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sustainability

Article

Evaluating theSignificance of Criteria Contributing to Decision-Making on Brownfield Land Redevelopment Strategiesin Urban Areas

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Abstract: Brownfield land is one of the least exploited resources forurban development in a number of Eastern European countries. Establishing a rational strategy for redeveloping brownfields is an unambiguously complex task that requires considering a number of different economic, social, physical and environmental factors. The strategic decision-making has a long term impact on the quality of life, ecological balance and urban structure. Therefore, the paper is aimed at developing a comprehensive set of criteria that contribute to the redevelopment of brownfield land in urban areas. Itfocuses on six main development strategies that embrace creating residential, green, commercial, recreational activity and industrial areas or leaving land as a reserve. Geographic information system (GIS) tools are employed to collect thespatial information, obtain the initial set of criteria and derive the statistical data. Expert's evaluations along with a statistical method of gauging the level of concordance of their opinion combined with Delphi method areusedfor determining significance of criteria within economic, social, physical (urbanistic) and environmental criteria groups. This studyestablishes the most significant criteria for implementing different scenarios of the brownfield land redevelopment in Vilnius, Lithuania.Developed framework will support the decision-making process in the brownfield land redevelopment aiding a sustainable urban planning.

Keywords: brownfield land, decision making, criteria analysis, sustainable urban development

1. Introduction

The reclamation of brownfield land, including old industrial and commercial areas, remains one of the priorities set by the EU policy aimed at gradually increasing density of population in urban areas. It has been estimated that approximately 500 000 hectares of brownfields suitable for reclamation were in Europe in 2005. Today, the large proportion of the brownfield land is still available for regeneration. It can be utilized for raising the economic attractiveness of cities to new investment, preserving urban identity, improving social climate and developing the prevention of natural elements in the city.

The brownfields can be defined as a land that has previously been developed, but is not in current use [1]. Derelict (abandoned) and vacant (not occupied) land can also be classified as the brownfield land. However, it should be noted that the definitions of the brownfield land vary significantly in various countries and are shaped by deindustrialization, urbanization, high density of population or other socio-economic factors [2]. Brownfields are also described as a territory that is affected by the previous use or the impact of the surrounding land and becomes unused or useless without further intervention [3]. Brownfield land provides a possibility of using free space and potential for additional urban development considering changes in the needs of the population [4]. Regeneration is the most commonly used way to exploit the potential of brownfields [5-7].

The research on brownfields provides a number of excellent examples of how such areas can be reclaimed thus achieving anew quality of the environment [8-12]. The reclamation of brownfields in Europe has been pursued through the effective integration of the concept of sustainable development into the EU projects such as RESCUE [13,14] and CABERNET [15]. The projects have been aimed at simplifying the procedure for new practical solutions seeking a sustainable development of the brownfield land. Notably, a public-private partnership (PPP) model has been increasingly successful for implementing projects on the redevelopment of brownfields [16-18]. A regeneration projectin coastal area of Liverpool, UK, providesan excellent example of the partnership between public and private sectors [9,19]. In 2005, the EU and UK together with the private sector have paid a total of 560 million Euros for the redevelopment of the Waterfront area situated in the city. On the principle of the PPP, business and leisure complexes consisting of mixed-use areas have been built in brownfields and unused territories. About 2,500 new jobs and an environmental aesthetic image have been created. Some of the old buildings have been renovated thus preserving the cultural heritage and city's identity. A flood protection system has also been installed. The adoption of various environment-friendly solutions has resulted ina significantly decreased need for water, as well as a reduced air and water pollution in the Waterfront area of Liverpool.

The regeneration of territories and redevelopment of the brownfield land are progressively running through sustainable development and should integrally solve social, economic and environmental issues as well the problems of the physical environment [20-23].However, the imbalance between the volumes of urban development objects and brownfields still remains high, particularly, in many countries of theEastern Europe [24-26].After dissolution of Soviet bloc, Eastern European countries have experienced a sudden transition from central planning to the decentralized regulation of the market economy [27,28]. The need to reclaim unused urban brownfields, including military, industrial, and commercial buildings that do not perform their primary function, has significantly increased due to intensive economic processes, growing number of the population in big cities and the implementation of sustainable development policy [29-32].However, due to a tight financial situation, the problem of brownfields in some Eastern European countries still remains a serious challenge. For example, in Czech Republic and Slovakia the ongoing redevelopment processes of brownfields take place only in high-priority inner urban areas [24]. Moreover, many post-Soviet countries require methodology and strategies for brownfields redevelopment.

The paper is aimed at establishing the framework for supporting decision-making processes in the brownfield land redevelopment. The research was performed using data acquired in twenty districts (neighborhoods) of Vilnius, the capital city of Lithuania. It allowed determining the most significant criteria contributing to decision-making on brownfield land redevelopment strategies in urban areas.The obtained results will facilitate the decision-making process in the brownfield land redevelopment and assist the urban planning.

