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The goal is to propose a set of criteria for comparing the geoportals of EU cities from the point of view of city visitors and residents and compare the geoportals of selected cities in the EU according to these criteria sets.

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- Geospatial information and web mapping.
- Geoportals evaluation concepts.
- Proposal of comparison procedure for EU cities geoportals.
- Application of the comparison on selected EU cities geoportals.

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ANOTACE

Práce je zaměřena na porovnání geoportálů vybraných evropských měst – Prahy, Berlína, Dublinu a Vídně. Věnuje se jejich použitelnosti, přístupnosti, technické výkonnosti a kvalitě GIS služeb. V teoretické části představuje základní pojmy použitelnosti a prostorových dat, v praktické části jsou portály analyzovány a srovnány. Výsledkem je shrnutí silných a slabých stránek každého geoportálu a doporučení pro jejich zlepšení.

KLÍČOVÁ SLOVA

geoportály, gis systémy, použitelnost, přístupnost, prostorová data

TITLE

Comparison of Geoportals of Selected EU Cities

ABSTRACT

The thesis focuses on a comparison of geoportals of selected European cities – Prague, Berlin, Dublin, and Vienna. It examines their usability, accessibility, technical performance, and the quality of GIS services. The theoretical part introduces basic concepts related to usability and spatial data, while the practical part analyses and compares the portals. The result is a summary of the strengths and weaknesses of each geoportal along with recommendations for improvement.

KEYWORDS

geoportals, gis systems, usability, accessibility, spatial data

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LIST OF ABBREVIATIONS AND SYMBOLS

API – Application Programming Interface

CSV – Comma-Separated Values

GIS – Geographic Information System

GEOJSON – Geographic JSON (data format for geospatial information)

HTTP – Hypertext Transfer Protocol

JSON – JavaScript Object Notation

OGC – Open Geospatial Consortium

REST – Representational State Transfer

SEO – Search Engine Optimization

UI – User Interface

UX – User Experience

WFS – Web Feature Service

WMS – Web Map Service

WCAG – Web Content Accessibility Guidelines

URL – Uniform Resource Locator

EU – European Union

ICT – Information and Communication Technologies

INSPIRE – Infrastructure for Spatial Information in the European Community

CKAN – Comprehensive Knowledge Archive Network

SUS – System Usability Scale

FAC – Functionality Assessment Checklist

INTRODUCTION

One of the main factors of the effectiveness of using GIS is the convenience of the interface and accessibility for different users. The ISO usability standard defines it as the ease and convenience with which users can achieve their goals with the best efficiency in a given context (Unrau & Kray, 2019). Over time, this concept has evolved and moved from the issue of “pure accessibility” and “pure usability” to “universal usability” which solves the problem for users with and without disabilities (Komárková et al., 2017).

In general, two methods can be used to assess the usability of GIS: formative and summative. Formative evaluation takes place at the design stage, which makes it possible to identify problems before launch, and the opposite is summative evaluation, where the final product is already evaluated, comparing it with alternatives or according to certain indicators (Komárková et al., 2017). There are various techniques for usability testing, from traditional user-based and expert-based tests to more innovative approaches, such as eye tracking or cognitive modeling.

With the advancement of GIS technologies, like any other, they are increasingly becoming part of a web platform, where the use of their services has crossed the boundaries of professional domains, and casual users and beginners can interact with it (Longley, 2011). These users often have problems with specific GIS elements, such as map layers, simple analysis tools, icons, and others. Understanding the needs and expectations of these users plays an important role in creating understandable and accessible interfaces. Poor usability reduces the potential of a system, while well-designed systems enable users to perform complex tasks with ease and satisfaction (Unrau & Kray, 2019). This study examines the potential of GIS in the form of web-based geoportals. Looking at the existing literature and considering the requirements for

web-based applications, the study focuses on evaluating different parts of web-based GIS such as design and usability of geoportals in selected EU cities. Rather than delving into the technical details of GIS functionality, the study focuses on the user interface (UI) and overall accessibility of these portals. By analyzing popular problems and practices, the study aims to contribute to the creation of more user-friendly and effective GIS through its analysis.

1.1 The Role and Importance of Geographic Information Systems (GIS)

Understanding GIS

In general, Geographic Information Systems (GIS) are certain tools for analyzing and visualizing data. These systems have an applied value and allow you to solve critical problems related to geographical location and its possible characteristics, which is of great importance in a large spectrum of related fields. We can say for sure that as more and more human activities occur on the surface of the earth, the ability to understand and plan these activities on the basis of geographic information becomes a truly important condition for society. (Longley, 2011).

GIS includes both hardware and software for collecting and interacting with this geographic information. By integrating spatial and attribute data, GIS provides a platform for visualizing patterns of relationships and trends. Examples include land use control, optimizing transportation networks, and improving systems. (Komárková et al., 2017).

Applications of GIS

The ability of GIS to solve a wide range of problems makes it indispensable in solving societal problems.

Examples:

- **Urban Planning:** Assisting in zoning, resource allocation, and infrastructure development by mapping population density and land use (Longley, 2011).
- **Environmental Monitoring:** Supporting sustainable development by analyzing deforestation, air quality, and water resources. (Fu, 2011).
- **Disaster Management:** Enhancing disaster preparedness and recovery by mapping flood zones, wildfire risks, and evacuation routes (Komárková et al., 2017).
- **E-Government Services:** Facilitating efficient service delivery through accessible geoportals that enable citizens to interact with geographic data, such as property boundaries, utility maps, and transport schedules (Komárková et al., 2017).

Importance of Location-Based Decision-Making

Decision-making is an important part of any process in many areas. Whether we are determining the optimal location of a retail store, planning a defense infrastructure plan, or simply managing resources, geographic context provides important information for decision-making (Longley, 2011). Decisions made without understanding spatial considerations risk being ineffective and unclear about the consequences, which underscores the importance of GIS in strategic planning.

1.1.1 Technical Aspects of GIS

GIS applications use databases that store and serve datasets related to geographic data, which can include vector data (points, lines, polygons) and raster data (satellite images). Modern databases support various data types such as 3D models and GPS and various geodetic measurements. They allow for multi-user editing, which ensures data reliability and integrity, and use complex rules for relationships. (Fu, 2011). Reliable GIS databases are the basis for good

analysis to be reliable and high-quality, and their quality directly affects the results of projects. (Komárková et al., 2017).

GIS systems have increasingly expanded the accessibility and capabilities of GIS thanks to the Internet. They allow users to access geographic data and tools through web browsers or various mobile or sometimes even desktop applications, eliminating the need for special equipment. These systems enable various usage scenarios from simple viewing to advanced analysis (Komárková et al., 2017).

1.1.2 Evaluating Usability in GIS Applications

Usability as a Key Factor in GIS Success

The ease of use of GIS applications is one of the key values for their implementation and effectiveness. Usability is a measure of how easily and effectively one can interact with the system for their various purposes. If we talk in the context of GIS, usability is how well we, the users, experts or other community can use these geoportals and applications to access geographic data (Komárková et al., 2017).

Usability assessment methods have generally been developed to address the complexity of GIS interfaces. Models such as GOMS (Goals, Operators, Methods, Selection Rules) and cognitive modeling provide approaches to assessing user interaction. These methods take into account various possible factors including user knowledge, design, speed of the interface, and possible improvements for different users (Komárková et al., 2017).

1.1.3 Frameworks for Usability Assessment

There are several structures for assessing the usability of GIS, for example.

- **Task Models:** These describe how users perform activities to achieve specific goals, emphasizing the interaction between users and the system interface (Komárková et al., 2017).
- **Cognitive Models:** By predicting human performance, these models identify bottlenecks in user interactions and suggest improvements (Komárková et al., 2017).
- **Accessibility Evaluation:** This involves testing applications with panels of disabled and non-disabled users to identify barriers and ensure inclusivity (Komárková et al., 2017).

