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Toward the quality assessment of multi-criteria data in planning for housing areas

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Abstract

An efficient accomplishment of sustainable development demands, among others, requires the incorporation of multiple and hierarchized data, combined as a result of comparative evaluation of particular criteria in the pre-planning process. Therefore, the issue of spatial design support systems (SDSS) is an extremely important, still expanding, field of research. The paper is embedded in a larger project of IT tool called FAST (Fast Simulation Tool), an original analytical model integrated with CAD software. The tool, through an object-oriented database and mechanisms of simulation, allows for both effective study of key parameters which influence the development ratio as well as its application in planning practice. It proposes a three-stage approach for the implementation in the planning process: the validation, giving a holistic balance of the key parameters for certain spatial planning entities, the simulation of the development process used for analysis and forecast, and finally, the clear evaluation of spatial scenario.

In the outlined method, the paper is focused on the creation of the framework for evaluation of the planned housing development, based on collected data and prepared information. Although the general mechanism of FAST tool has already been presented in literature, the stage connected with the multi-criteria assessment requires a wider characterization. The difficult process of synthesis of quantitative and less precise quality description of spatial development in essential terms of economical, ecological and social topics, involves the incorporation of the tool in the planning procedures, both for professionals and other decision makers. The description of the methodology for the creation of evaluation framework embedded in the study of literature and implementations is an autonomous and significant worth exposing issue. It covers the operations research in SDSS with emphasis on formulation of decision variables, their substantiation and accuracy,

and on the other hand flexibility of adaptation to different situation in spatial planning. Ultimately, the goals are to explain the root model, tools for its enhancement, and finally, to explain adjusted, expert model for the decision-making process in planning of residential areas, taking FAST as a principal framework.
Keywords: FAST, GIS, spatial planning analysis, sustainable planning.

1 The elaboration field and context

The creation of effective spatial policy is a duty of great responsibility, because choosing the exact development scenario can permanently define the spatial reality [1]. According to the principles of sustainable development, the multitude of challenges and variables lead to the perception of space as a system both on local and supralocal scale [2]. While the management of such a complexity involves obtaining holistic data and processing it for substantive analyses, spatial design support systems are successfully implemented in whole planning procedure [3, 4]. Moreover, this implies the orientation of the planning process towards the clear methodical framework based on verified references and factual arguments. FAST is the original IT tool which fits this trend. Its goal is to create a flexible evaluation and forecasting model, currently focused on residential areas for both the effective study of urban tissue, as well as the implementation in the design practice and planning procedures. The general concept and its implementation was described in 2014 [5] and subsequently, the selected aspects and implementations were presented [6, 7]. To draw a more complete, multitasking picture of the tool, it is worth mentioning that the main assumption is the capability for a flexible reuse of the tools in a variety of conditions, locations and projects. Sugumaran and DeGroote [8] identify adaptability as the key feature for successful SDSS application. It encourages to contribute special effort to this direction, however, it also implies an alternative strategy than a single case study project. This

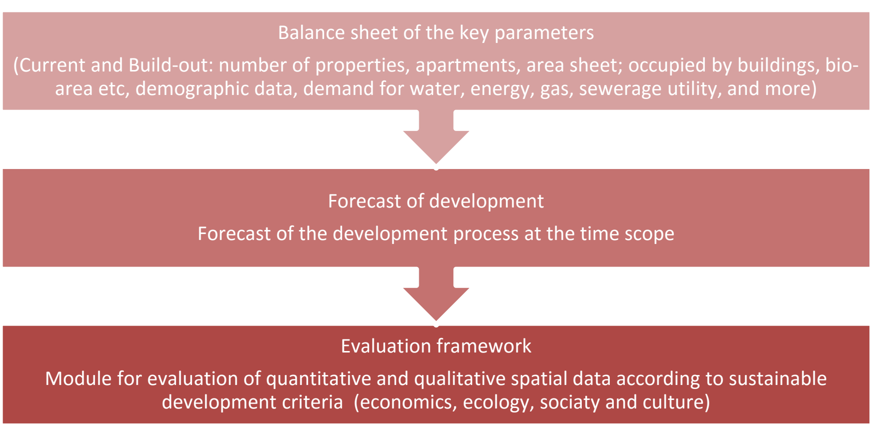

Figure 1: Three fundamental functions-components of FAST.

