This is pre-publication author-version of a manuscript which has been published in Journal of Environmental Management, (Accepted: 20th September, 2015)

The manuscript did undergo copyediting, typesetting, and review of the resulting proof before it was published in its final form. To find or request access to the final version, please see the link http://dx.doi.org/10.1016/j.jenvman.2015.09.030

Pizzol, L., Zabeo, A., Klusacek, P., Giubilato, E., Critto, A., Frantal, B., Martinat, S., Kunc, J., Osman, R., & Bartke, S. (2016). Timbre Brownfield Prioritization Tool to support effective brownfield regeneration. Journal of environmental management, 166, 178-192.

https://www.sciencedirect.com/science/article/pii/S0301479715302826

Timbre Brownfield Prioritization Tool to support effective brownfield regeneration

Lisa Pizzol[a] Alex Zabeo[a] Petr Klusacek[b] Elisa Giubilato[a] Andrea Critto[a] Bohumil Frantal[b] Standa Martinat[b] Josef Kunc[b] Robert Osman[b] Stephan Bartke[c]

[a] University Ca' Foscari Venice, Department of Environmental Sciences, Informatics and Statistics, Venice, Italy
[b] Institute of Geonics, Academy of Sciences of the Czech Republic, Brno, Czech Republic
[c] UFZ – Helmholtz-Centre for Environmental Research, Department of Economics, Leipzig, Germany

Abstract

In the last decade, the regeneration of derelict or underused sites, fully or partly located in urban areas (or so called “brownfields”), has become more common, since free developable land (or so called “greenfields”) has more and more become a scare and, hence, more expensive resource, especially in densely populated areas. Although the regeneration of brownfield sites can offer development potentials, the complexity of these sites requires considerable efforts to successfully complete their revitalization projects and the proper selection of promising sites is a pre-requisite to efficiently allocate the limited financial resources. The identification and analysis of success factors for brownfield sites regeneration can support investors and decision makers in selecting those sites which are the most advantageous for successful regeneration. The objective of this paper is to present the Timbre Brownfield Prioritization Tool (TBPT), developed as a web-based solution to assist stakeholders responsible for wider territories or clusters of brownfield sites (portfolios) to identify which brownfield sites should be preferably considered for redevelopment or further investigation. The prioritization approach is based on a set of success factors properly identified through a systematic stakeholder engagement procedure. Within the TBPT these success factors are integrated by means of a Multi Criteria Decision Analysis (MCDA) methodology, which includes stakeholders' requalification objectives and perspectives related to the brownfield regeneration process and takes into account the three pillars of sustainability (economic, social and environmental dimensions). The tool has been applied to the South Moravia case study (Czech Republic), considering two different requalification objectives identified by local stakeholders, namely the selection of suitable locations for the development of a shopping centre and a solar power plant, respectively. The application of the TBPT to the case study showed that it is flexible and easy to adapt to different local

contexts, allowing the assessors to introduce locally relevant parameters identified according to their expertise and considering the availability of local data.

Keywords

Regeneration of brownfields, Prioritization, MCDA, Web-based tool

1. Introduction

Since the second half of the 19^{th} century, de-industrialisation and abandonment of productive and mining sites have led to many brownfield sites all over Europe. A brownfield site can be defined as a “site that has been affected by former uses of the site or surrounding land, is derelict or underused, mainly in fully or partly developed urban areas, require intervention to bring it back to beneficial use; and may have real or perceived contamination problems” (CEN, 2014).

In the last decade, the regeneration of brownfield sites has become a more common practice, since free developable land (or so called “greenfields”) has more and more become a scare and, hence, a more expensive resource, especially in densely populated areas. Moreover, changing policies, the development of economic instruments such as Public Private Partnerships and management tools supporting the regeneration processes as well as the increasing number of various projects and research platforms supported by the European Commission or national grant systems emphasize the increasing interest of policy makers in brownfield regeneration (Tölle, 2009; Bartke, 2013).

Although the regeneration of brownfield sites can offer immense development potentials, including economic, social and environmental benefits (Sousa, 2002; Lange and McNeil, 2004; Carroll and Eger, 2006; Ganser and Williams, 2007; Chen and Khumpaisal, 2009; Strazzera et al., 2010; Schädler et al., 2012; Wang et al., 2011; Sun and Jones, 2013), the inherent complexity of these sites requires considerable efforts to successfully complete revitalization projects. For this reason, in the perception of many potential developers these sites still do not represent an economically competitive option when compared with greenfield sites (when available), which do not require private or public intervention (Thornton et al., 2007). Unfortunately, this reluctant attitude combined with uncertainties regarding the risks brownfield sites can pose in terms of decontamination costs, high rehabilitation costs, and reduced real estate value (Thornton et al., 2007) prevent investments in land potentially affected by pollution (Bartke, 2011; Schädler et al., 2012). Moreover, according to Rizzo and colleagues (Rizzo et al., 2015), along with the concern for potential environmental pollution, the loss of property value of the surrounding area is a major concern to stakeholders who have to deal with brownfield sites or are affected by their presence.

The identification of factors determining a successful brownfield site regeneration (so called “success factors”) in different geographical and political contexts (i.e., in different European countries) is crucial to support investors and decision makers in reducing the above mentioned uncertainties and thus incrementing the likelihood of success of the regeneration process (Meyer and Lyons, 2000; Thornton et al., 2007; Dixon et al., 2011; Frantál et al., 2013, 2015a).

The redevelopment of an individual brownfield site already poses several, oftentimes complex and difficult questions – however, this complexity is even further increased if a portfolio of many areas has to be managed. Here, the prioritization of brownfield sites according to the identified success factors can support investors in selecting those sites which are the most critical, urgent or profitable to invest money, time and energy, and have the highest prospects to undertake a successful regeneration process and thus to be profitably re-used – or where more appropriate, be finally released from the property life cycle and be recultivated (Wedding and Crawford-Brown, 2007; Doleželová et al., 2014; HOMBRE, 2013).

Prioritization of brownfield sites can be defined as their evaluation and classification and, where appropriate, their ranking, in order to assist the allocation of limited resources (funding, staff, time and energy) to those brownfield sites that turn out to be the most critical, practical or profitable to be revitalized. During the prioritization process, decision makers (urban planners, regional development agencies, state and regional authorities, grant agencies, etc.) who are responsible for wide territories (cities, regions or states) aim to identify which brownfield sites should be preferably considered for further investigation or ultimately redevelopment (Chrysochoou et al., 2012). Prioritization is also crucial for property holders of real estate portfolios that can be scattered in place.

Prioritization methodologies and tools for contaminated sites and brownfield sites regeneration have already been proposed in literature. They focus on different aspects and phases of the regeneration process, including environmental and health risk assessment, remediation cost assessment, uncertainty assessment, evaluation of the sustainability of projects, management of the negotiations and partnership among involved stakeholders, etc. Among them, a majority of existing tools and manuals, being developed for a case-by-case approach, are designed to assess management options for a single brownfield site (or 'megasite'), and are beyond the scope of this paper. Only few tools enable a comparison of sets (clusters) of different brownfield sites with the purpose of prioritizing them in the context of large areas or institutional portfolios (e.g., Chrysochoou et al., 2012, Cheng et al., 2011; Thomas, 2002; City of Colorado, 2000; Pizzol et al., 2011; Zabeo et al., 2011; Agostini et al., 2012). These 'site prioritization and selection' tools are designed specifically for stakeholders who are responsible for wide territories such as cities, districts, regions or states, and need to identify which brownfield sites should be preferably considered for further investigation and redevelopment (Chrysochoou et al., 2012). However, the available tools include neither the analysis of success factors identified according to stakeholders' perceptions, needs and perspectives nor appropriate methodologies for the integration of the identified success according to stakeholders' interests and viewpoints when dealing with brownfield sites. Moreover, recent studies on the identification of success factors of brownfield sites regeneration usually linked their conceptual approach to sustainability concept (Meadows, 2004), where economic, social and environmental dimensions are supposed to be balanced. As Pediaditi and colleagues (Pediaditi et al., 2010) stressed, while a successfully regenerated urban brownfield is perceived as the indicator of urban sustainability that prevents urban sprawl and avoids developments on greenfields, failures are more visible reminders of unsustainability (Dixon, 2007). This aspect is of crucial importance for the successful brownfield site regeneration that has to meet not only economic criteria, but environmental and social criteria as well. Notwithstanding, it might depend on the specific local context what the concrete proportions of these elements to one another are (Bleicher and Gross, 2010). Moreover, the above mentioned approaches and tools are not easily accessible, because they are "desktop" software solutions which need to be installed on the computer before they can run. Therefore, there is need for support tools more accessible to stakeholders, for example through web-based systems which are delivered on demand via internet (Qi et al., 2006).

Accordingly, the objective of this paper is to present the Timbre (Tailored Improvement of Brownfield Regeneration in Europe) Brownfield Prioritization Tool (TBPT), which has been developed as a web-based solution to assist stakeholders to identify which brownfield sites should be preferably considered for redevelopment or further investigation, taking into account a set of success factors properly identified through a systematic stakeholder engagement procedure. Within the TBPT these success factors are integrated by means of a Multi Criteria Decision Analysis (MCDA) methodology which includes stakeholders' requalification objectives and perspectives related to the brownfield regeneration process and takes into account the three pillars of sustainability (i.e., economic, social and environmental dimensions). The tool will help to allocate available and limited resources, time and energy to those areas that are assessed to be the most critical, urgent or profitable to be regenerated. The targeted users of the tool are represented by state, regional and local authorities and other representatives of public administration, urban planners, regional development agencies, grant agencies, site owners (individuals or consortia of owners), investors, developers, consultants, and researchers.

The tool has been applied to the South Moravia case study (Czech Republic) considering two different requalification objectives identified by stakeholders, namely the selection of a suitable location for the development of a shopping centre and the identification of a suitable location for a solar power plant.

In the following, the paper introduces the ranking methodology and the modular structure of the TBPT. Chapter three will elaborate on the web design and programming. Chapter four will demonstrate the capabilities of the TBPT in the case study application. Chapter five will conclude.