1.1.4 Challenges in Web-Based GIS Usability

Web-based GIS applications face many problems due to dependency on browsers and similar programs.

These include:

- **Complexity of Spatial Data:** Representing and interacting with multi-dimensional spatial data on limited screen real estate can overwhelm users.
- **Performance Issues:** Rendering large datasets in real time requires optimization to ensure smooth user experiences.
- **Accessibility Concerns:** Ensuring compatibility with assistive technologies and meeting accessibility standards is essential for inclusive design (Komárková et al., 2017).

The importance of usability is not just for user satisfaction. Poorly designed GIS applications can hinder the success of initiatives such as e-government where usability directly affects citizen engagement and adoption (Komárková et al., 2017).

1.1.5 Geospatial Information and Web Maps

Geospatial information is data related to a specific location on the Earth's surface. It plays a vital role in a variety of areas, from urban planning and environmental monitoring to disaster relief and government service delivery (Longley, 2011). The integration of geospatial data with modern digital technologies has led to the widespread adoption of geographic information systems (GIS), which allow spatial information to be collected, analyzed, and visualized.

One of the key developments in GIS technology has been the transition from desktop GIS to web-based GIS, also known as web mapping. Web maps allow users to access and interact with spatial data through a web browser without the need for specialized software (Fu, 2011). These systems use web technologies such as Web Map Services (WMS) and Web Feature Services (WFS) to dynamically deliver geospatial content, support real-time data updates, and user interaction. (OGC, 2024)

1.1.6 Web Mapping Methods and Technologies

The effectiveness of web GIS applications depends on several technological approaches:

Tessellation – Web maps are typically displayed using pre-generated mosaics to improve performance. This technique, used by services such as OpenStreetMap and Google Maps, provides smooth navigation and speeds up loading (Fu, 2011).

Vector visualization – Modern web GIS applications increasingly use vector visualizations (e.g. Mapbox GL) instead of raster tiles, which provides smoother scaling and better user interaction (Longley, 2011).

Client-server architecture – Web GIS platforms rely on client-server communication, where the client (browser) sends requests to a GIS server,

which processes spatial queries and returns data in formats such as GeoJSON or XML. (Fu, 2011).

Geospatial APIs – Many geoportals use APIs such as the Google Maps API, Leaflet, OpenLayers, and ArcGIS API for JavaScript to create interactive mapping applications (Unrau & Kray, 2019). These APIs allow developers to overlay geospatial data, create interactive features, and integrate external datasets.

Open standards and interoperability – Organizations such as the Open Geospatial Consortium (OGC) define standards such as WMS, WFS, and Web Coverage Service (WCS) to enable interoperability between different GIS platforms (Fu, 2011).

1.1.7 The role of web mapping in public services

Web mapping has had a significant impact on e-government and public services by making spatial information accessible to citizens. Geoportals serve as centralized platforms where users can view land use maps, traffic conditions, real estate data, environmental reports, and other spatial datasets. (Longley, 2011).

The usability and accessibility of these geoportals vary significantly across cities, requiring a structured approach to assessing their effectiveness. The following sections of this study will review a usability assessment framework and propose a systematic comparison of geoportals in selected EU cities.

Generally speaking, geoportals act as gateways to geospatial data and services, they can offer access to a large amount of spatial data and various mapping tools. Usually, usability is crucial for the needs of a variety of users from experts to ordinary web tourists. Methods for assessing the usability of geoportals can be divided into several approaches:

Heuristic Evaluation: Experts analyze the interface against known usability standards to identify potential problems. (Macgregor, 2019)

User Testing: Observes users as they interact with the geoportal, helping to identify difficulties and areas for improvement.

Surveys and Questionnaires: Collect feedback from users about their experience and satisfaction with the geoportal.

Each research method offers unique advantages, and their combination allows for a comprehensive understanding of the usability of a geoportal.

Proposing a benchmarking procedure for EU city geoportals

A structured methodology is proposed to systematically assess and compare the usability of geoportals across different cities in the European Union.

1.3 Geoportals evaluation concepts:

One of the most important things in building a good GIS is understanding what a GIS is all about, and therefore evaluating georeports is a really important thing to make sure they are going to be useful. There are different methodologies for different components of a web GIS: productivity, usability, and functionality. Below are the main ones:

1.3.1 ISO 9241-11 Framework

ISO 9241-11 provides a structured approach to assessing usability, focusing on these key components (Madan et al., 2022):

- **Effectiveness:** the completeness and accuracy of data that enables the user to achieve their goals
- **Efficiency:** the resources expended in relation to the accuracy and completeness of the goals achieved.
- **Satisfaction:** the comfort for its users.

We can find this framework in projects like GeoTest, which evaluated the usability of Swedish geoportals for implementing some INSPIRE specifications.

1.3.2 System Usability Scale (SUS)

The System Usability Scale is a popular tool that provides a quick and fairly accurate measurement of system usability. The system consists of a 10-item questionnaire covering various aspects of system usability and providing a score that reflects usability. This scale has been used to evaluate geoportals by assessing user experience and satisfaction levels. The SUS method remains one of the most widely adopted tools for rapid usability assessment in software and web systems (Brooke, 1996).

1.3.3 Functionality Assessment Checklist (FAC)

The FAC is a tool specifically designed to assess the functionality of tourism geoportals, particularly tourism planning portals. It includes criteria that assess the presence and quality of use of this functionality, ensuring that geoportals meet the content needs of users in this area. Functionality checklists are based on heuristic principles and were originally developed for rapid expert review of user interfaces (Nielsen & Molich, 1990).

1.3.4 Heuristic Evaluation

Heuristic evaluation involves an expert review of a geoportal to identify usability issues based on established principles known as heuristics. This method is cost-effective and efficient and allows for the identification of user interface design issues without extensive user testing. Heuristic evaluation enables a fast and structured identification of usability flaws in geoportals, particularly where formal user testing is impractical or resource-limited. (Brooke, 1996).

1.3.5 User Experience (UX) Heuristics for Geoportals

Building on traditional heuristic evaluation, UX heuristics have been developed specifically for geoportals. They include principles such as:

- **Map Clarity:** Ensuring the clarity and readability of maps.
- **Layer Management:** Providing intuitive controls for managing map layers.
- **Spatial Data Quality:** Ensuring the accuracy and reliability of the spatial data presented.

These heuristics offer a structured approach to evaluating the unique aspects of geoportal interfaces. By extending general usability heuristics, geoportal-specific criteria provide evaluators with targeted insights into spatial interaction, data interpretation, and map-based navigation. (Madan et al., 2022)

1.3.6 Retrospective Analysis

Retrospective analysis involves evaluating the usability of geoportals over time and examining how design changes affect user interaction. This method provides insight into the evolution of geoportal interfaces and the effectiveness of implemented improvements.

Using these different evaluation methods, developers and stakeholders can systematically evaluate and improve geoportal usability and ensure that these platforms effectively meet user needs and facilitate access to geospatial information. Retrospective usability evaluation allows for the identification of long-term patterns in user interaction and the validation of design decisions through historical interface performance.

1.4 Proposal of a Comparison Procedure for Geoportals of Selected EU Cities

Comparing geoportals is important for understanding how different European cities provide their residents and visitors with digital access to geographic information. This section presents a detailed methodology for comparing geoportals based on a multidimensional approach. The comparison focuses on technical accessibility, usability, data accessibility, accessibility for people with disabilities, integration potential and logical structure.

1.4.1 Technical Analysis Using Web Tools

Page load time analysis

The performance of a geoportal can be evaluated using the Network tab in Chrome DevTools. Key metrics include Time to First Byte (TTFB), which measures the additional file server, DOMContentLoaded, an indication of when the HTML is fully parsed, the time it takes to fully load, and the full number of features processed. A waterfall chart will help identify errors with source codes, such as unoptimized images or blocking scripts. A strategy for optimizing hard image compression (e.g., using WebP format), minifying JavaScript and CSS, applying caching, and eliminating additional block creations. There is a lot of additional information gained in 2-3 seconds for optimal user experience and improved SEO. Chrome DevTools includes integrated features to verify HTTPS, certificate trust chains, and security headers (Google, 2023).

