Master's Thesis in the Course of Study Geodesy and Geoinformatics

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Development of a Location Based Interactive Mobile Web Application For Enriching Visitors' Knowledge And Experience

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Abstract

This thesis explores the development of a location-based interactive mobile web application aimed at enhancing the visitor experience at tourist sites. Recognizing the limitations of traditional and existing digital aids in providing accessible, engaging, and comprehensive information, this study seeks to bridge the gap by leveraging advancements in mobile web map technologies. Herrenhausen Gardens, one of Europe's most significant historical gardens, renowned for their Baroque and Renaissance-inspired designs, serve as the chosen test area for this study. The proposed solution offers a user-friendly platform that improves information dissemination through personalized experiences. By integrating interactive features and location-based services, the application dynamically adapts to users' interests and navigational behaviors, presenting tailored Points of Interest (POIs) suggestions. The methodology encompasses the design and development, culminating in a thorough evaluation of its user interface (UI), usability, and effectiveness in meeting its objectives. Feedback from users across various age groups confirms the application's alignment with modern design principles and highlights areas for future enhancement, particularly in cross-platform compatibility and optimization. This thesis contributes to the field of digital mapping and visitor guidance by showcasing the potential of advanced technology in creating engaging and personalized user experiences, underscoring the importance of user-centered design in the development of location-based applications.

Zusammenfassung

Diese Arbeit untersucht die Entwicklung einer standortbezogenen interaktiven mobilen Webanwendung, die darauf abzielt, das Besuchererlebnis an touristischen Orten zu verbessern. In Anerkennung der Grenzen traditioneller und bestehender digitaler Hilfsmittel, die zugängliche, fesselnde und umfassende Informationen bereitstellen, sucht diese Studie, die Lücke zu schließen, indem sie Fortschritte in den mobilen Webkartentechnologien nutzt. Die Herrenhäuser Gärten, einer der bedeutendsten historischen Gärten Europas, bekannt für ihre barocken und renaissance-inspirierten Gestaltungen, dienen als ausgewähltes Testgebiet für diese Studie. Die vorgeschlagene Lösung bietet eine benutzerfreundliche Plattform, die die Informationsverbreitung durch personalisierte Erlebnisse verbessert. Durch die Integration interaktiver Funktionen und standortbezogener Dienste passt sich die Anwendung dynamisch den Interessen und Navigationsverhalten der Benutzer an und präsentiert personalisierte Vorschläge für Points of Interest (POIs). Die Methodik umfasst das Design und die Entwicklung und mündet in eine gründliche Bewertung ihrer Benutzeroberfläche (UI), Benutzerfreundlichkeit und Effektivität bei der Erreichung ihrer Ziele. Feedback von Benutzern verschiedener Altersgruppen bestätigt die Ausrichtung der Anwendung auf moderne Designprinzipien und hebt Bereiche für zukünftige Verbesserungen hervor, insbesondere in Bezug auf plattformübergreifende Kompatibilität und Optimierung. Diese Arbeit trägt zum Bereich der digitalen Kartierung und Besucherführung bei, indem sie das Potenzial fortschrittlicher Technologie zur Schaffung fesselnder und personalisierter Benutzererlebnisse aufzeigt und die Bedeutung eines benutzerzentrierten Designs bei der Entwicklung standortbasierter Anwendungen unterstreicht.

Declaration of Authorship

I, Ismail Cagri GENCTÜRK, declare that the dissertation, which I hereby submit for the degree *Master's Degree* at the Gottfried Wilhelm Leibniz University Hannover, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signed:

Date:

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List of Abbreviations

CSS - Cascading Style Sheets
DOM - Document Object Model
GDPR - General Data Protection Regulation
GIS - Geographic Information System
GPS - Global Positioning System
HTML - Hypertext Markup Language
LBS - Location-Based Services
LESS - Leaner Style Sheets
OS - Operating System
OSM - OpenStreetMap
POI - Point of Interest
QGIS - Quantum Geographic Information System
SASS - Syntactically Awesome Style Sheets
UI - User Interface
UX - User Experience
VGI - Volunteered Geographic Information
WGS84 - World Geodetic System 1984

Chapter 1

Introduction

In the contemporary digital era, the exploration of touristic destinations has transcended traditional boundaries, necessitating innovative solutions to augment the visitor experience. This thesis presents the development of a location-based interactive mobile web application designed to enrich the knowledge and experience of visitors at tourist sites. This effort is motivated by the need to address the shortcomings in the way information is currently provided and how engaging the existing methods are for users.

1.1 Motivation

This study is driven by the need to address the significant shortcomings of existing tools and aids provided to tourists at historical, cultural, and natural sites. Visitors often encounter places full of history and significance but struggle to fully engage with them due to the lack of accessible, engaging, and comprehensive information. Traditional resources such as brochures, flyers, and signs are limited in their ability to cater to the varied interests and needs of each visitor. Additionally, while digital guides and map applications aim to improve the experience through technology, they often fall short by overwhelming users with too much information or failing to engage them effectively. These tools typically lack interactive features that could truly capture the visitors' interest and deepen their connection with the site.

There's an urgent need for more advanced solutions as tourists nowadays expect more personalized and immersive experiences than what current traditional and digital tools offer. The potential for technology to enhance the visitor experience is great but largely untapped, highlighting a significant gap in how information is shared and engagement is fostered at touristic sites. This gap not only affects the quality of the visitor experience but also restricts the educational opportunities these sites could offer. Each point of interest has a story that could greatly enrich the visitor's understanding and appreciation of the site if shared effectively.

1.2 Objectives

This thesis aims to bridge the identified gap by leveraging advancements in mobile and web technologies to offer an enhanced navigational and informational tool. The proposed mobile web application seeks to overcome the limitations of traditional and existing digital aids by providing a location-based, interactive, and user-friendly platform. Specifically, the application aims to:

- Deliver personalized and contextually relevant information to visitors, based on their precise location within a touristic site, thereby facilitating a deeper understanding and appreciation of the site's historical, cultural, or natural significance.
- Enhance user engagement through interactive elements such as recommendations of nearby point of interests according to the user's personalized experience, thereby transforming the visitor experience from passive observation to active participation.
- Address the issue of information overload by curating content based on user preferences and historical interaction data, ensuring that the information presented is both relevant and manageable.
- Improve navigational aids within touristic sites by integrating real-time mapping and directional tools, thereby enabling a more efficient exploration experience.
- Facilitate two-way interaction by integrating a feedback mechanism within the application, allowing users to rate their experience, offer insights, and contribute to the collective knowledge base of the POI. This feature aims to provide valuable data for continuous improvement of the content and functionality of the application.
- Provide information and navigate to detailed context for each point of interest to enable a deeper understanding and connection with the site.

1.3 Structure of the Thesis

This thesis is structured into six chapters, each dedicated to a different aspect of the research, development, and evaluation of the work. The organization of the thesis is as follows:

- **Chapter 1: Introduction -** This opening chapter sets the stage for the research, outlining the motivation behind the development of the mobile web application, the objectives aimed at improving visitor experiences through technology, and the significance of the work. It establishes the context within which the research is conducted and highlights the need for a solution that bridges the gap between traditional informational mediums and the evolving expectations of tourists.

- **Chapter 2: Literature Review -** In this chapter, the evolution and significance of digital mapping technology, particularly its transformative impact on tourism and navigation, are explored. It outlines the transition from traditional paper maps to advanced digital formats that offer real-time updates, GPS integration, and interactive features, enhancing the visitor experience by improving accessibility and engagement at tourist sites.
- **Chapter 3: Data and Tools -** Chapter 3 provides a comprehensive overview of the technologies and tools utilized throughout the thesis. This chapter systematically catalogs the software, frameworks, and digital resources that were instrumental in the construction and functioning of the mobile web application. It delves into the specifics of each technology, explaining its role and the reason for its selection, thereby offering insights into the foundational choices that underpin the project's technical infrastructure.
- **Chapter 4: Methodology -** This chapter combines an in-depth examination of the research methodology with a thorough exploration of the technical intricacies involved in creating the mobile web application. It covers the entire spectrum from the initial design and development stages to the final implementation, detailing the selection of tools and technologies, data collection techniques, and the iterative cycles of testing and refinement that were critical to the project's success. The methodology not only outlines the process for selecting and curating Points of Interest (POIs) to ensure their relevance and enhance user engagement but also dives into the system architecture, design decisions, and the integration of interactive features and location-based services that contribute to an intuitive and immersive user experience. Furthermore, this chapter also discusses the challenges encountered during the development process and the solutions employed to overcome them.
- **Chapter 5: Evaluation -** This chapter outlines the evaluation processes, including the collection and analysis of user feedback, engagement metrics, and results from usability testing. The primary goal of this evaluation is to offer a detailed review of how effectively the application's UI meets its objectives, showcasing the successes while also pinpointing areas where enhancements are needed. By concentrating on the UI, this chapter aims to shed light on the crucial aspects of user satisfaction, providing insights into the application's overall usability and the impact it has on the user experience.
- **Chapter 6: Conclusion -** The final chapter summarizes the key findings of the research, reflects on the contribution of the work to the field of interactive mobile applications for tourism, and explains the performed methodology and evaluation by identifying areas for future improvements.

Chapter 2

Literature Review

This chapter delves into the development and importance of digital mapping technology, focusing on its revolutionary role in tourism and navigation. It discusses the shift from conventional paper maps to sophisticated digital versions, which provide up-to-the-minute updates, GPS functionality, and interactive capabilities. This transition has significantly enhanced the experience of tourists by making destinations more accessible and engaging.

2.1 Digital Mapping

Digital mapping synthesizes street information into a virtual depiction. Its primary objective is to yield maps that accurately reflect a chosen area, including significant thoroughfares and landmarks. The technology further enables users to calculate distances between various locations. It involves the integration of GPS and GIS to create spatial information systems (Robles-Ortega et al. 2013).

The evolution of digital mapping traces back to the era of paper maps, which served as a manual and transportable method for illustrating geographical data.Paper maps, though handy and easily transportable, lack the flexibility of being updated unless a new edition is acquired. On the other hand, Digital maps are designed to receive updates directly from servers, allowing them to be refreshed regularly. This dynamic nature of digital mapping allows for real-time updates and ensures that users have access to the most current information available.

Early digital maps primarily offered the same basic functionality as their paper counterparts, serving as a virtual representation of roads and terrain. However, with the advent of GPS technology and the proliferation of mobile devices over the past decade, digital maps have undergone a significant transformation within integrations of points of interest and service locations.

Additionally, the emergence of platforms for user-generated content, such as OpenStreetMap, has made the process of creating and updating map data more democratic, allowing for continuous refinement and updates by a worldwide community of contributors (Haklay & Weber 2008). Furthermore, Goodchild (2007) introduces the concept of Volunteered Geographic Information (VGI), highlighting its importance in offering geographic data. This approach not only aids geographers in better understanding the Earth's surface but is also cost-effective and valuable in supplying information for tourist purposes, travel logs, and serving as a geographic information source in areas where access may be limited.

Digital mapping technologies significantly enhance visitor engagement at tourist sites by offering detailed and interactive views of the physical world. They improve navigation and enrich the user experience through sophisticated visualization and interaction with geographical data. The importance of digital mapping in advancing location-based services (LBS) is highlighted by its role in driving the expansion of the digital map market, which is expected to grow at an annual rate of 15% (The Business Research Company 2024). The surge in the digital map market is fueled by the growing need for location-based services across marketing, advertising, and navigation sectors.

2.1.1 The Role of Digital Mapping in Tourism

Digital mapping technologies offer a multitude of benefits for enhancing visitor experiences at tourist sites.

2.1.1.1 Navigation and Accessibility

Digital maps, particularly those with GPS-based navigation and route guidance, have significantly improved the tourist experience by making it easier to find specific locations and attractions. Hsu et al. (2018) developed iTour, a system that transforms tourist maps into digital maps, allowing users to navigate using GPS-enabled tourist maps on their mobile devices. This change opens up the opportunity to enhance numerous tourist maps with digital map functionalities. Wilson et al. (2008) introduced a web-based system for maintaining attractions and an electronic map application with navigation, nearby place search, and route recommendation functions. The paper proposes a new navigation system for tourist attractions, discusses the use of GPS, presents a dataset for outdoor attractions in Ancient Siam, and evaluates an Android map application. It also suggests potential future directions for the work. Curran & Smith (2006) documented the E-Local Advisor application, which provides street maps, directions, and location of local services using GPS and online mapping services and users can discover points of interest, determine their current location, and request precise directions from one place to another through the system. These studies collectively demonstrate the significant benefits of digital maps in enhancing the tourist experience.