2. Methodology

2.1. Hierarchical System of Criteria

To determine the most significant criteria for implementing different scenarios of the brownfield land redevelopment, a comprehensive set of 152 criteria was establishedthrough theliterature review [33-40]. As described previously [41], this initial set of criteria was used to develop the hierarchical system including economic, social, physical (urbanistic) and environmental criteria groups.

A hierarchical system of criteria used in this study allowed the following: 1) Overcoming difficulties arising from using a sufficiently large set of criteria for multi-criteria analysis; 2) Reducing the complexity and bias in eliciting weights of importance of criteria by experts; 3) Exploiting the flexibility and convenience of the tool of hierarchical structures.

Moreover, there are a number of other prominent features of hierarchical systems, which provide advantage whenever complexity is involved [42-52]. Hierarchical systems are built in blocks, which imply a faster speed of creating them. Higher levels of hierarchy have influence on the lower ones. Hierarchies are flexible, which means they can be modified in the creation process [53]. There are no formalized methods for building a hierarchical system. Usually, it is built using tradition, intuition, or structures of databases [54]. Hierarchical system can be deduced using literature or communication with experts of the related field [53].

In this study, an expert's ranking in combination with a multiple criteria decision making (MCDM) method [41] was used to identify a final set of criteria.

2.2. Data Collection

The GIS technology was used to capture and digitize spatial data obtained for brownfield land in twenty districts of Vilnius city, as well as to combine and link up various data, including economic, social, physical and environmental indicators as described previously [55]. GIS data were thenused for evaluation of eachcriterion from the final set of 18 criteria.As a result, the data set of 360 different multi-dimensional indicators was established. These indicators were then used for establishing criteria relative weights.

2.3. Relative Weights of Criteria

The task of establishingrelative weights of criteria is a compulsory stage of any multiple criteria analysis. There are several approaches how to estimate weights of criteria by eliciting opinions from experts. The simplest and easiest to understand for experts would be using Likert scale of an appropriate number of grades. This approach unfortunately would hardly satisfy natural precision prerequisite as vague weights would correspond to each grade [56]. At the other extreme popular worldwide AHP (Analytic Hierarchy Process) method proposed by Saatycan be used. The latter method uses the 9-point scale, in which usually only 5 grades in fact are used [57]. In the study, having a relatively large number of criteria, this would be a serious limitation [58].In addition, the AHP method can only be used by experts familiar with this method. Such method as UTA [59] is attempting to resemble decision-maker's global preferences omitting the stage of obtaining weights. It requires from each expert not only the evaluation of utilities induced by each value of each criterion, but also the estimation of differences between utilities of different projects. Its upgraded version UTASTAR uses a group decision-support aggregation-disaggregation procedures for obtaining estimates of decision-makers' preferences. It is a multiple stage complicated process of reciprocal communication with experts, which again is a serious limitation in the case, when experts are chosen from the field other than operational research. Taking all above into consideration, a more favourable Delphi technique was chosen for working with a group of experts aiming to obtain consistent estimations [60].

In present study, the multiple criteria analysis was aimed at determining the most suitable redevelopment scenario $T_i$for each urban brownfield land. Therefore, relative weights of criteria were established for every brownfields redevelopment scenario $T_{1\text{-}6}$ by using expert opinions as described previously [41]. The experts were chosen by following strict selection criteria, requiring that each expert met at least one of the following requirements: 1)To have three years of experience in spatial planning, economic, environmental protection, sociology and real estate management; 2)To have three years of experience in the field of architecture and at least two designed and implemented projects; 3) To have three years of experience in policy making with respect tourban development, spatial planning and real estate market.

In total, twelve experts agreed to participate in the survey.Relative weights of criteria were determined within each group including economic, social, urbanistic and environmental.The maximum number of criteria per criteria group was five, making the task more feasible, since a smaller number of criteria required be comparing and evaluating by the expert. Experts were asked to fill in created proprietary forms in which they were required to state weights of criteria in per cent. Overall, 12 experts have responded.

2.4. Non-Parametric Statistical Analysis

In order to assess agreement among experts in respect to criteria weights, the theory of Kendall was applied [61]. Initially, themagnitudes of criteria weights were ranked. Since, each brownfields regeneration scenario is perceived in different way, weights of the criteria were determined considering each scenario T_1-T_6separately. Such ranks were denoted as e_{ik}, where i =1,2,..., m is the index of criteria (in our case, m is equal to 4 or 5) while k=1,2,..., r is the index of denoting experts (r – is the number of responded experts, which counts 12 in our case). Kendall'sW was used in the chi-squared test statistics for gauging the level of concordance, which depends on the sum of squared deviations of all ranks e_{ik} by all experts.

$$e_i = \sum_{k=1}^{r} e_{ik} \tag{1}$$

From the mean of such sums

$$\bar{e} = \frac{\sum_{i=1}^{m} e_i}{m} \tag{2}$$

Consequently, Kendall's W equals the ratio between the sum S mentioned above, calculated by formula (3), and its largest deviation, denoted by S_{max} , calculated by formula (4). The latter sum is observed in the case of the absolute concordance of expert opinions in terms of ranks of importance of criteria.