Responsive Testing: Chrome DevTools device mode is used to ensure the geoportal works smoothly on different devices. Testing includes checking responsiveness across different screen resolutions, including desktop (1920x1080, 1366x768), tablet (768x1024), and mobile (360x640, 414x896). Key aspects evaluated include proper aspect ratio, smooth layout using CSS

Flexbox or Grid, and touch-sensitive UI elements. A slower network can also simulate slower connections (3G/4G) and measure real-world performance. The expected result is a fully responsive design with no horizontal scrolling or shifting of elements.

The Assets and Sources tabs in DevTools allow you to explore the geoportal codebase in detail. This includes the choice of external frameworks such as React, Angular or Vue, as well as rendering libraries such as Leaflet or OpenLayers. Code quality is assessed based on modules (e.g. ES6 modules, Webpack), CSS methodology (BEM, SCSS) and lazy image loading techniques. Performance improvements such as code splitting and optimized API calls are also examined. The result should be a database that is well-organized, easy to maintain and uses modern web technologies.

HTTPS Inspection Security Security is a critical component of any web application. The Security tab in DevTools allows you to monitor your HTTPS traffic, valid SSL/TLS certificates, and the display of attachments (HTTP resources on HTTPS pages). Key security enhancements such as Consent-Without-Security-Policy (CSP), X-Frame-Options, and Strict-Transport-Security (HSTS) are examined. For the rest, you can use tools like Lighthouse or OWASP ZAP to find vulnerabilities. The expected result is a secure geoportal with no vulnerabilities. Lighthouse is an open-source auditing tool provided by Google for evaluating performance, accessibility, and best practices (Google, 2023).

To ensure optimal performance across different browsers, manual compatibility testing was performed in Chrome, Firefox, Edge, and Safari. Minor features such as map view, search features, and filters are tested, and any JavaScript errors are checked in each application. For more advanced testing, specialized equipment such as diagnostic tools or measurement probes may be used. Recyclable processes, such as polyfill for unacceptable materials, ensuring

consistency across the entire value chain. The goal is that the user can compare without significant differences.

1.4.2 Accessibility for People with Disabilities

Geoportals should be designed with accessibility features so that they can be used effectively by all users, including those with vision, mobility, or cognitive disabilities. The assessment focuses on the user interface, ensuring compliance with WCAG 2.1 and meeting global standards.

Keyboard Navigation and Operability

The initial accessibility interface relies on full keyboard operability, great for people who don't want to rely on mouse navigation. Every element of the interaction – from basic buttons to complex map controls – must be accessible and usable via keyboard input alone. This includes checking logical tab ordering, visible focus indicators, and using keyboard shortcuts correctly. Special attention should be paid to avoiding keyboard traps where users may become trapped in some element of the interface with no way to escape. The testing process includes testing all tasks using only the Tab, Enter, and Arrow keys to simulate real-world tasks.

Screen Reader Compatibility and Content Structure

For people with visual impairments, a good screen reader makes it easy to understand visual information. Comprehensive testing with popular screen reading software revealed how well the interface communicated its structure and content. This includes testing whether the readership follows the visual pattern, whether the dynamic content updates are well explained, and whether all interactive elements have a defined purpose. The analysis focuses on how interactive map and spatial data flows are in an unobtrusive way, to ensure that geographic information can still be retrieved when the physical objects are removed.

Visual Design and Color Accessibility

Color discrimination goals represent more than just technical specifications – they provide real-world specifications for people with low vision or color vision deficiencies. Robust tests measure contrast ratios throughout the interface, with special attention paid to overlaid map backgrounds. The analysis extends current color classifications by examining whether information absorbed by color alone can achieve implicit coding through patterns, labels, or other visual indicators. This ensures that map highlights and boundaries remain distinct regardless of whether users view them by color.

Alternative Content Presentation

Visual elements need to be thought of as alternative ways to hold information. Every meaningful image, icon, and map component requires an additional textual description that communicates equivalent information. For various geospatial visualizations, this may involve providing data tables, advanced explanations, or simple presentations. The visualization process analyzes the availability and quality of other content, to ensure that the text description captures the relevant information without exposing users to irrelevant information.

Semantic Structure and ARIA Implementation

Appropriately used semantic HTML and ARIA to create bridges between standard interface components and custom geospatial controls. The evaluation examines whether all the elements of the interaction achieve appropriate functions, features, and levels of support technologies responsiveness. This includes ensuring that custom map controls and dynamic components are able to explain their features and functionality clearly to screen readers. Special attention is given to the various complex interactive elements of the geospatial

applications, to ensure that they get optimal benefits through the careful use of ARIA.

Comprehensive Accessibility Approach

True accessibility extends beyond technical compliance to encompass all aspects of user experience. While automated tools can identify many problems, deeper analysis requires an understanding of how real people with different abilities interact. The most effective accessibility strategies combine technical solutions with user-centred design principles, to create geospatial tools that are not only minimally invasive but also truly usable by everyone. Future reforms should include explicit communication to people with disabilities and ongoing assessment throughout the development lifecycle, ensuring accessibility is a consideration rather than an afterthought. (Longley, 2011)

1.4.2 API Availability and Integration Potential

Analyzing the state of the API domain begins with an analysis of the state of its documentation and architecture methods. A well-designed API should provide detailed documentation detailing available endpoints, request/response patterns, and error handling. The implementation of the system should be thoroughly reviewed - whether it complies with RESTful protocols or complies with established OGC standards such as WMS and WFS. Security standards constitute another important area for analysis, particularly the authentication methods used, whether through API keys, OAuth tokens, or other security mechanisms. The analysis should consider practical constraints such as cost limits and potential impacts on aggregation behavior.

Data sharing capabilities represent an important aspect of API evaluation. Modern platforms should support modern formats like GeoJSON alongside more traditional options like XML, with a focus on browsing efficiency and responsiveness. The true measure of an API's value lies in its interoperability –

how seamlessly it can interoperate with different platforms including mobile applications, web services, and data analytics tools. Applied testing using tools like Postman helps validate real-world performance, examining things like response times under different loads and the API's ability to handle different environmental requests across different applications.

Usability and Usability Measurement

Navigation infrastructure requires careful analysis for flexibility and efficiency. The interface should allow users to discover and access useful functionality without unnecessary hassle. Search capabilities need special attention, with analyzes focusing on prediction accuracy, handling ambiguous variables, and advanced filtering options. The ability of the system to recognize and process local search variables demonstrates its sensitivity.

Multilingual support goes beyond simple translations to include detailed metadata encoding and climate-friendly presentation. Support systems and management tools should be readily available and helpful, with appropriate support available at key points of contact. The map interface itself requires careful exploration of the user interface elements - from pan and zoom functions to more advanced features like segment management and terrain measurement. Every interaction should feel responsive and reliable, with clear visual feedback guiding user actions.

Structural and organizational culture analysis

The technological philosophy behind geospatial data visualizations significantly affects its usefulness. Components should be grouped by topic in a way that reflects users' mental models of domain information. The presentation of data through privacy and signaling requires careful analysis for clarity and accessibility, ensuring that information remains intelligible at different magnification levels and for users with different visual abilities.

The interactive relationship between the data units reveals the complexity of the system. A well-designed site should allow for easy exploration of connected resources, appropriate filtering and queries to respond to user input effectively. Transparency about the data's currency and source makes another important implication — users should be able to easily identify when data has been completed updated and understand its source. Finally, data export systems should be robust enough to support a wide variety of use cases while maintaining data integrity and including relevant data.

This comprehensive evaluation methodology combines systems analysis with user observations, examining the environment from multiple perspectives in order to analyze its functionality and potential uses. The approach balances performance estimates with optimal measures of structural and functional flexibility. By considering all these factors, we can build a comprehensive understanding of the strengths of the property market and areas for improvement.