2.1.1.2 Interactive Engagement

Digital mapping facilitates interactive engagement with the physical environment through map-based data visualization, providing access to real-time information on essential datasets. This approach grants both domain experts and tourists deep insights into particular areas (Wada et al. 2022). Salovaara (2016) discusses the role of digital maps in producing environmental knowledge, including mapping environmental damage, endangered species, and human-induced disasters. Additionally, Wilson et al. (2008) explores how individuals interact with map interfaces, concluding that this interaction helps to identify and enhance the understanding of the fundamental theoretical principles of geospatial user interaction.

2.1.1.3 Enhanced User Experience

The fusion of artificial intelligence (AI) with aerial imagery in digital mapping tools offers users vivid digital portrayals of streets, landmarks, and places of interest. This enriched digital interaction allows tourists to virtually experience destinations before their actual visits, significantly improving pre-visit engagement and anticipation (The Business Research Company 2024).

Research over the past few decades has concentrated on the amalgamation of AI with digital mapping technologies. Mckeown (1987) initially pointed out AI's capability to broaden the functionalities of geographic information systems, especially in refining user interfaces and the depiction of spatial data. Zhang et al. (2001) further investigated this in the arena of 3D road network reconstruction, employing knowledge-based image analysis to enhance the accuracy and dependability of the outcomes. Sowmya & Trinder (2000) highlighted AI's utility in the automated extraction of features from aerial and satellite imagery, focusing on the importance of knowledge representation and modeling. In a more recent study, Sun et al. (2019) showcased the benefits of incorporating crowdsourced GPS data for improved road mapping from aerial images, indicating advancements in the precision and robustness of mapping models. These collective investigations underline AI's transformative impact on making digital mapping more accurate and efficient.

2.1.1.4 Location-Based Services

Digital mapping technologies are crucial for providing location-based services, encompassing location-based advertising, business intelligence, and analytics. These services leverage the user's geographic location to deliver tailored information and promotions, significantly improving the relevance and impact of marketing efforts. The utility of these services is augmented by interactive paper technology, enabling the fusion of digital location-based functionalities with traditional paper maps, as noted by Grossniklaus et al. (2006). The evolution of online maps and the support of cloud-based location-based services have been propelled by the merging of diverse technologies, as discussed by Kroepfl et al. (2012). Furthermore, the significance of contemporary cartography in enhancing location-based services through spatial modeling and effective cartographic communication is emphasized, highlighting its pivotal role as outlined by Gartner (2013). This comprehensive integration and innovation in digital mapping and cartography underscore their foundational role in refining and expanding location-based services.

Chapter 3

Data and Tools

This chapter delves into the essential data sources and software tools that form the backbone of the development process for a location-based interactive mobile web application designed to enhance visitors' knowledge and experiences. The focus is on web languages, the Leaflet JavaScript library for interactive maps, and the OpenStreetMap (OSM) as a primary source of geographic data.

3.1 WEB Languages

Web application development is fundamentally anchored in three primary languages: HTML (HyperText Markup Language), CSS (Cascading Style Sheets), and JavaScript. Together, they form the backbone of web applications, with HTML organizing the content, CSS managing the visual presentation, and JavaScript facilitating interactive features.

3.1.1 HyperText Markup Language(HTML)

HTML, or HyperText Markup Language, acts as the foundational support for web page design, providing developers with a comprehensive framework to organize a webpage's numerous components. It is the standard markup language for creating and designing web pages, specifying elements like headings (ranging from <h1> to <h6> tags to denote importance and structure), paragraphs (<p>), links (<a href="">), and embedded content, including images (<img>) and videos (<video>) tags. These elements are crucial in delivering textual and multimedia information clearly and systematically (Raggett 1994).

Figure 3.1 illustrates a simple HTML code that creates a basic webpage with a heading and a paragraph. This code defines a basic HTML structure with a heading (<h1>) displaying "Hello, World!" and a paragraph (<p>) with some text. Storing this code within a file possessing a .html extension (for instance, index.html) and subsequently accessing it via a web browser will display the outcome.

Let us go through each part of the HTML code and explain its purpose:

- <!DOCTYPE html>: This is a document type declaration. It tells the browser that the document is an HTML5 document.
- <html lang="en">: This is the root element of the HTML document. The lang attribute specifies the language of the document, which is set to English (en).
- <head>: This is the head section of the HTML document. It contains meta-information about the document, such as character encoding, viewport settings, and the document title.
- <meta charset="UTF-8">: This meta tag specifies the character encoding for the document. UTF-8 is a widely used character encoding that supports a vast range of characters from various languages.
- <meta name="viewport" content="width=device-width, initial-scale=1.0">: This meta tag sets the viewport properties for responsive web design. It ensures that the webpage is displayed properly on devices with different screen sizes. The width=device-width sets the width of the viewport to the width of the device, and initial-scale=1.0 sets the initial zoom level to 1.0.
- <title>My Simple Webpage</title>: This is the title of the HTML document, which appears in the browser's title bar or tab.
- <body>: This is the body section of the HTML document. It contains the content of the webpage that is displayed to the user.
- <h1>Hello, World!</h1>: This is a heading element (<h1>) that displays the text "Hello, World!". Headings are used to define the structure of the document, with <h1> being the highest level of heading.
- <p>This is a simple webpage created using HTML.</p>: This is a paragraph element (<p>) that contains text content. Paragraphs are used to structure and organize text content on the webpage.

▼ HTML

```html
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>My Simple Webpage</title>
</head>
<body>

    <h1>Hello, World!</h1>

    <p>This is a simple webpage created using HTML.</p>

</body>
</html>
```

FIGURE 3.1: Simple HTML code

Figure 3.1 shows the result of the html code in a web browser.

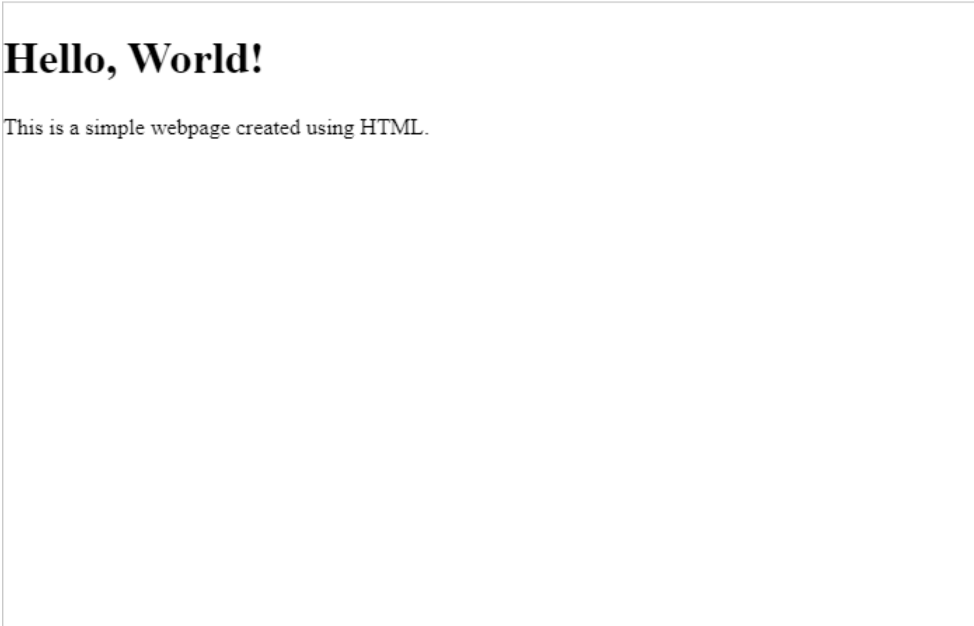

FIGURE 3.2: Showcase of simple HTML code on the browser

In location-based applications, the significance of HTML for embedding maps and organizing user interface components, such as menus, informational panels, and forms, cannot be overstated. This capability is crucial for crafting interactive and user-friendly applications. Furthermore, HTML plays a pivotal role in structuring the user interface, which includes navigation menus (<nav>), panels for information (<div> or <section> for consolidating related content), and forms (<form>) for interactions like search submissions or data entry.

HTML5, the most recent iteration, introduces novel semantic elements and attributes that substantially improve the web's capacity for directly managing multimedia and graphical content. This encompasses the <canvas> element for graphic creation, <audio> and <video> elements for media playback, and semantic tags such as <article>, <footer>, <header>, and <section>, enhancing the structure and legibility of web content. These enhancements elevate HTML's functionality and adaptability, making it ideal for developing sophisticated, interactive web applications that meet the demands of contemporary users.

The advanced structuring capabilities of HTML, extending beyond fundamental elements to include complex, interactive functionalities, ensure developers have the tools to build more captivating, accessible, and efficient web pages and applications.

Given HTML's status as a fundamental and standard tool in web development, alternatives are typically considered for other purposes, such as data interchange and presentation. For this project, HTML was selected due to its universal support across all web and mobile browsers. Moreover, HTML seamlessly integrates with Cascading Style Sheets (CSS) for styling and JavaScript for enhancing interactivity, making it the cornerstone of web development.

3.1.2 Cascading Style Sheets(CSS)

Cascading Style Sheets (CSS) play an essential role in web design, setting the tone for how HTML elements are visually presented across websites. This styling language is key to defining the layout, color schemes, fonts, and animations, significantly enhancing the visual appeal and usability of web applications (Walsh 1997). CSS enables precise control over the presentation of page elements, including the spacing, alignment, size, and positioning of both images and text. Figure 3.3 illustrates the application of inline CSS for text colorization within a basic HTML code structure. Figure 3.4 also displays the outcome of these styling choices as seen in a web browser, demonstrating how inline CSS can modify the appearance of text elements directly within the HTML markup, thereby affecting the visual presentation of content on the webpage.

▼ HTML

```html
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>My Simple Webpage</title>
</head>
<body>

    <h1 style="color: blue;">Hello, World!</h1>

    <p style="color: red;">This is a simple webpage created using HTML.</p>

</body>
</html>
```

FIGURE 3.3: An example for inline styling CSS

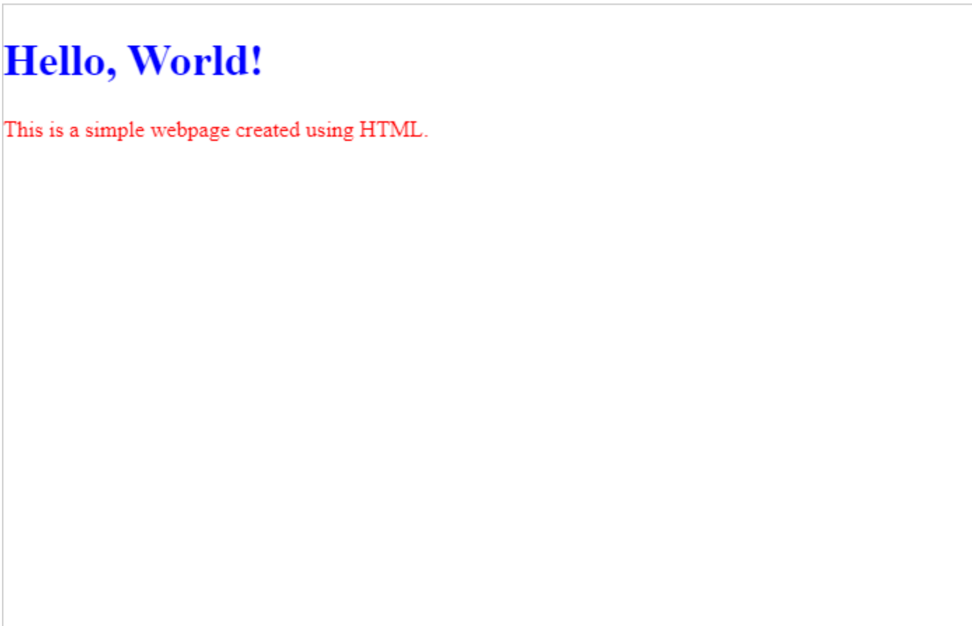

FIGURE 3.4: Showcase of CSS code on the browser

CSS also stands at the forefront of responsive design, ensuring web applications are fully functional and aesthetically pleasing across a diverse range of devices, from desktops to mobile phones and tablets. This adaptability is achieved through media queries, a CSS functionality that allows the layout to adjust based on the device's screen size and resolution, providing a flawless user experience in a mobile-first world.