2. Methods

The Timbre Brownfield Prioritization Tool (TBPT) has been developed to assist stakeholders in ranking brownfield sites according to their redevelopment potential. In order to achieve this objective and to be at the same time simple to use for the target users, the TBPT has been structured in four modules: the system registration and user management module, the project setting module, the ranking methodology module and results visualization module, as reported in Fig. 1.

MODULES	FUNCTIONALITIES	
User management	Log in and log out management Stakeholders information collection and storing	
Project setting	Naming of the projects Management of previous projects (i.e. visualization, modification and removal)	
Ranking methodology	Input data	Dimensions definition Factors definition Indicators definition Collection of indicators values
	Normalization	Selection of the most suitable normalization function (i.e. ascending or descending options) Estimation of indicators normalized values
	Weights attribution	Indicators weights attribution Factors weights attribution Dimensions weights attribution
Results visualization	Table with the results ranked according to their redevelopment potential Google maps showing the spatial distribution of brownfields visualized with different colors according to their redevelopment potential	

Fig. 1. Timbre Brownfield Prioritization Tool modules and main functionalities. In bold the core module of the system represented by the ranking methodology.

In the next sections the ranking methodology is explained, followed by a description of the software tool structure and the presentation of the developed modules.

2.1. Ranking methodology

The ranking of brownfield sites according to their redevelopment potential is performed by means of a MCDA methodology for multi-factor assessment, which makes use of different components such as **Dimensions**, **Factors** (of success) and **Indicators** (Klusáček et al., 2014). **Dimensions** are specific aspects of the redevelopment potential such as (i) local development potential, (ii) site attractiveness and marketability, (iii) environmental risks, and/or (iv) other specific criteria (defined by the end-user) that support the classification of factors from the end-user perspective. Therefore, for each dimension, some factors are identified. **Success factors** represent conditions, circumstances, actors, agencies that are determinants and contributors to successful regeneration of brownfield sites. These factors are the causes of the interest of investors, politicians, experts or other actors for specific brownfield sites. Success factors are expression of complex phenomena that can be expressed in general (qualitative) terms or nominal variables and need to be measured. **Indicators** represent simplifications and quantifications of complex factors into measurable variables. Usually one factor can be measured by applying more alternative or complementary indicators.

The interaction between all these components at different levels and their integration has been assessed by means of a MCDA methodology, which includes the following steps:

1) Creation of the brownfield sites prioritization framework (generic);

2) Identification of effective dimensions, factors and indicators;

3) Normalization of selected indicators;

4) Weighting/Aggregation of indicators into factors;

5) Weighting/Aggregation of factors into dimensions;

6) Weighting/Aggregation of dimensions into the final prioritization score.

2.1.1. Creation of the framework (generic)

In order to support the ranking of brownfield sites according to their redevelopment potential according to stakeholders' requirements, the proposed MCDA methodology combines the components described above (i.e., dimensions, factors and indicators) with experts' judgements and mathematical algorithms. The relationships between the different aspects are reported in the MCDA framework in Fig. 2.

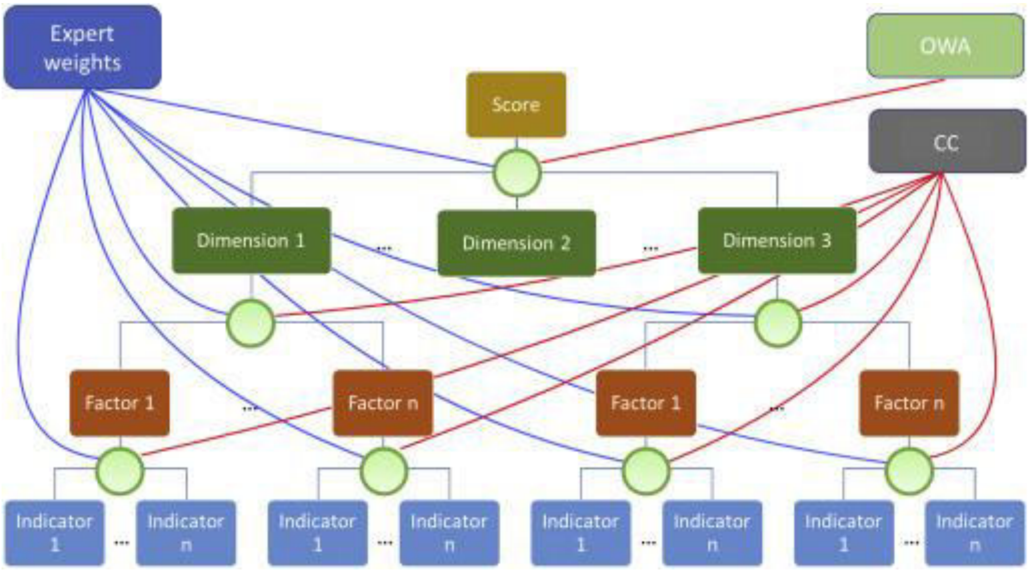

Fig. 2. Hierarchical structure at the basis of the MCDA methodology applied in the TBPT. CC stands for Convex Combination and OWA for Ordered Weighted Average.

According to Fig. 2, the identified indicators represent the first hierarchical level of the MCDA framework. Indicators are aggregated by Convex Combination (CC – i.e., a subset of Weighted Average where weights are forced to sum up to 1) in order to estimate a score for each factor. All factors describing the same aspect of the redevelopment potential (i.e., a dimension) are integrated again by the CC function in order to estimate a score for each dimension. The final ranking score for each analysed brownfield site is obtained by integrating the scores of the different dimensions using the Ordered Weighted Average (OWA) function. Both CC and OWA require the intervention of experts for the attribution of weights to indicators, factors and dimensions. This step is represented in Fig. 2 by circles.

2.1.2. Identification of effective factors and indicators

The identification of effective factors and indicators is a preliminary phase described in (Klusáček et al., 2013) and based on the following aspects:

✓ Relative significance defined according to the literature retrieval and comparative analysis of previous studies, interviews and surveys with stakeholders from different countries, and statistical data analysis;

✓ Availability and comparability of data from the analysis of existing databases, inventories, registers of brownfield sites and other statistical databases;

✓ Measurability, including that indicators should be readily available or made available at a reasonable cost/benefit ratio, adequately documented and of known quality, updated at regular intervals in accordance with reliable procedures (OECD, 2012).

2.1.3. Normalization of selected indicators

In order to allow the aggregation and comparison of indicators, they need to be all rescaled into a common numerical domain; this rescaling procedure is named "normalization" (Zabeo et al., 2011). The selected normalization domain used by the TBPT is the closed interval [0, 1], which perfectly suits with the most widely used aggregation functions in MCDA.

The TBPT is able to process two input data types: text and number. Text data type, or so-called string type, is used for indicators whose value is always selected from a finite number of labelled states (e.g., for *specific localisation*: *i)* inner settlement; *ii)* edge of settlement; and *iii)* out of settlement), while number data type is used for every numerical value regardless of the unit of measurement.

In order to normalize textual indicators, an expert has to associate a score in the [0, 1] closed interval to each of the indicator's labelled states. The system gives a default score equal to 1 to every state which can be modified by the expert if necessary (two or more states can share the same score).

Numerical indicators are, instead, automatically normalized by linear interpolation between minimum and maximum values. According to the influence of the analysed indicators on the objective of the prioritization process, experts can select the ascending or descending slope of the interpolated line for normalization (default is ascending). Ascending direction associates increasing scores to increasing values, while descending direction associates decreasing scores to increasing values (e.g., *proximity to regional centre* indicator presupposes that lower distances from regional centre correspond to higher likelihood of regeneration, therefore the pre-set ascending normalization should be replaced by the descending one). The normalization functions are reported in Eq. (1).

$$X_i = \begin{cases} \frac{x_i - i_{min}}{i_{MAX} - i_{min}} & \text{ascending} \\ \frac{i_{MAX} - x_i}{i_{MAX} - i_{min}} & \text{descending} \end{cases}$$

Where x_i is the value x to be normalized for indicator i, i_{MAX} and i_{min} are respectively maximum and minimum values for indicator i and X_i is the normalised value.

This kind of automatic normalisation process has been selected in order to fulfil the initial project design requirements for an automatic procedure, easy to use and understand, suitable in the majority of cases that require few or no inputs from the user. Accordingly, the only input required to user in the numerical data normalization process is the selection of the ascending or descending slope of the interpolated line.

2.1.4. Aggregation of indicators into factors and factors into dimensions

Once indicators have been normalised, they are ready to be aggregated. This aggregation step takes into account user insights by utilising a user-based weight for each indicator, representing its importance in relation with other indicators associated to the same factor. Including these user weights could be contested as it may introduce subjectivity. However, we regard this as one of the advantages of the TBPT as we will discuss in the case study and conclusion sections. Weights given by users for an indicator must be in the [0, 1] closed interval and sum up to 1. Default TBPT weights are assigned by equally subdividing the unit interval by the number of indicators of concern.

The aggregation formula consists of the Convex Combination (CC) of normalised indicators and user weights. The corresponding formula is reported in Eq. (2).

$$f_i = \sum_{j \in f_i} w_j X_j$$

Where f_i is the i^{th} factor, X_j s are the normalised indicators included in factor f_i and w_j s are the related weights assigned by the user.

The same procedure is used to aggregate factors belonging to the same dimension in order to estimate a score for each dimension. The proposed aggregation functions are applied to each brownfield site. While the aggregation of indicators into factors does not produce any ranking of brownfield sites, the aggregation of factors into dimensions produces a ranking of sites according to the aspects analysed in each dimension (e.g., local development potential, site attractiveness and marketability, or environmental risks, users defined dimensions).

2.1.5. Aggregation of dimensions into the final prioritization score

For the final aggregation step, which integrates dimensions into a final prioritization score, two different methods of calculation were selected: Convex Combination (CC) and Ordered Weighted Average (OWA). The first type of aggregation has been chosen in order to satisfy the users interested in the simplest evaluation methodology by preserving the same approach followed in the previous two aggregation steps (indicators into factors and factors into dimensions). The CC aggregation formula is the one already presented in the previous section and reported in Eq. (2), where indicators must be replaced by dimensions alongside their corresponding weights selected by the user.