1.5 Comparison of Web GIS Portals in Selected EU Cities

The main objective of this comparison is to assess the usability, accessibility and functionality of geoportals in selected EU cities. While geographic information systems (GIS) have become an important tool for e-government, urban planning and public services, their web-based versions (geoportals) need to be accessible, user-friendly and technically sound. By comparing several geoportals in European cities, the study aims to identify best practices, highlight common problems and suggest improvements that can be applied in other regions.

1.5.1 Selected Cities

- **Prague** (Czech Republic)
- **Berlin** (Germany)
- **Vienna** (Austria)
- **Dublin** (Ireland)

Reasons for selection:

- All cities operate publicly accessible web GIS portals.
- They represent geographical and cultural diversity within the EU.
- Each city has an active approach to open data, digitalization, and urban information systems.
- They vary in terms of technical implementation, UI/UX, and support for accessibility standards, allowing a meaningful comparison.

Table 1 – Overview of selected city geoportals and their characteristics

City	Geoportal URL	Year Established	API Types Provided	Accessibility (initial estimate)
Berlin	Berlin URL	1996	WMS, WFS, GeoJSON	High (96%)
Prague	Prague URL	2003	WMS, WFS, REST, GeoJSON	Highest (100%)
Dublin	Dublin URL	2015	REST, GeoJSON	Medium (68%)
Vienna	Vienna URL	1995	WMS, WFS, REST, GeoJSON	High (95%)

1.5.2 Accessibility Analysis

1.5.2.1 Evaluation of the Prague Geoportal

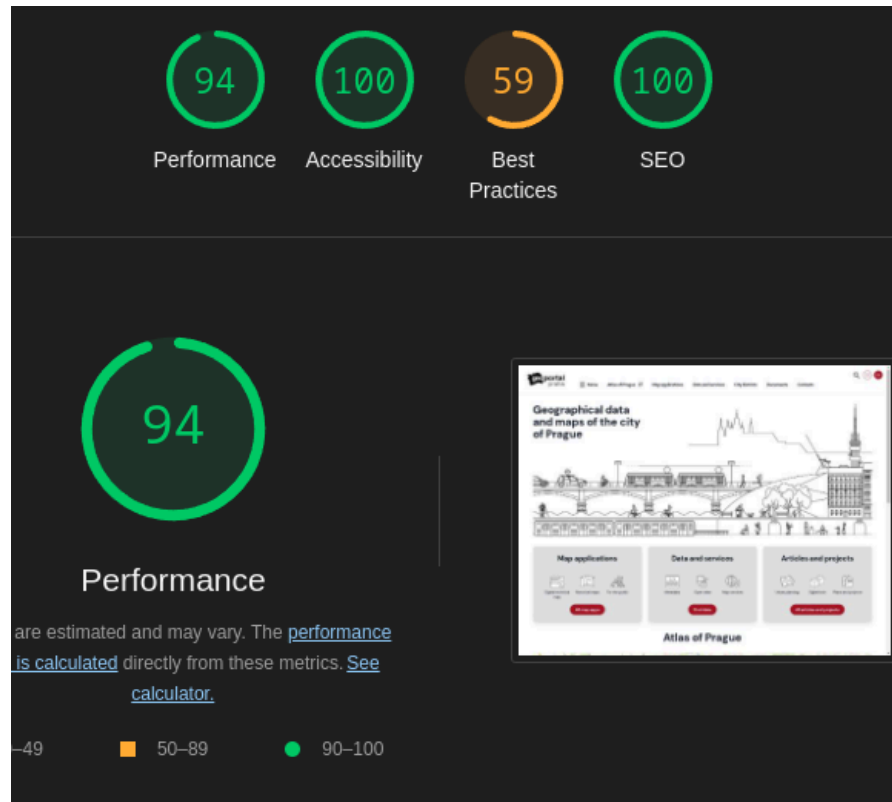


Figure 1 - Technical evaluation of the Prague geoportal (Lighthouse audit)

The Prague geoportal demonstrates good technical performance (Lighthouse Performance 94) and overall performance (100%). A high score for fast applications and efficient rendering, browsing, other optimized resources, and caching. Its perfect SEO score (100) indicates well-formed HTML metadata (e.g., descriptive <meta> tags and product reviews) and responsive design that can be visited and indexed. (W3C, 2018).

A low score for interface usability (59) is a strong indicator of poor implementation quality, often observed in geoportals built on generic templates or without specialized user experience design. Moreover, the lack of a Content

Security Policy (CSP) header (developer.chrome.com) can make the site vulnerable to front-end script injection attacks.

A 100% usability rating means strict adherence to the WCAG recommendations images, products, assets, text placement, app element labeling, and navigation for soft phone classification are programmable.

From a user perspective, Prague's interface is clean and simple. The landing page clearly highlights sections like "Map Applications" and "Data Services" to help residents and visitors quickly find data spaces. The interactive maps and data catalogs on the portal should load smoothly, increasing user satisfaction. One caveat regarding usability is that some content is divided into subdomains (like the other Prague Atlas app). New users may find this division confusing, and the additional switching between sections can disrupt the browsing experience. Overall, the simple site seems fast and intuitive for performing standard tasks. Its perfect SEO score means that the city's services and data are easy to find in search. Thus, the Prague geoportal is highly optimized and easily accessible, although its fragmented architecture may create difficulties for users who rely on smooth navigation.

1.5.2.2 Evaluation of the Berlin Geoportal

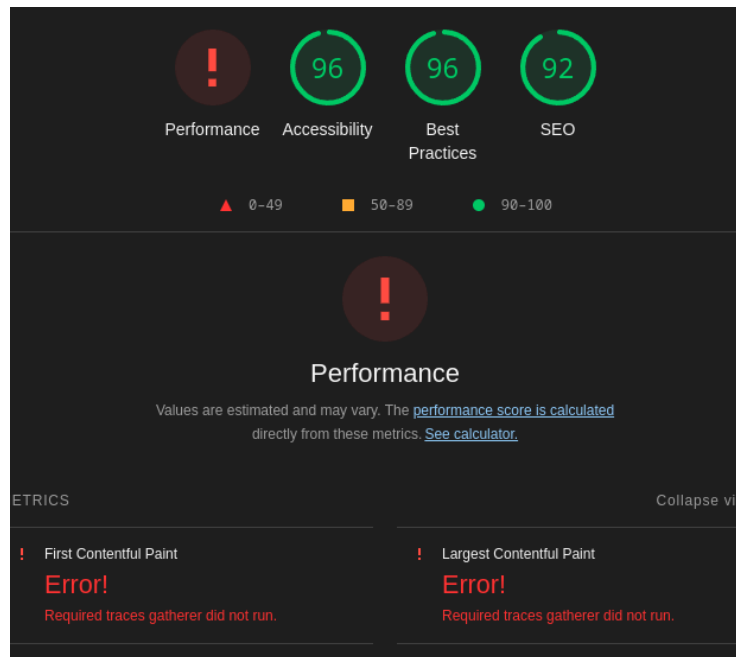


Figure 2 - Technical evaluation of the Berlin geoportal (Lighthouse audit)

The Berlin geoportal audit revealed a very solid design but unusual performance reporting: Lighthouse flagged a performance “Error,” indicating that some important timing metrics could not be collected (possibly due to complex scripts or an unstable load). This suggests that the portal may need to optimize large resources or render-blocking scripts. In contrast, Berlin scored 96% in both Accessibility and Best Practices, indicating a solid implementation. Its structure likely fully supports features such as high-contrast displays and keyboard navigation (in line with WCAG principles), and it likely uses HTTPS and the latest libraries. The SEO score (92) is also high, meaning that most SEO criteria are met — for example, the site likely uses meaningful titles and headings, a meta description, and a mobile-friendly layout. Small gaps (e.g. missing structured data or minor HTML validation issues) may cause not reaching 100%.