Moreover, CSS facilitates the crafting of dynamic and interactive user interfaces by incorporating animations and transitions, thereby enriching the user engagement. The advent of CSS3 has ushered in advanced features such as gradients, shadow effects, and the flexbox layout, empowering designers to achieve more complex visual effects and layouts. These capabilities allow for innovative designs that enhance user interfaces without the need for additional graphics or intricate scripts, marking a significant advancement in web design technology.

Tailwind CSS is a utility-first CSS framework favored for crafting contemporary web interfaces. It eliminates the need for custom CSS for common styles, such as margins, paddings, and text alignment (Rifandi et al. 2022). Developers use pre-defined utility classes within their HTML markup to style components efficiently. This approach streamlines the design process, enabling quick prototyping and customization without extensive custom CSS.

CSS, foundational to web development, is supported by all web browsers natively, without requiring compilation. Modern web technologies offer alternatives like SASS, LESS, and Stylus for preprocessing, and frameworks like TailwindCSS and Bootstrap to enhance coding efficiency and modern styling. In this project, alongside CSS, the TailwindCSS framework is chosen for its utility-first methodology, allowing for swift in-HTML element styling. This accelerates development and prototyping, while also fostering design consistency throughout the project, thus mitigating the risk of CSS bloat and specificity conflicts in larger projects.

3.1.3 JavaScript

JavaScript is a crucial scripting language that introduces dynamic features to web applications, allowing for the real-time modification of webpage elements based on user actions (Flanagan 2020). This functionality supports instant content updates, interactive maps, and smooth server communication, markedly improving the interactive nature and user experience of websites. Its utility is enhanced by a wide range of frameworks and libraries, such as Leaflet, which facilitate the creation of sophisticated interactive elements while promoting code efficiency, maintainability, and scalability.

The adaptability of JavaScript spans client-side and server-side programming, as evidenced by platforms like Node.js, promoting a unified development experience and reducing the need to juggle different languages for front-end and back-end tasks. The advent of contemporary JavaScript frameworks like React, Angular, and Vue has transformed the way user interfaces are developed, employing reactive and component-based approaches to accelerate and improve web application creation.

As the fundamental language for client-side scripting in browsers, JavaScript's main alternatives are languages or frameworks that compile into JavaScript. TypeScript, for instance, enhances JavaScript by adding optional static typing, which helps identify errors during the development phase, although it requires familiarity with type annotations and TypeScript-specific functionalities. Dart, originally designed for mobile app development, can also be used for web applications via Flutter, encouraging cross-platform code reuse. However, Dart may encounter challenges such as performance concerns and a smaller community when compared to JavaScript's vast ecosystem.

Considering these factors, JavaScript is selected for this project owing to its direct support in all major web browsers, negating the need for any compilation or extra layers. Its essential role in contemporary web development, alongside its capacity to craft dynamic, efficient, and advanced web applications without the drawbacks of its alternatives, justifies its choice as the primary technology for the project.

3.2 Leaflet

Leaflet is an open-source JavaScript library developed with the intention of supporting the creation of mobile-friendly interactive maps. It is recognized for its straightforward usability, adaptability, and efficient performance, positioning it as a preferred choice among developers for the incorporation of mapping functionalities into web applications (Edler & Vetter 2019). Leaflet offers a wide range of features such as tile layers, which facilitate the integration of map tiles from various sources; markers, for indicating specific locations on the map; popups, which provide additional information upon interaction with markers; and vector shapes, allowing for the depiction of geometric figures on maps. These capabilities enable the assembly of detailed, interactive mapping interfaces with a moderate level of coding.

Despite its simplicity, Leaflet's architecture is robust, maintaining compatibility across various browsers and platforms, particularly for mobile applications. It efficiently handles the display and management of map data, interactive elements, and bespoke overlays, proving to be a reliable foundation for location-based services. This balance of efficiency and versatility renders Leaflet an effective tool for developing sophisticated, location-based web applications, delivering engaging map interactions for users. Through its array of features and optimization for mobile usage, Leaflet serves as a fundamental resource in the development of comprehensive mapping applications, affirming its importance in the field of web-based geographic information systems.

Mapbox GL JS is an alternative to Leaflet, leveraging WebGL for rendering, which ensures fluid performance with intricate visualizations and extensive datasets. Nonetheless, unlike Leaflet, Mapbox GL JS is not entirely free. Given that Leaflet is open-source, lightweight, and not subject to the terms and pricing of any particular service, it is selected for the project.

3.3 OpenStreetMap

OpenStreetMap (OSM) represents a global initiative aimed at constructing an editable, freely accessible map of the world, distinguished by its comprehensive coverage of geographic information (Bertolotto et al. 2020). The project thrives on the contributions of an extensive network of volunteers who gather, refine, and perpetually update data, encompassing intricate details of road networks, building outlines, natural landscapes, and various points of interest. This collaborative effort ensures that OSM serves as an essential tool for developers of location-based services, providing a rich, constantly evolving depiction of geographical landscapes.

The ethos of OSM is rooted in its open data philosophy, which not only facilitates the creation of precise and current maps but also fosters a spirit of innovation and adaptability. Utilizing OSM data, developers are empowered to devise customized mapping solutions that are perfectly aligned with the specific demands and nuances of their projects. Whether the aim is to develop straightforward navigational resources or intricate tools for spatial analysis, OSM's versatile dataset offers the necessary foundation for a broad spectrum of applications. This open model democratizes access to geographic information, enabling a wide range of uses from academic research to commercial projects, thereby contributing significantly to the advancement of geospatial technologies and services.

Google Maps and Bing Maps serve as alternatives to OpenStreetMap. Google Maps is frequently recognized for its current and precise data across numerous locations, attributed to its extensive resources and large user base. Bing Maps, on the other hand, is closely integrated with Microsoft's range of products and services, presenting benefits for businesses deeply rooted in the Microsoft ecosystem. Despite these advantages, the selection of OpenStreetMap for the project is due to its community-driven methodology for collecting and updating map data, alongside its fully open and free access model, distinguishing it from the proprietary and potentially cost-associated nature of Google Maps and Bing Maps.

Chapter 4

Methodology

4.1 User interface design and implementation

The user interface (UI) serves as the pivotal point of interaction between the user and the application's core features. In the context of a location-based interactive mobile web application, the UI design is centered around providing a clear, intuitive, and adaptable experience (Faghih et al. 2014). The initial phase of the design process entails the development of wireframes and mockups. These visual blueprints detail the arrangement of key elements such as maps, lists of points of interest (POIs), and navigation menus, laying the groundwork for the application's layout.

The subsequent phase transitions these conceptual designs into a tangible user interface through the application of web development technologies, including HTML, CSS, and JavaScript. Employing responsive design principles is crucial to adapt the application for a seamless operation across diverse devices and screen dimensions. The utilization of libraries and frameworks, such as Bootstrap or Material-UI, facilitates a uniform aesthetic and accelerates the development timeline by offering ready-made components.

Enhancing user engagement, the interface incorporates interactive features like touch gestures and visually appealing animations and transitions. Essential to the UI is the implementation of feedback mechanisms, for instance, loading indicators and error notifications, which play a vital role in communicating the application's status and responses to the user.

Incorporating accessibility from the design phase through to implementation ensures the application accommodates users with disabilities. Strategies to achieve this include the provision of textual substitutes for visual content, adherence to color contrast standards for visual clarity, and ensuring all functionalities are accessible through keyboard inputs, thereby embracing a wide user base.

4.1.1 Figma Design Prototyping

Before initiating any project, a crucial initial phase involves the creation and decision-making around a prototype. Design prototyping carries a multitude of significant advantages, such as the rapid visualization of ideas, early identification of potential issues, and notably, the potential to decrease development costs. Through the prototyping process, designers gain a deeper understanding of the project requirements and how it may interact within various contexts. For this specific project, Figma, a cloud-based design tool renowned for its utility in crafting user interfaces, developing prototypes, and facilitating collaborative design endeavors, has been selected. Figma stands out for its widespread adoption among UI/UX designers due to its comprehensive feature set that supports design iteration and user experience testing directly within the browser (Hong 2023).

Given that this project is aimed at mobile platforms, choosing the appropriate mobile viewport within Figma was a preliminary step. Figma offers a range of predefined viewport sizes that mirror actual device dimensions. As of 2024, the typical mobile viewport dimensions span from about 320 pixels in width for smaller devices to 414 pixels for larger ones. While the height can vary based on the device's aspect ratio, common ratios include 16:9 and 18:9. In light of these statistics, a base device dimension of 393x852 pixels was selected, situating it within the average range for contemporary mobile devices.

Subsequently, the design process involved placing and stylizing UI elements on the chosen base device. Given the application's focus on mapping, example map tiles were extended across the entire screen, complemented by a navigation bar essential for facilitating user navigation through menus and settings panels. To enhance usability on mobile screens, the navigation bar was designed to be collapsible, allowing users to maximize screen space for map viewing without distraction. Following the navigation bar's integration, additional panels were developed and sized appropriately.

The next phase centered on defining the aesthetic aspects of the UI, including color schemes, font sizes, and font types. After various trials, specific font sizes and types were chosen based on readability and accessibility on the chosen viewport size. The default font family chosen was Tailwind CSS, offering three font family utilities: a sans-serif stack, a serif stack, and a monospaced stack, ensuring cross-browser compatibility. These font stacks are renowned for their widespread availability and suitability for digital platforms. For the color palette, shades of green and their variations were chosen to echo the natural theme of the project's focus, the Herrenhausen Gardens, known for their verdant landscapes and botanical diversity.

Figure 4.1 showcases the initial stage of design prototyping in Figma. This platform is invaluable not just for visualizing design concepts but also for extracting precise element dimensions, CSS attributes, and detailed code-related information. These insights are crucial during the development phase, allowing developers to concentrate on coding and logic rather than design adjustments.

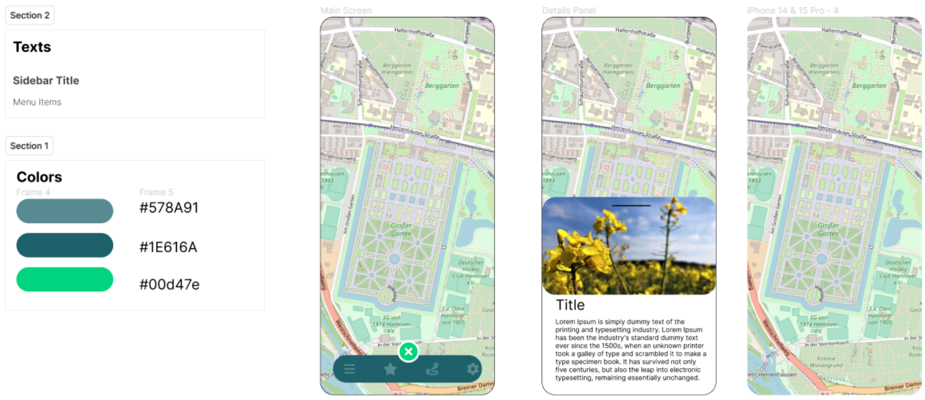

FIGURE 4.1: Initial figma design

This approach ensures that the bulk of visualization and design decisions are finalized early on, streamlining the development process. Any subsequent changes to UI elements, if made during the coding phase without prior design consideration, could significantly delay project progress. By frontloading design decisions through comprehensive prototyping in Figma, the project sets a solid foundation for efficient development, aligning closely with modern design and development workflows.

4.1.2 Screen and Panels

The previous discussion highlighted the significance of design prototyping, underscoring its key advantages such as time efficiency and its role in facilitating decision-making. This section presents the panels and screens of the application along with their respective use cases.

4.1.2.1 Main Screen

The design of the main screen in location-based applications should prioritize minimalism to avoid user distraction while ensuring an optimal user experience. Central to this philosophy is the integration of essential elements that enhance usability without overwhelming the user. The main screen is depicted in Figure 4.2. It features a standard, freely available map tile from OpenStreetMap in the background, offering a detailed representation of the user's surroundings. This map provides a clear view of various environmental and geographical elements, facilitating user orientation and interaction with the space around them.