$$S = \sum_{i=1}^{m} \left(e_i - \bar{e}\right)^2 \tag{3}$$

$$S_{\max} = \frac{r^2 \cdot m \cdot \left(m^2 - 1\right)}{12} \tag{4}$$

Consequently,

$$W = \frac{S}{S_{\max}} = \frac{12 \cdot S}{r^2 \cdot m \cdot \left(m^2 - 1\right)} \tag{5}$$

Chi-squared test statistics for this variable is

$$\chi^2 = W \cdot r \cdot (m-1) = \frac{12 \cdot S}{r \cdot m \cdot (m+1)} \tag{6}$$

The number of degrees of freedom $\upsilon = m - 1$. For the test statistics, the level of significance α=0.05 was chosen.Next, equal ranks within 6 sets of criteria were found. There were only two equal ranks at most. For the cases when ranks were equal, the following adjustment of the coefficient of concordance was applied [61].

$$W = \frac{12 \cdot S}{r^2 \cdot m \cdot (m^2 - 1) - r \cdot \sum_{\varphi} (t_{\varphi}^3 - t_{\varphi})} \quad (7)$$

whereϕdenotes the sets of equal ranks, and t_{ϕ} denotes the number of equal ranks within a set within ϕ.

Averages of weights elicited from experts, which were found to be concordant, were used in the followed analyses. The overall methodology pipeline is shown in Figure 1.

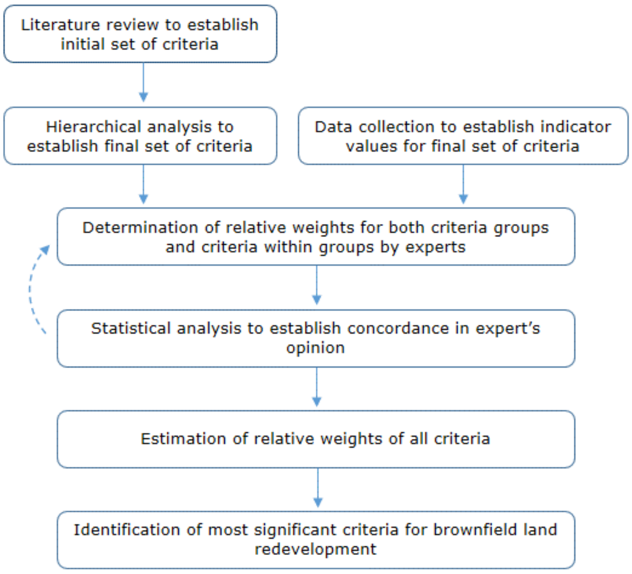


Figure 1. Methodology pipeline.

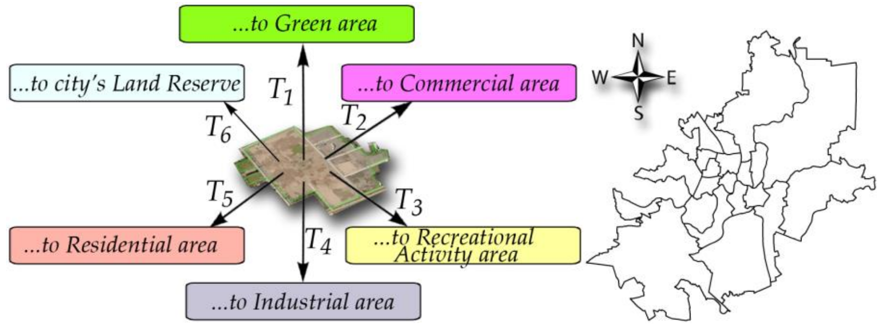
3. Results

3.1. Brownfield Land Redevelopment Scenarios

In order to build a framework that can support the decision-making on the brownfield land redevelopment in urban areas and to assist urban planning and development, this study was aimed to establish what criteria are the most significant for redevelopment of brownfield land into the urban land of a different use. Whereas a number of models, involving different types of the urban land use, have been describedpreviously [62,63], the following six scenarioscan be distinguished for the redevelopment of brownfield land in urban areas (Figure 2a):

- redevelopment to agreen area (T_1);
- redevelopment to acommercial area (T_2);
- redevelopment to a recreational area (T_3);
- redevelopment to aindustrial area (T_4);
- redevelopment to a residential area (T_5);
- leaving land as a city reserve (T_6).

The brownfield land redevelopment scenarios $T_i$were considered for twenty districts of Vilnius city (Figure2b) [64]. Resulting scenarios may reflect the character of the urban area and the possible potential of the locality. Such brownfield land redevelopment opportunities can then be successfully used for developing partnerships between public and private capital applying the PPP principle [65].



(**a**) (**b**)

Figure 2. Redevelopment of urban brownfields to the land of a different function **(a)** and districts of Vilnius city **(b)**.

