecological optimization enabled the determination of optimum states of area development - Table 4.

Table 4. Summary of the optimum forms of land use.

| No | Current form of land use | Optimization of land use – function | Optimization of land use – function | Optimization of land use – function |
|----|--------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
|    |                          | Social | Economic – income | Economic – cost | Ecological | 
| Area 1 | ZPN | US | US | MW | ZP | US |
| Area 2 | ZPN | US | US | UC | ZP | US |
| Area 3 | ZPN | P  | U  | P  | ZP | P  |
| Area 4 | ZPN | US | US | MN | ZP | US |
| Area 5 | ZPN | ZP | US | MW | ZP | ZP |
| Area 6 | ZPN | MN | U  | P  | ZP | P  |
| Area 7 | ZPN | MW | U  | P  | ZP | MW/ZP |
| Area 8 | ZPN | US | US | MN | ZP | US |
| Area 9 | ZPN | ZP | U  | MN | ZP | ZP |
| Area 10 | ZPN | ZP | U  | US | ZP | ZP |

MN – Residential areas with single-family homes, MW – Residential areas with multi-family homes, P – Areas of productive facilities, depots and stores, UC – Areas of large format stores, ZP – Green areas (parks), ZPN - Green area (natural green), US – Sport and recreation areas, U – Areas of retail-service buildings, source: own elaboration
The results of the analysis show that social expectations often coincide with the economic optimization proposals. If this analysis did not show an optimal function unambiguously, the choice was made by combining the least conflicting functions.

4. Conclusions
The need to develop decision-making support systems in the spatial economy and property management arise from the need to predict the states and the behaviour of local (but also global) property markets, which, under market economy conditions, should be one of the basic instruments of economic planning, and in the dimension directly related to individual space users, also of spatial planning.

Going through the process of optimisation or poly-optimisation while selecting land use offers possibilities for its use as a tool supporting the process of taking planning decisions. All information collected in the optimisation process should become a tool in creating a rational, optimum policy of space and property administration, and the adopted criteria provide a basis for sustainable development of a particular area and should be considered in the process of planning the area development. An analysis of the way to develop the areas designated in the process of spatial monitoring, i.e. qualitative and quantitative observation of problem (conflict, the so-called "non-urban") areas helps determine the optimum states of the space. Social optimisation will show the directions for a spatial policy both on the scale of the entire city and in a specific district or its part. Economic optimisation will indicate how to make the best use of the economic potential, the values of the space and the current situation in the property market. Ecological optimisation will show how to make the best use of the natural values of the space. The application of optimisation methods enables finding the best solution while taking several criteria into account at the same time, which provides a basis for the designation of a compromise solution. The methodology for an assessment and classification of spatial structures is a significant component of a market analysis and of the system supporting the process of decision making by the participants of a property market.

The developed decision-making algorithm, thanks to the tools of which it will be constructed, will enable the designation of an optimum intended use of an area, with clearly defined actions necessary to accomplish the assumed task. Social optimisation will indicate which forms of land development are in the greatest demand in a particular time. Economic optimisation will indicate the form whose introduction is most justified from the economic perspective.

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