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Identification of Potential Urban Development Areas and Extraction of Urban Land Use Information Based on Open Source Data

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Abstract. The optimization of urban land use is a very important aspect of sustainable urban development, including recycling abandoned land and further developing in-use areas. However, limited knowledge of these kinds of areas and their properties have been restricting end-users from exploring and reusing them. URBIS (URBan land recycling Information services for Sustainable cities) is a European project aimed at identifying urban areas which have potential to be further developed, as well as to extract their land use information based on open spatial data. URBIS first selected and stored possible sites as polygons in a Green or Grey Layer. In a second step, the information about the sites like size, vegetation coverage, and transportation connections are also calculated and attached as attributes to the polygons. At the end, the project results are presented through online services giving end-users the possibility to not only view all these areas but also select their own areas of interest according to particular attributes. The URBIS strategy has been successfully implemented in three pilot cities already. Since the methodology and the service system developed in the project are based on open source data and open source software, URBIS could easily be expanded to other European cities.

Keywords: vacant land, brownfield, open geospatial data.

Conference topic: sustainable urban development.

Introduction

Decades of never-ending and uncontrolled extension of urban development has resulted in fewer green areas as well as increasingly more fragmented areas in several European countries. However, in the meantime, significant built-up areas have been abandoned. In contrast, a sustainable urban development approach includes recycling abandoned land, integrating fragmented land, as well as providing accurate land use information to users. Urban land use information is essential for better land use management and a better land use market. Recently, increasingly enforced geo-information systems have made it possible to access large amounts of open spatial data sources, especially within the European Union (EU). For instance, the European Environment Agency provides abundant geospatial data sets and (interactive) maps for different environmental topics. Under this background, URBIS (URBan land recycling Information services for Sustainable cities) aims to provide information for optimizing urban land use with open data. The potential end-uers of URBIS could be governmental, including a split between the territorial level of the EU, national, regional, and local level, non-governmental orgnisations, as well as other actors such as real estate companies or agricultural associations. At the local level, end-users are interested in local specific urban development problems. In this case, URBIS has conducted experiments with local data for extraction of specific information which could benefit or constrain urban land use. The project has developed a methodology for an inventory of potential development sites and has implemented it in three pilot cities: the city of Osnabrück, Germany, Greater Amiens, France, and the Moravian-Silesian Region, Czech Republic. The methodology has been developed in a way, so that it can be directly applied to other European cities, and the produced services can also be extended to all member states of the EU.

Identifying Potential Development Areas (PDAs) – challenges and solutions

URBIS focuses on urban areas which have been used before but are now underused or vancant, as well as areas which have never been used before but are suitable for future urban exploration. These kinds of areas have been named as brownfields (Maliene *et al.* 2012), derelict and vacant land (Kivell, Lockhart 1996), greenfields (De Sousa 2000), as well as vacant land and abandoned structure (Newman *et al.* 2016). URBIS has reviewed the recent projects at the EU level, the national level, and the regional level which share the same topic and defined the following typology according to the outcomes of the CirsUse project (Preuß, Verbücheln 2013):

– *Greenfields with development perspective* have not been developed and connected to the city infrastructural system, but are located within the scope of the preparatory land use area. Typically, there is no sealing or building activitiy on site.
– *Vacant or underused land* was previously used and is now unused or used in a suboptimal way. The connection to the city infrastructural system remains on site. Such sites are often covered by vegetation, but former activities are obvious such as fragments of sealed surface.
– *Gaps in built-up areas* are underused or unused areas that usually have a small size and are located within the existing urban fabric. They are suitable for construction due to the nearby infrastructure.
– *Brownfields* typically have construction on site and could have contamination problems. Previous types of use include for example industry, military, agriculture, or commerce. Due to these heterogeneous former land uses, the appearance and morphology of brownfields varies strongly.

Challenges

The above classification applies to the conceptual level. In practice, it is challenging to identify these types of sites separately, based on open geospatial data. Suppose all unused urban areas are already known, then brownfield may consist of contaminated sites. Then, from the remaining areas, those with small size are taken out as gaps. At the end, vacant land is left with others. It could be separated by its previously used condition. Through this procedure (shown in Fig. 1), the unused areas could be distinguished. But the procedure does not work the other way around. That means even if contamination, size, and previously used conditions are already known, it cannot be ascertained if this site is unused (see Fig. 1). Considering the available data source (e.g. Urban Atlas), size and previous land use can be determined while contamination might be known from a local data source. Meanwhile, URBIS intends to detect these sites remotely with a certain degree of automation. Therefore, URBIS needs a completely different strategy to overcome these problems.

