

An Interactive Decision Support System for Land Reuse Tasks

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Experts face the task of deciding where and how land reuse—transforming previously used areas into landscape and utility areas—can be performed. This decision is based on which area should be used, which restrictions exist, and which conditions have to be fulfilled for reusing this area. Information about the restrictions and the conditions is available as mostly textual, nonspatial data associated to areas overlapping the target areas. Due to the large amount of possible combinations of restrictions and conditions overlapping (partially) the target area, this decision process becomes quite tedious and cumbersome. Moreover, it proves to be useful to identify similar regions that have reached different stages of development within the dataset which in turn allows determining common tasks for these regions. We support the experts in accomplishing these tasks by providing aggregated representations as well as multiple coordinated views together with category filters and selection mechanisms implemented in an interactive decision support system. Textual information is linked to these visualizations enabling the experts to justify their decisions. Evaluating our approach using a standard SUS questionnaire suggests that especially the experts were very satisfied with the interactive decision support system.

Land reuse of former open-pit mines is an important topic, as these areas need to be renaturalized and should be made available again. Renaturalization becomes necessary after open-pit mining activities due to soil contamination, remnants of waste, and unstable soil. The goal of this process is to obtain natural areas, but also to gain areas for recultivation, e.g., for tourism. In the following, we summarize both renaturalization and recultivation as land reuse. In order to decide where and how land reuse can take place, a large amount of information has to be considered in detail during planning.

Context

To improve the planning and decision processes for land reuse, a project was established bringing together a company entrusted with land reuse tasks and

researchers from visualization and interaction. Five experts from the geoinformatics department of that company having between 5 and 20 years of expertise and all being familiar with the use and development of geographic information systems (GIS) were involved in this project.

Data

The data underlying the land reuse process comprises geographical data and expert knowledge. The geographical data follows the *Simple Feature Access* specification,¹ and is called *feature*, here. In general, a feature could be a point (e.g., a *well*), a line (e.g., a *road*), a polygon (e.g., a *dismantling site*), or a multipolygon (e.g., a feature that consists of geographically separated areas that logically form a single unit). With each feature, nonspatial attributes, such as water level or year of construction, are associated. Moreover, expert knowledge, such as forecasts of water level changes of lakes or restrictions on the use of areas (e.g., entering certain areas is prohibited because contaminated soils are present) is connected to the features.² All features are grouped into different thematic categories, such as *nature reserves* or *lakes*.

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TABLE 1. Questions/problems and the solutions (visualization and interactions) developed to support answering the questions and solving the problem.

Number	Question/Problem	Visualizations/ Interactions
Q1	Which data are available for the target area?	Feature selection and information panel
Q2.1	Where are the features exactly and how many are there?	Aggregated representation, and feature selection
Q2.2	Which features overlap?	Information panel
Q2.3	With which other features does a certain feature overlap (not only in the target area, but also outside it)?	Aggregated representation, multiple coordinated views, and information panel
Q2.4	Do different features overlap perfectly in a certain area?	Multiple coordinated views
P1	Several features could overlap strongly. Therefore, the expert might overlook important information.	Aggregated representation and multiple coordinated views

A test dataset was provided by the company we are cooperating with. It contains 36,623 features with a total of 21 different categories. All these data are needed by the experts during the planning and realization phase so that the land reuse can be performed safely and as quickly as possible.

Tasks

To enable the renaturalization of areas, experts need to handle requests related to these areas. A typical request that the experts need to answer is:

Can Particular Facilities be Built in Certain Target Areas?

Facilities could be, for example, houses, production plants, or amusement park installations.

While handling requests like this, the experts answer a large variety of questions (see Table 1). In this case, the expert wants to know:

- 1) which data are available in the target area (Question Q1, Table 1); and
- 2) whether there is an overlap with features that immediately prohibit building the amusement park installations (Question Q2.3, Table 1).

For identifying restrictions on the planned use of (part of) the target areas, all features need to be identified that overlap the target areas. This allows the expert, then, to divide the target areas depending on the amount of overlap with features. For those parts without overlaps, no restrictions apply. For those parts with overlapping features, it has to be decided whether or not those features are in conflict with the intended use. Thus, the size and the location of the different parts of the target areas without restrictions (no overlapping features) and with specific restrictions (overlapping features) are of interest to the experts. In this case, a conflict that immediately prohibits building the amusement park installations is looked for.

In other cases, the combination of restrictions is valuable information needed by the experts to solve their tasks. As the experts reuse previously gained knowledge from similar projects, they have to be able to identify similar areas. How our system supports answering the questions and solving the task will be described in the "Use Case" section of this manuscript.

State of the Art

Currently, the experts use a GIS that was self-developed 20 years ago and is self-maintained since then. This GIS shows features as spatial data on a map. The expert is able to select features for showing details about the selected features on demand.