The second proposed aggregation method allows for a more precise evaluation of the ranking by the use of the OWA, which is neither as compensatory as average nor as conservative as maximum. OWA was originally introduced by Yager in (Yager, 1988), it represents a generalization of many of the most widely used aggregation formulae like minimum, maximum and average. The different aggregation typologies of the OWA are guided by the attribution of specific OWA weights, which are fixed a priori, must be in the [0, 1] closed interval and sum up to 1. The basic idea behind OWA is first to order in descending order the values to be aggregated and then associate the corresponding predefined weight to each value according to its position; then a CC with the value-weight couples is performed. The formal definition of OWA is reported in Eq. (3).

$$OWA\left(x_1,\ldots,x_n\right)=\sum_{i=1}^{n}\omega_i\cdot x_{\sigma(i)}$$

Where $\{\sigma(1),\ldots,\sigma(n)\}$ is a permutation of $\{1,\ldots,n\}$ such that $a_{\sigma(i-1)}\geq a_{\sigma(i)}$ for all $i\in[2,n]$ and ω_i are the OWA predefined weights.

For the application of OWA in the TBPT, a set of predefined weights has been selected so that as the value to be aggregated decreases, its weight is halved, i.e. given that the sum of the OWA weights must sum up to 1, the weights have been assigned as follows: $\omega_1 = 0.571$, $\omega_2 = 0.286$, $\omega_3 = 0.143$. These weight values have been selected in order to obtain an aggregated result lying in between the maximum and mean operators.

As in the TBPT a set of importance weights w_* is already present, its integration with the OWA weights ω_* has been obtained by calculating a new set of aggregated weights W_*, which are then normalized before being applied to the values to be aggregated. Formally, the aggregated weights are calculated as:

$$W_i=w_{\sigma(i)}\cdot\omega_i$$

Where $w_{\sigma(i)}$ are important weights re-ordered with the same permutation that orders their related values decreasingly.

The new weights are then normalized into W'_* in order to sum up to 1 while preserving their relative distances:

$$W'_i=\frac{W_i}{\sum W_i}$$

Finally, the aggregated score S is obtained by:

$$S = \sum_{i=1}^{n} d_{\sigma(i)} \cdot W_i'$$

Where $d_{\sigma(i)}$ is the i^{th} dimension value of the descendent dimension values' permutation. Eq. (6) is applied to each brownfield site in order to obtain a ranking of sites on the basis of their redevelopment potential.

3. TBPT software architecture

As indicated in the introduction, a majority of available prioritization tools are desktop-based solutions. The TBPT was designed as a web-based application to combine the advantages of a cloud and stationary solution as far as possible. This means, the TBPT has the look and feel of a desktop application, while being in reality an internet web site (available through the URL http://www.timbre-project.eu/prioritization-tool.html). The main advantage of this architecture lies in its easy access through standard web browsers, which frees the users from the typical but demanding download-and-install procedure. Moreover, given an internet connection, a web application is accessible from anywhere, via different PCs and tablets, it supports sharing of information and projects between users in different locations, and is easier to maintain since new versions and upgrades developed on the host server are instantly available.

Moreover, in the TBPT, the classical web pages interaction has been hidden by the use of advanced web programming technologies and techniques in order to have a more user-friendly tool and to lower the load on the server. The web application is designed using the Front Controller Pattern, meaning that all users' requests are redirected to a unique URL, which dynamically servers the corresponding requested content.

The utilised programming techniques can be subdivided in server side tools and client side tools. Server side tools are PHP (recursive acronym for *PHP: Hypertext Preprocessor*) scripts running on the server where the tool is stored in order to provide clients with the requested web pages. Client side tools consist in ECMAScript (i.e., a version of Javascript standardized from the European Computer Manufacturers Association, ECMA) scripts utilising the jQuery library running on user's local computer in order to make web pages dynamic.

One of the functionalities of the web-based prioritization tool is the spatial visualisation of the produced results. A map displaying the results is obtained by the use of Google Maps JavaScript API v3, which allows embedding and visualizing maps with user defined data identified by polar coordinates (latitude and longitude).

The input data of the TBPT web application are organized in a MySQL relational database, all information is extracted from the database using SQL (Structured Query Language) queries. The relational schema of the database is reported in Fig. 3. The database contains both users' data needed for authentication and identification of users, and assessment data used for prioritization.

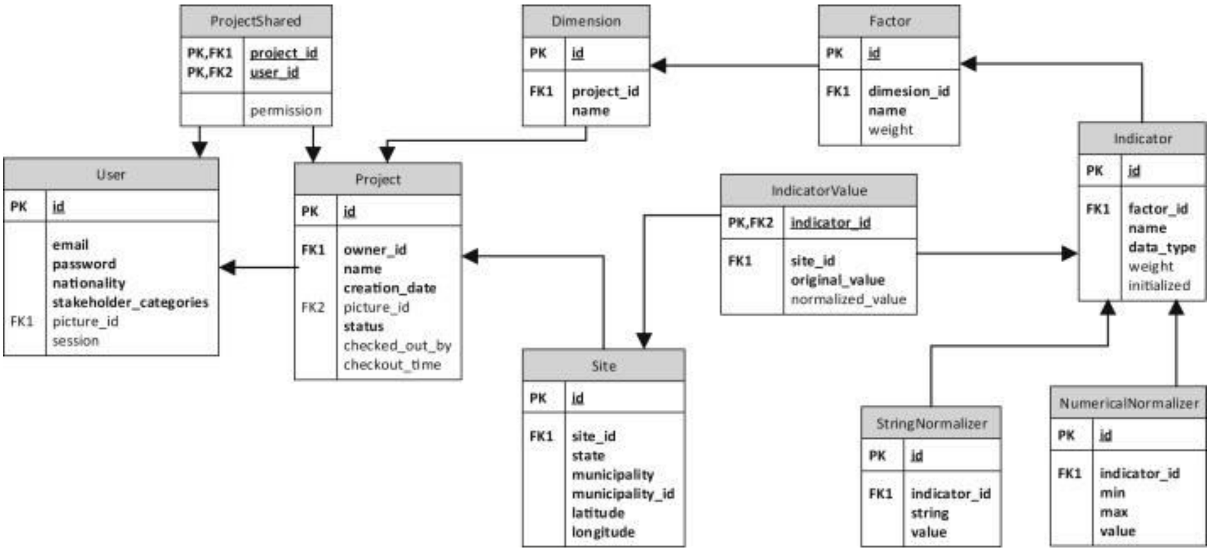

Fig. 3. Relational model of the MySQL database of the TBPT.

The TBPT is a sectional system organised in four modules as already introduced and depicted in Fig. 1. First, the user management module is focused on the supervision of all issues related to users, such as registration, log-in and log-out, password setting and retrieval. The TBPT has been designed to protect users' data against miss-uses. To this end, each end-user is asked to create its own identity and perform the assessment in a protected session of the tool. Second, the project settings module has been designed to manage the assessment projects. A project is managed as a folder containing all information related to the portfolio of sites to be evaluated. A single user can have as many projects as he needs. Projects store information about sites and their geographical position, indicators' data, user's weights and results. Projects can be created, modified, cloned and deleted. Third, the ranking methodology module is devoted to the application of the ranking method as described in the previous section. It allows the user to supply the input data, to set up weights, to select normalizations and to perform calculations through the graphical user interfaces, which are presented in Fig. 4a and b.

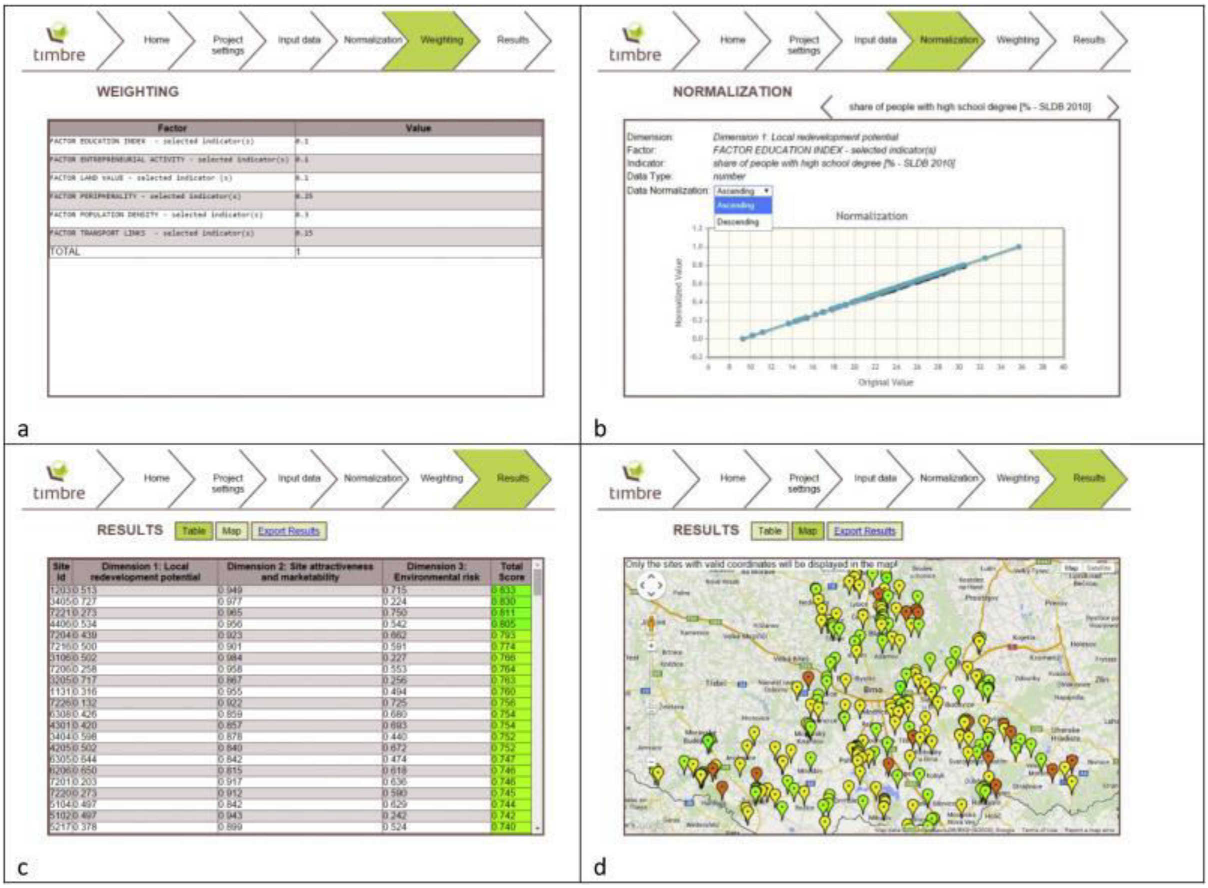

Fig. 4. Screenshots of TBPT graphical user interface for: a) weights set-up; b) normalization; c) tabular results presentation; and d) map results presentation.