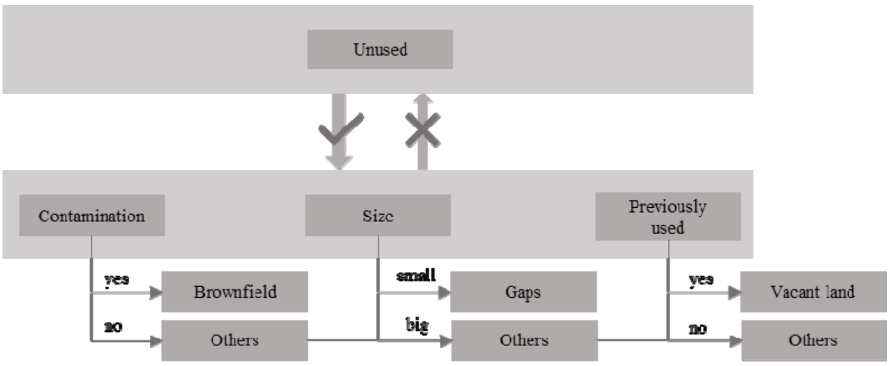

Fig. 1. Concept of classification of unused land

URBIS's solution

Since it is impossible to precisely classify these sites due to their varied land use information and morphology only based on open data, URBIS decided to take a broader scope of sites of interest to ensure that all the above-mentioned types are included. Furthermore, it provides sufficient information about these sites for further evaluation. Finally, URBIS makes it possible for end-users to access the information and filter through their own sites of interest.

It means that besides brownfields, gaps, vacant land, and greenfields, it also incorporates other green urban areas which are in use such as public gardens. However, even if a site is in use, as reported by end-users, it may still have potential to be further developed. For example, a large garden in residential areas may be considered for building new houses in case a densification of the urban fabric is intended by urban planners. Therefore, all green and open areas as well as abandoned sites which could have the potential to be further developed are taken into account and are therefore possible Potential Development Areas (PDAs).

If an end-user intends to search for one type of PDA from the classification mentioned above, URBIS provides sites of interest with sufficient information that could be used to distinguish different types. The information comprises a comprehensive list of attributes such as degree of sealing and vegetation coverage. By comparing the status of sites at two different reference years, the changes of a site are also determined within the project to assist an evaluation of the site's development over time. This can be a hint for evaluating the use of the site, such as increased vegetation coverage, reduced degree of sealing, or decreased number of buildings within the area.

In general, the sites' potential for (re-)development has a very wide range and varies depending on different perspectives of users. On the one hand, these sites may have potential to be further developed: for example, an abandoned industrial zone can be transformed into a museum, or a gap between two houses within dense residential areas can be filled with a newly built house. On the other hand, the sites can serve for the preservation of green land in order to strengthen the city's green infrastructure. To assist the evaluation of a site's potential, URBIS collected and calculated the attributes which – in this case – are land use potential criteria (in the following just "criteria"), like physical properties, land coverage, and surrounding local context. Within URBIS's scope, a Green Layer comprising green and open space and a Grey Layer including brownfields are produced. In a second step, the status criteria and change criteria by comparing different years are calculated for these sites. At the end, with the involvement of end-users, PDAs can be detected from Green and Grey Layers.

Technical support

Since the final decision on PDAs involves end-users, the produced Green Layer and Grey Layer should be accessible and operable through web platforms, which is realized by URBIS web services. The overall architecture of the web-based information system consists of three parts (Fig. 2). A spatial database collects input data and stores URBIS products layers. Open source software PostgreSQL with the spatial PostGIS extension was selected as database management system. The database operation for criteria calculation reaches a much higher degree of automation compared to manually conducting it with GIS software. Detailed information about implementation within the database has been elaborated by Manzke *et al.* (2016). A central server component connects database and the client component, as well as receives and responds to client requests. It is supported by open source software GeoServer which is part of GeoNode software package. URBIS results are disseminated through the web platform: URBIS Integration Tool (URBIS 2017). Clients can view, download the URBIS layers, and operate data through this interactive online tool. For further analysis of PDAs, users can directly apply criteria filter through the Evaluation Tool which is part of the URBIS Integration Tool or process the downloaded vector layer with their own GIS software. It is worth mentioning that to realize a high level of interoperability of geospatial services, URBIS made its download services and meta-data INSPIRE-compliant (for more details about INSPIRE, see European Parliament, Council 2007)