consideration results with bringing the user to the role of the analyst who uses a tool to build an aware decision-making process on the basis of available data. FAST is founded on the three fundamental functions-components: instant access to the balance sheet of the key parameters, forecast of development and established workflow for creation of the evaluation framework. The following diagram describes the main goals and variables considered in the algorithm.

It also expresses the structure which assumes the three basic functions to be consecutive stages of the procedure, each subsequent based on the data from previous calculations. All these sections share the same object-oriented paradigm and apply the same project described in the information model connected with a 2d vector model. However, in terms of methodology and implementation, they are independent and due to their significant scope, each of them requires a separate elaboration.

2 The scope of the study

The following paper is dedicated to the process of establishment of the evaluation framework which is the last phase of the implementation of FAST in a project. Despite mentioned association, this component differs substantially from the previous one. Awareness of these disparities is crucial for successful development. First of all, the scope of the study can be placed on the field of operational science which indicates a need for exploration of scientific elaborations and case studies. While the assessment process and its assumptions are commonly connected with conflict of interest, it is important to build clear references and methodology to support the decision-making process [9]. The subsequent element described in the article is the placement of the presented framework both in FAST and generally, in the proposed concept of sustainable spatial policy, based on different scenarios simulations. Finally, the paper presents the proposal of evaluation system for residential development in context of sustainability terms of social balance, economy and ecology. As a practical implementation in the process of spatial agenda for municipality it serves both as a case study and procedure of adaptation and utilization of FAST tool module for evaluation for selected location and objectives. In the conclusion, the discourse relates to two important issues. Initially, it is an attempt to find, estimate and highlight strengths and weaknesses apparent during the project. The next-stage is the formation of perspectives and directions for the IT tool.

3 Spatial analyses and operations research

Extraordinary advances of databases and GIS tools open up new horizons for spatial analysis, but also creates problems to be solved. Jelokhani-Niaraki and Malczewski [10] present the study of methods and strategies for building Spatial Design Support Systems (SDSS) based on GIS, in which the problem of proceeding acquired data to information useful in the decision-making process is considered as primary issue. From the data collection, a long way leads to support the creation of overall framework for substantive analysis which allows the orientation of the planning process toward the postulate of the sustainability. It is a difficult task, since it relies on the extensive pool of qualitative and quantitative information, both connected with the current state, as well as variants of the development scenarios [11]. At the same time, the problem of relativism is entered in the characteristics of operational research on complex structures, based on social systems. However, the survey of management methodologies and case studies literature allows one to formulate demands for the efficient workflow of the evaluation tools. The first issue is the distinction made in work of Fan and Kuang [12]. It indicates that, in qualitative methods, it is necessary to propose a simplified structure describing the mechanism and its verification, contrary to hard system method, where the structure of the decision-making problems is possible to be directly illustrated. At the same time, the authors derive compatibility multi-criteria decision making (MCDM) from soft system management (SSM). Furthermore, Jiang and Eastman [13] identify the establishing of the weights for the assessment as the key issue for project success. Chojnacki [14] lists the key factors conditioning this classification to soft system management (SSM) as follows: incomplete data pool, uncertain description information and qualitative nature of the information. The uncertainty description may also be related to a large influence of random factors and a limited pool of references. In the practical application of the evaluation tool, a complete description of the phenomena is also connected to other limitation such as data deficit, time and human resources, financial reasons or even available computing power. Taking into account these difficulties, it is worth to formulate assumptions to help in creation and management of the analytical tool in the most useful way. The first and most important step is to identify and formulate the problem [15]. It allows for the declaration of the basic variables and the expected effect. The next step is to create the analytical model and validate it on the actual spatial tissue [16]. This stage presupposes the presentation of the proposed evaluation together with the specified sets of assumptions (weights and variables). It will help to keep the awareness of the relativity of the process in the most subjective of all the components of the FAST tool.