For the mobile Berlin portal, it is logically organized, has a menu bar and loads content for maps, data sets and for delivery. The German-language site is a good German-language site, although data extraction or services can be offered in German. The interface of the program is more text-based and formal (typical of native sites), which can be effective for mobile evaluation, but may require a small level of ad delivery. Visibility in search engines is higher for the program with a full SEO message; the Berlin portal is good at ranking for relevance reasons. The city, the Berlin site is good for phone audio, with excellent audio features. The objective element is the potential ease of performance - the programming of the language (memory, resource compression) ensures participation with use without compromising the online standards of freeness and site efficiency.

1.5.2.3 Evaluation of the Dublin Geoportal

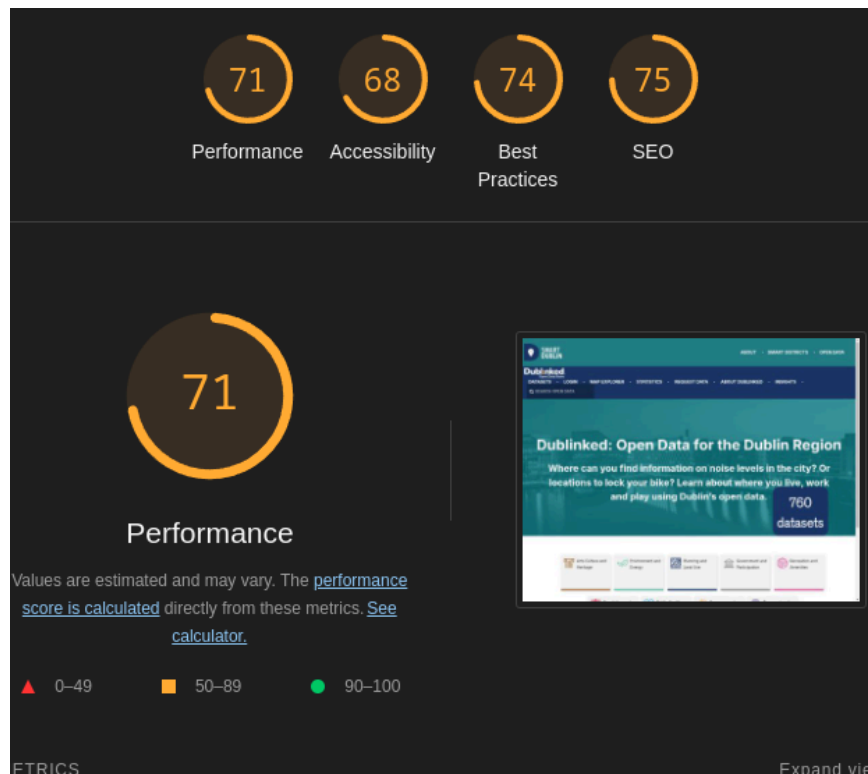


Figure 3 - Technical evaluation of the Dublin geoportal (Lighthouse audit)

The Dublin geoportal (Dublinked) shows weaker metrics: Performance 71, Accessibility 68, Best Practices 74, SEO 75. The average performance score (71) indicates slower load times, likely due to large data resources or inefficient code. The very low accessibility score (68) reveals significant issues with WCAG compliance. For example, many interactive elements lack ARIA labels and some controls cannot be operated via keyboard, which hinders users with screen readers or mobility impairments. The Best Practices score (74) suggests outdated or insecure components (e.g. missing HTTPS redirects or legacy APIs), and the SEO score (75) indicates incomplete use of metadata - perhaps missing meta descriptions or viewport tags.

In terms of usability, the Dublin portal emphasizes open data (e.g., “760 datasets” on the landing page), but the interface seems overwhelming to the average user. Navigation relies on links and text, which can be difficult for non-technical visitors. Features like data search and maps are available, but without clear instructions, they can be less user-friendly. On mobile devices, poorly optimized layouts or images can ruin the experience, leading to suboptimal performance and SEO. From a resident’s perspective, the site works for searching raw data, but the user experience is not as friendly as others. To improve Dublin, it is necessary to add missing alt text and ARIA attributes (improve accessibility and SEO), optimize images and scripts (improve performance), and add metadata (improve SEO). Currently, the Dublin portal is functional, but lags in usability and visibility compared to other cities.

1.5.2.4 Evaluation of the Vienna Geoportal

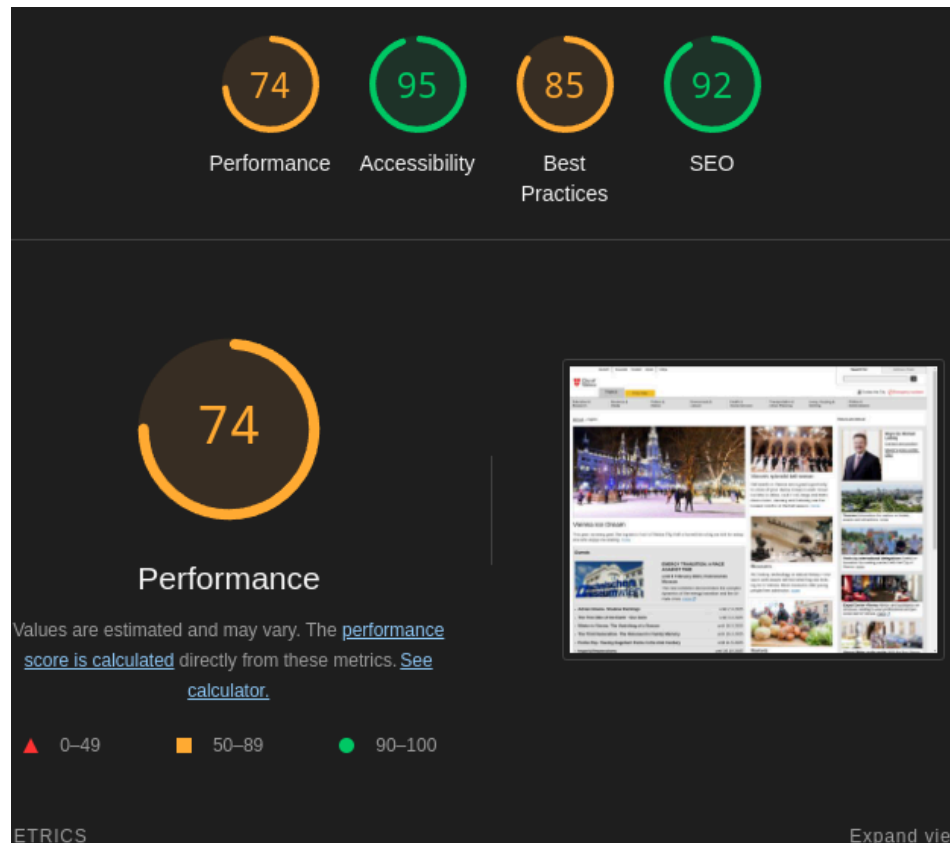


Figure 4 - Technical evaluation of the Vienna geoportal (Lighthouse audit)

The geoportal of Vienna has a balanced profile: Productivity – 74, Substantiation – 95, Recommended Practicality – 85, and SEO – 92. The productivity rating of 74 is acceptable, though slightly lower than ideal, and could be improved (for example, productivity relates to optimization). Accessibility of 95% is based on the fact that the WCAG criteria for content are: markup and email programs, sales, properties, alternate alt and text text, and layout for screen readers and keyboard shortcuts. Recommended Practices rating 85 indicates that there are very few problems (possibly libraries are outdated due to calling by zoology), but overall, the site is a country of recommended practices and free programs. The high SEO score (92) is a surprise considering the factors of click optimization (described the use of <meta>, scanned the

appastic design), and possible personal production (production factor optimization was performed for a mobile device).