Problems and Challenges

Analyzing the data for handling requests using the self-developed GIS is tedious and time-consuming due to two problems. First of all, when processing requests, the expert can select feature categories of interest to visually compare them in the GIS. However, the expert usually has to analyze the categories one after the other, because otherwise too much data are visualized, which leads to visual clutter. Due to the large amount of feature categories, this type of analysis is tedious and time-consuming.

Second, the database management system used enables intersecting features based on selected polygons using SQL queries. However, these intersections have to be recalculated for every query whenever the coordinates of the polygons of the selected features change. Subsequently, all features overlapping the selected polygons are visualized in the GIS for further analysis. This type of analysis is also very time-consuming whenever a large number of features overlap.

Finally, as the features overlap quite strongly, information that is critical to planning could easily be overlooked (see Figure 1).

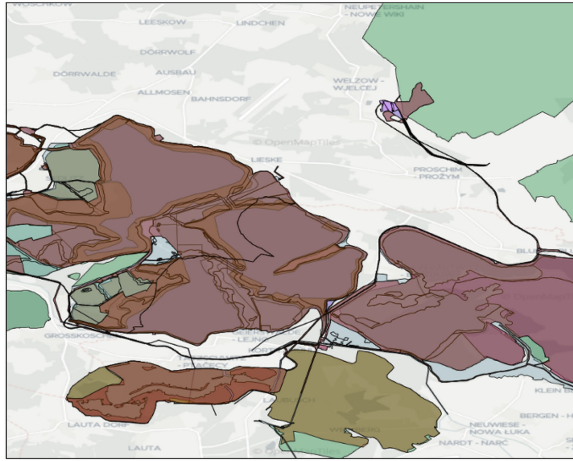


FIGURE 1. Features of four different categories are displayed on a map. They cannot be clearly distinguished from each other because of the way they are overlapping. The fact that and how the features overlap hold important information, but which features overlap where exactly is not recognizable.

Requirements

During seven discussions with the experts from our cooperation partner, we collected the questions that the experts need to address in order to process requests (see Table 1). In addition, the experts stated a problem that might be encountered and that needs to be solved.

Moreover, we derived two constraints that have to be considered:

- C1) *The features should be displayed on a map.* This is required because the underlying data are related to surfaces and regions and because the experts have experience with map-based visualizations. This implies that a large part of the available screen space should be used to display the map on which the features are drawn.
- C2) *The information needs to be displayed on screens having a size of 24" and a resolution of 1980×1080 pixel (FullHD).* This is due to the currently used and available screens of our cooperation partner and restricts the amount of displayable information.

Therefore, our solution (visualizations and interactions, Table 1) is required to adhere to the constraints and to enable the experts:

- › answering the questions quickly and conveniently;
- › perceiving all important information; and
- › comparing different features or groups of features.

Development Process

We applied an iterative development process. An initial solution containing several (alternative) approaches was developed based on the requirements taking the problem and the constraints into account. Afterward, we met with the experts, first presenting the solution and afterward discussing the approaches. After the meeting, the solution was improved. Based on the discussions during the meeting, some approaches were discarded and some approaches were adapted making them easier to understand and more usable. Moreover, new approaches were developed. After preparing the improved solution, we met again with the experts. Meeting with the experts and improving the solution was repeated several times. Finally, we performed an evaluation for assessing the solution.

DATA PREPROCESSING

Our dataset contains 36,623 features. The large majority are areas described by polygons and multipolygons (33,955 features, 92.7%). The remaining features are wells and other features described by point data (2668 features, 7.3%).

The dataset contains problematic points, lines, and polygons due to the data acquisition process. Among others, these are redundant points and lines as well as self-intersecting polygons. These issues might cause problems (e.g., when intersecting polygons with each other). Therefore, a data preprocessing step³ was performed removing redundancies and resolving self-intersections. This affected 6345 features (17.3%).

The range of the sizes of the areas is quite large. There are a few areas that are smaller than 10 m² and that probably only overlap with a few other features. Due to their small size, they can easily be overlooked. There are also a few particularly large areas, up to 5000 km² in size. Because of their large size, they potentially overlap with many other features.

SYSTEM OVERVIEW

In the following, we give an overview of the system and describe how it supports answering the questions listed in Table 1. The individual components of the system are described in detail in the subsequent section.

As required by Constraint C1, the system developed is a GIS. The expert can analyze single features or a small amount of features (e.g., checking if features overlap and how strong this overlap is), using the view in which all features are displayed on a single map. In addition, the expert can examine how individual features change over time and precisely compare the geometries of the features using this view.

Whenever the amount of features becomes too large for displaying all of them on a single map, the expert can switch to an aggregated view and obtain an overview of the features' distribution in the target area. Using this view, the expert can determine where the features are exactly and how many there are. To determine with which other features a certain feature overlaps, the aggregated view can be filtered to only show specific categories.