Fourth and finally, the results visualization module allows for calculated rankings and intermediate data to be visualized through a prioritization ordered table and a geographical map of sites location, as reported in Fig. 4c and d. Both visualizations classify results in five classes of redevelopment potential (very high, high, medium, low and very low), attributing to each class a different colour. Intermediate and final results can also be exported in a standard excel file for further offline processing and utilization. According to Klusáček and colleagues (Klusáček et al., 2014), some disadvantages of the system can be represented by the prejudices among some stakeholders, who can perceive the system as too complicated for users who do not have strong competences in models applications (which always simplifies reality) and in commercial or noncommercial Geographic Information Systems (GIS) for results visualization.

4. Case study application

The TBPT has been pilot tested on selected databases available for the four case-studies of the Timbre project, located in the Czech Republic, Germany, Poland and Romania, respectively. In the Czech Republic, the TBPT was applied on a portfolio of urban sites of the Brno municipality and on the database of brownfield sites developed by the Regional Development Agency of South Moravia, which covers the territory of the South Moravian region. In Germany, the TBPT was tested on two databases: the database of brownfield sites located in the territory of Saxony owned by the Corporation for Brownfield Development and Decontamination (GESA) and the database of brownfield sites located in Thuringia owned by the State Development Corporation of Thuringia (LEG). Finally, in Poland and in Romania, tests were conducted on the Regional database of brownfields developed by the Silesian Voivodship and on the national database of brownfield sites provided by the National Environmental Protection Agency (NEPA), respectively (Bartke et al., 2014; Klusáček et al., 2014). The case study discussed in this paper makes use of the Czech database of the South Moravian Region, which covers a portfolio consisting of 235 brownfield sites located in 6 districts (i.e., Blansko, Brno-venkov, Břeclav, Hodonín, Vyškov and Znojmo), as shown in Fig. 5. The total area of the case study covers 6965 km², with 792,570 inhabitants and a population density of 113.8 inhabitants/km² (Czech statistical office, 2013). The database is considered of great value for the region and has been already analysed from different perspectives in some previous studies, such as Frantál et al. (2013) and Klusáček et al. (2013).

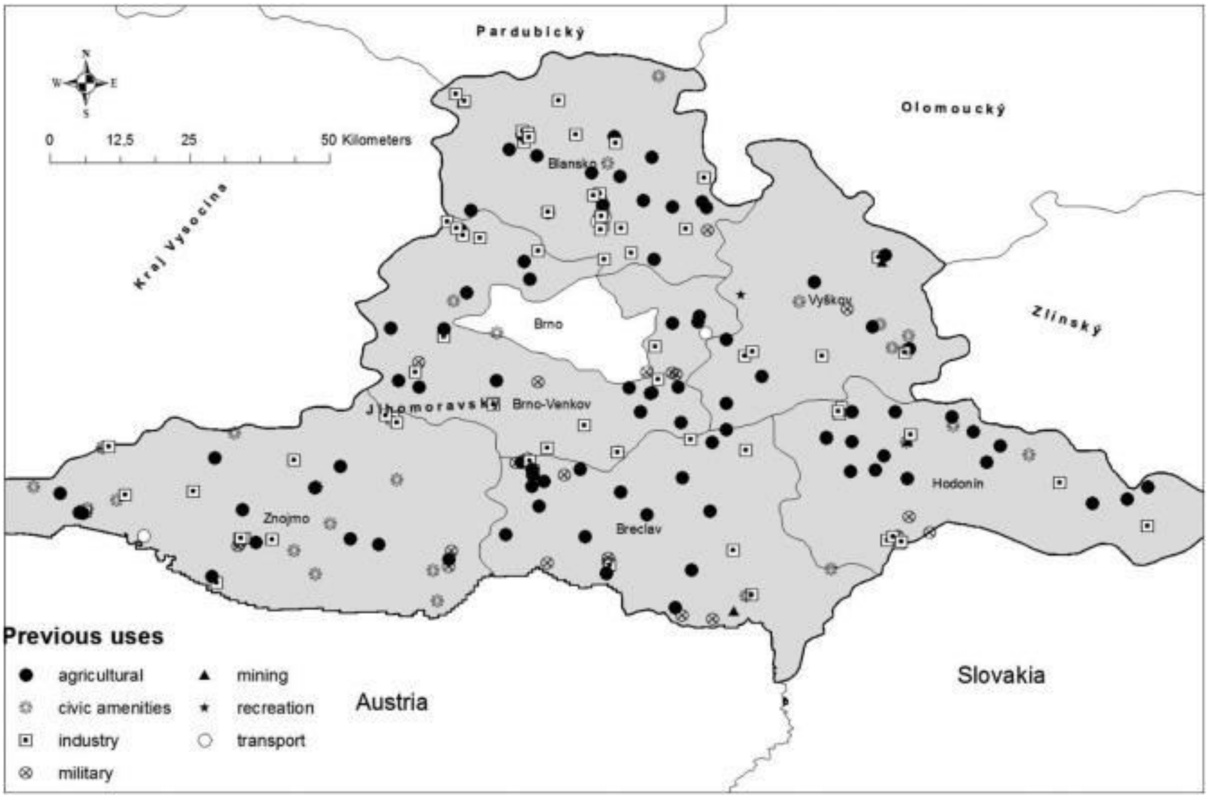

Fig. 5. Spatial distribution of brownfield sites and information on the previous use of the sites.

General information related to the brownfield sites collected in the database is reported in Table 1. According to Table 1, it is possible to affirm that the total area covered by brownfield sites is 889 ha, representing about the 0.13% of the total area of the six districts. Furthermore, most brownfield sites located in the region were previously used for agricultural activities, followed by those with former industrial use. The explanation for the high number of agricultural brownfield sites can be rooted to the post-communism collapse of many agricultural cooperatives and former state farms in the period after 1989 (Klusáček et al., 2013; Konečný, 2014; Skála et al. 2013). Moreover, the database contains information for districts characterised by *per se* predominant rural character. However, it has to be underlined that the total area covered by industrial sites is wider than the area covered by former agricultural sites, since the average area of industrial sites is much wider. The spatial distribution of brownfield sites is reported in Fig. 5.

Table 1. General information on brownfield sites collected in the database created by the Regional Development Agency of South Moravia in 2011, Czech Republic.

Previous use	Number of brownfields	% On total number	Total area (ha)	% Of total area	Average area (ha)
Agricultural	94	40.0%	291.44	32.8%	3.10
Civil amenities	34	14.5%	23.64	2.7%	0.70
Industrial	75	31.9%	296.27	33.3%	3.95
Military	23	9.8%	231.88	26.1%	10.08
Mining	4	1.7%	34.69	3.9%	8.67
Recreation	1	0.4%	0.38	0.0%	0.38
Transport	4	1.7%	10.74	1.2%	2.69
Total	235	100.0%	889.04	100.0%	3.78

Source: RRAJM, 2011. Own calculations.

It has to be highlighted that the database does not contain information about potentially contaminated sites in the Brno-město district (which equals to the municipality of the South Moravian region, Brno). Brno holds its responsibility for contaminated sites' assessment and management policy in its territory and created its own database, which was not available for this assessment.

Since the South Moravian region was selected as a case study area on the basis of the high number of brownfield sites located in the region and the related high importance posed by local authorities for their requalification, the Regional Development Agency of South Moravia worked in close cooperation with the TBPT developers during the different phases of the tool development as well as during the application stage. Through meetings with the responsible persons of the Regional Development Agency and the tool's developers, the objectives of the prioritization was identified and concerned the test of the prioritization tool on two different prioritization logics. The first goal is related to the identification of the most suitable set of brownfield sites for building a shopping centre, while the second concerns the identification of the most suitable set of brownfield sites where a new solar power plant can be located.

Accordingly, the TBPT database for the application was developed on the basis of the framework reported in Section 2.1.1. As reported in Table 2, the basic TBPT database is composed of 22 indicators, 15 factors and 3 dimensions, if no additional dimension is added by the end-user, as in the case of the application reported in this paper. Indicators selected for the first dimension (i.e., local development potential) assess the characteristics of the municipalities where the analysed brownfield sites are located, while indicators belonging to the second and the third dimensions (i.e., site attractiveness and marketability and environmental risks) describe relevant characteristics of the analysed brownfield sites.

Table 2. Structure of TBPT database including the different components of the framework (i.e., dimensions, factors and indicators) and the types of data used to evaluate the selected indicators.