3.2. Development of the Hierarchical System of Criteria: Case Study of Vilnius City

In order to determine the most suitable redevelopment scenario for each urban brownfield land, weights of criteria have to be evaluated for each scenario $T_i$establishing the most significant criteria. Therefore, an initialset of 152 criteria was established as described in *Methodology*.To reduce complexity,the study was confined to 48 criteria (selected set of criteria), and only highest ranked 18 criteria (final set of criteria) (Figure 3) were used for further analyses.

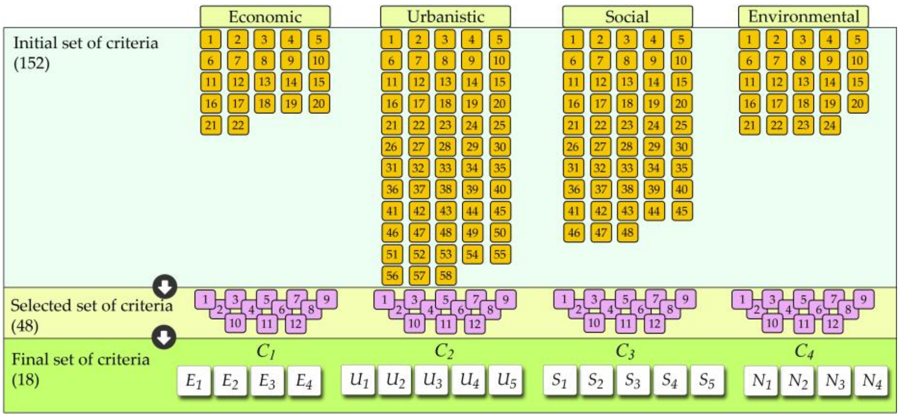


Figure 3. Hierarchical system of criteria.

The GIS data collected in Lithuania showed that the capital city Vilnius contains a brownfield land area of 10,9 km^2 (Figure4), the major part of which (83%) is a vacant land. Twenty districts of Vilnius city, identified as important for redevelopment of brownfield land, were selected for case study.With the help of GIS technology the data set of 360 different multi-dimensional indicators was created for 20 districts of the city providing data platform for the multiple criteria evaluation.All investigated indicators were attributed to a certain group of criteriaC_j as in Figure3. In the final set of criteria, each criteria group comprises of up to five criteria as follows: $\{E_1 \dots E_4\} \in C_1$; $\{U_1 \dots U_5\} \in C_2$; $\{S_1 \dots S_5\} \in C_3$; $\{N_1 \dots N_4\} \in C_4$. Altogether they form list of criteria (Table 1) used for further expert evaluation and establishing the most significant criteria.

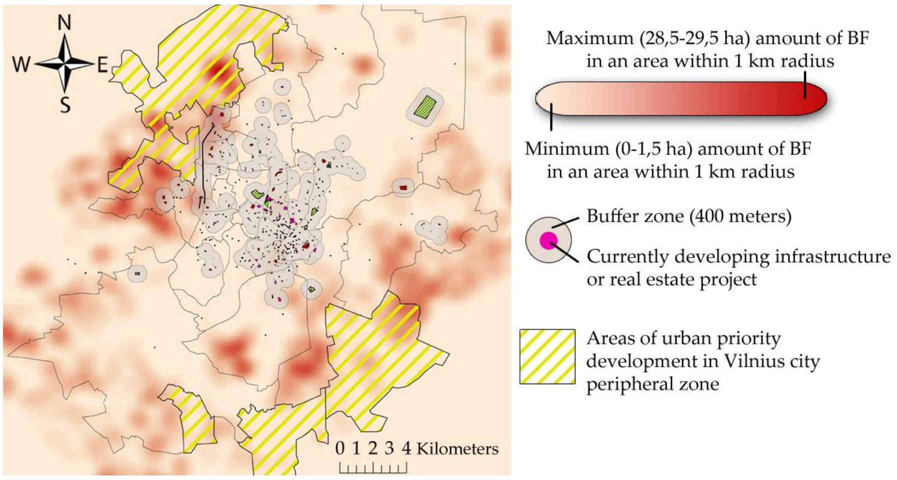


Figure 4. Spatial dispersion of urban projects developed in the brownfields of Vilnius city.

.3. Establishing the Weights of Criteria

Most important criteria (Table 1) of different groups allow comprising facets that can influence the choice of scenario for brownfield land redevelopment from different perspectives. In this study, the mathematical model described below was used for deriving weights of key 18 criteria. This is a compulsory initial step required for applying multiple criteria evaluation.

Table 1. Definitions of criteria

Group of Economic criteria	Group of Urbanistic criteria
• E_1– Infrastructure investment • E_2– Cost for new real estate • E_3– Number of projects funded by EU • E_4– Number of workspaces	• U_1– Empty sites • U_2– Number of schools • U_3– State and average age of new constructions • U_4 – Magnitude of new constructions • U_5 – Distance to the city centre
Group of Social criteria	Group of Environmental criteria
• S_1– The level of unemployment • S_2– The level of poverty • S_3– Household incomes • S_4– The level of public crimes • S_5– Access to educational institutions	• N_1– Soil contamination • N_2– Heavy industry pollution • N_3– Green areas • N_4– Transport pollution

As described in the *Methodology*, the relative weights of criteria were established using the Delphi technique involving a group of experts.