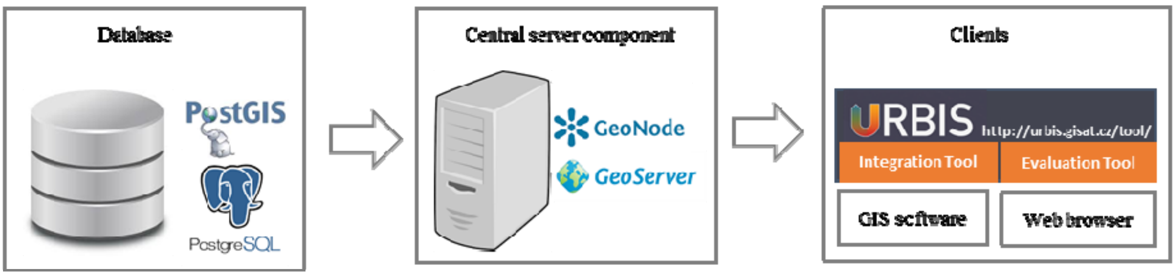

Fig. 2. Overall architecture of URBIS services system

URBIS workflow for the identification of PDAs

The basic procedure for identification of PDAs consists of three levels: site selection for the Green and Grey Layer, criteria calculation for each layer, and evaluation of PDAs from end-users (see Fig. 3). URBIS generated a workflow model in such a way that the methodology developed can be directly applied to other European cities. Input data sources are chosen from those that are available from within the EU. Intermediate products are then generated from input data. Afterwards, both input data and intermediate products are employed to select polygons and calculate their attributes for generating the Green and Grey Layer.

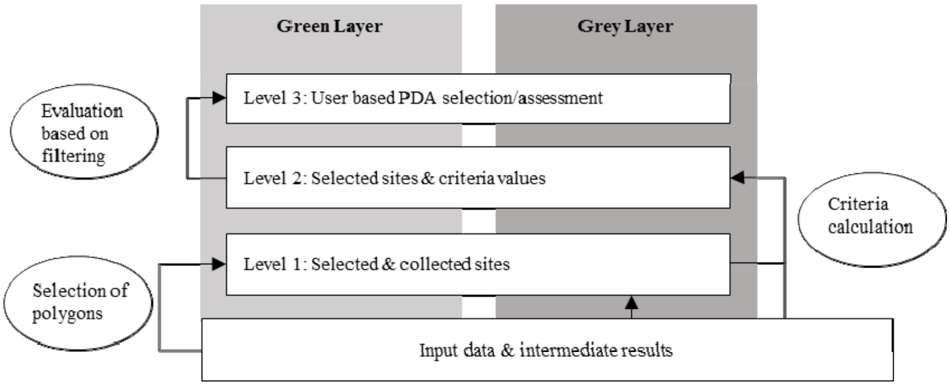

Fig. 3. Overall workflow for the identification of PDAs

Input data for information extraction

URBIS intends to explore the potential of European open data sources. Data available in the framework of Copernicus initiatives such as Urban Atlas are used as the main data source. Urban Atlas provides land use maps for European cities. It can be directly downloaded as vector layers. URBIS incorporated its land use information into its service layers as well as used it for considerable criteria calculation. In a nutshell, it represents a backbone data source of information for URBIS services. SPOT-5 satellite images are the original data source for producing Urban Atlas. These images have a resolution of 2.5 m and are used to generate intermediate products. The project also exploits crowd-sourced OpenStreetMap (OSM), which provides free and freely editable geospatial data for the whole world. This could make the data unreliable. However, the street network is considered sufficient (Neis *et al.* 2012) and is used to calculate criteria related to transportation connections such as distance to highways. The overall input data specification for produce Green and Grey Lay see as in the following table.

Table 1. Input data specification for producing the Green and Grey Layer

Input datasets	Data type	File format	Coordinate Reference System
Brownfield database	Vector	ESRI Shapefile	ETRS 1989 LAEA (EPSG:3035)
Urban Atlas	Vector	ESRI Shapefile	ETRS 1989 LAEA (EPSG:3035)
Satellite imagery (SPOT-5)	Raster	GeoTIFF	ETRS 1989 LAEA (EPSG:3035)
OSM buildings	Vector	Osm-xml file	ETRS 1989 LAEA (EPSG:3035)
OSM transportation network	Vector	Osm-xml file	ETRS 1989 LAEA (EPSG:3035)

Through image analysis processes, URBIS generated intermediate products: vegetation maps, imperviousness maps, and land cover maps from SPOT-5 images (for details, see Krylov *et al.* 2016). The land cover maps are beneficient for site selection. Vegetation maps and imperviousness maps are used for calculating criteria related to vegetation coverage and sealing respectively.