Dimension	Factor	Indicator	Data type
Local redevelopment potential (d1)	f1 Education index	Proportion of people with high school degree [%]	Number
		Proportion of people with university degree [%]	Number
	f2 Entrepreneurial activity	Number of entrepreneurs per 1000 inhabitants (2010)	Number
	f3 Land value	Average price of agriculture land (2002) [CZK]	Number
	f4 Peripherality	Proximity to regional centre [km]	Number
	f5 Population density	Population density [number of inhabitants per km²]	Number
	f6 Transport links	Proximity to highway [km]	Number
		Rail station in municipality [yes = 1/no = 0]	Number
Site attractiveness and marketability (d2)	f7 Estimated regeneration costs	Estimated regeneration costs [in mil. CZK per 1 ha]	Number
	f8 Ownership	Number of owners	Number
	f9 Previous USE	Previous use	String
	f10 Specific localization	Specific localization	String
	f11 Infrastructure	Connection to domestic water [yes = 1/no = 0]	Number
		Connection to drinking water [yes = 1/no = 0]	Number
		Connection to electricity [yes = 1/no = 0]	Number
		Connection to gas [yes = 1/no = 0]	Number
		Connection to sewage [yes = 1/no = 0]	Number
Environmental risk (d3)	f12 Area	Total area of site [m²]	Number
	f13 Contamination	Contamination status	String
	f14 Nature protection	Protection category	String
		Proximity to protected zones [m]	Number
	f15 Zoning	Current land use designation	String

4.1. Normalisation and weighting

The prioritization and weighting process was conducted in collaboration with representatives of the Regional Development Agency. The results of this consultation process are reported in Table 3 and Table 4. Table 3 shows, for each selected indicator and for each prioritization objective (i.e., shopping centre or solar power plant), the normalization function and the reason for choosing it. The selected normalisation methods and the associated motivations represent the local concerns, perceptions and preferences expressed by the Regional Development Agency. For this reason, they are not generally valid, but are representative of the local context where the tool is applied. In Table 4, the weights estimated by the local experts from the Regional Development Agency for the components of the prioritization framework (i.e., dimensions, factors and indicators) are reported according to the prioritization objectives (i.e., shopping centre or solar power plant).

Table 3. Indicators' normalization functions and rationale expressed by local experts for the two scenarios (i.e., shopping centre and solar power plant)

Indicators	Normalization – shopping centre		Normalization – solar power plant	
	Method of normalization	Reasoning	Method of normalization	Reasoning
Proportion of people with high school degree [%]	Ascending	Inhabitants with better education have usually higher salaries and purchasing power.	Descending	Solar energy is quite unpopular in the region and developers fear that higher educated people are more likely to protest effectively.
Proportion of people with university degree [%]	Ascending	Inhabitants with better education have usually higher salaries and purchasing power.	Descending	Solar energy is quite unpopular in the region and developers fear that higher educated people are more likely to protest effectively.
Number of entrepreneurs per 1000 inhabitants (2010)	Ascending	Indicate municipalities with higher incomes.	Descending	Potential opposition from active people is expected and therefore areas with less entrepreneurs are preferred in this region.
Average price of agriculture land (2002) [CZK]	Ascending	The land in successfully developing municipalities will have higher price than in declining municipalities.	Descending	The lower land prices indicate problems of declining - even solar energy projects are welcomed.
Proximity to regional centre [km]	Descending	The closer to the regional centre the better, because proximity to costumers.	Ascending	The higher distance the better, because many projects were realised in peripheral municipalities
Population density [number of inhabitants per km²]	Ascending	The higher density, the higher concentrations of potential customers.	Descending	The lower population density, the lower number of potential opponents

Proximity to highway [km]	Descending	Many customers use cars for shopping needs.	Ascending	Local perception is claiming that land close to highway is more attractive for other kind of investors and should not be used for solar power plants
Rail station in municipality [yes = 1/no = 0]	Ascending	Selected customers can use railway.	Descending	Local perception is claiming that land close to railway station is more attractive for other kind of investors and should not be used for solar power plants
Estimated regeneration costs [in mil. CZK per 1 ha]	Descending	Investors tend to decrease the estimated costs.	Descending	Investors tend to decrease the estimated costs
Number of owners	Descending	The lower number of owners, the easier negotiations for investors.	Descending	The lower number of owners, the easier negotiations
Previous use	Civil amenities, industrial, and transport = 1; military = 0.5, other type = 0	Civil amenities, industrial and transport brownfield sites are usually located in areas with many inhabitants	Mining and agricultural = 1; recreation and military = 0.5; civil amenities, industry and transport = 0	The previous investments were conducted in "rural" type of brownfield sites
Specific localization	Inner settlement = 1; edge of settlement = 0.5; out of settlement = 0	Many potential costumers live in the inner part of a settlement	Inner settlement = 0; edge of settlement = 0.5; out of settlement = 1	The ideal location is out of settlements - usually no NIMBY effects
Connection to domestic water [yes = 1/no = 0]	Ascending	It is good if the site is connected	Ascending	It is good if the site is connected
Connection to drinking water [yes = 1/no = 0]	Ascending	It is good if the site is connected	Ascending	It is good if the site is connected
Connection to electricity [yes = 1/no = 0]	Ascending	It is good if the site is connected	Ascending	It is good if the site is connected

Connection to gas [yes = 1/no = 0]	Ascending	It is good if the site is connected	Ascending	It is good if the site is connected
Connection to sewage [yes = 1/no = 0]	Ascending	It is good if the site is connected	Ascending	It is good if the site is connected
Total area of site[m²]	Ascending	Search for some kind of larger site	Ascending	Search for some kind of larger site
Contamination status	No (confirmed) = 1; not expected = 0.8; not available = 0.4; expected = 0.2; yes (confirmed) = 0	Decreasing investments for decontamination	All categories 1	Local perception is claiming that contamination is not a relevant issue since other solar plants were already located by the end-user of the assessment at some polluted mining sites (uranium mines)
Protection category	No environmental protection in distance = 1; two strongest level of protection = 0; other level of environmental protection = 0.5	Environmental protection creates problems related to permission	No environmental protection in distance = 1; two strongest level of protection = 0; other level of environmental protection = 0.5	Environmental protection create problems for investors
Proximity to protected zones [m]	Ascending	Environmental protection creates problems for investors	Ascending	Environmental protection create problems for investors
Current land use designation	Residential area and commercial area = 1; industrial and agricultural area = 0.3	It is good to be located in residential areas or in areas with concentration of commercial activities	Residential area = 0; commercial and industrial area = 0,5; agricultural area = 1	Majority of solar power plants are located in agricultural areas

Table 4. Weights for indicators, factors and dimensions attributed according to local expert judgment to the two scenarios (i.e. shopping centre and solar power plant).

Dimension	Factor	Indicator	Weighting – shopping centre			Weighting – solar power plant		
			Dimension level	Factor level	Indicator level	Dimension level	Factor level	Indicat level
Local redevelopment potential	Education index	Proportion of people with high school degree [%]	0.38	0.10	0.50	0.38	0.10	0.50
		Proportion of people with university degree [%]			0.50			0.50
	Entrepreneurial activity	Number of entrepreneurs per 1000 inhabitants (2010)		0.10	1		0.20	1
	Land value	Average price of agriculture land (2002) [CZK]		0.10	1		0.20	1
	Peripherality	Proximity to regional centre [km]		0.25	1		0.20	1
	Population density	Population density [number of inhabitants per km²]		0.30	1		0.20	1
	Transport links	Proximity to highway [km]		0.15	0.80		0.10	0.50
		Rail station in municipality [yes = 1/no = 0]			0.20			0.50

Site attractiveness and marketability	Estimated regeneration costs	Estimated regeneration costs [in mil. Czk per 1 hectare]	0.38	0.20	1	0.38	0.15	1
	Ownership	Number of owners		0.25	1		0.30	1
	Previous use	Previous use		0.10	1		0.30	1
	Specific localization	Specific localization		0.25	1		0.15	1
	Infrastructure	Connection to domestic water [yes = 1/no = 0]		0.20	0.20		0.10	0.30
		Connection to drinking water [yes = 1/no = 0]			0.20			0.10
		Connection to electricity [yes = 1/no = 0]			0.20			0.30
		Connection to gas [yes = 1/no = 0]			0.20			0.10
		Connection to sewage [yes = 1/no = 0]			0.20			0.20
Environmental risk	Area	Total area of site[m²]	0.24	0.15	1	0.24	0.20	1
	Contamination	Contamination status		0.20	1		0.30	1
	Nature protection	Protection category		0.30	0.55		0.25	0.50
		Proximity to protected zones [m]			0.45			0.50
	Zoning	Current land use designation		0.35	1		0.25	1

4.2. Discussion of results

The results of the application of the TBPT to the South Moravian region are reported in <u>Table 5</u> and <u>Fig. 6</u> for the shopping centre scenario and in <u>Table 6</u> and <u>Fig. 7</u> for the solar power plant scenario. For each scenario, the analysis of the results will be based on the top 10 brownfield sites identified by TBPT within the three dimensions and, eventually, according to the final score which integrates the dimensions' scores.

Table 5. Results for the shopping centre scenario: for each dimension and for the final score (obtained through the OWA aggregation method), the top ten ranked brownfield sites are identified along with the municipality they belong to, the obtained score and the previous use of the site. Previous uses of the brownfields sites can be distinguished according to the different text formats as follows: **agricultural**, <u>industry</u>, civic amenities, **<u>military</u>**, *mining*.