In order to establish the level of concordance of expert opinions for each scenario T_1-T_6 within all groups C_1-C_4 of criteria, calculations of the Kendall's W along with the Chi-squared test statistics, were performed for sets of criteria within the groups and criteria groups (Table 2).

Table 2. The values of the Kendall's W and Chi-squared for the sets of criteria within groups, and criteria groups prior to corrections

	W	χ^2	No. of objects	χ^2_{cr}	$\chi^2 - \chi^2_{cr}$
T_1					
Groups	0.330	11.87	4	7.81	4.06
Economic	0.821*	29.56*	4	7.81	21.75
Urbanistic	0.361	17.33	5	9.49	7.84
Social	0.314	15.08	5	9.49	5.59
Environmental	0.337	12.13	4	7.81	4.32
T_2					
Groups	0.815	29.33	4	7.81	21.52
Economic	0.767	27.60	4	7.81	19.79
Urbanistic	0.301*	14.43*	5	9.49	4.94
Social	0.174	8.33	5	9.49	**-1.16**
Environmental	0.185	6.67	4	7.81	**-1.14**
T_3					
Groups	0.550*	19.79*	4	7.81	11.98
Economic	0.633	22.80	4	7.81	14.99
Urbanistic	0.443	21.25	5	9.49	11.76
Social	0.417*	20.00*	5	9.49	10.51
Environmental	0.715	25.73	4	7.81	17.92
T_4					
Groups	0.456	16.40	4	7.81	8.59
Economic	0.744	26.80	4	7.81	18.99
Urbanistic	0.663*	31.81*	5	9.49	22.32
Social	0.328	15.75	5	9.49	6.26
Environmental	0.604	21.73	4	7.81	13.92
T_5					
Groups	0.626	22.53	4	7.81	14.72
Economic	0.685	24.67	4	7.81	16.86
Urbanistic	0.191*	9.15*	5	9.49	**-0.34**
Social	0.344	16.50	5	9.49	7.01
Environmental	0.078	2.80	4	7.81	**-5.01**
T_6					
Groups	0.278	10.00	4	7.81	2.19
Economic	0.167	6.00	4	7.81	**-1.81**
Urbanistic	0.587	28.17	5	9.49	18.68
Social	0.198	9.50	5	9.49	0.01
Environmental	0.104	3.73	4	7.81	**-4.08**

*adjusted Kendall's W and Chi-squared value, whenever equal ranks are found in a set, are denoted with an asterisk

In the sixsets of responses the expert opinions appeared to be non-concordant (Table 2). The most divergent cases were presented to the same experts along with a summary of the results elicited from the group of experts, by following the Delphi method recommendations [66,67]. Therefore, the adjusted relative weights of criteria, as a remedy to the discrepancies in the expert opinion, were determined (Tables3-8).

Table 3. Corrections in Scenario 2 by expert 10 (social criteria)

Criterion	Unemployment rate	Poverty rate	Total household income	Crime index	Accessto schools and pre-schools
Before	27%	12%	8%	19%	35%
After	22%	17%	27%	19%	15%

Table 4. Corrections in Scenario 2 by expert 11 (environmental criteria)

Criterion	Soil pollution	Pollution from factories etc.	Spread of forests and green areas	Pollution from transport
Before	30%	10%	35%	25%
After	10%	30%	35%	25%

Table 5. Corrections in Scenario 5 by expert 11 (urbanistic criteria)

Criterion	Empty sites	Number of schools	State and average age of new constructions	Magnitude of new constructions	Distance to the city centre
Before	25%	30%	10%	15%	20%
After	10%	30%	25%	15%	20%

Table 6. Corrections in Scenario 5 by expert 2 (environmental criteria)

Criterion	Soil pollution	Pollution from factories etc.	Spread of forests and green areas	Pollution from transport
Before	35%	10%	25%	30%
After	10%	35%	25%	30%

Table 7. Corrections inScenario 5 by expert 5 (environmental criteria)

Criterion	Soil pollution	Pollution from factories etc.	Spread of forests and green areas	Pollution from transport
Before	30%	11%	33%	26%
After	11%	30%	33%	26%

Table 8. Corrections in Scenario 6 by expert 2 (economic criteria)

Criterion	Investments in infrastructure	New construction cost	Number of undertaken EU projects	Number of work-places

Before	15%	23%	27%	35%
After	35%	23%	15%	27%

Following the first round of Delphi-adjustment only, along with the feedback communicating the results obtained from the first round, the amended opinions of experts appeared to be concordant. Calculations of the adjusted Kendall's *W* along with the Chi-squared test statistics for the new opinions of experts, for each scenario T_1-T_6 within all groups C_1-C_4 of criteria, and for the groups, revealed the results presented in Table 9.