Furthermore, the expert can use the multiple-coordinated-views representation to check how a selected feature actually overlaps with a target area. Finally, the expert can use the information panel for obtaining further information about individual features in text form. This includes lists that indicate which features overlap each other.

VISUALIZATION AND INTERACTION

To support the experts in handling requests, they are enabled to answer the corresponding *Questions* (see Table 1). To facilitate their work, the *Problem* currently hindering their tasks needs to be solved. Moreover, Constraints C1 and C2 need to be adhered to.

Therefore, visualizations and interactions were developed and implemented in an application that adheres to these constraints and enables experts to answer the questions while minimizing the effects of the problem. In Table 1, we provide the information from which visualization and/or interaction facility supports answering which question as well as which visualization and/or interaction facility reduces the problem.

Each feature is divided into two parts:

- 1) its coordinates in the *GeoJSON* format⁴ (spatial data); and
- 2) its associated nonspatial data.

The spatial data are used for visualizing the feature on a map (Constraint C1) using one of the visualizations described in the subsequent sections. The nonspatial data are displayed in an information panel also described in the subsequent sections.

Visual Representation of Features

Each feature is represented by a polygon. The category of the feature is mapped to the color of the polygon and the polygon is slightly transparent. This polygon is drawn on a grayscale map.

Using colors for categorical data is an appropriate mapping.⁵ The transparency of the polygon keeps the underlying map visible.

To draw the polygon on a map is required by Constraint C1. Using a grayscale instead of a colored map

avoids color distortions of the colored, transparent polygons.

Aggregated Representation of Overlapping Features

Representing features as colored, transparent polygons on top of a grayscale map works fine for single features. However, this approach fails already for two features whose polygons are almost exactly on top of each other. Moreover, if too many features (polygons) overlap, the resulting visual clutter impedes the analysis.

To overcome these limitations and drawbacks, we provide an overview by aggregating overlapping features using a quadtree-based visualization. Therefore, the currently visible area of the map is subdivided into quadratic areas (cells) using a quadtree. All features are added to the cells of the quadtree. The root of the quadtree comprises the complete area and all features. Cells of the quadtree that are fully covered by the same combination of features as well as empty cells are not subdivided.

The layer of the quadtree being displayed can either be linked to the zoom level of the map [see Figure 2(A) and (B)] or chosen independently of the map's zoom level using a slider [see Figure 2(D)]. If it is linked to the zoom level of the map, a coarser layer of the quadtree is displayed when zoomed out, and a finer layer when zoomed in.

Since it is time-consuming to calculate which features a cell of the quadtree covers, the quadtree as well as the coverage of the cells are precalculated. The individual features are further linked to the corresponding cells in the quadtree. Thus, each cell of the quadtree contains information about the number of features covered per category. This way, the response time of the application is reduced making it interactive. The maximal depth of the quadtree (number of layers, currently 11) is limited by the amount of memory available.

Visual Mapping

Each cell c of the quadtree layer being displayed at zoom level n is represented by a square sq. The relative amount of features (partially) overlapping a cell $r_n(c)$ is computed using (1). If the number of features covered by a cell $f(c) = 0$, then cell c is not displayed. Therefore, \min_n and \max_n in (1) are always greater than zero. The logarithm is used because the largest values can be orders of magnitude larger than the smallest values.

The relative amount of features (partially) overlapping a cell $r_n(c) \in [0, 1]$ is mapped to saturation. The hue is set to red, the value is set to 1, and the alpha value is set to 0.6 [see Figure 2(A)]. Using this color scheme, cells with a small number of features covered

$$r_n(c) = \begin{cases} \frac{\ln(f(c) - \min_n + 1)}{\ln(\max_n - \min_n + 1)}, & \text{if } \max_n > \min_n, f(c) \geq \min_n \\ 1, & \text{otherwise.} \end{cases} \quad (1)$$

Equation for computing the relative amount of features $r_n(c) \in [0, 1]$ (partially) overlapping a cell c of the quadtree at zoom level n . $f(c)$ is the number of features covered, i.e., the sum of the category counts, \min_n and \max_n are the smallest and the largest values for $f(c)$ at zoom level n , respectively.

occlude underlying features least. The higher the number of features covered by a cell, the more the cell occludes underlying features and the map.

IQR Filter

Outliers might reduce the perception of differences between relative amounts of features $r_n(c)$ covered by a cell c . To limit the influence of outliers, an interquartile range (IQR)⁶ filtering can be used. Therefore, the first quartile q_1 and the third quartile q_3 of the set of the number of features covered by a cell $\{f(c)\}$ are computed. The IQR is computed as $IQR = q_3 - q_1$ and the interval $I = [q_1 - 1.5 \cdot IQR, q_3 + 1.5 \cdot IQR]$ covers 50% of the data and the mild outliers.⁷ Then,

$$f'(c) = \begin{cases} \min(I), & f(c) < \min(I) \\ \max(I), & f(c) > \max(I) \\ f(c), & \min(I) \leq f(c) \leq \max(I) \end{cases}$$

is computed and used instead of $f(c)$ for computing $r_n(c)$ in (1). Using the IQR filter increases the visual differences for all data within the interval I .