From a user perspective, the Vienna Geoportal is a rich content offering the latest news from the city, as well as interactive maps and services. The layout of the homepage is dominated by text, but organized into clear sections, which helps users find information. The navigation menu is logical and the design is consistent (the site is also mostly in German). Residents should be able to easily find ways to access spatial data or contact city departments. A high accessibility score means that most users, including people with disabilities, can navigate the web effectively. Overall, the Vienna Geoportal is user-friendly and well-optimized, requiring only minor performance tweaks. Strict SEO compliance ensures that the information is easily indexed by search engines.

1.5.4 Conclusion

All four city geoportals serve public GIS data but differ in technical quality and user experience. Prague stands out for its fast loading and perfect SEO/Accessibility scores, making its content easy to access and discover (although there is a slight disadvantage of a fragmented multi-domain layout). Berlin and Vienna both achieve high accessibility and good SEO, demonstrating strong compliance with WCAG and meta standards; Berlin in particular shows a good example of implementing best practices. Vienna's design is information-dense but logical, while Dublin's site, in contrast, has the lowest scores and would benefit most from improvements in loading speed and compliance (e.g., adding ARIA labels, optimizing assets and metadata). In practice, users in Prague, Berlin, and Vienna can reliably access the city's mapping tools, while the Dublin portal can feel slow and less intuitive. This is consistent with the Lighthouse guideline: higher performance scores, accessibility, and best practices translate directly into better user experience and search rankings. Addressing the weaknesses of each site (through code

optimization, complete metadata, and more rigorous accessibility checks) will improve usability for residents and improve visibility in search engines across all cities.

1.6 Comparative Evaluation of Municipal GIS Platforms

1.6.1 Evaluation of the Prague Geoportal

The Prague Geoportal, managed by the Institute for Planning and Development (IPR Prague), serves as a modern platform that provides citizens and experts with comprehensive spatial information. Its structure reflects a strong emphasis on usability, technical optimization, and data openness. The portal received a Lighthouse score of 94, 100% for accessibility, and 100% for SEO, although the score for best practices was slightly lower at 59%. These results demonstrate fast loading and strict adherence to accessibility standards (WCAG 2.1), although some minor technical issues still need to be resolved (e.g. missing security headers). Ease of use is a key advantage of the Prague Portal. The main interface clearly separates important functions and offers sections such as “Map Applications”, “Open Data”, and “Spatial Services”. Bilingual support (Czech and English) makes the platform accessible to a wider audience, including tourists and international researchers. Interactive map browsers, such as the Prague Atlas, allow users to explore topics related to urban planning, cultural heritage protection, environmental monitoring, and infrastructure. Basic GIS tools, including zooming, ball control, search functions, and measurement tools (distance and area), are integrated into the map interface, ensuring that users without GIS training can still navigate the content effectively. The Prague Atlas offers a multi-thematic environment where users can choose from different categories such as land use, public transportation, environment, and demographics. Markers are logically grouped

and legends are automatically generated based on the active selection. Users can click on individual objects to obtain information about attributes such as section IDs or zoning plans, allowing for detailed exploration of urban structures. The system also supports 3D visualization through an optional 3D city model display, although this functionality runs in a separate module that is somewhat separate from the user interface.

In terms of analytical capabilities, the public web interface in Prague offers basic but practical tools such as distance and area measurements as well as object recognition. More complex spatial analysis, including geoprocessing operations such as buffering or overlay analysis, is available through backend services (WPS - Web Processing Service), but is not directly accessible through simple web tools for regular users. This provides a balance between simplicity for the general public and powerful services for developers and advanced users.

Prague's data transfer services are particularly reliable. The geoportal offers a wide range of datasets for download via ArcGIS Hub with options such as Shapefile, GeoJSON and GeoPackage. Each dataset is accompanied by metadata, ensuring transparency regarding update cycles, coordinate systems and licensing. The city also publishes a wide range of real-time map services via OGC-compliant WMS and WMTS endpoints. Although direct WFS feature retrieval is not widely available on English-language websites, many layers support real-time queries via Esri FeatureServices or WFS equivalents. The portal supports the local Czech S-JTSK projection and the international WGS84 system, which improves integration with global applications. API support is also robust, offering Esri REST API and OGC standards. Developers can integrate map services directly into their own applications, perform attribute queries, or dynamically use raster tiles. The presence of OGC standards ensures compatibility with open source GIS software such as QGIS, while ArcGIS

REST interfaces simplify the creation of web applications using Esri's JavaScript API.

From a technical and organizational perspective, Prague's platform reflects a clear commitment to open government data principles and GIS best practices. The portal includes detailed documentation, metadata catalogs, and example connections for desktop and online GIS users. A slight weakness remains in the system's fragmentation: different map applications (e.g., Atlas of Prague, Urban Plan Viewer) sometimes require users to adapt to slightly different interfaces or loading speeds. Nonetheless, data consistency is maintained across services, and all applications link back to the central geoportal homepage.

Strengths:

- Excellent performance and accessibility optimization.
- Comprehensive thematic coverage and 3D visualization.
- Robust open data availability with modern formats and APIs.
- Compliance with international GIS standards (OGC, WMS, WMTS).

Weaknesses:

- Minor fragmentation across separate mapping modules.
- Some technical best-practice issues (e.g., missing security headers).
- Advanced spatial analysis tools limited to backend services.

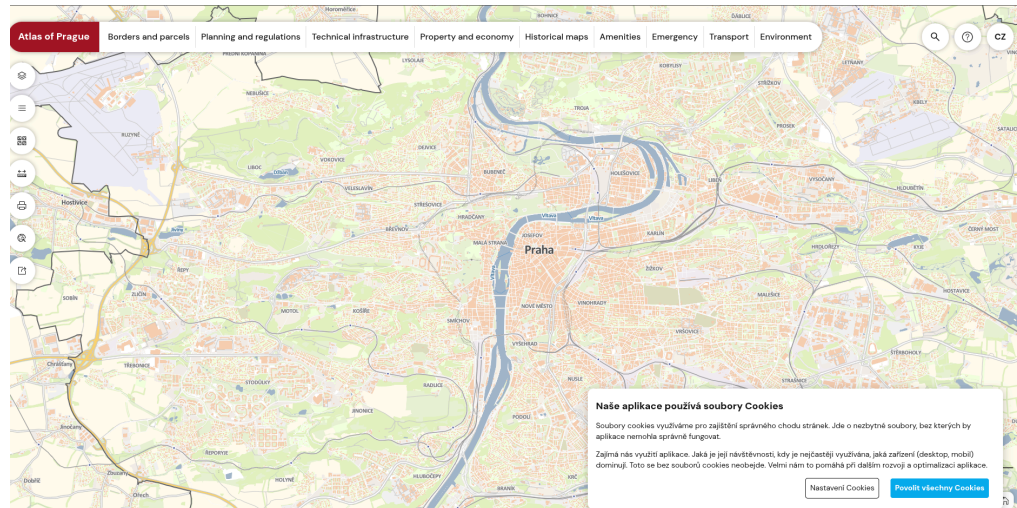


Figure 5 - Interactive base map view in the Prague Geoportal (Atlas of Prague)

1.6.2 Evaluation of the Berlin Geoportal

The Berlin Geoportal, which operates primarily through the FIS-Broker system, is one of the most comprehensive open geodata platforms among European cities. Its main goal is to provide public access to a huge number of thematic datasets covering urban planning, environment, transport and infrastructure. Although the technical accessibility of the portal is high — achieving 96% accessibility, 96% best practices and 92% SEO in Lighthouse audits — it has suffered from performance measurement errors, indicating that dynamic content or resource-intensive mapping applications can hinder loading speeds in certain test environments.

The Berlin Geoportal is highly functional, but somewhat outdated in design. The main interface of the FIS-Broker offers a basic map viewer with a view of datasets by category. Users can search for layers based on keywords, select a thematic dataset and visualize it on a base map of Berlin. Available tools include layer management, address search, zoom/pan navigation, and feature identification by clicking on features. However, the interface has a steep

learning curve, especially for non-expert users, due to its outdated structure and difficulty switching between datasets.