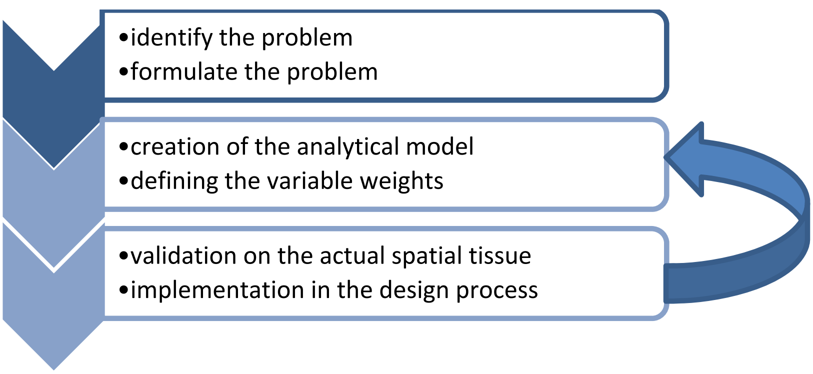

Figure 2: The concept of implementation of the FAST module for evaluation.

4 Evaluation procedure

4.1 Placement of the module in FAST tool

In the introduction, the basic functions and application of FAST tool were presented, however a more accurate description of the evaluation component requires an outline of the operational assumption. This concept is integrated with Autocad via Visual Basic, however can be applied to any similar software such as DraftSight or ZWCAD. It can also be adopted to programs which share the same paradigm. Such a solution, along with the implementation of GIS technology, on the one hand creates the opportunity to process a rich pool of spatial information and on the other, leaves a lot of flexibility to build original algorithms based on Autocad abstract entities and extensive support of programming environments. The object-oriented model is the basis for the whole analytical procedure. It means the extension of an existing vector drawing of spatial project, both in small and large scale. The user marks Autocad entities with categories known in spatial planning and eventually assigns them additional data. Additionally, the methods of automatic data entry are implemented (input-output connection with excel, ArcGIS etc.). The object can be divided into two groups: Primary objects which are the subjects of calculations (specified housing areas) and secondary interaction entities (watercourses, conservation areas, urban areas, strategic buildings and much more). Richer description of the procedure can be found in previous papers [17]. Most of the data and information are defined for earlier stages: the balance sheet and the forecast, so execution of the evaluation phase can be focused on determining the weights of variables for the assessment.

4.2 Evaluation process

The last module, dedicated to evaluation, is associated with the previous stages, because it is a response to the demand for dwellings forecast. Therefore, the first step is to define the planned development and its structure with the basic distinction to single and multi-housing. When those primary quantitative parameters are estimated, the vision of spatial policy can be established [18]. For this purpose, the IT tool introduces a comprehensive taxonomy of housing development and allows to specify the planned distribution. The proposal included in the FAST module, is to simulate certain spatial scenarios fulfilling the quantitative estimations and then to evaluate their influence in reference aspects. Of course, the spatial policy is not only the choice of certain locations for a specific type of housing, but many other factors including degree of limitations affecting local housing development. For example, a completely different effect will be caused by designation of large area to choose from in contrast to a few selected locations and thus avoiding many of the negative effects of spatial (including extended costs), but on the other hand it can reduce the growth rate [19]. In this case, another relation with the previous forecast module appears. The prognosis clarifies the development scenario and allows for more effective assessment. Therefore, the proposed procedure is to estimate the potential impact on the selected area, and adjusting it by the information from the forecast to compare different scenarios. The estimation procedure involves the series of actions, based on information from the previous steps (forecast and balance sheet). First, the influence of certain value included in the variable sheet of each sustainability aspect on primary objects (marked residential areas) is measured. The range of influence is a fraction from 0 to 1. The fraction is based on the input data (mostly regulations) or can be automatically retrieved from the model (e.g. area of environmental protection, lakes etc.). Subsequently, the area of certain development type is multiplied by the fraction of influence and the variable weight and summed with other variables of certain sustainability aspect. In the final ranking, all the values are presented separately for each area as well as the sum to compare with other scenarios. The ultimate step is the multiplying the result for build-out (100% development) by local forecast and dividing by the estimated number of residents for the assessment of a given scenario. The output data defines the negative influence on each aspect of sustainable development, so the lower the value is, the minor the consequences are.