Key features are made accessible through an intuitively designed navigation bar located at the bottom of the screen. This bar houses four critical buttons: menu access,

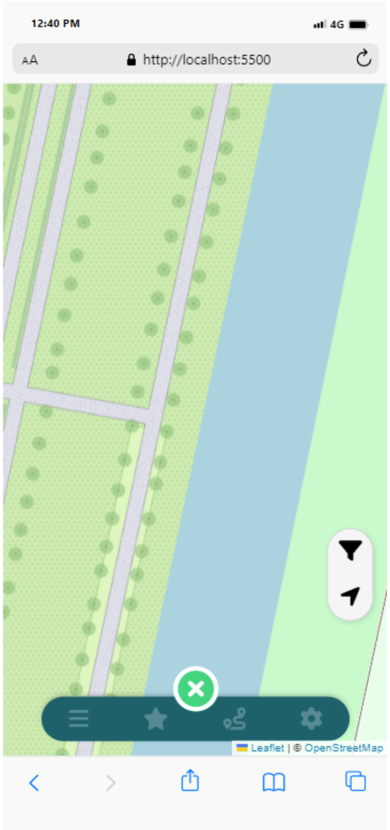

FIGURE 4.2: Main screen

which opens a side panel for application navigation; a ratings panel for user feedback; a route panel to plan paths; and a settings button for application customization. Additionally, a toggle is provided to hide the navigation bar, allowing users to view the map unobstructed, enhancing the immersive map experience.

To the right of the screen, a vertical panel contains two significant buttons. The upper button opens a filtering panel, enabling users to customize map overlays according to their interests or needs, such as highlighting specific points of interest or areas. The lower button activates the geo-location feature, a crucial functionality that pinpoints the user's current location, centering and highlighting it on the map for easy reference and navigation.

The application's user interface is further refined with the use of icons from the Font-Awesome icon library, chosen for its comprehensive collection of symbols and its free accessibility. These icons play a pivotal role in guiding user interaction, offering visual cues that help identify the purpose of each button swiftly. This choice not only enriches the modern web experience but also aligns with contemporary UI/UX design standards, making for a more intuitive and user-friendly interface.

The combination of a carefully curated main screen with strategic use of navigation aids and visual elements ensures that users can easily interact with the application, access its features, and enjoy a seamless navigation experience. This approach to design emphasizes the importance of user-centricity, functionality, and aesthetic appeal in creating engaging and effective location-based applications.

4.1.2.2 Menu Panel

Upon interacting with the bar icon button located on the navigation bar, users are greeted with a menu panel that elegantly unfolds through a sliding animation, revealing a series of options designed to enhance their experience as it is shown in Figure 4.3. Central to this menu is the highlighted feature of the Herrenhausen Gardens, accompanied by a succinct description of the application. This menu serves not only as a navigational aid but also as an informational resource, offering quick links to vital aspects such as the homepage, opening hours, accessibility features, legal information (Imprint / Privacy), and a language selection menu.

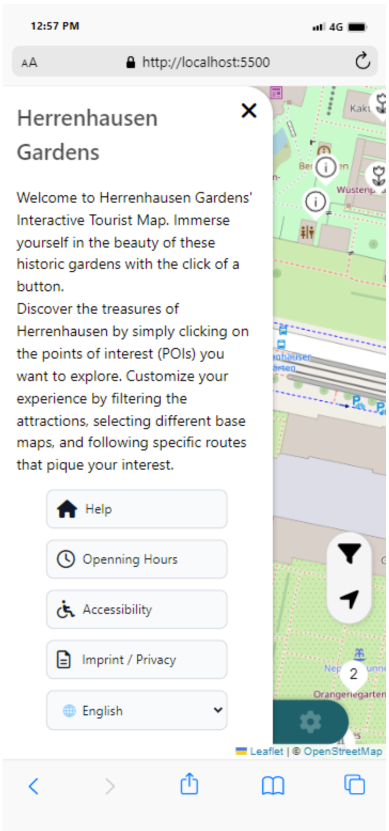

FIGURE 4.3: Menu panel

The homepage link directs users to the official website of the Herrenhausen Gardens, where they can find an array of detailed information, updates, and news pertinent to their visit. This feature ensures that users have access to the most comprehensive and current insights about the garden, enriching their visit. The opening hours link is another critical inclusion, guiding users to a webpage that lists the operational hours of the Herrenhausen Gardens. Recognizing the importance of this information for planning visits, this feature has been prominently integrated into the application to facilitate visitor scheduling.

Accessibility is another key component of the menu, providing essential information and guidance for visitors with special needs. This inclusion underscores the application's commitment to inclusivity, ensuring that all visitors, can navigate and enjoy the Herrenhausen Gardens with ease. The application also addresses the necessity of legal compliance and user privacy through quick links to the imprint and privacy policy, making these legal documents readily accessible to users and maintaining transparency regarding data handling and user rights.

Acknowledging the international appeal of the Herrenhausen Gardens, the application features a bilingual interface, offering content in both English and German. This design decision caters to the diverse demographic of visitors, including foreign tourists, ensuring that the application is accessible and useful to a wide audience. The inclusion of a language selection menu empowers users to choose their preferred language setting, thereby enhancing the usability and user experience of the application. By default, the language selection is determined by the user's browser language settings. This menu enables users to switch between languages if they wish to do so while using the application.

In the context of creating a bilingual application, the use of the data-i18n attribute within HTML is a pivotal technique for identifying text elements that require translation or localization. This approach is instrumental in web development for enhancing the user experience by catering to a diverse audience with different language preferences (Escobar-Velásquez et al. 2020). The example below provided elucidates the application of the data-i18n attribute to facilitate language switching within an application.

```
<p data-i18n="filter_panel_opening_hours"></p>
```

This line of code introduces a paragraph element (<p>) that is marked with a data-i18n attribute. The value assigned to this attribute, "filter_panel_opening_hours," serves as a unique identifier linking the element to its corresponding translations. This marking strategy is essential for dynamically updating the element's text based on the user's language selection.

```
const translations = {
  en: {
    "filter_panel_opening_hours": "Opening Hours",
  },
  de: {
    "filter_panel_opening_hours": "Öffnungszeiten",
  }
}
```

This object, named translations, acts as a repository for the multilingual content. It is structured to map language codes (en for English, de for German) to their respective translations. Within this object, the unique identifier "filter_panel_opening_hours" is used to access the actual text that should be displayed in the HTML element for each supported language. In this case, the translations provided are "Opening Hours" for English and "Öffnungszeiten" for German.

Overall, the thoughtful organization and content of the menu panel reflect a deep understanding of the users' needs, providing them with convenient access to essential information and features. This attention to detail in the application's design not only serves to facilitate a more enjoyable and informed visit to the Herrenhausen Gardens but also exemplifies best practices in creating user-centered mobile applications.

4.1.2.3 Information Panel

Upon selecting a point of interest (POI) on the map, users are presented with an informational panel that elegantly emerges with a sliding animation, occupying 70 percent of the viewport's height. This panel prominently features an image of the selected POI, with these images sourced directly from the official website of the Herrenhausen Gardens. This approach ensures that the visual representation of each point of interest provides an authentic glimpse into what visitors can expect, enhancing the user's engagement and anticipation.

In Figure 4.4, the name of the attraction is displayed, followed by a concise description that offers insights into the significance and allure of the POI. This textual content aims to provide users with a brief overview, igniting their interest and enriching their understanding of the garden's features.

For POIs that are accompanied by extensive information available on reputable websites, an additional "more information" option is presented. Selecting this option directs users to the respective website in a new browser tab, ensuring that they can easily access in-depth details without leaving the application. This functionality is designed to keep the transition seamless and user-friendly, allowing users to return to the application effortlessly and continue their exploration right where they left off, without the need to restart the application.

The technical aspects of how image data, text, and titles are stored and integrated into the points of interest within the application will be covered in a dedicated chapter on integrating POI information. As the current focus is on UI design, the discussion here refrains from delving into the technicalities behind the content management system or the database architecture supporting these features.

Figure 4.4 would typically illustrate the layout and visual design of the informational panel, providing a clear example of how information is displayed and interacted with within the application. This visual aid would help to convey the user experience more vividly, demonstrating the panel's functionality and aesthetic appeal as part of the overall design strategy aimed at enhancing visitor engagement

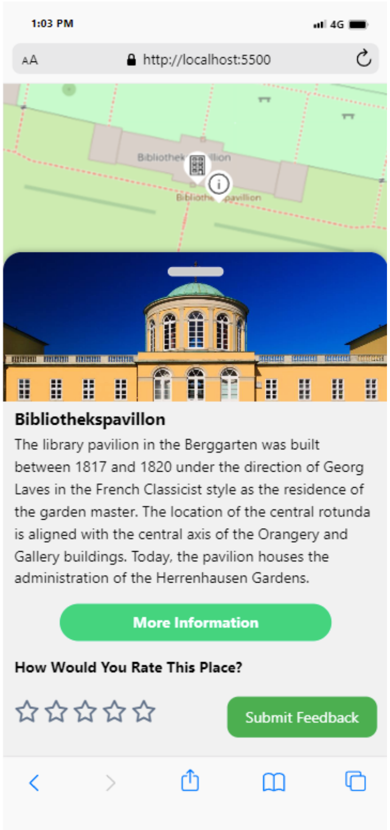

FIGURE 4.4: Information panel

with the Herrenhausen Gardens through a thoughtful and informative digital interface.

4.1.2.4 Map Filtering Panel

Activating the filtering button situated on the right side of the main screen unveils the map filter panel, a feature designed to streamline the user experience by allowing for the selective display of points of interest (POIs) on the map as it is shown in Figure 4.5. This functionality enables users to tailor their exploration and concentrate on aspects most relevant to their visit.

The categorization of POIs into three distinct groups facilitates this customization process. The "Utensils" category encompasses essential amenities such as restaurants, cafes, and restrooms, addressing the practical needs of visitors. The "Plant" group focuses on the natural beauty and botanical elements of the environment, including gardens, individual plants, and broader natural attractions, inviting users to explore the verdant aspects of the locale. Meanwhile, the "Monuments" category showcases the historical and cultural landmarks within the area, such as memorials, statues, and architectural monuments, enriching the visitor's understanding and appreciation of the site's heritage.

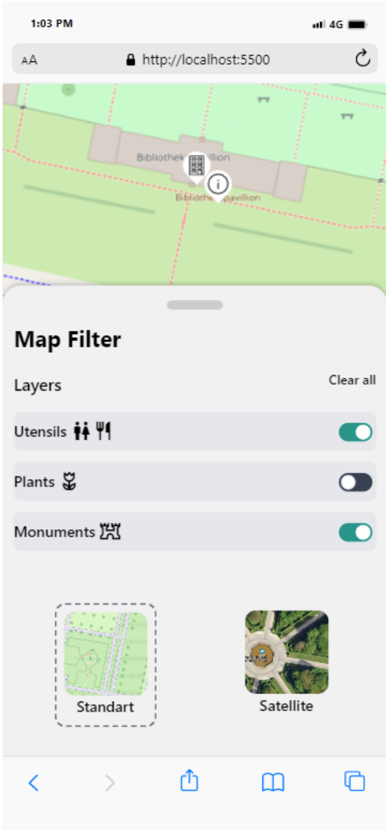

FIGURE 4.5: Map filtering panel

To assist users in navigating these categories, distinct icons represent the type of POIs contained within each group, making it easier to identify and select interests. An additional feature of the map filter panel is the ability to toggle between the standard OpenStreetMap (OSM) basemap and a satellite basemap. The satellite basemap option offers an aerial view of the terrain, providing a realistic depiction of the surroundings. This can be particularly beneficial for users who find it challenging to orient themselves using traditional map representations, as it gives a clearer sense of location and spatial relationships within the environment.

This map filter panel not only enhances user navigation and customization but also significantly contributes to a more focused and personalized visit, allowing users to effectively plan their exploration based on specific interests and preferences. By offering a straightforward means to filter POIs and switch basemap views, the application ensures a user-friendly experience that accommodates a wide range of visitor needs and enhances their engagement with the environment.

4.1.2.5 Predefined Routes Selection Panel

The Predefined Routes Selection Panel is a distinctive feature within the application, meticulously designed to enhance the user experience by guiding them along popular paths throughout their visit. This panel provides users with access to a curated selection of routes that lead through the most celebrated attractions and highlights of the area, enabling a structured exploration of notable points of interest.

These predefined routes are not static; they are subject to updates and refinements by the garden's management to ensure they remain relevant and informative. The ability to edit and adjust these routes allows for the incorporation of new attractions or seasonal highlights, ensuring that visitors are offered an experience that is both enriching and reflective of the garden's current state. This dynamic aspect of route selection empowers management to directly influence the visitor experience, guiding them toward must-see features and optimizing their journey through the garden.

An integral component of the Predefined Routes Selection Panel is the "clear all" button, a user-centric tool that simplifies interaction with the application. By providing a quick and efficient way to deselect previously chosen options, this button allows users to effortlessly reset their selections and start a new, facilitating a seamless navigation experience. This feature is particularly useful for visitors who wish to explore different routes or adjust their journey on the fly, ensuring they have the flexibility to tailor their experience according to their interests and time constraints.