Site ID	Municipality	Dimension 1: Local redevelopment potential	Site ID	Municipality	Dimension 2: Site attractiveness and marketability	Site ID	Municipality	Dimension 3: Environmental risk	Site ID	Municipality	OWA
1101	Adamov	<u>0.74</u>	3106	Oslavany	<u>0.98</u>	6302	Ivanovice na Hané	*0.76*	1203	Boskovice	<u>0.83</u>
3405	Šlapanice	<u>0.73</u>	3405	Šlapanice	<u>0.98</u>	7221	Blížkovice	0.75	3405	Šlapanice	<u>0.83</u>
3205	Kuřim	<u>0.72</u>	7221	Blížkovice	0.97	6303	Rostěnice-Zvonovice	0.75	7221	Blížkovice	0.81
3204	Kuřim	**0.72**	7206	Vranov nad Dyjí	0.96	7226	Vratěnín	0.73	4406	Pohořelice	0.80
3608	Židlochovice	<u>0.66</u>	4406	Pohořelice	0.96	1213	Uhřice	0.72	7204	Hrušovany nad Jevišovkou	**<u>0.79</u>**
3304	Rosice	<u>0.66</u>	1131	Vysočany-Molenburk	<u>0.95</u>	1203	Boskovice	<u>0.72</u>	7216	Znojmo	**<u>0.77</u>**
3306	Rosice	**0.66**	1203	Boskovice	<u>0.95</u>	6307	Hvězdlice	0.70	3106	Oslavany	<u>0.77</u>
6206	Slavkov u Brna	<u>0.65</u>	5102	Hodonín	<u>0.94</u>	4201	Borkovany	**0.70**	7206	Vranov nad Dyjí	0.76
6203	Slavkov u Brna	<u>0.65</u>	7102	Moravský Krumlov	<u>0.94</u>	6309	Hvězdlice	**0.70**	3205	Kuřim	<u>0.76</u>
6305	Vyškov	**0.64**	7224	Blížkovice	<u>0.93</u>	3105	Oslavany	**<u>0.70</u>**	1131	Vysočany-Molenburk	<u>0.76</u>

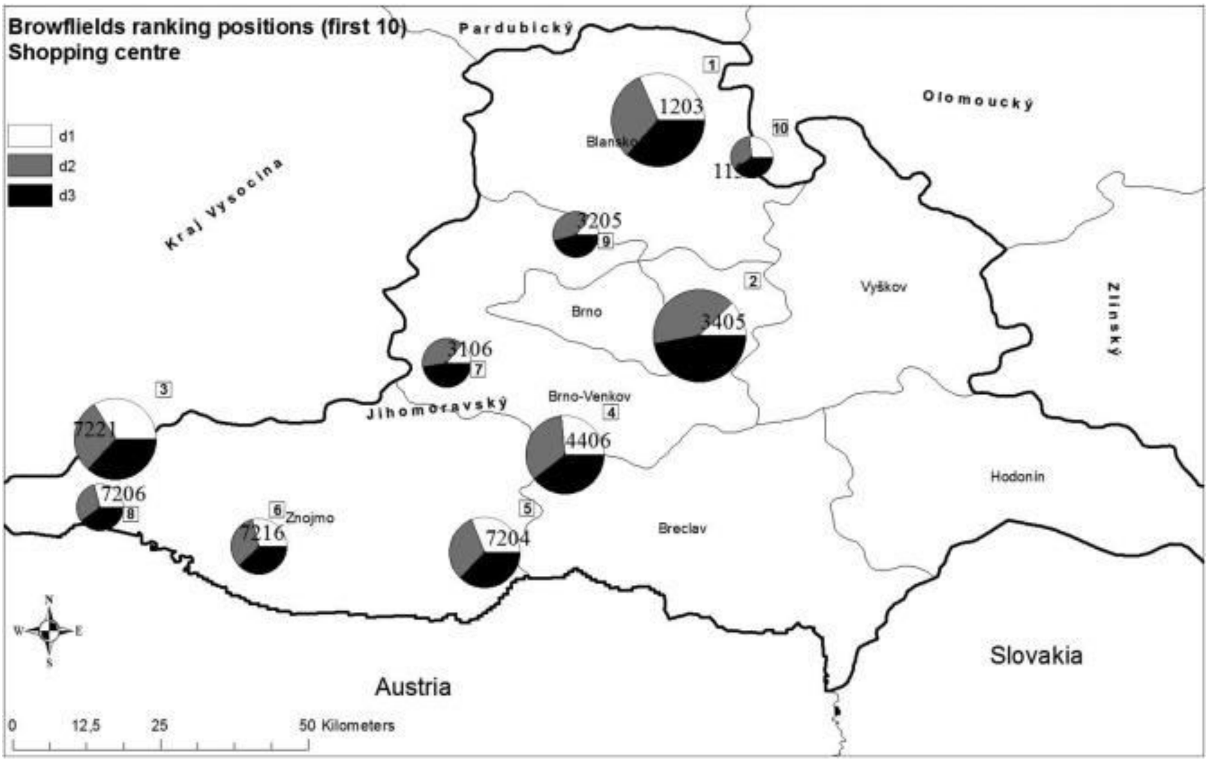

Fig. 6. Map of the spatial distribution of the 10 top ranked brownfield sites for the shopping centre scenario according to the final score. The contribution of the three dimensions (i.e.,

d1 = local development potential, d2 = site attractiveness and marketability, d3 = environmental risks) is reported in the pie charts. The ranking position of the site is reported in the squares closed to the pie chart, while the dimension of the pie charts gives a relative indication of the scores distribution among the first ten ranked sites.

Table 6. Results for the solar power plant scenario: for each dimension and for the final score (obtained through the OWA aggregation method), the top ten ranked brownfield sites are identified along with the municipality they belong to, the obtained score and the previous use of the site. Previous uses of the brownfields sites can be distinguished according to the different text formats as follows: **agricultural**, industry, civic amenities, **military**, *mining*.

Site ID	Municipality	Dimension 1: Local redevelopment potential	Site ID	Municipality	Dimension 2: Site attractiveness and marketability	Site ID	Municipality	Dimension 3: Environmental risk	Site ID	Municipality	OWA
1212	Újezd u Boskovic	0.76	3306	Rosice	**0.95**	5106	Hodonín	**0.81**	7219	Lančov	**0.84**
7212	Vratěnín	**0.75**	4203	Kurdějov	**0.94**	4207	Velké Pavlovice	**0.72**	4203	Kurdějov	**0.82**
7211	Vratěnín	**0.75**	5204	Kyjov	**0.93**	3603	Těšany	**0.72**	1205	Kunice	**0.79**
7226	Vratěnín	0.75	7219	Lančov	**0.93**	5202	Kyjov	*0.71*	5204	Kyjov	**0.79**
7219	Lančov	**0.75**	1205	Kunice	**0.90**	3509	Tišnov	0.68	3306	Rosice	**0.77**
1210	Valchov	**0.74**	4201	Borkovany	**0.90**	4416	Pasohlávky	**0.68**	7106	Skalice	**0.77**
1131	Vysočany-Molenburk	0.74	4412	Pohořelice	**0.89**	3403	Sokolnice	**0.68**	7202	Borotice	**0.76**
1207	Olešnice	0.73	7202	Borotice	**0.87**	1126	Újezd u Černé Hory	**0.68**	4415	Vranovice	**0.76**
1206	Olešnice	0.73	3505	Šerkovice	**0.86**	7106	Skalice	**0.68**	4412	Pohořelice	**0.75**
1208	Olešnice	0.73	1202	Boskovice	**0.85**	4415	Vranovice	**0.67**	3505	Šerkovice	**0.75**

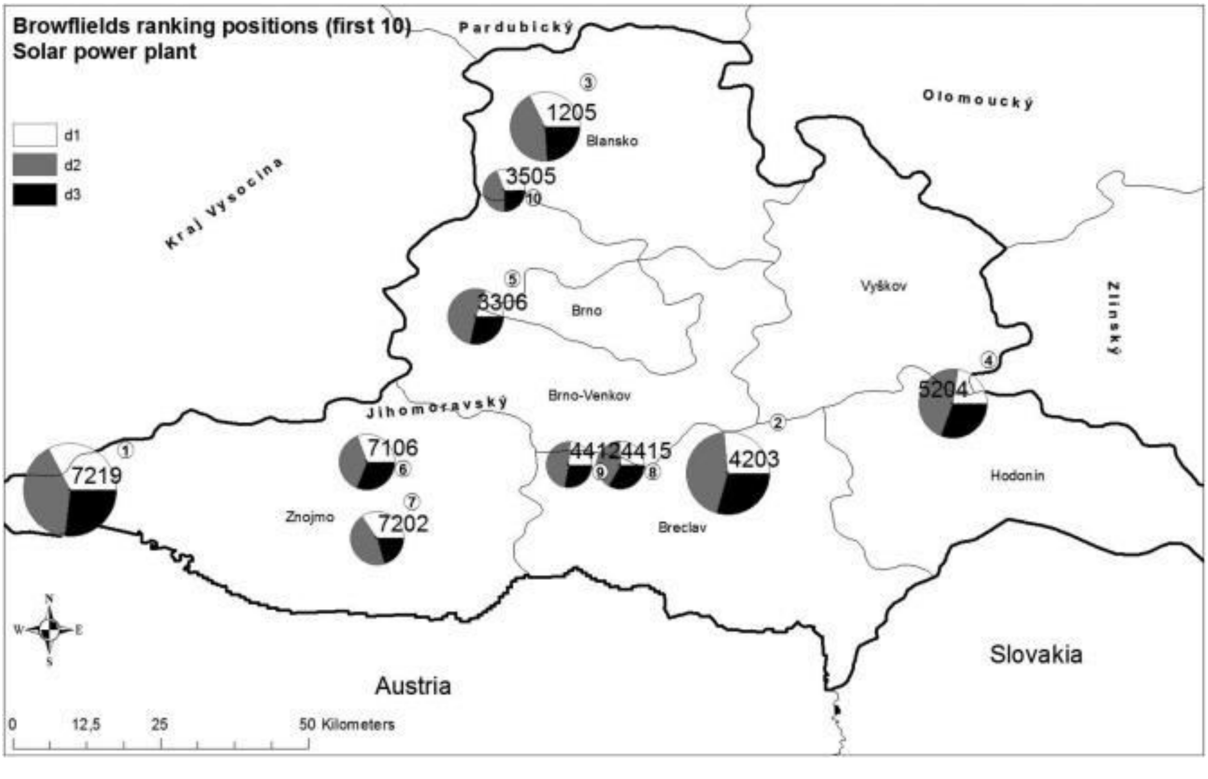

Fig. 7. Map of the spatial distribution of the 10 top ranked brownfield sites for the solar power plant scenario according to the final score. The contribution of the three dimension (i.e., d1 = local development potential, d2 = site attractiveness and marketability, d3 = environmental risks) is reported in the pie charts. The ranking position of the site is reported in the circle closed to the pie chart, while the dimension of the pie charts gives a relative indication of the scores distribution among the first ten ranked sites.