Category Filter

The data can be filtered by category. The category filter enables the expert to select which categories (and thus, the features contained therein) are included in the calculation, and which ones are excluded. This enables a direct comparison of a category that is excluded from the calculation with the group of categories included in the computation [see Figure 2(C) and (D)].

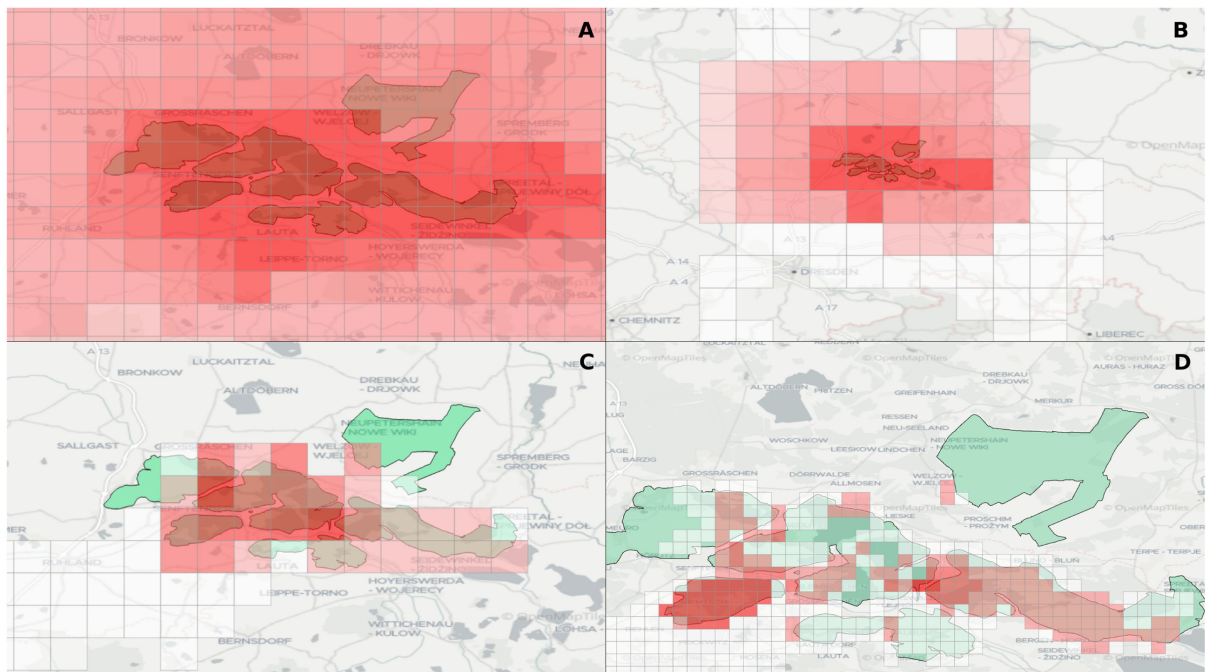


FIGURE 2. A layer of the quadtree is displayed together with the claimed target areas. (A) With IQR filter, zoom level 9. (B) With IQR filter, zoom level 7. (C) Without IQR filter, zoom level 9, with category filter. (D) Without IQR filter, layer 11, map zoom level 10, with category filter.