Table 9. The values of the Kendall's *W* and Chi-squared for the sets of criteria within groups, and criteria groups after adjustment

	W	χ^2	No. of objects	χ^2_{cr}	χ^2- χ^2_{cr}
T_1					
Groups	0.330	11.87	4	7.81	4.06
Economic	0.821*	29.56*	4	7.81	21.75
Urbanistic	0.361	17.33	5	9.49	7.84
Social	0.314	15.08	5	9.49	5.59
Environmental	0.337	12.13	4	7.81	4.32
T_2					
Groups	0.815	29.33	4	7.81	21.52
Economic	0.767	27.60	4	7.81	19.79
Urbanistic	0.301*	14.43*	5	9.49	4.94
Social	0.326	15.67	5	9.49	6.18
Environmental	0.274	9.87	4	7.81	2.06
T_3					
Groups	0.550*	19.79*	4	7.81	11.98
Economic	0.633	22.80	4	7.81	14.99
Urbanistic	0.443	21.25	5	9.49	11.76
Social	0.417*	20.00*	5	9.49	10.51
Environmental	0.715	25.73	4	7.81	17.92
T_4					
Groups	0.456	16.40	4	7.81	8.59
Economic	0.744	26.80	4	7.81	18.99
Urbanistic	0.663*	31.81*	5	9.49	22.32
Social	0.328	15.75	5	9.49	6.26
Environmental	0.604	21.73	4	7.81	13.92
T_5					
Groups	0.626	22.53	4	7.81	14.72
Economic	0.685	24.67	4	7.81	16.86
Urbanistic	0.263*	12.67*	5	9.49	3.18
Social	0.344	16.50	5	9.49	7.01
Environmental	0.337	12.13	4	7.81	4.32
T_6					
Groups	0.278	10.00	4	7.81	2.19

Economic	0.315	11.33	4	7.81	3.52
Urbanistic	0.587	28.17	5	9.49	18.68
Social	0.198	9.50	5	9.49	0.01
Environmental	0.332	11.97	4	7.81	4.16

In order to derive relative weights of criteria considering all 18 criteria listed in the Table 1, the method of deriving weight of each criterionusing both weights of the group and of each criterion within the group, as proposed byPodviezko [54], was applied. This method is appropriate to use in cases when hierarchical system of criteria isbuilt. The weights of criteria groups are multiplied by the weights of criteria within each group as shown in Formula (8):

$$\omega_i = \omega_{i_k} \cdot \omega_k \tag{8}$$

where k is the index of groups, i_k is the index of criteria within group C_k.

For each brownfield redevelopment scenario T_1-T_6, the weights of the criteria groupswere calculated using Formula (8) (Figure5). This allowed to establish the significance of each group of criteria in the case if the brownfield land is redeveloped on the basis of particular scenario T_i. Then, the weights of each criterion within each criteria group were established (Table 10). This allowed to conclude that the application of the Formula (8) can assist significantly in calculating weights of criteria in a hierarchical system of criteria.

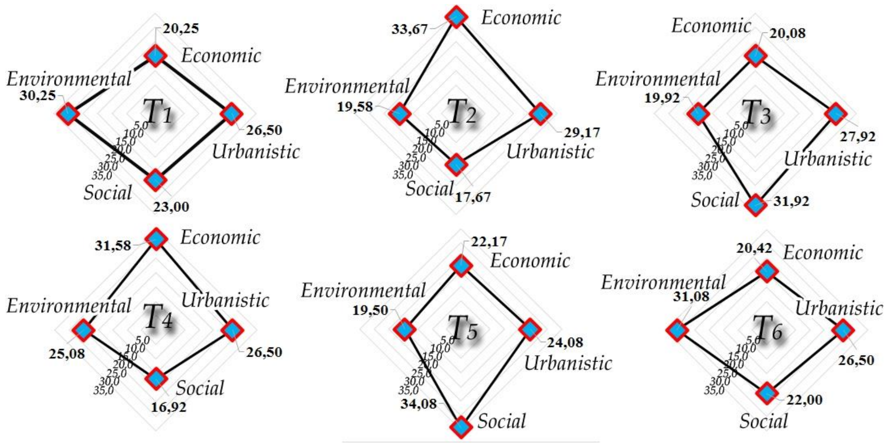


Figure 5. Relative weights of each group of criteria for each brownfield redevelopment scenario, %.

Table 10. Weights of individual criteria for each brownfield scenario $T_{1\text{-}6}$ in each group of criteria, %

	T_1	T_2	T_3	T_4	T_5	T_6
E_1	34,33	33,25	33,08	30,50	29,83	31,92
E_2	28,42	29,42	27,25	23,75	30,67	23,50
E_3	18,58	16,50	21,08	16,67	18,92	20,08
E_4	18,67	20,67	18,67	28,92	20,42	24,50
	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%
U_1	22,75	21,25	27,58	28,83	14,50	30,92