The mapping tools have a wide range of available data but are modest in usability. Users can load base layers (topographic maps, aerial photos) and add thematic overlays such as green areas, noise maps, building contours, or land use plans. Clicking on features usually opens a pop-up window with attribute information. The portal also offers coordinate search and a zoom scale, but it lacks modern dynamic interaction such as real-time filtering or advanced symbology customization. While multiple layers can be layered, the interface can struggle to handle complex combinations, sometimes resulting in cluttered visualizations.

In terms of analysis capabilities, the Berlin public portal offers limited direct GIS analysis. Users can perform attribute-based queries (e.g. find all schools in a district) and view related metadata, but there are no built-in spatial operations such as buffering, intersection analysis or network analysis for the general public. More advanced processing is expected to be done externally, by loading data and using desktop GIS applications.

Berlin's data services are highly standardized and extensive. Almost every dataset available through the portal is accessible via OGC-compliant WMS and WFS services that support dynamic use on external GIS platforms. (OGC, 2024). (Janssen et al., 2017). WMS (Web Map Service) allows users to visualize maps in any compatible browser, while WFS (Web Feature Service) allows for direct queries and loading of vector features. Metadata is provided for each dataset, which complies with the INSPIRE Directive standards. (OGC, 2024). Unlike some portals, Berlin does not actively promote file-based uploads (e.g. Shapefile, GeoJSON); instead, it encourages the use of data in real time via WFS queries, ensuring that the data is up-to-date.

API support is based on open standards. Developers can integrate WFS and WMS services into their own applications, which provides great flexibility. Although a proprietary REST API is not promoted, adherence to international standards ensures that developers can use libraries such as OpenLayers, Leaflet, or desktop GIS software to directly access Berlin's datasets. Additional documentation and tutorials are available to help with connecting to the services, although they require some technical GIS knowledge.

One of Berlin's main strengths is the breadth and frequency of updates to its datasets. Topics include administrative boundaries, demographic data, urban development projects, environmental monitoring, and transportation systems. Many datasets are regularly updated, ensuring their relevance to planners, researchers, and developers.

However, shortcomings remain. The user interface feels outdated compared to modern web GIS standards, limiting accessibility for non-expert users. The portal also lacks user-friendly instructions for configuring data connections via WFS, making it difficult for regular users to use the full power of the services. Performance optimizations could improve usability on slower connections or mobile devices.

Strengths:

- Extremely broad availability of datasets on urban topics.
- Full support for OGC WMS and WFS services, ensuring open access.
- Regular updates and compliance with European data exchange standards (INSPIRE).

Weaknesses:

- Outdated web design and complex navigation.
- Limited functionality for in-situ GIS analysis.

- Dependence on external GIS tools

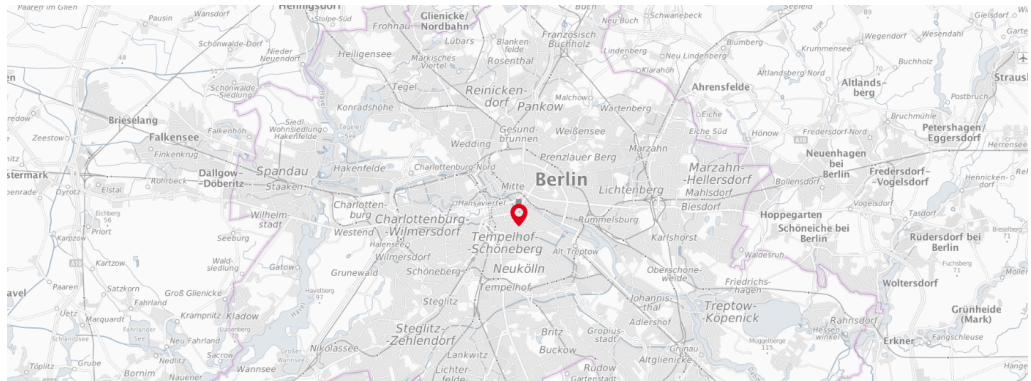


Figure 6 - Central Berlin map layer in the FIS-Broker portal

1.6.3 Evaluation of the Dublin Geoportal

Dublin’s open data portal, known as Dublinked, offers a modern platform focused primarily on data transparency rather than traditional GIS interaction. The portal prioritizes access to datasets and basic visualization over advanced spatial analysis. According to Lighthouse audits, the Dublin portal scored 71% for performance, 68% for accessibility, 74% for best practices, and 75% for SEO, indicating a moderate level of optimization but significant accessibility deficiencies, likely due to the lack of ARIA attributes and insufficient keyboard navigation.

In terms of usability, Dublin’s interface is simple and community-oriented. The main open data catalog contains datasets in categories such as transport, environment, housing, and public services. The map explorer provides basic geographic visualization by overlaying selected datasets on a Bing Maps background. However, the platform is largely data-centric, with an emphasis on uploading files and browsing open data rather than a full GIS experience. Navigation through the dataset catalog is efficient, but experienced

users looking for a more complete map exploration experience may find the system limited.

The mapping tools are minimalistic but effective for basic tasks. Users can search for datasets by keyword, select geospatial datasets, and overlay them on a base map. (Fu, 2011). Multiple layers can be displayed simultaneously, and basic map operations such as panning and zooming are supported. However, the map interface lacks features such as coordinate querying, advanced symbology settings, or thematic filtering. (Unrau & Kray, 2019). The platform's strength is its easy integration of data layers, but it lacks dynamic interaction beyond basic feature identification.

In terms of analysis capabilities, the Dublin platform offers only basic functionality. Users can click on features to get attribute information, but they cannot perform spatial analysis such as caching, overlaying, or network tracing in the web interface. Users who require analytical capabilities must upload datasets (e.g. in GeoJSON, CSV or KML formats) and perform analysis in external GIS or data visualization tools. While Map Explorer supports geographic exploration, its analytical capabilities remain limited.

Data services are an important aspect of Dublin's open data strategy. Most datasets are available for download in user-friendly formats such as CSV, GeoJSON, KML and Shapefile. For geospatial data, the platform automatically generates WMS services using the GeoServer backend, allowing datasets to be visualized not only on an online map but also in external GIS applications. (Wikipedia contributors, 2024). The portal infrastructure likely supports WMS dynamically, but does not actively support Web Function Services (WFS) or real-time feature-level attribute queries.

API support is present, but it is relatively basic. The open data platform appears to rely on CKAN-based APIs to retrieve metadata and access datasets. While developers can programmatically retrieve metadata and create links, the

portal lacks a dedicated GIS-focused REST API that offers real-time feature queries or advanced spatial operations. However, the presence of WMS endpoints for most datasets provides a reasonable level of web services access for developers who need map-based integration.

One of the significant advantages of the Dublin approach is its emphasis on openness and usability for the public. The portal simplifies the process of accessing government datasets and encourages their reuse by developers, researchers, and the public. Smart Dublin initiatives also integrate real-time data streams, such as traffic data feeds, although these are typically hosted separately from the main Dublinked portal.

However, the limitations of the platform are evident in the GIS industry. The lack of advanced mapping tools and analytical capabilities limits users to simple browsing and downloading. Accessibility compliance is another weakness, as evidenced by relatively low audit scores, indicating that improvements are needed to better serve users with disabilities.

Strengths:

- Easy-to-use open data catalog with direct download options.
- Creation of WMS services for geospatial datasets, facilitating external use.
- Tight integration with Smart City initiatives and real-time data streams.

Weaknesses:

- Minimal spatial analysis functionality in the web interface.
- Lower accessibility standards compared to similar cities.
- Limited GIS-specific API functionality beyond basic WMS access.