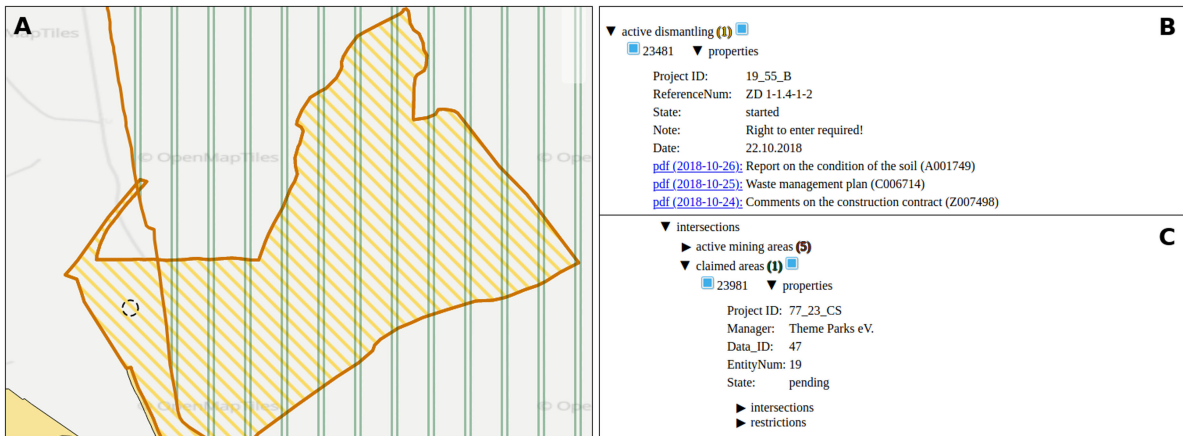


FIGURE 3. A feature was selected by mouse click [black dotted circle in (A)]. It is displayed with (1) a thick orange border, (2) a striped texture with stripes in the color of the category from the top left to the bottom right, and (3) a completely transparent surface. The information panel is displayed on the right-hand side. It contains the nonspatial data (B) as well as the overlaps of the selected feature with other features (C). Using the information panel, an additional feature was selected [see the selected checkbox in (C)]. It is displayed with a vertically striped texture (double green stripes).

Feature Selection

Selecting Single Features

The expert selects a single feature by clicking on it. A circle represents the selected position on the map. All features overlapping the circle are highlighted. A feature is highlighted by drawing it with

- 1) a thick orange border;
- 2) a striped texture with stripes in the color of the category from the top left to the bottom right; and
- 3) a completely transparent surface.

As the surface is transparent, the area behind the feature is easier to recognize [see Figure 3(A)]. This shows that features were selected and distinguishes them from the features that were not selected. In addition, all features that were selected are listed according to their categories [see Figure 3(B) and (C)] within the information panel to the right of the map view.

Selecting Multiple Features

Alternatively, several features are selected by drawing a selection box (“lasso”). A rectangle with a black dashed border represents the selection box on the map. All features overlapping the selection box are highlighted and listed within the information panel.

Selecting a Quadtree Cell

A quadtree cell is selected by clicking the quadtree cell. A circle represents the selected position on the

map. The selected quadtree cell is highlighted by drawing it with

- 1) a thick red dashed border; and
- 2) a completely transparent surface.

In addition, all features that are (partially) covered by the quadtree cell that was selected are listed according to their categories within the information panel to the right of the map view.

Selection Shown in and Using the Information Panel

The information panel provides the expert with further information for determining the data being available for the target area (Question Q1, Table 1). For each category, its name and a list with all features belonging to this category are shown. Moreover, the number of selected features of this category is shown next to the name of the category. The features can be selected and deselected individually using the checkbox next to their description. Alternatively, all features of a category can be selected or deselected using the checkbox next to the category name. Deselecting a feature removes its highlighting.

Multiple-Coordinated-Views Representation of Overlapping Features

A complementary strategy to the aggregated representation of overlapping features for avoiding missing

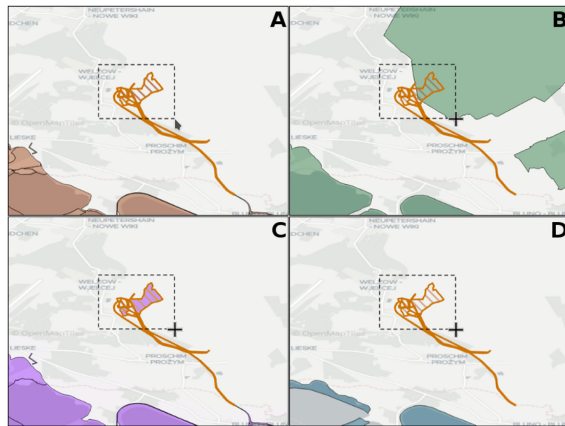


FIGURE 4. Features of four different categories are displayed on four maps by using multiple coordinated and linked views, which are arranged side-by-side. Brushing is used to indicate the exact location of a feature in the other maps.

information (Problem P1, Table 1) is using multiple coordinated views. Therefore, the available screen space is used for displaying four maps. These four maps have the same size and show the same area at the same zoom level.

We restrict the number of maps to four, because otherwise the maps would become too small. This is due to Constraint C2, which currently limits the available space to one 24" FullHD monitor. With a higher resolution and correspondingly larger screen size, more than four maps might be displayed.

Each category to be analyzed can now be assigned to one of the maps. Zooming and panning are performed synchronously on all maps. Moreover, selected areas are highlighted on all maps using brushing which eases the analysis of which features overlap the selected part.

The expert can select a feature on one map by clicking on it with the mouse. Then, the feature will be marked as selected with a thick orange border and a striped texture [see Figure 4(A)]. At the same time, it is also displayed in this way on all other maps, even on a map where the corresponding category was not selected for display [see Figure 4(B)–(D)]. This supports identifying any overlaps.

The mouse position is symbolized by a cross on all maps, except for the map the mouse is over. This provides the exact position in each map. The connection between the maps can be released, for example, to zoom the maps independently. This enables getting a better overview on one map while showing more details on another map. Furthermore, it also facilitates

setting up a map to display a particular feature in its entirety, among others.