Interpretation and discussion of the results do accept the perspectives and preferences expressed by the specific end-user of the TBPT for the case at hand, i.e. the Regional Development Agency. The indicator reasoning, normalization patterns, weightings of indicators, factors and dimensions reflect both the site-specific conditions of the studied region and the perceptions and preferences of the end-user who is the owner of the brownfield sites portfolio.

The obtained results were evaluated in cooperation with the representatives of the Regional Development Agency in charge of the selected database. The final ranking of sites for the shopping centre scenario is dominated by former industrial sites (5) and civil amenities (3), accompanied by 2 former military sites, one of which with a very special and complicated history (a monastery used by the army during socialism time). Most of these sites are close to the main communication routes (highway and railway corridors system) and in proximity to regional centres. According to the dimension of the sectors in the pie charts in Fig. 6, for most of the top ranked sites the three dimension have a similar influence. In other words, the contribution of the three dimensions to the final score, which is a function of dimension weights and dimension value and should not be confused with dimension importance (based only on dimension weights), is almost similar. Some exceptions are represented by positions 2, 7 and 9, where dimensions 2 and 3 have a higher value and therefore a higher influence to the final score than dimension 1. As far as the solar power plant scenario is concerned, the sites which had a former agricultural use dominate in the top ranked brownfield sites. Moreover, these sites are located in municipalities in the peripheral rural regions with limited development opportunities. Interest of investors for these sites is strongly influenced by public incentives. According to the dimension of the sectors in the pie charts in Fig. 7, among the three dimensions, dimension 2 has higher value and therefore higher influence in the final score estimation.

In order to better understand the final results of the assessment, the results obtained for each dimension need to be analysed. The maps of the spatial distribution of the results for each dimension are reported in the Supplementary Material (Figure S1–S6) along with the influence of the different factors (f1–f15) to the dimensions' scores.

The results of the **first dimension** (i.e., Local redevelopment potential, Figures S1 and S4 of Supplementary Material) show that the spatial distribution of the top 10 ranked sites for the two scenarios is very different. The highest scores in the shopping centre scenario are associated to sites located in towns influenced by suburbanisation processes in the proximity of Brno (for example in Adamov, Šlapanice, Kuřim, Rosice, Slavkov), while the top ten brownfield sites for solar power plant scenario are located in municipalities in the peripheral regions (for example Vratěnín in Znojmo district or Olešnice in Blansko district). In both scenarios, no one among the six identified factors for Dimension 1 (i.e., f1–f6 in Table 2) has predominant influence, but dimension 1 scores result from the even contribution of the six factors.

In the case of the **second dimension** (i.e., Site attractiveness and marketability, see Figures S2 and S5 of Supplementary Material), the highest scores for the shopping centre scenario have been achieved by brownfield sites which had former industrial or civil amenities use. This identification is in line with examples of already regenerated brownfield sites, which were collected by the Regional Development Agency of South Moravia, and which are available at http://rrajm.cz/publikace. According to this publication, many former industrial sites were regenerated as shopping centres after the so-called Velvet revolution in

Czech Republic. Similar experience has been reported for brownfield sites regenerated in Brno (Brno Brownfields, 2013; Frantál et al., 2015b), where many industrial sites were simply demolished and replaced by supermarkets during the two decades after 1989. On the contrary, among the top ten brownfield sites for the solar power plant scenario, only former agricultural brownfield sites were selected. This is in line with the locations of existing solar power plants with output higher than 1 kW. Among the 22 large solar power plants created on brownfield sites in the South Moravian region, 14 were located on former agricultural sites (Klusáček et al., 2014, p. 521).

The factors mostly influencing dimension 2 scores differ in the two analysed scenarios. In the shopping centre scenario, factor 7 (estimated regeneration costs) and factor 8 (numbers of site owners) have a strong influence, followed by factor 11 (connection to existing infrastructures). In the solar plant scenario, factors 7 to 10 have a similar influence in the dimension 2 scores estimation, while factor 11 (infrastructure) has a very low influence.

In the **third dimension** (i.e., Environmental risk, Figure S3 and S6 of Supplementary Material), among the top ten brownfield sites for the shopping centre scenario, most of the sites have former civil amenities use, while only one site (the first ranked site) is a former mining site, one site is a former industrial site, two site are former agricultural sites, which had long history and which were located in proximity to centres of settlements, and the last site is a former military site. The most influent factors for the dimension 3 scores estimation are f13 (contamination) and f15 (zoning, represented by the current land use). In the solar power plant scenario, most of the top ranked sites are former agricultural sites, which are accompanied by one military, one mining and one industrial site. The most influent factors are those already identified in the shopping centre scenario (i.e. f13 and f15), with the exception of the first ranked site, where also factor f12 (total area of the site) has strong influence.

Discussion with the person in charge of the investigated brownfield database demonstrated that the perception of the end-user regarding the obtained results was quite positive, because the results were in line with their expectations. Furthermore, the end-user very much appreciated the fact that, once all data and information are collected in the system, it allows to easily modify the weighs of dimensions, factors and indicators, and it can quickly recalculate the prioritisation results. This functionality turned out to be beneficial during face to face meetings with stakeholders to support the analysis of the presented results and to answer specific questions made by participants. In this context, it is necessary to emphasize that the TBPT can be particularly useful in those countries where brownfield sites databases are already available, while additional efforts should be made in those countries where the expertise and experiences on brownfield sites assessment and management are still limited (Tintěra et al., 2014).

5. Conclusion

The regeneration of brownfield sites is a challenging task, prevented by depollution needs, environmental concerns, cost uncertainties and competition from so-called greenfield sites. If a problem-owner has been challenged by having to take care for the security and re-development of a portfolio of sites, instruments that allow for the prioritization of the sites according to the portfolio specific action needs are vital to allocate limited resources in an efficient way.

After the screening of available support instruments, the Timbre Brownfield Prioritization Tool has been developed in close collaboration with European brownfield experts as a web-based support tool to provide user-friendly assistance in assessing the suitability of brownfield sites. A multi-criteria approach has been designed to be simple and as such as understandable as possible for users. At the same time, it offers a high degree of freedom to adjust the assessment to the portfolio in order to include regional and end-user specific regeneration success factors and urgency determinants.

Several case studies have applied the TBPT out of which the South Moravian with 235 brownfield sites has been presented here. The evaluation of the results concluded that the web-based prioritization tool could be a very useful tool especially in two ways:

a) It helps the pre-selection of concrete brownfield sites: even if it could be easy to presuppose that agricultural brownfield sites are the most suitable sites for the location of new solar power plants, the TBPT is very useful in identifying (based on other important criteria) the agricultural brownfields with the highest potential among the total sample of 94 agricultural brownfield sites for the selected case study;
b) It provides end-users with additional information about location of existing brownfield sites with high potential and their spatial distribution. This additional information can be a good starting point for end-users who need to collect detailed information related to the pre-selected top 10 sites among which the final and the most suitable solution will be identified (i.e., identification of the final location where the shopping centre or the solar power plant will be located).

The presented tool can be easily applied in other contexts, as the proposed methodology allows for the adjustment of the weights and even dimensions by the specific experts and problem owners. They can modify the proposed dimensions, factors and indicators, their weights and their normalisation functions on the basis of the distinct regionally or portfolio specific conditions or given the aims of the prioritization exercise. The tool integrates a Multi Criteria Decision Analysis technique, which assures a comprehensive and sound evaluation of all different criteria considered in the assessment. The application of the TBPT to the case study showed that it is flexible and easy to adapt to different local contexts, allowing the assessors to introduce locally relevant parameters identified according to assessors' expertise and local data availability.

The final results can be presented through a GIS based interface, which conveys the final outputs to decision-makers and stakeholders in a more direct and effective way. The web-based design and utilization of standard software solutions allows for an easy uptake and communication of the assessments.

The developed prioritization methodology, giving the freedom to end-users to weight the determinants according to distinct needs and implemented in the hands-on web-based manner, is promising for being taken up by problem owners. A sensitivity analysis should be performed in order to assess the robustness of the proposed methodology in relation to input data variations and to the identification of relevant parameters and related normalisation functions, considering the possible subjectivity of these choices. This will provide a better understanding of the relationships between input and output variables and will support a correct consideration and use of the results by decision-makers.

Acknowledgement

The research leading to these results was elaborated within the framework of the collaborative project TIMBRE – An Integrated Framework of Methods, Technologies, Tools and Policies for Improvement of Brownfield Regeneration in Europe, funded by the European Commission's Seventh Framework Programme in the theme ENV.2010.3.1.5-2 under grant agreement no. 265364 (2011–2014). More information on TIMBRE is available on www.timbre-project.eu.