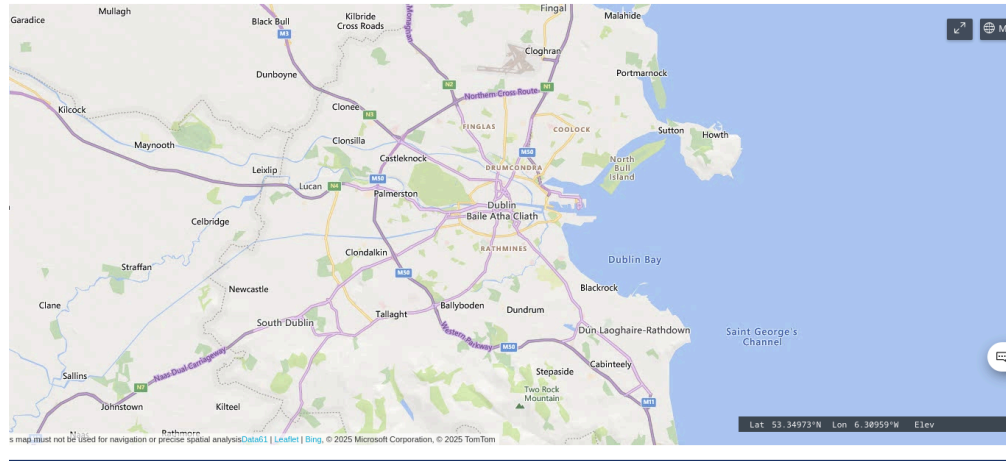


Figure 7 - General view of the Dublin Geoportal map interface

1.6.4 Evaluation of the Vienna Geoportal

The city of Vienna offers one of the most modern and comfortable hotels in Europe with its ViennaGIS system. ViennaGIS, integrated into the city's wider website (wien.gv.at), combines a huge amount of data with an emphasis on everyday use. Recent technical assessments have shown that the platform is highly optimized, with productivity of 10%, availability of 95%, best practices of 85% and SEO of 92% in Lighthouse audits. These results indicate a generally strong technical infrastructure, high productivity is still possible, especially when optimizing dynamic segmentation.

From a user perspective, ViennaGIS provides well-organized and accessible content. Features such as "barrier-free tracing" for pedestrians demonstrate the platform's focus on accessibility and offer practical tools that directly affect the quality of urban life.

Mapping tools are available. In addition to basic interactions such as zooming and shape switching, Vienna measures distances and areas, visually

overlays traffic data and networks, and also provides access to dynamic datasets of civic objects and filters visible data in attribute views.

The city publishes several datasets on the City of Vienna optical data portals for transport, energy and infrastructure. These datasets are available in various formats, including CSV, GeoJSON, Shapefile and KML, and are calibrated to ensure accuracy. It is important that Vienna supports real-time WMS and WFS services so that users and developers can integrate city data directly externally into a complete security or web add-on. This combination of downloads and real-time data streams ensures that users and professionals have access to the information they need, in accordance with the format.

In addition to the basic download, Vienna also provides extensive API support. Developers can connect to OGC-compliant services or use specialized APIs to access datasets in real-time chat, thin parking spaces or public bike stations. For those interested in connected data, Vienna offers access points to the Semantic Web, such as SPARQL endpoints, although it is primarily aimed at research institutions and professional users.

Vienna differs from the others not only in the amount of funding available, but also in the way it presents information. Metadata and reader calculations, service licenses, extended authoring (especially in German and English) make the platform accessible even to novice users. Although the huge number of available options may initially seem primitive, and the presence of help functions significantly reduces the user experience.

In terms of design, ViennaGIS prioritizes functionality over minimalism. Although the visual presentation is somewhat traditional compared to new web trends, this choice emphasizes the clarity and completeness of a comprehensive urban GIS.

Strengths:

- Wide thematic coverage and practical mapping tools for the community
- More real-time information.
- Reliable API, including real-time smart city services.
- High availability and multilingual support.

Weaknesses:

- Maybe too complex for new users.
- Somewhat outdated visual style compared to modern standards.

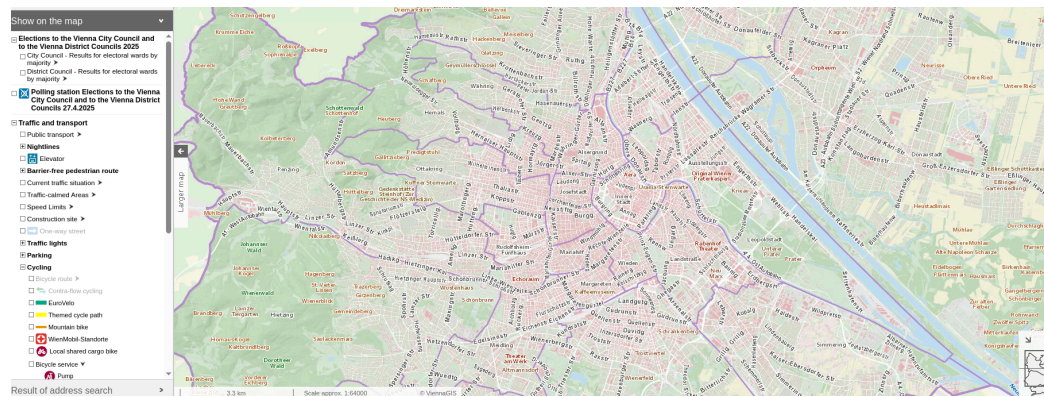


Figure 8 - Thematic map interface of ViennaGIS with transport and election data

CONCLUSION

A comparative analysis of geoportals and GIS systems in Prague, Berlin, Dublin and Vienna shows the diversity of approaches used by European cities to provide spatial information services. Each city platform reflects the priorities of the local government, the technology strategy and the target group, resulting in different strengths and weaknesses.

From a technical perspective, Prague stands out for its excellent performance, accessibility, and integration with modern GIS services. The combination of ArcGIS-based infrastructure and open data policies ensures that everyday users and developers have broad access to high-quality, frequently updated spatial information. Some fragmentation between individual programs remains a problem, but overall Prague is a model of efficiency and usability.

Berlin, on the other hand, offers a unique catalog of datasets that closely adhere to open standards such as WMS and WFS. Its FIS-Broker platform is comprehensive but suffers from an outdated interface and higher entry barriers for inexperienced users. For the professional audience, however, Berlin's commitment to INSPIRE compliance and real-time data access through services is a valuable asset.

Dublin takes a clearly defined approach to open data, focusing on ease of access and public engagement rather than the depth of traditional GIS. Its Map Explorer offers basic visualization capabilities but lacks more advanced mapping and spatial analysis capabilities. While Dublin excels in data openness and simplicity, improvements in accessibility and GIS-specific features will increase its effectiveness for a wider range of users.

Vienna offers a balanced citizen-centric GIS platform that combines interactive mapping tools, comprehensive thematic coverage, and strong support for open standards. ViennaGIS provides real-time data integration and supports

the needs of advanced users without compromising overall usability. Although the interface may seem dense due to the large number of layers and options, Vienna successfully meets both technical and civic requirements.

Several common trends can be observed across all four cities. First, adherence to open standards (such as WMS, WFS, and open data formats) has become the norm, ensuring interoperability and fostering innovation. Second, there is a clear shift towards integrating real-time data into government services, supporting the broader smart cities agenda. Third, while technical accessibility standards (WCAG compliance) have improved, not all platforms fully address the needs of users with disabilities.

In general, best practices identified include maintaining a high level of accessibility, providing datasets in a variety of formats, providing real-time access to data via APIs, and balancing the needs of everyday users with those of professional GIS users. Conversely, weaknesses such as outdated interfaces, limited built-in spatial analysis, and performance issues reveal areas for potential improvement.

In conclusion, although every assessment carries an element of subjectivity and improvements in geoportal systems are often incremental, the integration of Prague's technical performance, Berlin's depth of available data, Dublin's focus on interoperability and Vienna's user-centric design could together form a model for the next generation of urban geoportals. Realizing this vision will require continued investment, particularly in bottom-up system design, ongoing technical refinement and open data management. As cities become increasingly dependent on spatial information systems for planning, management and public engagement, these improvements will play a key role in shaping a more accessible and efficient digital urban infrastructure.

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