This approach fosters analyzing the differences and the commonalities of four categories or combinations of categories by assigning them to one of the maps, respectively. This allows for determining other features a certain feature overlaps (Question Q2.3, Table 1) as the environment of the target area can be examined. Furthermore, it can be checked whether or not different features overlap perfectly in a certain area (Question Q2.4, Table 1). Moreover, it is possible to assess whether features actually overlap with the target area because the exact position of the features is shown (Question Q2.1, Table 1). Zooming in as well as switching individual features on and off using the checkboxes further facilitate these analyses.

The multiple-coordinated-views representation of overlapping features can be combined with the aggregated representation of overlapping features.

Information Panel

The information panel provides detailed information about each feature. The submenu *intersections* [see Figure 3(C)] of the fold-out menu lists all features that intersect with a selected feature. This menu can be extended recursively since each of these features again contains such a list of intersections. Features already included in the path of features under investigation are grayed out to indicate a cycle. Thereby, the available data for the target area can be identified (Question Q1, Table 1).

While it is possible that a category was not considered or overlooked during the previous visual investigation (e.g., if the features are very small compared to the target area), with this list, the expert knows exactly which features are involved, which nonspatial information could be relevant for the task, and how many features are available in each category. Moreover, by recursively extending the *intersections* submenu, experts can examine 1) whether or not features actually overlap (Question Q2.2, Table 1) and 2) which features a feature overlaps by getting an overview of those categories overlapping with a specific feature (Question Q2.3, Table 1).

The nonspatial information as well as the associated expert opinions can provide information about additional usage restrictions.

Alternative Designs

Alternatives for the visual representation of overlapping features, the quadtree construction, and the color scheme are described in the supplemental material,

which can be found at <https://doi.org/10.1109/MCG.2022.3175604>.

DESIGN RATIONALE

Our design follows the “Visual Information Seeking Mantra.”⁸ Moreover, as the main tasks involve comparisons, we apply the general findings of “Considerations for Visualizing Comparisons”⁹ and “Comparative Layouts Revisited: Design Space, Guidelines, and Future Directions”¹⁰ as well as the specific findings for the domain of geographic visualization of “An Evaluation of Interactive Map Comparison Techniques.”¹¹ Finally, we followed the “Guidelines for Using Multiple Views in Information Visualization”¹² for designing the multiple-coordinated-views representation.

Visual Information Seeking Mantra

Following the visual information seeking mantra,⁸ an overview is provided by the aggregated representation of overlapping features. *Zooming* is available for all visualizations proposed: for the aggregated representation of overlapping features as well as for the multiple-coordinated-views representation of overlapping features. *Filtering* can also be performed on the features using the category filter. In addition, *details* are provided on demand by the information panel.

Visualizing Comparisons

Our design for visualizing comparisons is based on the considerations and guidelines proposed by Gleicher *et al.*⁹ and L’Yi *et al.*,¹⁰ as well as on the evaluation of map comparison techniques by Lobo *et al.*¹¹ Using the terminology of Gleicher *et al.*,⁹ the features are the *targets* (comparative elements), the number of features is the *number of targets*, and their overlaps are *complex relationships* (comparative challenges).

For scalability, we provide the strategy of *summarize somehow* by the comparative design *explicit encoding* of the aggregated representation of overlapping features. The scalability strategy *select subset* is implemented as a category filter. This is complemented by the comparative design *juxtapose* implemented as a multiple-coordinated-views representation of overlapping features. Most importantly, the aggregated visualization, the multiple-coordinated-views representation, and the category filter can be combined.

Both the scalability strategy *scan sequentially* and the comparative design *superpose* are available. However, they quickly lead to visual clutter that impedes the analysis.

The different layouts described by Gleicher *et al.*⁹ have certain advantages but also some drawbacks. These are summarized by L’Yi *et al.*¹⁰ Our multiple-coordinated-views representation is a *chartwise juxtaposition layout* that retains the original visualization and by displaying different data, it is possible to perform comprehensive analyses. Likewise, it can be used to reduce visual clutter effectively. However, smaller differences between features can be more difficult to detect in direct comparison, because of the distance between the elements under comparison.

Our aggregated representation is a *superposition layout*, where features are displayed in a visualization with a uniform coordinate system. Smaller differences between elements can be perceived more clearly in this representation. The representation is also suitable because the features depend on their spatial position and extension. However, it is less scalable: displaying too many elements leads to visual clutter.

By combining both the multiple-coordinated-views representation and the aggregated representation into a *hybrid layout*, we overcome their disadvantages while preserving their advantages.