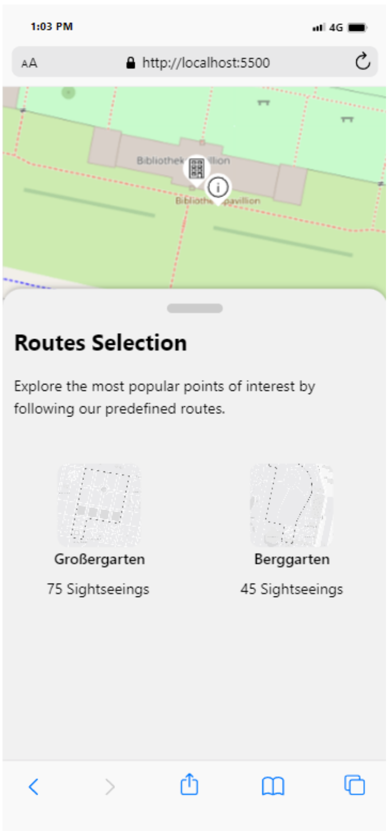

FIGURE 4.6: Predefined routes selection panel

Figure 4.6 showcases the thoughtful design and user-friendly interface of the routes selection panel. Through the implementation of the predefined routes selection panel, the application not only enriches the visitor experience but also enhances the navigational efficiency, making it an indispensable tool for discovering the garden's most popular attractions and ensuring a memorable visit.

4.1.2.6 Interests Selection Panel

To enhance the personalization of the user experience and ensure the relevance of Points of Interest (POI) suggestions, the application features an interest selection panel. This panel is readily accessible to users through the settings button located on the navigation bar, designed to allow users to tailor the application according to their preferences by selecting their areas of interest.

Figure 4.7 presents users with three checkboxes, each representing a group of related categories. These groupings are thoughtfully organized to cover a broad spectrum of interests while maintaining simplicity in the user interface. The categories and their groupings are as follows:

1. Plants and Gardens: This checkbox combines interests related to both individual plant species and larger garden areas. It caters to users who are enthusiasts of botany or those looking to explore serene garden landscapes.
2. Memorials: By selecting this option, users express their interest in historical memorials. This category is aimed at users fascinated by history, culture, and artistic expressions within the environment they are exploring.
3. Artworks, Attractions and Viewpoints: The final checkbox encompasses major attractions, various forms of artwork and scenic viewpoints. It is designed for users interested in experiencing the highlights of a location, including panoramic views and notable landmarks.

Upon the user's selection of their preferred categories, the application stores these preferences locally on the user's device using the localStorage feature. This approach ensures that the user's selections are preserved between sessions, providing a consistent and customized experience each time the application is used.

The stored preferences play a crucial role in the application's scoring algorithm, which determines the relevance of POI suggestions presented to the user. By analyzing the user's selected interests, the algorithm can prioritize POIs that align with these preferences, thereby enhancing the relevance of the suggestions. For instance, if a user has shown a preference for "Plants and Gardens," the scoring algorithm will adjust its calculations to favor POIs within this category, ensuring that the user receives suggestions that are most likely to appeal to their interests.

This dynamic scoring mechanism, underpinned by the user's personalized selections, significantly improves the application's utility and user satisfaction. By enabling users to customize their experience based on specific interests, the application fosters a more engaging and meaningful interaction with the environment, guiding users to discover POIs that truly resonate with their preferences. The integration of the interest selection panel and its direct impact on the scoring algorithm exemplifies the application's commitment to delivering a user-centric navigation and exploration experience.

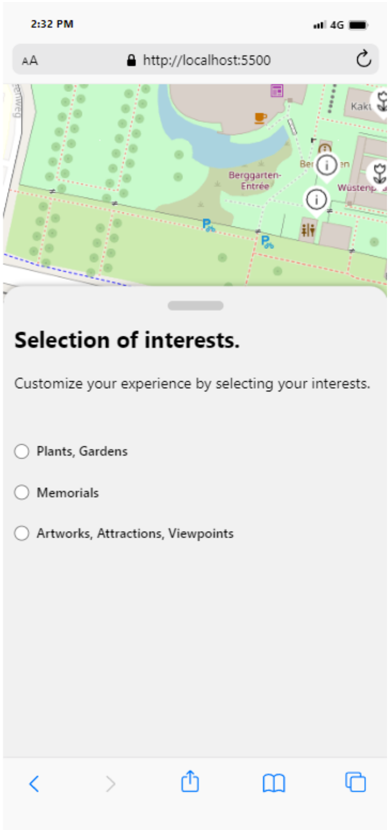

FIGURE 4.7: Interests selection panel

4.1.2.7 Feedback Panel

Within the application, a dedicated feedback panel has been implemented, offering users the opportunity to contribute their insights and evaluations concerning the application itself or the places they have visited. This panel is intuitively designed to encourage user interaction, ensuring that providing feedback is as straightforward and accessible as possible.

As Figure 4.8 shows that the feedback mechanism is structured to allow users to assign a rating, ranging from 1 to 5 stars, reflecting their overall satisfaction or experience. This star rating system is a universally understood method for quickly conveying approval or disapproval, making it easy for users to express their level of satisfaction at a glance. Additionally, the panel includes a text box where users have the option to elaborate on their ratings with written feedback. This feature is especially valuable as it enables users to share specific thoughts, suggestions, or experiences in greater detail, providing rich qualitative data that can inform improvements.

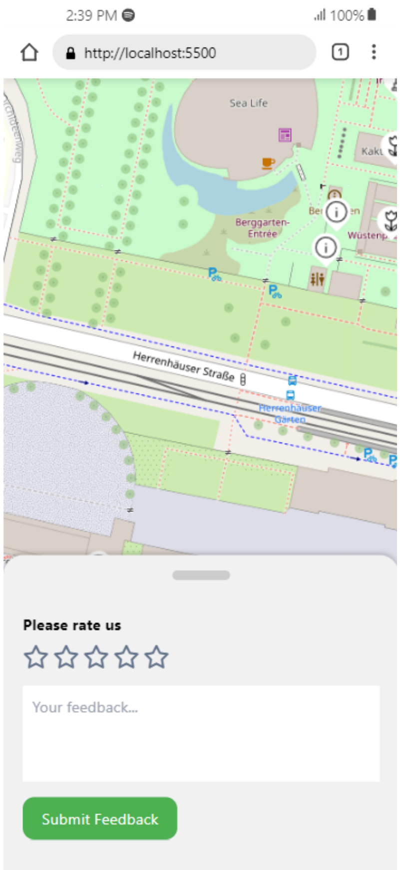

FIGURE 4.8: Feedback panel

The feedback collected through this panel is directly managed and reviewed by the administrative team responsible for the garden's management. This direct line of communication between users and management plays a crucial role in the continuous improvement process. By analyzing the feedback, the management team can identify common themes, pinpoint areas of success or concern, and understand user expectations more clearly. This insight is instrumental in guiding strategic decisions, from minor adjustments in the application's functionality to broader enhancements in the garden's layout, amenities, or visitor services.

Moreover, this feedback loop fosters a sense of community and engagement among users, as they can see their suggestions and opinions being taken into consideration. It demonstrates a commitment to user satisfaction and continuous improvement, which can enhance the overall visitor experience and encourage repeat visits. For the management team, leveraging user feedback is an invaluable tool for maintaining high standards of visitor satisfaction, adapting to changing user needs, and ultimately ensuring that the garden and its associated application remain vibrant, engaging, and responsive to the people they serve (Joanna Tonge & Taplin 2011).

In essence, the feedback panel is not merely a feature of the application; it is a strategic asset that empowers users to contribute to the ongoing development and enhancement of the garden experience. By providing a simple yet effective platform for feedback, the application bridges the gap between user experiences and management action, fostering a dynamic environment of continuous improvement and user-centric development.

4.2 Integration of POI information

Points of interest (POIs) are central elements within map applications, encompassing attractions, objects, and botanical gardens. These features significantly enhance the utility and informational depth of mapping tools. In the Leaflet.js framework, POIs are represented through point features, each defined by specific latitude and longitude coordinates (Krösche & Boll 2005). The acquisition of POI data leverages the comprehensive, up-to-date, and reliable datasets available from OpenStreetMap. The vector data obtained from OpenStreetMap (OSM) for the specified garden boundary is categorized into two distinct types: points and polygons. The dataset comprises 611 point vector data entries and 641 polygon vector data entries. Each data entry is enriched with a variety of attributes that provide detailed information about the spatial objects they represent. These attributes include osm_id, which serves as a unique identifier for each object within the OSM database, access details, the name of the object, and disuse status, among others that they vary depending on the nature of the spatial object; for example, objects classified as restaurants feature an 'amenity' attribute with the value 'restaurant'.

In addition to these descriptive attributes, every spatial object is associated with specific coordinates articulated within the geographic coordinate system using the WGS84 datum. The World Geodetic System 1984 (WGS84) is a global reference system for geospatial data, widely adopted for its accuracy in representing geographical locations on the Earth's surface.

Upon reviewing the data procured from OSM, a structured approach was undertaken to refine and reorganize the attributes to better align with the project's requirements. This involved prioritizing and formatting the attributes to ensure they are readily accessible and interpretable for the purposes of the project. Table 4.1 outlines the reorganized data attributes and their corresponding value types, providing a clear overview of the dataset's structure and content. This restructured data framework facilitates efficient data manipulation and utilization, ensuring that spatial objects within the garden boundary are accurately represented and leveraged to enhance the project's geographic information system (GIS) capabilities.

The table labeled 4.2 provides a comprehensive overview of the values associated with the "fclass" attribute, which serves as a crucial categorization mechanism for various Points of Interest (POIs) depicted on the map. This attribute plays a pivotal role in organizing and distinguishing the diverse range of POIs, facilitating effective navigation and exploration for users. The "fclass" attribute encompasses a total of 14 distinct categories, each representing a unique classification of POIs based on their

Attribute	Value Type	Description
osm_id	integer	Unique OSM identification number
id	integer	Project specific unique identification number
name	string	Name of the feature
fclass	string	Feature class or category
has_image	boolean	Indicates whether the feature has an associated image
info_title	string	Title or heading for informational purposes
info_description_en	string	Description of the feature in English
info_description_de	string	Description of the feature in German
info_link	string	URL associated with the feature

TABLE 4.1: Data Structure

Categorie Name
garden
toilet
artwork
theater
viewpoint
fountain
cafe
plant
restaurant
attraction
memorial
building
tourist_info
water_well

TABLE 4.2: Categorization of features

characteristics, functions, or significance within the mapped environment. These categories have been carefully curated to encompass a broad spectrum of POI types, ensuring comprehensive coverage and granularity in the mapping dataset.

- Garden represents areas designated for the cultivation and display of plants, often for aesthetic or recreational purposes.
- Toilet denotes public or private facilities for human waste disposal and personal hygiene.
- Artwork refers to sculptures, murals, or other artistic installations that are typically displayed in public spaces.
- Theater indicates venues for live performances, such as plays, concerts, or other theatrical productions.
- Viewpoint designates locations that offer scenic views or panoramas, often attracting tourists or visitors.
- Fountain represents structures that emit water, often for decorative or recreational purposes.
- Cafe denotes establishments that serve beverages and light refreshments, typically with seating for patrons.
- Plant represents individual plants or groups of plants, such as trees, shrubs, or flowers, within a given area.
- Restaurant indicates establishments that offer prepared meals and dining services to customers.
- Attraction refers to notable points of interest or landmarks that draw visitors or tourists to a particular area.
- Memorial represents monuments, plaques, or other structures erected to commemorate a person, event, or historical significance.
- Building denotes structures constructed for shelter, occupation, or other purposes.
- Tourist info represents locations where tourists or visitors can obtain information about local attractions, accommodations, or services.
- Water well indicates sources of water, typically wells or springs, where water can be extracted for various purposes.