U_2	13,92	11,75	22,33	12,67	23,67	14,75
U_3	20,58	18,92	17,33	17,92	21,58	18,00
U_4	17,25	25,42	14,50	23,75	20,33	22,17
U_5	27,75	23,00	18,25	16,83	20,17	14,17
	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%
S_1	15,00	18,17	16,50	26,42	17,42	15,25
S_2	18,42	19,83	15,08	20,92	18,42	21,42
S_3	17,17	24,83	17,67	21,08	20,92	16,00
S_4	25,17	22,67	25,92	17,00	16,58	23,17
S_5	24,42	14,58	24,75	14,42	26,58	24,33
	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%
N_1	20,00	18,92	18,00	30,92	17,17	22,00
N_2	19,33	28,75	31,92	29,33	30,83	20,83
N_3	29,50	29,67	30,67	18,92	26,08	32,92
N_4	31,25	22,67	19,42	20,83	25,75	24,33
	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%	Σ = 100%

3.4. Establishing the Most Significant Criteria Contributing to Brownfield Land Redevelopment Strategies

In order to establish the most significant criteria contributing to the redevelopment scenarios of brownfield land, the weights of all criteria for each brownfield redevelopment scenario were derived as described in *Methodology*(Figure 6). For convenience of decision-making process the calculated weights of individual criteria for each redevelopment task in each group of criteria are presented in this paper in the scalar distribution form. This comparison allows a decision-maker to assess the meaningfulness of each criterion in redevelopment processes while working out a solution for one of the problems T_i.

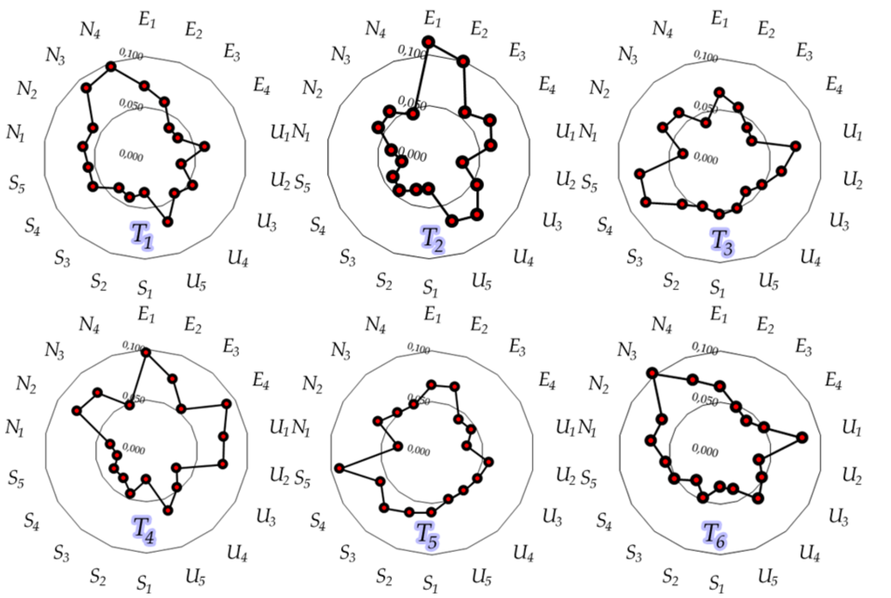


Figure 6. The weights of individual criteria for each brownfield redevelopment scenario ($\omega_{Mi|T1..6}$).

The results revealed the most significant criteria contributing to the redevelopment of brownfield land applying a particular scenario T_i. As a result, the following most significant criteria for each case of brownfield land redevelopment scenario were identified:

Scenario T_1– the criteria of the environmental group have a decisive impact, particularly criteria N_3 (green areas per inhabitant, ω_{N3} = 0,089) and N_4 (pollution from transport, ω_{N4} = 0,095).

ScenarioT_2 – the criteria of the economic group have a decisive impact, particularly criteria E_1 (investments in infrastructure, ω_{E1} = 0,112) and E_2 (cost of new rental estate, ω_{E2} = 0,099).

ScenarioT_3 – the criteria of social and urbanistic groups have a decisive impact, particularly criteria S_4 (crime index, ω_{S4} = 0,083), S_5. (access to educational institutions, ω_{S5} = 0,079) and U_1. (empty sites, ω_{U1} = 0,076).

ScenarioT_4 - the criteria of almost all groups, except those of the social one, equally strongly determine this redevelopment scenario. Among the prevailing criteria, E_1 (investments in infrastructure, ω_{E1} = 0,096), E_4. (number of work-places, ω_{E4} = 0,091), U_2. (number of schools, ω_{U2} = 0,076), U_5. (distance to the city centre, ω_{U5} = 0,063) and N_2 (pollution from heavy industry, ω_{N2} = 0,078) have the major impact.

ScenarioT_5 – the criteria of the social group have a decisive impact, particularly criteriaS_5 (ω_{S5} = 0,091) specifying accessibilityto education and pre-school educational establishments.

ScenarioT_6- is strongly affected by environmental and urbanistic criteria among which criteria N_3 (green areas per inhabitant, ω_{N3} = 0,102) and U_1 (empty sites per inhabitant, ω_{U1} = 0,082) have the major impact.