$$\sum_{j=1}^{Y}\sum_{i=1}^{Z}\frac{a_j f_j m_j s_j b_i w_i v_i}{n_j},$$

w_i - weight of each variable (for single-housing);
v_i - weight of each variable (for multi-housing);
b_i - fraction of impact of each variable on certain area, $b_i(a_j)$;
a_j - selected area;
s_j - fraction of single housing on area;
m_j - fraction of multi housing on area;
f_j - forecast of the selected area fulfillment for a given time;
n_j - the estimated number of people in selected area1, $n_j>0$;
Y - total number of planned housing areas;
Z - total number of variables for assessment of a given sustainable development aspect.

The very process of evaluation refers to the fundamental aspects of sustainable development with the restrictions on this rich pool to the selected areas related with residential development. Dalal-Clayton and Bass [20] distinguish three pillars of sustainable development: environmental, economic and social. After this classical division, the more extended classifications were put forward. It is worth mentioning the concept of the "Circles of Sustainability" which describes the sustainability assessment according to four groups: economic, ecology, politics and culture [21]. Seghezzo [22] emphasizes the role of the time scope as a reference in his evaluation model. The transfer of the above aspects into the proposed module for housing areas requires the consideration of residential specifics, practical reasons and the implementation scale. Finally, the variables were assigned to three aspects: economic, ecological and social, however these general keywords cannot be perceived without the following elaboration. The factors provided below have been developed for implementation in the municipal

Rokietnica which is located 20 km from Poznań city- the capital of the region of Poland. It is a rapidly developing area where the population has doubled since 2004 to about 15.000. A set of weights without significant changes can be applied in all municipalities surrounding the city of Poznan or similar. In the case of a different density and quantity of population, certain changes would have to be made, especially in the weights connected with urban zones.

Table 1: Impact weights (environment).

Environment	Single-housing	Multi-housing
Protected areas:		
Buildings prohibited	Limitation prompt	Limitation prompt
Buildings allowed according to protection plan	30/ha	50/ha
Buffer zone of protected areas	15/ha	40/ha
Ecological corridor between protected areas	25/ha	40/ha
Neighborhood of protected areas 600m	7/ha	20/ha
Neighborhood of protected areas 1500m	3/ha	8/ha
Water protection:		
Area of protect water intakes	Limitation prompt	Limitation prompt
Area of influence on surface water intakes	10/ha	30/ha
Area of influence on groundwater intakes	3/ha	12/ha
Rating of local vegetation		
0–10	Rating x 0.25/ha	Rating x 0.5/ha
Planned urban greenery		
Green buffer	- Rating x 0.12/ha	- Rating x 0.5/ha
Compact urban green areas	- Rating x 0.12/ha	- Rating x 0.5/ha
Special conditions for the protection of the environment		
Additional services charging environment allowed	2/ha	3/ha
Additional services allowed	0.1/ha	0.1/ha
Noxious energy sources (coal, coke, waste incineration) allowed	1/ha	4/ha
Only sustainable energy sources	-0.5/ha	-1/ha
Buildings exceeding standard of thermal performance (usually existing)	0.3/ha	0.8/ha
Low-energy buildings (no standard - energy-plus, autonomous)	(-0.25 to -1) /ha	(-0.25 to -2) /ha
Septic tank allowed/ Individual septic plants	1/ha	2/ha
Individual wells	0.2/ha	0.7/ha
Obligatory rain collectors (gray water)	-0.3/ha	-0.5/ha
Bio-area percentage (total)	$1{,}77 \times e^{-0{,}07x}$	$-0{,}026x1{,}28$
Current land use		
Municipal greenery	15/ha	15/ha
Forest	7/ha	10/ha
Meadow (or similar ecosystem)	5/ha	8/ha
Agricultural areas	1.5/ha	3/ha
Barren grassland	1/ha	2/ha
Urban area with high % bio-area	0	1/ha
Urban area with low % bio-area	-1/ha	0