Following the organization of data types, the polygon data was refactored by removing duplicates found within the point data. This process resulted in 37 polygons that did not exist in the points data. These polygons were then converted to points by selecting the center of each polygon using the QGIS software system. The selected points were subsequently added to the points data in OSM. After the removal of objects associated with the natural environment, such as benches, trees, and gates, a total of 253 point features remained. The data was then extracted in the geojson format. Below is an example of the extracted geojson data featuring a single item.


```
{
    "type": "FeatureCollection",
    "name": "POIs",
    "crs": {
        "type": "name",
        "properties": {
            "name": "urn:ogc:def:crs:OGC:1.3:CRS84"
        }
    },
    "features": [
        {
            "type": "Feature",
            "properties": {
                "osm_id": "270730056",
                "fclass": "fountain",
                "name": "Große Fontaine",
                "id": 1000,
                "info_title": "Große Fontaine",
                "has_image": true,
                "info_description_de": "Die Große Fontäne ...",
                "info_description_en": "The Great Fountain ..." ,
                "info_link": "https://www.hannover.de/Kultur-Freiz...",

            },
            "geometry": {
                "type": "MultiPoint",
                "coordinates": [ [ 9.6959682, 52.3860138 ] ]
            }
        }
        ...
    ]
}
```


Here's a explanation of each property in the provided geojson.

1. "type": "FeatureCollection": Specifies the type of data structure, indicating that the JSON represents a collection of geographic features .
2. "name": Provides a name or label for the collection of features. In this case, "POIs" likely stands for "Points of Interest."

3. "crs": Defines the coordinate reference system (CRS) used for georeferencing the features.
   - "type": "name": Indicates that the CRS is referenced by name.
   - "properties": Contains properties related to the CRS.
     - "name": Specifies the CRS using a Uniform Resource Name (URN) format. Here, it refers to the WGS 84 geographic coordinate system which is "urn:ogc:def:crs:OGC:1.3:CRS84" in this case.
4. "features": Contains an array of individual features within the collection. Each feature consists of:
   - "type": "Feature": Indicates the type of feature being described.
   - "properties": Contains attributes or properties associated with the feature.
     - "osm_id": OpenStreetMap ID.
     - "fclass": Feature class or category, indicating that the feature is an fountain.
     - "name": Name of the feature, which is "Große Fontaine" in this case.
     - "id": 3000: Unique identifier for the feature.
     - "info_title": "Große Fontaine": Title or heading for informational purposes.
     - "has_image": true: Indicates whether the feature has an associated image.
     - "info_description_de": Description of the feature in German.
     - "info_link": URL associated with the feature.
     - "info_description_en": Description of the feature in English.
   - "geometry": Contains the spatial information (geometry) of the feature.
     - "type": Indicates the type of geometry, in this case, a MultiPoint.
     - "coordinates": Specifies the coordinates of the feature's geometry. Here, it represents a single point with longitude 9.652841254177609 and latitude 52.411481618569084.

4.2.1 Marker Clustering

Incorporating a large number of custom markers on maps can significantly enhance the visual appeal and functionality of mapping applications. However, this comes with its own set of challenges, particularly regarding performance on various devices. In the case of adding 253 custom markers to a map, significant performance issues were observed, especially when interacting with the map through panning, zooming in, and zooming out on mobile devices. These performance issues can be attributed to several factors.

The primary cause of the slowdown was identified as the use of custom markers instead of the default markers provided by Leaflet, a leading open-source JavaScript library for mobile-friendly interactive maps. Leaflet's default markers are designed to be lightweight, ensuring minimal impact on performance. They achieve this by utilizing simple icon images and minimal DOM elements, which reduces the workload on the browser's Document Object Model (DOM) and maintains smoother interactions.

Custom markers, on the other hand, allow for a higher degree of customization, which can include the addition of CSS styles and more complex DOM structures to create unique and visually appealing markers. However, this increased complexity can lead to a heavier load on the DOM, resulting in noticeable performance degradation, particularly on devices with limited processing capabilities, such as smartphones and tablets.

In the implementation of custom markers, additional CSS stylings and DIV elements were introduced, contributing to the performance issues. To mitigate these issues, several optimization strategies were employed. Firstly, the complexity of the marker's code was reduced by minimizing the number of stylings and DOM elements. Additionally, the size of the icon files was decreased to 1.5 KB to further lessen the load on the browser.

Despite these optimizations, the performance improvements were not sufficient to achieve the desired level of interactivity and smoothness. As a result, marker clustering was implemented as a solution. Marker clustering is a technique that groups markers into a single cluster at various zoom levels. This method significantly reduces the number of markers rendered on the map at any given time, thus decreasing the load on the DOM and improving map interaction performance.

Marker clustering is not only beneficial for performance reasons but also enhances the user experience by providing a clearer and more organized visual representation of data points on the map. As users zoom in, clusters break apart to reveal individual markers, allowing for detailed exploration of specific areas. Conversely, zooming out combines markers into clusters, giving a high-level overview of the data distribution (Meier 2016).

Leaflet.MarkerCluster is a popular plugin specifically designed for Leaflet to implement clustering functionality. It offers various features such as customizable clustering options, the ability to handle thousands of markers without significant performance impact, and animations that provide visual cues to the user as clusters expand and contract. This plugin is an essential tool for developers looking to manage large sets of markers efficiently while maintaining optimal performance and providing an engaging user experience (Meier 2016).

In summary, while custom markers offer enhanced visual customization for mapping applications, they can lead to performance issues, particularly on less powerful devices. Through code optimization and the implementation of marker clustering with tools like Leaflet.MarkerCluster, it's possible to achieve a balance between customization and performance, ensuring a smooth and interactive mapping experience for users across all devices.

4.3 Algorithms and techniques for determining relevant POIs

The application boasts a dynamic feature that caters to displaying Points of Interest (POIs) in proximity to the user, tailored to their individual preferences and the direction they are facing. As users navigate through the area with the application, an intelligent system triggers the display of suggested POI buttons on the screen whenever the user comes within 30 meters of relevant POIs. This suggestion mechanism is governed by four key conditions:

Firstly, the application takes into account the user's selected preferences. Users rate their interests in different categories through a preference panel within the app mentioned in UI design section. These preferences are weighted, with higher importance given to those POIs that align closely with the user's indicated interests.

Secondly, the system considers the user's historical interactions with the application. It tracks the POIs that users have previously clicked on, which suggests an expressed interest in those specific types of POI categories.

Thirdly, the direction in which the user is moving is a determining factor. The app calculates which nearby POIs are aligned with the user's forward path and assigns a higher weight to these, assuming that POIs in the user's immediate trajectory are of more interest.

Fourthly, the application records whether the user has dismissed or ignored similar suggestions in the past. If a user consistently closes or does not engage with suggested POIs, the system adapts and takes this behavior into account for future suggestions.

To facilitate these suggestions, the POIs are categorized into three main types: memorials, plants, and artworks. The 'Plants' category encompasses both individual plants and broader garden areas. 'Artworks' include points such as viewpoints, attractions, and individual art pieces, while the 'Memorial' category is reserved for locations of commemorative significance.

Within these groups, a weighting algorithm is applied based on the four outlined conditions, ranking nearby markers accordingly. The most relevant suggestions, as determined by this weighting, are then presented to users via interactive buttons on their screen.

4.3.1 User's historical interactions

User interactions within the application are tracked to enhance the personalized experience. For instance, when a user taps on a marker to learn more about an attraction within the garden, the information panel activates. Simultaneously, the POI's classification, such as 'garden', is saved locally on the user's device in an array named 'clickedInterests'. This data persists locally, thanks to the storage capabilities of the device, ensuring that even if the application is closed, the user's history of clicked interests is not lost. This persistent tracking allows the app to maintain a nuanced understanding of the user's preferences, enhancing the accuracy of future POI suggestions and contributing to a more tailored and engaging user experience.

The code on the application runs with the following progress.

- **Retrieving Clicked Interests**

  It starts by retrieving a string from the browser's localStorage under the key 'clickedInterests', which presumably contains a JSON representation of an array. This array represents the interests the user has clicked on. JSON.parse() is used to convert this string back into an array (clickedInterests). If nothing is found in localStorage, clickedInterests will be null.

- **Counting Interests**

  An empty object counts is initialized to keep track of how many times each interest has been clicked. The code loops through the clickedInterests array (if it's not null) and for each interest:

  – If the interest already exists as a key in counts, its value (count) is incremented by 1.

  – If the interest does not exist as a key in counts, it's added with an initial value (count) of 1.

- **Aggregating Counts into Categories**

  An object clickedClasses is created to aggregate counts of specific interests into broader categories:

  – The category artwork aggregates counts of artwork, viewpoint, and attraction.

  – The category memorial directly maps to the count of memorial.

  – The category plant aggregates counts of plant and garden.

- **Sorting Categories** The keys of the clickedClasses object (which are the category names) are sorted based on their counts in descending order, resulting in an array sortedKeys of category names, sorted from the most clicked category to the least clicked.
- **Assigning Scores**

  An empty object clickedScores is initialized for storing scores assigned to each category. The sorted category names in sortedKeys are iterated over, and scores are assigned based on their position in the sorted list:

  - The top 3 categories (first 3 indices) are assigned scores based on their position: the highest gets 3, the second highest gets 2, and the third gets 1.
  - Any categories beyond the top 3 are assigned a score of 0.

4.3.2 User's selected preferences

Within the preferences panel, there are four categories represented by checkboxes: 'Artwork', 'Viewpoint', 'Memorial', and 'Plant'. These categories are designed to encompass the diverse range of POIs that users may encounter.

When users engage with these checkboxes, the application assigns boolean values to the corresponding categories, which are then stored as variables on the user's device using local storage. This ensures that the user's preferences are preserved across sessions, allowing for a consistent and personalized experience each time the application is used.

For instance, when a user selects the 'Artwork' category in the preferences panel, the application saves this preference with a key-value pair such as "artwork-radio": true in the local storage. Conversely, if the user deselects the 'Artwork' checkbox, the application updates this value to "artwork-radio": false. This binary system allows for straightforward tracking of the user's preferences, making it easy to determine which POI categories are of interest to the user and should be featured more prominently in their suggestions.

Subsequent to the selection or deselection of preferences, the local storage variables are updated in real-time to reflect any changes. For example, if a user initially selects 'Artwork' but later decides to focus on 'Plants' instead, the variables for 'Artwork' and 'Plants' in local storage are updated to false and true respectively, tailoring the experience to the user's current interests.

- **Initialize Selection Scores**

  It starts by creating an object selectionScores with keys corresponding to categories (artwork, memorial, plant) and initializes their values to 0. This object will keep track of the scores assigned to each category based on the user's selections.

- **Check Local Storage for User Selections**

  The code then checks the browser's localStorage for specific keys that indicate the user's selections. These keys are in the format of <category-name>-radio, where <category-name> represents each of the categories (e.g., artwork-radio, memorial-radio, plant-radio). The values of these keys are expected to be strings 'true' or 'false', indicating whether the user has selected each category.

- **Assign Scores Based on Selections**

  For each category:

  – Artwork: If the user has selected either artwork or viewpoint (as indicated by localStorage. getItem("artwork-radio") === 'true' or localStorage. getItem("viewpoint-radio") === 'true'), the artwork category in selectionScores is set to 3.

  – Memorial: If the user has selected memorial (localStorage.getItem("memorial-radio") === 'true'), the memorial category in selectionScores is set to 3.

  – Plant: If the user has selected plant (localStorage.getItem("plant-radio") === 'true'), the plant category in selectionScores is set to 3.

4.3.3 User's direction

The application incorporates a sophisticated mechanism that takes into account the user's direction as the third condition for refining POI suggestions. This mechanism enhances the personalization of the app by adjusting the visibility and priority of various categories of markers—such as "artwork," "memorial," and "plant"—based on the user's navigational patterns.

The initial step in this process involves calculating the proximity of POIs relative to the user's current position. This proximity calculation is crucial as it determines which markers are considered 'nearby' and therefore candidates for being highlighted as suggestions. To accomplish this, the application employs the Haversine formula, a mathematical equation used to determine the great-circle distance between two points on the Earth's surface. The Haversine formula accounts for the spherical shape of the Earth and provides an accurate distance measurement based on the latitude and longitude coordinates of the user's location and those of the markers (Prasetya et al. 2020).

$$d = R \cdot c \tag{4.1}$$

$$a = \sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1)\cdot\cos(\phi_2)\cdot\sin^2\left(\frac{\Delta\lambda}{2}\right) \tag{4.2}$$

$$c = 2\cdot \text{atan2}\left(\sqrt{a}, \sqrt{1-a}\right) \tag{4.3}$$

where:

d is the distance between two points on the Earth's surface,

R is the Earth's radius (mean radius = 6,371km),

$\Delta\phi$ is the difference in latitude, in radians,

$\Delta\lambda$ is the difference in longitude, in radians,

ϕ_1 and ϕ_2 are latitudes of points 1 and 2, respectively, in radians,

λ_1 and λ_2 are longitudes of points 1 and 2, respectively, in radians,

a is the square of half the chord length between the points,

c is the angular distance in radians, obtained from a using the inverse of the Haversine function.