To conclude, the average weights of criteria significance (ω_{Mi}) and standard deviation (d_i) were calculated. Subsequently, they were ranked (Figure7)showingthat, overall, E_{a1} (investments in infrastructure; $\omega_{avg.E1}$ = 0,079), N_{a3} (green areas per inhabitant; $\omega_{avg.N3}$ = 0,073), E_{a2} (cost of new real estae; $\omega_{avg.E2}$ = 0,067), U_1 (areas of empty sites per inhabitant; $\omega_{avg.U1}$ = 0,065) and N_2 (pollution from heavy industry; $\omega_{avg.N2}$ = 0,064) are the most influential criteria in making decisions on brownfield redevelopment.

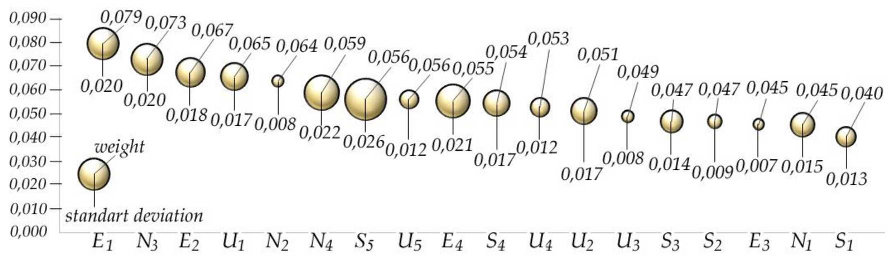


Figure 7. The calculated average values ($\omega_{Mi,di}$) of criteriaweights and their standard deviations.

4. Discussion and Conclusions

Brownfields represent specific challenges for the environment and adjacent community as it has been affected by former uses; is derelict or underused; requires intervention to bring it back to beneficial use; and may have real or perceived contamination problems [68,69]. Moreover, all brownfields sites vary concerning their unique characteristics, such as location, size, extent of potential contamination resulting from previous use, etc. As a result, diverse stakeholders have heterogeneous concerns regarding successful and sustainable brownfield land regeneration [25].

In order to deal with the complex decision-making processes, several multi-criteria decision analysis (MCDA) approaches and tools have been developed and increasingly applied in different fields, including the land-use context. Prioritization tools based on sustainability frameworks and MCDA allow assessing requalification options from different points of view, respecting the needs of multiple stakeholders [20,43,68]. Due to MCDAability to combine heterogeneous inputs with cost/benefit information and stakeholder views and being recognized as suitable tool to support the ranking of regeneration alternatives based on the sustainability framework [21-23], the previously described MCDA method [41]in combination with the expert's ranking was used to identify a final set of criteria in this study.

With this study we aimed to establish the framework of criteria for supporting decision-making processes in the brownfield land redevelopment. The research was performed using data acquired in twentydistricts of Vilnius city. A complex structure of criteria was required for such a multifacetedtask. The division of criteria into groups has proved to be the most helpful solution allowing both to cast the set of criteria and enabling experts to estimate the weights of criteria.

The paper proposes a new approach for evaluation of criteria importance. The method utilizesrelativeweights of criteria groups and relative weights of criteria within the groups for estimation of the weights of individual criteria for each brownfield redevelopment scenario. In particular, results revealed that the redevelopment of brownfields to the commercial area is primarily related to economic criteria ($\omega_{E|T2,\%}$ = 31,58%). Whereas, redevelopment of brownfield land to residential areas is influenced by the social criteria ($w_{S|T5,\%}$ = 34,08%). Not surprisingly, the economic criteria has the greatest impact on brownfields redevelopment into industrial areas ($\omega_{E|T4,\%}$ = 31,58%).

Notably, the most significant criteria contributing to the decision-making strategies for the redevelopment of brownfield land in urban areas were determined in this study. Not surprisingly, majority most important criteria for redevelopment to green, commercial, recreational, or residential areas were very relevant to the redevelopment strategy and were from the criteria groups such as environmental (green areas per inhabitant and pollution from transport), economic (investments in infrastructure and cost of new rental estate), social (crime index and access to educational institutions) and social (accessibility to education and pre-school educational establishments), respectively. Interestingly, results revealed that for redevelopment to the industrial area, criteria from three criteria groups including economic, urbanistic and environmental were found to be equallyimport.

Overall, the analysis of brownfield land redevelopment scenarios and evaluation of the criteria significance will assist in developing decision-making guidelines for various brownfield land redevelopment solutions.

Author Contributions

All authors contributed equally to this work. MarijaBurinskienė developed project idea, led the development of the methodology and contributed to draft the paper. Vytautas Bielinskas conducted the expert interviews, created graphs and figures, outlined conclusions and recommendations, contributed to draft the paper. Askoldas Podviezko developed the model of quantitative and qualitative data collection, performed multiple criteria analysis and calculations, and contributed to draft the paper. VirginijaGurskienėcontributed to the revision and improvement of final paper. Vida Maliene analysed data, contributed to draft the paper and was responsible for the final paper revision and improvement. All authors discussed the results and commented on the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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