References

P. Agostini, L. Pizzol, A. Critto, M. D'Alessandro, A. Zabeo, A. Marcomini **Regional risk assessment for contaminated sites Part 3: spatial decision support system** Environ. Int., 48 (2012), pp. 121-132, 10.1016/j.envint.2012.07.005

S. Bartke **Valuation of market uncertainties for contaminated land** Int. J. Strateg. Prop. Manag., 15 (2011), pp. 356-378, 10.3846/1648715X.2011.633771

S. Bartke **Editorial: improving brownfield regeneration – a sustainable land take solution** Thematic Issue 39 Science for Environment Policy: Brownfield Regeneration, European Commission's DG Environment, Bristol (2013), pp. 3-4

S. Bartke, A. Bielke, A. Homuth, K. Roselt, T. Zill **Das TIMBRE Priorisierungstool: Brachflächenbewertung von Grundstücksportfolien in Sachsen und Thüringen** altlastenspektrum, 23 (5) (2014), pp. 202-210

A. Bleicher, M. Gross **Sustainability assessment and the revitalization of contaminated sites: operationalizing sustainable development for local problems** Int. J. Sustain. Dev. Amp World Ecol., 17 (2010), pp. 57-66, 10.1080/13504500903488263

Brno Brownfields **2013-Review of Brno Brownfields Revitalisation** (2013) [online] Available at: https://www.brno.cz/fileadmin/user_upload/Podnikatel/Brownfields_2013_EN.pdf

D.A. Carroll, R.J. Eger **Brownfields, crime, and tax increment financing** Am. Rev. Public Adm., 36 (2006), pp. 455-477, 10.1177/0275074006289645

CEN **Glossary of Terms for Holistic Management of Brownfield Regeneration (GoT-HOMBRE)** (2014) CEN Workshop Agreement 74 https://www.cen.eu/work/areas/env/Pages/WS-74.aspx

Z. Chen, S. Khumpaisal**An analytic network process for risks assessment in commercial real estate development** J. Prop. Invest. Financ., 27 (2009), pp. 238-258, 10.1108/14635780910951957

F. Cheng, S. Geertman, M. Kuffer, Q. Zhan**An integrative methodology to improve brownfield redevelopment planning in Chinese cities: a case study of Futian, Shenzhen** Comput. Environ. Urban Syst. Sustain. Urban Dev., 35 (2011), pp. 388-398, 10.1016/j.compenvurbsys.2011.05.007

M. Chrysochoou, K. Brown, G. Dahal, C. Granda-Carvajal, K. Segerson, N. Garrick, A. Bagtzoglou **A GIS and indexing scheme to screen brownfields for area-wide redevelopment planning** Landsc. Urban Plan., 105 (2012), pp. 187-198, 10.1016/j.landurbplan.2011.12.010

City of Colorado, 2000. http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheadername1=Content-Disposition&blobheadername2=Content-Site Prioritization Criteria [online] Available at: Type&blobheadervalue1=inline%3B+filename%3D%22Site+Prioritization+Criteria+and+Worksheets.pdf%22&blobheadervalue2=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251811748423&ssbinary=true.

Czech statistical office, 2013. [online] Available at: http://www.czso.cz/xb/redakce.nsf/i/vybrane_ukazatele_podle_okresu_v_roce_2013/$File/MZO_13.pdf.
T. Dixon **The property development Industry and sustainable urban brownfield regeneration in England: an analysis of case studies in Thames Gateway and Greater Manchester** Urban Stud., 44 (2007), pp. 2379-2400, 10.1080/00420980701540887
T. Dixon, N. Otsuka, H. Abe **Critical success factors in urban brownfield regeneration: an analysis of "hardcore" sites in Manchester and Osaka during the economic recession (2009–10)** Environ. Plan. A, 43 (2011), pp. 961-980
L. Doleželová, M. Hadlač, M. Kadlecová, S. Polednik **Redevelopment potential of brownfields: A-B-C classification and its practical application** EM Ekon. Manag., XVII (2014), pp. 34-44, 10.15240/tul/001/2014-2-003
B. Frantál, J. Kunc, E. Nováková, P. Klusáček, S. Martinát, R. Osman **Location matters! exploring brownfields regeneration in a spatial context (A case study of the South Moravian Region, Czech Republic)** Morav. Geogr. Rep., 21 (2013), pp. 5-19, 10.2478/mgr-2013-0007
B. Frantál, J. Kunc, P. Klusáček, S. Martinát **Assessing success factors of brownfields regeneration: international and inter-stakeholder perspective** Transylv. Rev. Adm. Sci., 18422845, S.l (2015), pp. 91-107 Available at: http://rtsa.ro/tras/index.php/tras/article/view/427
B. Frantál, G.W. Bryn, P. Klusáček, T. Krejčí, J. Kunc, S. Martinát **Exploring spatial patterns of urban brownfields regeneration: the case of Brno, Czech Republic** Cities, 44 (2015), pp. 9-18, 10.1016/j.cities.2014.12.007
R. Ganser, K. Williams **Brownfield development: are we using the right targets? Evidence from England and Germany** Eur. Plan. Stud., 15 (2007), pp. 603-622, 10.1080/09654310600852654
HOMBRE **D5.1-Valuation Approach for Services from Regeneration of Brownfields for Soft Re-use on Permanent or Interim Basis** (2013)
P. Klusáček, B. Frantál, J. Kunc, S. Martinat, R. Osmar, A. Zabeo, S. Bartke, M. Finkel, M. Morio, L. Cosmo, P. Pizzol **Prioritization Tool, Software, and Manual. TIMBRE Deliverable D3.2 Version 4** (2013), p. 68
P. Klusáček, B. Frantál, J. Kunc, S. Martinat, R. Osmar, A. Zabeo, L. Cosmo, F. Alexandrescu, C. Brückmann, S. Bartke, M. Finkel, M. Morio, P. Pizzol, J. Krupanek, A. Homuth, T. Sileam **Prioritization Tool: Results of Demonstration Studies and Outreach Material. TIMBRE Deliverable D3.3 Version 4** (2014), p. 138
O. Konečný **Geographical perspectives on Agritourism in the Czech Republic** Morav. Geogr. Rep., 22 (2014), pp. 15-23
D. Lange, S. McNeil **Brownfield development: tools for Stewardship** J. Urban Plan. Dev., 130 (2004), pp. 109-116, 10.1061/(ASCE)0733-9488(2004)130:2(109)
D.H. Meadows Limits to Growth: the 30-Year Update (3 edition), Chelsea Green Publishing, White River Junction, Vt (2004)
P.B. Meyer, T.S. Lyons **Lessons from private sector brownfield redevelopers** J. Am. Plann. Assoc., 66 (2000), pp. 46-57, 10.1080/01944360008976083
OECD **Compact City Policies** Organisation for Economic Co-operation and Development, Paris (2012)
K. Pediaditi, K.J. Doick, A.J. Moffat **Monitoring and evaluation practice for brownfield, regeneration to greenspace initiatives: a meta-evaluation of assessment and monitoring tools** Landsc. Urban Plan., 97 (2010), pp. 22-36, 10.1016/j.landurbplan.2010.04.007

L. Pizzol, A. Critto, P. Agostini, A. Marcomini **Regional risk assessment for contaminated sites Part 2: ranking of potentially contaminated sites** Environ. Int., 37 (2011), pp. 1307-1320, 10.1016/j.envint.2011.05.010
Y. Qi, D. Kung, E. Wong **An agent-based data-flow testing approach for web applications** Inf. Softw. Technol., 48 (2006), pp. 1159-1171, 10.1016/j.infsof.2006.06.005
E. Rizzo, M. Pesce, L. Pizzol, F. Alexandrescu, E. Giubilato, A. Critto, A. Marcomini, S. Bartke **Brownfield Regeneration in Europe: Identifying Stakeholder Perceptions, Concerns, Attitudes and Information Needs** Land Use Policy, 43 (2015), pp. 437-453, 10.1016/j.landusepol.2015.06.012
RRAJM, 2011. [online] Available at: http://www.rrajm.cz/databaze-bf.
S. Schädler, M. Morio, S. Bartke, M. Finkel **Integrated planning and spatial evaluation of megasite remediation and reuse options** J. Contam. Hydrol., 127 (2012), pp. 88-100, 10.1016/j.jconhyd.2011.03.003
J. Skála, J. Čechmánková, R. Vácha, V. Horvátthová **Various aspects of the genesis and perspectives on agricultural brownfields in the Czech Republic** Morav. Geogr. Rep., 21 (2013), pp. 46-55, 10.2478/mgr-2013-0010
C.A.D. Sousa **Measuring the public costs and benefits of brownfield versus greenfield development in the Greater Toronto area** Environ. Plan. B Plan. Des., 29 (2002), pp. 251-280, 10.1068/b1283
E. Strazzera, E. Cherchi, S. Ferrini **Assessment of regeneration projects in urban areas of environmental interest: a stated choice approach to estimate use and quasi-option values** Environ. Plan. A, 42 (2010), pp. 452-468, 10.1068/a4213
W. Sun, B. Jones **Using multi-scale spatial and statistical analysis to assess the effects of brownfiel redevelopment on surrounding residential property values in Milwaukee county, USA** Morav. Geogr. Rep., 21 (No. 2) (2013), pp. 56-64
M.R. Thomas **A GIS-based decision support system for brownfield redevelopment.** Landsc. Urban Plan., 58 (2002), pp. 7-23, 10.1016/S0169-2046(01)00229-8
G. Thornton, M. Franz, D. Edwards, G. Pahlen, P. Nathanail **The challenge of sustainability: incentives for brownfield regeneration in Europe** Environ. Sci. Policy, 10 (2007), pp. 116-134, 10.1016/j.envsci.2006.08.008
J. Tintěra, A. Ruus, E. Tohvri, Z. Kotval **Urban brownfields in Estonia: scope, consequences and redevelopment barriers as perceived by local governments** Morav. Geogr. Rep., 22 (4) (2014), pp. 25-38, 10.1515/mgr-2014-0021
A. Tölle **Report about Concepts and Tools for Brownfield Redevelopment Activities (Output No. 3.1.1 of the COBRAMAN Project)** (2009) Bydgoszcz, Poland. [online] Available at: http://www.central2013.eu/fileadmin/user_upload/Downloads/outputlib/cobraman_tools_brownfield_regeneration.pdf
L. Wang, L. Fang, K.W. Hipel **Negotiation over costs and benefits in brownfield redevelopment** Group Decis. Negot., 20 (2011), pp. 509-524, 10.1007/s10726-009-9179-5
G.C. Wedding, D. Crawford-Brown **Measuring site-level success in brownfield redevelopments: a focus on sustainability and green building** J. Environ. Manage., 85 (2007), pp. 483-495, 10.1016/j.jenvman.2006.10.018
R.R. Yager **On ordered weighted averaging aggregation operators in multi-criteria decision making** IEEE Trans. Syst. Man. Cybern., 18 (1988), pp. 183-190
A. Zabeo, L. Pizzol, P. Agostini, A. Critto, S. Giove, A. Marcomini**Regional risk assessment for contaminated sites Part 1: Vulnerability assessment by multicriteria decision analysis** Environ. Int., 37 (2011), pp. 1295-1306, 10.1016/j.envint.2011.05.005