After employing the Haversine formula to compute the distances between the user and various POIs, the application identifies those markers that are within a 30-meter radius of the user's current location, categorizing these as 'nearby markers.' This proximity threshold is set to ensure that suggestions are immediate and actionable, providing users with information about POIs they are likely to encounter imminently.

To determine the user's trajectory and predict which direction they may continue to move in, the application continuously records the user's positions. It stores the last five recorded locations in an array, which serves as a dataset for trend analysis. By applying a linear regression algorithm to this array of positions, the application calculates the best-fitting straight line through these points.

Linear regression is a fundamental statistical method used to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable (x), and the other is considered to be a dependent variable (y). In simple terms, linear regression attempts to draw a straight line that comes closest to the data by finding the equation of a straight line (y = mx + b), where m is the slope of the line and b is the y-intercept. This line can then be used to predict the value of y for any given value of x (Pearce 2009).

$$m = \frac{N(\sum xy) - (\sum x)(\sum y)}{N(\sum x^2) - (\sum x)^2} \tag{4.4}$$

$$b = \frac{\sum y - m(\sum x)}{N} \tag{4.5}$$

where:

N is the number of data points,

$N(\sum xy)$ is the sum of the product of each pair of x and y values,

$\sum x$ is the sum of all x values,

$\sum y$ is the sum of all y values, and

$\sum x^2$ is the sum of the squares of x values.

Once the slope (m) and y-intercept (b) are calculated, the linear equation can be used to make predictions:

$$y = mx + b \tag{4.6}$$

This equation will give us the predicted value of y for any value of x. The function is used to find the predicted longitudes at the start and end of the user's movement path. It then calculates the longitude of the first and last positions in the movement path using the regression line function, effectively projecting these points onto the regression line. This step helps in determining the general direction of the movement along the regression line rather than the actual path.

Following the establishment of the user's movement trend line via linear regression analysis, the application proceeds to a crucial subsequent step: calculating the bearing from the user's current location to each of the identified nearby markers. This calculation is essential for determining the direction in which the user must move to reach these Points of Interest (POIs) relative to their current heading. Here is a breakdown of the calculation of bearing.

Since trigonometric functions in most programming libraries expect arguments in radians, the first step converts the latitudes and longitudes from degrees to radians.

$$\text{radians}(\theta) = \frac{\theta \cdot \pi}{180} \tag{4.7}$$

The formulas for y and x are derived from spherical trigonometry, specifically from the formula to calculate the initial bearing (or forward azimuth) between two points on the surface of a sphere.

$$y = \sin(\lambda_2 - \lambda_1) \cdot \cos(\phi_2) \tag{4.8}$$

$$x = \cos(\phi_1) \cdot \sin(\phi_2) - \sin(\phi_1) \cdot \cos(\phi_2) \cdot \cos(\lambda_2 - \lambda_1) \tag{4.9}$$

where:

ϕ_1 and ϕ_2 are the latitudes of the start and destination points in radians, respectively,

λ_1 and λ_1 are the longitudes of the start and destination points in radians, respectively.

Bearing is calculated with arc tangent of the two variables y and x. And the finally the bearing is converted from radians degrees and normalized to a [0,360] range using module 360. The formula for bearing in radians is:

$$bearing = (\text{degrees}\,(\text{atan2}(y, x)) + 360) \mod 360 \tag{4.10}$$

In the concluding phase of personalizing Point of Interest (POI) suggestions based on the user's navigational context, the application undertakes a careful process to determine whether each nearby marker falls within the user's current direction of movement. This determination is crucial for ensuring that the suggested POIs are not only proximate but also practically accessible, aligning with the user's ongoing trajectory.

To accurately assess the alignment between the user's direction and the position of each marker, the application first standardizes the measurement of both the user's movement direction and the bearing from the user to each marker into a uniform scale ranging from 0° to 360°. This normalization process is essential for consistency and facilitates straightforward comparison, as it accounts for the full circle of possible directions relative to true north.

Subsequently, the application calculates the absolute difference between the user's current direction and the bearing to each nearby marker. This step involves subtracting one angle from the other and taking the absolute value of the result, ensuring the difference is expressed as a positive value regardless of which angle is larger.

This angle difference is a critical metric, as it quantifies the deviation of each POI from the user's forward path. To determine whether a marker is considered to be within the user's directional intent, the application applies a threshold of 90 degrees. If the calculated angle difference for a marker is less than or equal to 90 degrees, the marker is deemed to be within the user's line of movement. This threshold is chosen because it effectively encompasses the forward-facing semicircle relative to the user's direction, representing the area into which the user is most likely to proceed.

Markers that meet this criterion are prioritized in the suggestions presented to the user. This approach ensures that the application's recommendations are not only relevant in terms of proximity but also in terms of the user's actual navigational path. By focusing on POIs that are directly ahead or to the immediate left or right of the user's current direction, the application enhances the practicality and usefulness of its suggestions, facilitating a seamless exploration experience.

Here is a breakdown of the assigning scores to categories based after finding the markers in user direction on the application.

- **Initializing Scores**

  A directionScores object is initialized with categories artwork, memorial, and plant, each starting with a score of 0. These scores are intended to reflect the relevance or priority of each category based on certain criteria.

- **Accessing Global Trends**

  The code retrieves inTrends object. The inTrends array is expected to contain items that represent current trends, each with an options property that includes a className indicating the category of the trend.

- **Updating Scores Based on Trends**

  The code iterates over the inTrends array (if it exists) using the .map() method. For each item in the array:

  - If item.options.className matches artwork, attraction, or viewpoint, the score for the artwork category in directionScores is set to 3.
  - If item.options.className is memorial, the score for the memorial category is set to 3.
  - If item.options.className matches plant or garden, the score for the plant category is set to 3.

4.3.4 User's historical interactions with suggestions

The application is designed to learn from and adapt to the user's interactions with the system, particularly their responses to the suggestions presented. In order to cultivate a more refined and personalized user experience, the application tracks whether users dismiss or ignore the suggestions provided.

This tracking is accomplished through the use of local storage on the user's device. When a user dismisses a suggestion from a particular category—say, for instance, 'Plant'—the application logs this action. It records the class name associated with the dismissed suggestion, in this case, "plant," into a local storage array designated as "closedClassNames."

The array "closedClassNames" serves as a historical ledger of the user's preferences by capturing the categories of suggestions that have been declined. Each time a user dismisses a suggestion, the corresponding class name is added to the array. Here is a breakdown of its operations:

- **Initialization**

  An empty object closedCounts is initialized to keep track of the counts of closed items for each interest.

- **Retrieving Closed Interests**

  It retrieves a string from localStorage under the key 'closedClassNames', which likely contains a JSON-encoded array of interests corresponding to items the user has closed or dismissed. JSON.parse() converts this string back into an array (closedInterests). If nothing is found, closedInterests will be null.

- **Counting Closed Interests**

  The code iterates over closedInterests (if it's not null) and for each interest:

  – If the interest already exists as a key in closedCounts, its count is incremented by 1.

  – If the interest is not already a key in closedCounts, it's added to the object with an initial count of 1.

- **Aggregating Counts into Categories**

  An object closedScoresInitial is created to aggregate the counts of specific closed interests into broader categories:

  – artwork aggregates counts of artwork, viewpoint, and attraction.

  – memorial directly maps to the count of memorial.

  – plant aggregates counts of plant and garden.

- **Sorting Categories by Count**

  The keys of the closedScoresInitial object are sorted in ascending order based on their counts. This results in an array sortedClosedKeys of category names, sorted from the least closed category to the most closed.

- **Assigning Inverse Scores**

  An empty object closedScores is initialized to store the scores assigned to each category based on the sorted order. As the categories are iterated over (in ascending order of their counts), scores are assigned inversely starting from 1. This means that the category with the lowest count (indicating less frequency of being closed) gets a score of 1, and the score increases for categories with higher counts.

4.3.5 Final Scores Calculation

For each category, the final score is the sum of scores from four different sources:

- clickedScores: Presumably represents scores based on user clicks or interactions with items of these categories.
- selectionScores: Likely derived from user selections, such as choices made in a preferences settings.
- closedScores: Scores based on items of these categories that the user has closed or dismissed, indicating a lack of interest.
- directionScores: Scores that might be influenced by current trends or directions, indicating the popularity or relevance of categories.

4.4 Interactive Heatmap

In order to visually represent the distribution and intensity of the user's interests across the map, the application incorporates a heatmap feature. This innovative approach enhances the user experience by providing a clear, intuitive visualization of where Points of Interest (POIs) that align with the user's preferences are concentrated. By leveraging the heatmap, users can easily identify areas of high interest, facilitating a more targeted exploration of the environment (Aoidh et al. 2008).

The implementation of the heatmap is achieved through the integration of the Leaflet heatmap plugin, a powerful tool designed to work seamlessly with the Leaflet mapping library. This plugin enables the dynamic generation of heatmap visualizations directly on the map interface, overlaying the standard map view with a color-coded representation of data density or intensity. In the context of the application, the heatmap colors indicate the concentration of preferred POIs, with warmer colors (such as lime and blue) denoting higher concentrations of interests and natural colors (such as green) indicating lower concentrations.

The Leaflet heatmap plugin offers a range of customizable options to fine-tune the appearance and behavior of the heatmap. Key parameters that can be adjusted include the radius of influence for each data point, the maximum intensity level for the heatmap scale, and the gradient colors used to represent different intensity levels. These settings allow for the heatmap to be tailored to effectively convey the distribution of the user's interests based on the scores derived from their interactions and preferences (Słomska-Przech et al. 2022).

The heatmap is dynamically generated based on the weighted scores of nearby markers, which reflect the user's preferences and interactions with the application as shown in Figure 4.9. By assigning higher weights to POIs that match the user's selected preferences and those they have interacted with positively, the heatmap visually emphasizes areas rich in such POIs. Conversely, areas with fewer or no

FIGURE 4.9: Heatmap on the application

preferred POIs are represented with cooler colors, visually guiding the user towards zones of potential interest.

```
var heat = L.heatLayer(globalState.intensityPoints, {
    radius: 25,
    blur: 15,
    maxZoom: 17,
    gradient: { 0.0: 'blue', 0.5: 'lime', 1.0: 'green' }
}).addTo(map);
```

The provided code snippet demonstrates how to create and add a heatmap layer to a map using the Leaflet heatmap plugin, specifically leveraging the L.heatLayer method. This method is part of the Leaflet library, which is a widely used open-source JavaScript library for mobile-friendly interactive maps. The L.heatLayer function is used to generate a heatmap visualization based on a set of intensity points, which are likely latitude and longitude coordinates associated with a numerical intensity value indicating the level of interest or activity at each location.

Here's a breakdown of the code and its components:

- var heat = L.heatLayer(globalState.intensityPoints, ...).addTo(map);: This line creates a heatmap layer named heat using the L.heatLayer method. The globalState.intensityPoints parameter is expected to be an array of points where each point includes a latitude, longitude, and an intensity value. These points are used to generate the heatmap. The heatmap layer is then added to the map with the .addTo(map) method, where map is a previously defined Leaflet map object.

- radius: 25: This option sets the radius of each point in the heatmap in pixels. A larger radius means that each point will have a larger area of influence on the heatmap.
- blur: 15: The blur option controls the amount of blur applied to the heatmap points. A higher value produces a smoother transition between the points.
- maxZoom: 17: This option sets the maximum zoom level for which the heatmap will be calculated. Beyond this zoom level, the heatmap will not recalculate, which can help optimize performance for maps with a large number of points.
- gradient: 0.0: 'blue', 0.5: 'lime', 1.0: 'green' : The gradient option defines the color gradient of the heatmap. In this case, the colors transition from blue (for the lowest intensity values) through lime (for medium intensity values) to green (for the highest intensity values). This color scheme is customizable, and developers can choose any set of colors to visually represent the data in a way that aligns with the application's design and user experience goals.

Integrating a heatmap into the project not only enriches the visual experience but also provides users with valuable insights into their own interests and preferences. It serves as a guide, highlighting paths and areas worth exploring, and encourages discovery by drawing attention to hotspots of activity or interest that may not have been immediately apparent. This feature transforms the map from a simple navigational tool into a dynamic, interactive canvas of user interests, making exploration more engaging and personalized.

Overall, the inclusion of a heatmap powered by the Leaflet heatmap plugin significantly enhances the application's functionality. It provides users with a visually striking and easily interpretable overview of their interest patterns, enriching their exploration experience and enabling them to make informed decisions about where to direct their attention within the mapped environment.