Identification and selection of sites

By land use classification, Urban Atlas has identified several classes which belong to the scope of the sites of interest such as land without current use, green urban areas, and arable land. They are directly integrated into URBIS Green Layer. Limited by its minimum mapping unit of 25,000 m^2, Urban Atlas is not sufficient for detecting sites of interest with smaller size. SPOT-5 was thus taken to complement green site selection. Through land cover classification, high vegetation, low vegetation, and bare land were taken out and then a mask was applied. This mask is called Urban Envelope which is the outline of the Functional Urban Blocks Layer. This layer was generated by combining Urban Atlas classes which represent functional urban areas, such as urban fabric and industrial units. The produced layer includes greenfields, parts of gaps, parts of vacant land, as well as green urban areas. The result is a raster layer named Green and Open Space Layer. URBIS project partners have attempted to further classify this raster layer (for detailed information, see Jupová *et al.* 2017). Only parts of gaps and vacant land are chosen, because if there is sealing surface on these two kinds of sites, they will not be selected and the solution is discussed in the result and the discussion section of this paper. After transferring the Green and Open Space Layer from a raster format to a vector layer and merging it with polygons selected from Urban Atlas, the site selection of the Green Layer is complete.

The result from green site selection includes most of the sites of interest but excludes buildings that are brownfields, such as an abandoned factory. However, these kinds of buildings are registered in local city government departments or are at least known by the local administration. Thus, the project team determined to make use of the local brownfield database for generating the Grey Layer and placed emphasis on extract particular site information. The polygons of Grey Layer are collected from local databases or were digitized based on local knowledge.

Calculation of land use potential criteria

End-users are interested in the information which will affect the development of a site, such as environmental conditions. Through user surveys, URBIS obtained a list of criteria for assessing land use potential. However, due to the limit of data sources, not all of the required criteria can be implemented in the project. The URBIS team created a feasible criteria list which also satisfied end-users' requirements. These criteria were ordered into seven categories:

- physical properties such as size and location,
- shape characteristics including rectangularity, circularity, and convexity,
- land use including current land use and previous land use,
- land cover such as degree of sealing and degree of vegetation coverage,
- existing development such as number of buildings and volume of buildings,
- surrounding local context like distance to the regional center, as well as
- environmental context such as flooding risk and restriction of protected area.

Most of the criteria calculations were applied in a database. URBIS has developed and optimized the calculation of the algorithm for each criterion. However, it is not possible to elaborate all of them here due to page constraints. Some can be obtained by overlaying and intersecting Source Layer and Target Layer. It was applied to, for example, the Building Footprints Layer from OpenStreetMap to extract the number of buildings. For generating the degree of sealing, intersection has been implemented between imperviousness maps which are in raster format and Target Layer which is in vector format. It is also worth mentioning that the minimum distance to existing road networks is the shortest path following a routing on the road network rather than the linear distance. For two pilot cities, Greater Amiens and the Moravian-Silesian Region, SPOT-5 and Urban Atlas are available for both 2006 and 2012. Therefore, criteria were generated for both years. Afterwards, the criteria changes were calculated by comparison.

Analysis and evaluation of PDAs

Since each site has its individual characteristics, URBIS cannot make final decisions of further usage. An end-user will consider the comprehensive information of the site and then decide if it can be further developed. Therefore, URBIS selected mostly possible sites of interest which could be evaluated as PDAs as well as provides sufficient criteria. Later, an end-user can analyze and evaluate a PDA through site filtering based on criteria values or utilizing the URBIS Integration and Evaluation Tool.

Results

The following results show some PDAs based on the analysis of (hypothetical) development scenarios. In each scenario, more than one site is selected. But to make the figure legible, only one site is presented in each case as an example. Also parts of the criteria are presented to the selected PDAs, due to the length of the complete criteria list. By the time of submitting this paper, the project is still ongoing and the project team is still working on improving the URBIS Integration Tool. Hence, the results are displayed in ArcGIS instead of the online tool.