According to Lobo *et al.*,¹¹ our multiple-coordinated-views representation fosters the identification of extra elements as, for example, finding out which feature category actually provides features for an investigated area. For directly comparing features, the aggregated representation is used together with selection and brushing, simplifying the comparison of smaller differences. For such tasks, superposition is considered one of the most suitable representations (both in terms of time and correctness of task solution).¹¹

Guidelines for Using Multiple Views in Information Visualization

Our multiple-coordinated-views representation adheres to the guidelines introduced by Baldonado *et al.*¹² Different categories and combinations of categories can be assigned to each of the four maps. Then, each map contains different information (*Rule of Diversity*) that is complementary (*Rule of Complementarity*). Brushing is used to highlight selected areas on all maps (*Rule of Self-Evidence*). Finally, a feature is displayed the same way on all maps to keep the representation consistent (*Rule of Consistency*).

USE CASE

Consider the request introduced in the introduction:

Can particular facilities (e.g., facilities for an amusement park) be built in certain target areas?

To answer this request, the expert wants to know

- 1) which data are available in the target area (Question Q1, Table 1); and
- 2) whether there is an overlap with features that immediately prohibit building the amusement park installations (Question Q2.3, Table 1).

Therefore, the expert centers the map on the corresponding area and displays the associated features (e.g., the claimed areas). As there are too many features, the visualization becomes crowded due to the overlapping features leading to strong occlusion (Problem P1, Table 1).

Therefore, the expert switches to the *aggregated representation* (solving Problem P1, Table 1, while fulfilling Constraint C1). The expert obtains an overview seeing how the features are distributed in the target area (see Figure 2, Question Q1, Table 1). The expert spots where the features are and how many features there are (Question Q2.1, Table 1), since cells with a strong saturation indicate many features and weakly saturated cells indicate only a few.

To find out whether there is an overlap with features that immediately prohibit certain activities (Question Q2.3, Table 1), the expert filters for those categories containing these features, such as areas under nature conservation. This eliminates almost all target areas [see Figure 2(C)]. The area in the upper right corner is only covered at the edge. By zooming in, it can be seen that the area is only covered at one point [see Figure 2(D)]. This is currently the highest resolution due to memory constraints.

The expert now clicks on the cell, which only covers the target area slightly at the edge. Then, the expert reads in the information panel which features of the selected categories are located in this area. Now, the expert checks whether they actually overlap with the target area, using the exact positions of the features (Question Q2.1, Table 1). Zooming in as well as switching individual features on and off using the checkboxes shows that none of the features overlap the target area. Thus, there is no direct reason for rejecting this target area.

However, restrictions may still exist for the examined area (e.g., due to active mining or land reuse that has not yet been completed). To investigate this, the multiple-coordinated-views representation is used and the categories are distributed over four maps (see Figure 4). The expert selects the appropriate categories since the overlaps of individual features are of particular importance here. This representation shows how the small selected area in Map A perfectly (partially)

covers another feature in Map C (Map B), because the bordered area is filled with a purple (green) color (Question Q2.4, Table 1). This could not be seen if all features were displayed within the same map (see Figure 1), because of the way they are overlapping each other. By using the multiple coordinated views, the features could clearly be distinguished from each other (see Figure 4), and the expert is now aware that several categories can contribute information about this area (solving Problem P1, Table 1).

The fact that these two features are congruent in this case means the following: one feature describes the area at the time of active mining, while the other provides the information that this mining has now been completed, and the dismantling is taking place. This information is shown in the information panel, which also lists the nonspatial information via a fold-out menu beside the selected feature [shown in Figure 3(B)].

EVALUATION

The development process ensures that the system developed meets the requirements of the users. This can be verified using Table 1, where all proposed visualizations and interactions are linked to the questions and problems they answer and solve, respectively. In addition, we assessed the usability of our decision support system, the visualizations, and the interactions using the system usability scale (SUS),^{13,14} which is a frequently used standard evaluation method for assessing the usability of applications.¹⁴ Besides usability, which is reflected by Questions 1–3 and 5–9, learnability can be derived from Questions 4 and 10.¹⁴

The result of the SUS is a score between 0 and 100, where 100 represents the best score. Besides reporting the SUS score, we also report the labels according to the curved grading scale associated with the SUS score.¹⁴ The label A+ is the best possible score.

As the experience of the participants may influence the evaluation,¹⁵ we asked the participants to assign themselves to one of the following three groups (adapted to our setting from¹⁵):

- No experience:* Someone who has never used a GIS.
- Some experience:* Someone who has some but limited experience using a GIS.
- Extensive experience:* Someone who has extensive experience using a GIS.

The complete evaluation is provided in the supplemental material, available online.

Target Group

Our target group consists of experts working with data similar to the one used to develop our new approach and trying to solve tasks similar to the ones presented before (see also supplemental material, available online).

Participants

The evaluation was performed with four experts from the abovementioned company, including one of the experts who was involved in the discussions on the problem definition, and 11 researchers working at Leipzig University.