4.2.1 Ecology
The issue of ecology refers mainly (but not only) to a local scale. The variables can be divided into two groups. The first one is related to the characteristics of localization, especially with protection plans, whilst the second, is the result of planning regulation. Therefore, the FAST tool distinguishing feature is the ability for the holistic assessment of the current decisions process, besides existing spatial qualities. The variables (weights can be changed by a user) for the area take part in all aspects of evaluation, which help to find the most sustainable scenario.

4.2.2 Economy
While the residential planning and practice assumes a different degree of public and private participation, economic criteria are substantially divided. This division is of particular importance because the issue of affordability is crucial for the effective spatial policy [23]. The usage of this medium is an invaluable tool to drive development to specified areas with the preservation of areas valuable for other aspects of sustainability. With the conscious shaping of the budget, local authorities may direct their investments in such a way which induce investors to select the area, so not only the development prohibitions are the only solution to the problem of uncontrolled development.

4.2.3 Social sustainability and living quality
The elaboration of this element of the evaluation applies only to selected phenomena, however, the issue of social sustainability is incredibly broad. It is related to the limited scope of the design process, which in this implementation, is reduced to residential area, while more comprehensive assessment (culture, identity, politics) are implemented at the level of the overall spatial policy, so it is the action on a different scale and objectives. The purpose of this evaluation is, apart from the user satisfaction, the reduction of selected spatial problems.

5 Conclusion and perspectives

This proposal of the evaluation framework is one example of the spatial information exploration model, implemented in FAST. However, as the module of the most relative nature, its development is largely dependent on other modules, especially dedicated to forecast. The application of "soft methods" also determines that the process of the decision-making support should be considered as the building of the awareness of complex system rather than offering the exact solution. This places the planner in the role of an analyst and forces him to define, or at least to understand, the assessment assumptions. In conclusion, the fundamental concept of the evaluation framework should be highlighted. The analysis is a response to the spatial policy, expressed in estimation of the number of residents of certain development types (multi-housing, single-housing detached, semidetached, plot size etc.), because the comparison of scenarios takes place in per capita terms according to established division. The second key issue

Table 2: Impact weights (public expenditure, private costs).