Greenfield as PDA (Green Layer)

In an imagined case**,** an investor or a developer is searching for an agricultural field which could be transformed into a leisure park. It should be located inside the city and with convenient access from a nearby highway and main road. Here, the end-user could choose URBIS Green Layer and set the following criteria: *current land use = arable land & proximity to regional center ≤ 1,000 m & location inside the city = "true" & minimum distance to highway ≤ 20,000 m & minimum distance to main road ≤ 10,000 m*

In this case, 22 sites are selected within city Osnabrueck and Figure 4 shows one site as an example. The site is surrounded by residential areas and has a fast connection to the highway. That makes it fit to the above-mentioned criteria and could therefore be an option for a leisure park.

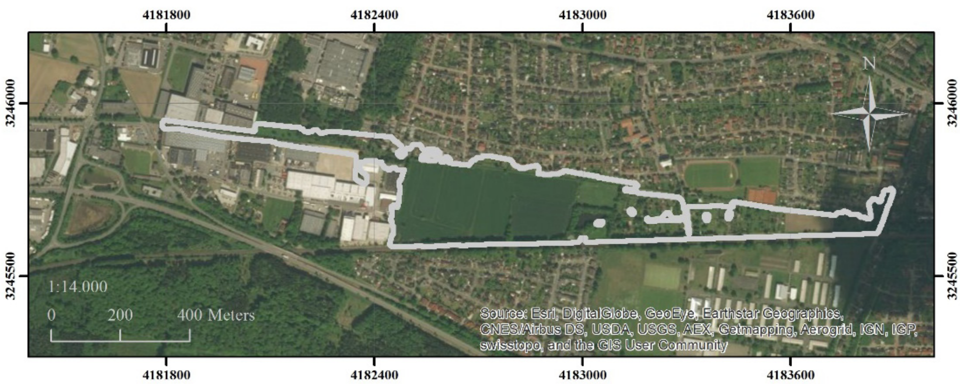

Fig. 4. A greenfield as a PDA
(Source of the background image: Google Earth)

Gap or green urban area as PDA (Green Layer)

In another case, a real estate company might search for a gap in a residential area that is suitable for building up a new house. The optional site can be found by filtering the Green Layer with a size of, for example, bigger than 1,000 m^2 and smaller than 2,500 m^2. The result includes gaps and green urban areas, or a mixture of both (see Fig. 5). However, a real estate company would not be concerned about the type but rather the individual character of the site. The site showed in Figure 4 could be an option. End-users can further consider its possibility for construction according to its attributes like shape charactistics and surrounding local context.

Area	1825 m^2
Proximity to regional center	3683 m
Location inside city	true
Shortest path to highway	992 m
Distance to nearest railway station	4327 m
compactness	0.21
rectangularity	0.53

Fig. 5. A gap in a built-up area as PDA
(Source of the background image: Google Earth)

Vacant land as PDA (Green Layer)

From the site selection process for Green and Open Space Layer, it can be seen if a vacant land has completely or partially sealed surface. Therefore, it could be completely or partly neglected due to the selection of only vegetated area and bare land. To complete site selection, based on the same principle of generating criteria for Green or Grey Layers, attributes are also calculated for Functional Urban Blocks Layer. If an end-user has an interest in this type of site, it can be obtained by filtering criteria changes such as the degree of sealing difference ≤ –0.15 and vegetation coverage difference ≥ 0.15. Figure 6 shows one of the filtered sites. From 2006 to 2012, the degree of sealing has reduced about 25 % and vegetation coverage has increased 24 %. The attributes show that it belongs to Urban Atlas class – land without current use. Thus, this site can also be found from the Green Layer. The selection result shows that there is a few of vacant land filtered out from the Functional Urban Blocks Layer and parts of them are already in the Green Layer. Therefore, the Green Layer is still the main product of URBIS to search PDAs from vacant land.

Degree of sealing change	-0.25
Degree of vegetation coverage change	0.24
Shortest path to highway	5295 m
Current land use	Land without current use

Fig. 6. A vacant land as PDA
(Source of the background image: Google Earth)

Estimation of demolition costs (Grey Layer)

For the Grey Layer, URBIS focuses on specific requirments from local end-users and searches for tailored solutions according to their specific data in hand. In the case of the city of Osnabrück, local authority is interested in the demolition costs of brownfield buildings and the removal costs of sealed surface. According to civil engineering experts, demolition costs directly depend on the volume of the buildings, with 20 €/m^3 as a reference value, while the removal costs of sealed surface rely on the surface area, with 12 €/m^2 as a reference value. Meanwhile, the city of Osnabrück shares digital surface data with the project. This data usually has high resolution and contains elevation information. Considering the estimation of demolition costs, the height of a building needs to be known. Therefore, URBIS decided to execute a volume criteria calculation for the city of Osnabrück. One example is showed in Figure 7 where demolition and removal costs are estimated at about 40,000 €.