Procedure

The procedure was always the same. First, the tool was introduced to the participants (15 minutes). A short explanation about the data and its origin from the area of land reuse was followed by an explanation about the use of the visualizations and interactions. Next, each participant received a handout containing three tasks (provided in the supplemental material, available online). The first task consists of coming to know the data and the visualizations in order to gain a first-person experience with the tool and lasted approximately 5 minutes. Tasks 2 and 3 are related to the request introduced in the introduction: *Can particular facilities (e.g., facilities for an amusement park) be built in certain target areas?* Several target areas were given and the participants had to check whether the target areas were free for subsequent use. The participants were encouraged to ask questions at any time. While processing the tasks, the participants shared their thoughts (think-aloud protocol). Once the tasks were completed, the participants received and answered the SUS questionnaire. Afterward, they were asked to provide their opinion and to propose possible improvements for a subsequent version of the tool.

Discussion

The results discussed here are provided in the supplemental material, available online.

Participants and Experience Groups

Overall, the usability and learnability of the tool were rated very high (92.5–77.5, A+ – B+, supplemental material Table 1, available online), with two outliers (supplemental material Figure 5, available online). The outlier score of 62.5 of the participants having extensive experience comes from an expert of the company who, due to age, was unsure whether it makes sense to adopt new concepts, such as an aggregated

representation. At the same time, however, this expert stated that it is possible to imagine that others would use the system frequently, which led to the decision to “agree” to “I think, that I would like to use this system” (Question 1). Removing the outliers for each group, the SUS scores given by participants with extensive experience are at least as high as or higher than those of participants with no experience (one participant in each group rated the system with 82.5). Moreover, the participants with some experience gave the lowest and the highest rating (outliers removed). This shows that evaluating the usability of a system with participants not belonging to the target group can be quite misleading.

Finally, only the two participants with the lowest scores (outliers in their groups) gave negative ratings (one each). All other participants (13) gave positive (127 ratings, 90%), or at least neutral (13 ratings, 10%) ratings.

Rating per Question

In summary, most ratings were *very positive* (61, 41%) or *positive* (68, 45%) while only some ratings were *neutral* (19, 13%) and only 2 ratings (1%) were *negative* with no *very negative* ratings (supplemental material Table 2, available online). This shows once more that, overall, the usability is high. Three properties were rated *positive* and *very positive*. Five properties had *very positive*, *positive*, and *neutral* ratings. The remaining two questions had *negative* ratings, one each.

Restricting the analysis to the participants with extensive experience and removing the outlier leads to an even stronger positive rating of the tool’s usability with 26 (52%) *very positive*, 21 (42%) *positive*, and 3 (6%) *neutral* ratings. Question 7 (*I would imagine, that most people would learn to use this system very quickly*) and Question 9 (*I felt very confident using the system*) were rated least positively.

Additional Feedback

The aggregated representation as well as the ability to filter it, splitting the data and displaying it on coordinated maps together with brushing, and the recursive search within the list of intersections (information panel) as well as displaying interesting features on the map were considered helpful by the participants. They proposed adding a direct way to specifically display individual features from the categories without first displaying the entire category on a map.

Providing a help system that describes the individual visualizations and provides examples for their usage would reduce the amount of support needed, especially for less experienced users, and could help

to increase the confidence in using the system. This emerges from the feedback we received and could lead to a better score for Questions 7 and 9. For example, the concept of an aggregated representation was completely new for four participants (including two experts from the company) and it required a longer training to understand the aggregated representation correctly.

Summary

In summary, the usability of our tool is high, especially from the point of view of participants with extensive experience. In addition, the evaluation helped us to identify points that still need to be improved, such as a more detailed description of the visualizations with examples, such that the participants with extensive experience can use the application with confidence.

SYSTEM

The data are stored in a *neo4j* graph database.¹⁶ For the spatial information, the *Neo4j Spatial* plugin¹⁷ is used. Furthermore, this plugin enables checking whether certain features overlap each other. The user interface is programmed in *HTML5* and *JavaScript*. The *JavaScript* library *OpenLayers*¹⁸ is used for displaying the map and the features. Advantages of using a web-based graphical user interface include:

- ▶ *Portability*: The application is independent from the server holding the data.
- ▶ *Accessibility*: The application can be accessed from anywhere.
- ▶ *Easy to deploy*: For the application, only a browser and the URL are required.

CONCLUSION

The visualization and interaction facilities of the application support experts answering a wide range of questions related to geographically located areas (spatial data) with a large number of massively overlapping features. Using *aggregated representations* as well as *multiple coordinated and linked views*, information about the overlaps is provided that would be difficult to obtain by displaying the features on a map, only. Selecting a combination of relevant categories in the aggregated representations using the *category filter* further reduces the amount of elements displayed on the map. Displaying nonspatial information interactively in the *information panel* provides the expert with a quick overview of existing usage restrictions of a selected feature.

We evaluated our approach using a standard SUS questionnaire. It showed that especially the experts were very satisfied with our tool.

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