Public expenditure [2425]	Single-hous.	Multi-hous.	**Financial availability (private costs)**	Single-housing	Multi-housing
A roads network on specified area Percentage (0–100%)			**A roads network on specified area Percentage (0–100%)**		
Planned public full road network	50/ha	30 /ha	Planned public full road network	0/ha	0 (rare) /ha
Planned public thoroughfare roads (other private)	20/ha	12/ha	Planned public thoroughfare roads (other private)	20/ha	12/ha
Planned private roads network	0	0	Planned private roads network	50/ha	16/ha
Existing public road network	2/ha	4/ha	Existing public road network	2/ha	4/ha
Road access			**Urban zones (individually for each project - based on land prices)**		
Direct access to the roads of higher category (above L)	4	0	Zone 1 – central and prestigious areas	50/ha	30/ha
Direct access to the full-size public road	0	0	Zone 2 – intermediate zone	35/ha	30/ha
Direct access to the roads of low category	2	8	Zone 3 – peripheral zone	20/ha	15/ha
Planned access by the asphalt road	8/100m	12/100m	Zone 4 – suburban zone	7/ha	10/ha
Planned access by the dirt road	4/100m		Zone 5 – external location (detached from agglomeration structure)	2/ha	8/ha
Underground infrastructure (0-100%)			**Special conditions**		
Lack of the water supply network	5/ha	2/ha	Noxious energy sources (coal, coke, waste incineration) forbidden	2/ha	0/ha
Lack of the sewerage network	3/ha	1/ha	Only sustainable energy sources	10/ha	2/ha
Other (0–100%)			Low-energy buildings (no standard – passive)	(1 to 8) /ha	(1 to 3) /ha
Municipal greenery	2/ha	3/ha	lack of public transportation (600m)	1 /ha	4 /ha
Lack of public transportation (600m)	0.2/ha	2/ha	Obligatory rain collectors (gray water)	-0.3/ha	-0.5/ha
			Ordinances for the greenery	(0 to 2) /ha	(0 to 10)/ha

Table 3: Impact weights (social sustainability).

	Single-housing	Multi-housing
Road network		
dirt road	20/ha	50/ha
paved roads	3/ha	10/ha
no road maintenance service	5/ha	15/ha
no lights	3/ha	6/ha
no sidewalks	5/ha	5/ha
less than 2 parking places per apartment	15/ha	15/ha
less than 1 parking places per apartment	20/ha	20/ha
less than 1 lot place in garage per apartment	3/ha	3/ha
Insufficient n.o. parking spaces for adjacent services	6/ha	10/ha
Accessibility		
Predicted road capacity (with local urban center)	10/ha	18/ha
Means of public transportation (500m)	6/ha	15/ha
Railway station (1200m)	1/ha	2/ha
Site specificity		
Zone 3 – peripheral zone	0	1/ha
Zone 4 – suburban zone	0	5/ha
Zone 5 – external location	2/ha	8/ha
No public green areas (600m)	5/ha	10/ha
Open forest (1000m)	-4/ha	-2/ha
Lakeside (1000m)	-6/ha	-6/ha
Riverside (1000m)	-2/ha	-2/ha
L. within impact of principal road of high traffic (500m)	5/ha	3/ha
Location within impact of manufacturing facility 500m	4/ha	6/ha
Location close to suspended infrastructural line (500m)	2/ha	6/ha
Location within impact of biogas facility (1500m)	6/ha	9/ha
Location within impact of windfarm (1500m)	3/ha	6/ha
Location within impact of waste management/ treatment/sewage treatment plant (2000m)	9/ha	15/ha
Vicinity of large farms (1000m2)	-2/ha	0/ha
Multi-housing neighborhood	1/ha	0
Access to services (600m)	0-2/ha	0-5/ha

is related to the transparent insight into other methods of spatial policy formulation than restrictions which tend to be more difficult to produce in a complex spatial system. For example, the allocation of budget funds increases the availability of certain areas while the high requirements for environmentally valuable areas generate low availability. Apart from the overall development of the IT tools, the assessment procedure will be further elaborated. First, further implementations are required for validation of both the procedures and the proposed weights. Valuable experience may also be provided by cooperation with other participants of spatial decision and planning process to verify whether adaptation of the variables to individual needs and assumptions is effective enough. Finally, the development of tools for an extension of the system to such an extent that the implementation of projects of different scale and location is possible smoothly without manual adaptation. This also applies to variations in the type of project, ranging from detailed studies, related to specific investment, to plans shaping the general spatial policy of the municipalities. The most probable scenario in this context is a closer and more effective connection with GIS systems, perhaps even the creation of a network database of referenced information.

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