Number of buildings	1
Area of buildings	364 m^2
Degree of building coverage	0.0364
Presence of trees	true
Volume of buildings	1548 m^3
Degree of sealing	0.104
Demolition costs	39148 €

Fig. 7. Calculating the demolition costs of a brownfield
(Source of the background image: Google Earth)

Discussion and conclusion

URBIS has implemented a strategy to integrate four types of potential urban areas for (re)use, which are mainly included in the Green and Grey Layer. Grey Layer focuses on producing information which can be used for evaluation and recycling brownfields. Green Layer targets potential sites from gaps in built-up areas, vacant lands and green urban areas. The sites with smaller size in green layer could be fulfilled into dense urban fabric, aiming to reduce fragmented urban land, the others could be preserved or transferred into natural landscapes such as urban parks and urban forests. The land use information provided by both layers could be beneficial for less land consumption and less soil sealing. Thereby more space could be preserved for natural environment. URBIS services could also support solutions to social and economic challenges in the urban context. Land recycling can remove financial burdens for site owners who are required to pay for site maintenance costs and reintroduce economic use to a site. Additionally, as persistent brownfields with no perspective after uses in sight will exacerbate economic and social decline of an area (European Court of Auditors 2012), land recycling will dramtically improve the community image. Regeneration of natural landscape in cities can mitigate urban heat island effect, satisfy people's requirements to visit natural areas and carry out outdoor activities (Chiesura 2004), hence contribute to the creation of more liveable cities.

URBIS covers all types of possible PDAs. However, the list is not complete. As mentioned, if a vacant land is completely or partially sealed it could be neglected. In another case, a gap with fully sealed surface and size smaller than 2,500 m^2 cannot be selected by the Green Layer because only vegetated areas and bare land were taken for the site selection. It would also not be included in the Functional Urban Blocks Layer because of its minimum mapping unit of 2,500 m^2. Apart from these extreme cases, most possible PDAs are incorporated into Green or Grey Layers.

On the one hand, URBIS makes use of all the possible data sources to complete site selection; on the other hand, some sites could be repeatedly selected: for example, a site with vegetation coverage could belong to the Urban Atlas classification of green urban area or land without current use, but also be registered as a brownfield by the local city government. Therefore, it will be selected three times – from the land cover map, Urban Atlas, and the brownfield database. In this case, the boundary of this site could be different from the three data sources and the final decision could be made according to its individual attributes.

The quality of input data has a great influence on URBIS results. As seen from Figure 4, the polygon from the Green Layer covers parts of the buildings nearby. Due to the resolution of the satellite image, the produced land cover map cannot be precise enough. One possible solution is to apply a mask made from building footprints from OpenStreetMap before applying land classification. However, the coverage of mapped buildings is still incomplete even for large cities (Hecht *et al.* 2013). Another problem is that SPOT-5 images in 2006 and in 2012 are not collected at the same time of the respective year which could lead to possible misjudgment. In the case a site has changing vegetation coverage over the year, the increased vegetation coverage is then not an indicator for the usage of the site.

More than 20 land use potential criteria have been calculated for each site during the project. However, the list is not yet complete. This is partly due to the availabilty of data, for instance, the environmental context category includes flood risk and protected areas but not other aspects of legal restrictions. Another reason is that the surveys for criteria acquisition were conducted to limited number of users. Depends on case specific situations and different end users, there will be various requirements to assess the land use potential. Ownership of a site could be an important factor on the operational level. The URBIS team concentrated less on the completeness of the list but more on developing a model with which the other needed parameters could be integrated.

Overall, URBIS worked out a feasible strategy to select as many potential sites and provide as much information for end-users as possible to date. Furthermore, the work procedure developed in the project is based on open source data and the service system is built upon open source software. In general, the data processing is dealing with raster and vector data which are commen formats. Therefore, the service scope could be easily extended when more data is available. Thus, the URBIS service model can be directly implemented to other cities within the EU.

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Disclosure statement

The authors do not have any competing financial, professional, or personal interests from other parties.

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