4.5 User trajectory collection

The collection of user trajectories is an integral part of enhancing garden management by identifying which Points of Interest (POIs) are frequented or overlooked by visitors. This data, gathered with the explicit consent of the users, offers valuable insights into visitor patterns and preferences, facilitating better planning and resource allocation within garden spaces. Through the analysis of these trajectories, or even without in-depth analysis, the popularity of specific POIs or areas within gardens can be readily visualized using Geographic Information System (GIS) software.

This process adheres strictly to privacy regulations, collecting trajectory information anonymously while complying with the European Union's General Data Protection Regulation (GDPR). To ensure legality and transparency, users are prompted at the application's launch to give their consent for cookie tracking. Consent is paramount; without it, no data is collected (Gjermundrod et al. 2016). Furthermore, the collection process is designed to respect user privacy by halting data gathering the moment a user exits the designated garden area, minimizing unnecessary data retention.

Initially, trajectory data is stored locally on the user's web browser. However, there is potential for future development where collected data could be securely transmitted to a backend server for more robust analysis and long-term storage. Such an advancement would necessitate stringent security measures to protect user data, including encryption and secure authentication methods, to maintain user trust and comply with legal standards.

The strategy for user trajectory collection embodies a balance between gathering insightful data for garden enhancement and upholding stringent privacy standards. By leveraging GIS technology and adhering to GDPR requirements, it is possible to significantly improve garden management and visitor experience while respecting user privacy.

Chapter 5

Evaluation

The objective of the application is to offer a modern user interface (UI) that operates seamlessly across various devices and browsers, catering to a broad audience of users who are primarily visitors of a specific area. Given the unique integration and navigation features tailored for the area, conducting widespread user testing directly within the intended environment poses challenges. However, the design and usability of the application's UI can still be evaluated effectively through the deployment of a questionnaire accessible via the website. This method allows users to interact with the application on their own devices, providing insights into the design's appeal and functionality based on their personal experience.

To gather comprehensive feedback, a questionnaire was developed and distributed to a diverse group of users spanning different age groups. The primary goals of this survey are to assess the application's compatibility with various browsers and mobile devices, and to gauge user satisfaction across different demographics. Such feedback is invaluable for identifying potential issues and preferences that may not be immediately apparent to the developers, enabling adjustments that enhance the user experience for a wider audience.

The questionnaire includes the following questions, designed to cover a range of aspects concerning user interaction and satisfaction with the application:

1. Age Group: 6-18, 19-30, 31-50, 51 and over.
2. Operating System (OS) used on your device: Android, iOS, Other.
3. Mobile browser used on the device.
4. Rate the overall aesthetic appeal of the application: 1 (Lowest) to 5 (Highest).
5. Is the color scheme of the application comfortable for long-term use? Yes/No.
6. Which UI element did you find most useful?
7. Which UI element did you find least useful or unnecessary?
8. Have you experienced any crashes or glitches? Yes/No.
9. If you have experienced any crashes or glitches, please describe them.

10. Please provide any additional comments or suggestions for improving the web map application.

Figure 5.1 displays the distribution of participants by age group who took part in a questionnaire designed to gather feedback for a web map application. It illustrates that the questionnaire was completed by 23 participants in total, with the majority of respondents falling within the 19-30 age group.

Specifically, the age distribution is as follows:

- The 6-18 age group had no participation.
- The 19-30 age group had the highest participation with 18 respondents.
- The 31-50 age group had 2 participants.
- The 51 and over age group had a slightly higher participation than the 31-50 group, with 3 respondents.

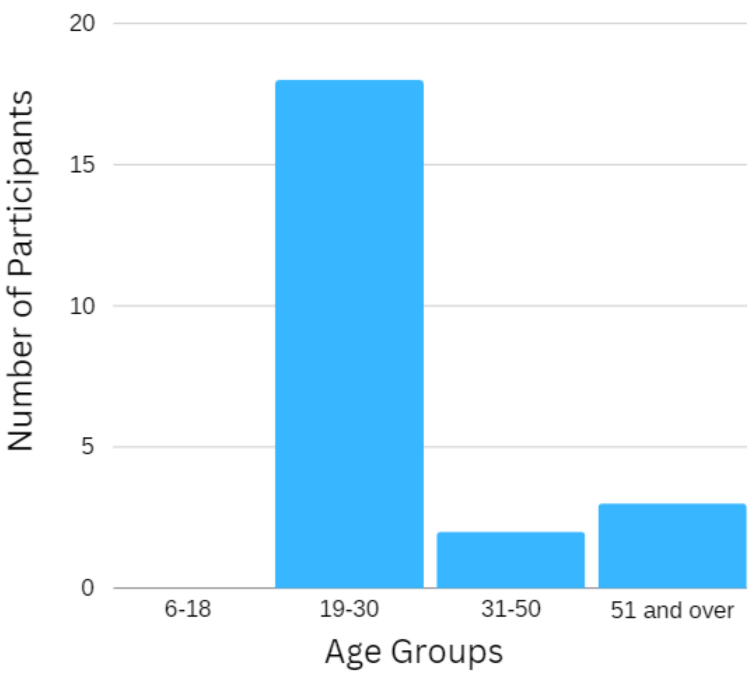

FIGURE 5.1: Distribution of participants by age groups

Figure 5.2 presents the User Operating System Distribution, illustrating the percentage of users on different operating systems who participated in the questionnaire. The User Operating System Distribution graph is a critical metric in evaluating whether users experience issues with the web map application, and it highlights the prevalence of the operating systems among the respondents. With a commanding 82.6% of users on Android devices, it suggests that the majority of the user feedback will be particularly relevant to the performance and user experience on this platform. Conversely, iOS users account for 17.4% of the responses, indicating a smaller, but still significant, portion of the user base.

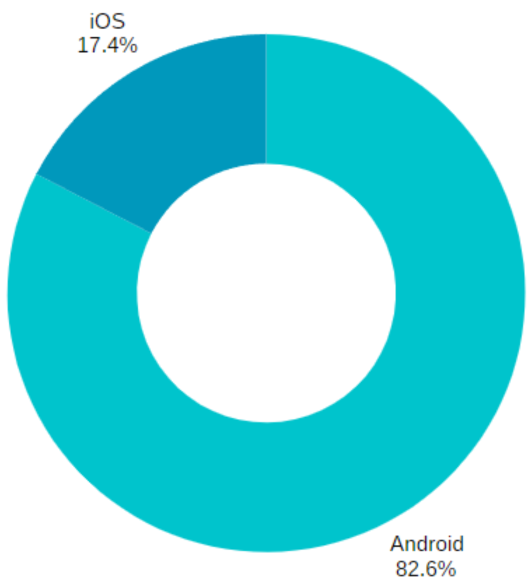

FIGURE 5.2: User operating system distribution

Figure 5.3 rates the overall aesthetic appeal of the application, providing insight into users' perceptions of its design quality. The majority of respondents have rated the aesthetic appeal highly, with the largest number of participants scoring it a 4 out of 5. This indicates that the application's design is generally well-received by its users. However, there is room for improvement to achieve the highest satisfaction, as indicated by the smaller number of users rating it a perfect 5. The graph points to the importance of not only maintaining the current design standards but also exploring ways to elevate the user experience to the highest level of visual satisfaction.

Regarding the feedback received, 100% of respondents found the color scheme comfortable for long-term use, confirming that the color choices are well-suited for the target audience. The results for the most useful UI elements varied, with the navigation bar and map filtering panel being highlighted by several users, although not all participants provided an answer to this question. Interestingly, there were no responses for the least useful or unnecessary UI element, which might suggest overall satisfaction with the current UI or a lack of strong opinions on this aspect.

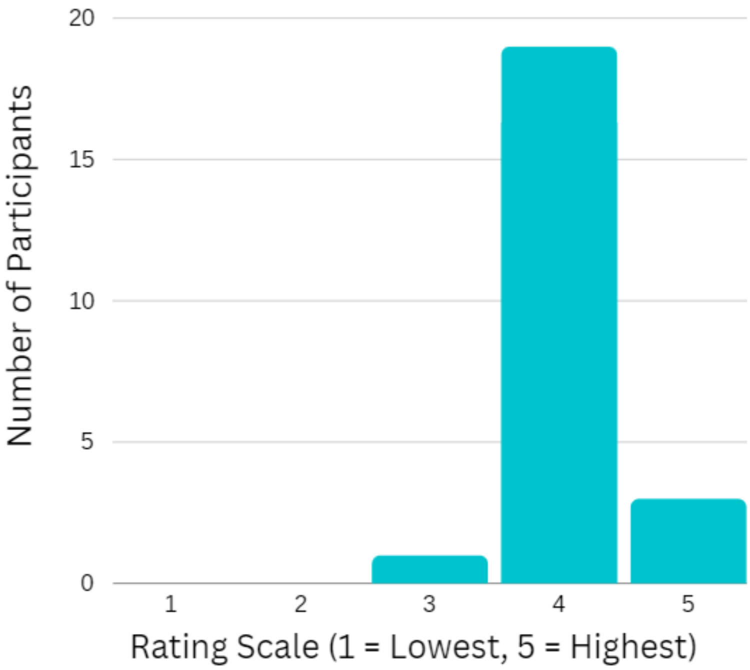

FIGURE 5.3: Rates the overall aesthetic appeal of the application

Only two responses were received for additional comments or suggestions. One user proposed the implementation of a dark mode to improve visibility when using the application in bright sunlight, while another suggested adopting a base map style similar to that of Google Maps. The latter could involve additional costs if custom map styling is desired by the garden management.

Incorporating this feedback into future iterations of the application could lead to improvements in user satisfaction. Addressing these suggestions, such as implementing a dark mode, could enhance the usability of the application in various lighting conditions. Meanwhile, considering a base map style change would depend on the available resources and the prioritization of such a feature by the garden management.

In analyzing satisfaction data across different age groups from the results of a questionnaire, it is evident that participation varied across the demographics. The 6-18 age group did not have any participants, which indicates that the application did not garner responses from this younger demographic. In the 19-30 age group, which had a total of 18 participants, a majority (16 individuals) rated their satisfaction as a 4 out of 5, while 2 participants gave a perfect score of 5. This suggests a generally high level of satisfaction within this group.

For the 31-50 age bracket, there were 2 respondents, with one assigning a satisfaction score of 5 and the other a score of 4. This group, although limited in sample size, also reflects a high satisfaction rate. In the oldest demographic, 51 and over, the three participants' ratings varied more, with two giving a score of 4 and one giving a 3. This could imply a lower satisfaction level or different expectations among this group.

Given the small and uneven sample sizes, particularly in the 31-50 and 51 and over groups, a descriptive analysis can offer a more precise understanding of the satisfaction data.

Given the data:

- 19-30: 18 responses (2 rated 5, 16 rated 4)
- 31-50: 2 responses (1 rated 5, 1 rated 4)
- 51 and over: 3 responses (2 rated 4, 1 rated 3)

For each group we will calculate mean, median and mode satisfaction. Mean, median, and mode are measures of central tendency in statistics, offering different ways to summarize the central point of a data set. Each has its own use and significance, particularly when analyzing satisfaction scores like in our survey. Understanding these concepts can help us interpret data more effectively.

The mean satisfaction level, or average, is the sum of all values in a dataset divided by the number of values present. It serves as a useful metric for gauging the overall satisfaction among respondents, offering a single value that encapsulates the essence of the entire dataset. However, its reliability can be compromised by the presence of outliers, which are extreme values that can disproportionately influence the mean, potentially rendering it unrepresentative of the dataset's true nature (Lawless 2013).

$$\text{Mean} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{5.1}$$

Where:

x is the ordered dataset,

n is the total number of values.

The median satisfaction level represents the central value in an ordered sequence of numbers. When the sequence contains an even count of observations, the median is determined by calculating the average of the two central numbers. This measure is beneficial when addressing datasets with outliers or those that are not symmetrically distributed, as it accurately reflects the central point of satisfaction without being swayed by extremes. Nevertheless, the median does not account for the actual distances between values, concentrating solely on their ranked position within the dataset (Lawless 2013).

$$\text{Median} = \begin{cases} x_{\left(\frac{n+1}{2}\right)}, & \text{if } n \text{ is odd} \\ \frac{x_{\left(\frac{n}{2}\right)} + x_{\left(\frac{n}{2}+1\right)}}{2}, & \text{if } n \text{ is even} \end{cases} \tag{5.2}$$

where:

x is the ordered dataset,

n is the total number of values.

The mode satisfaction level is the most recurrent value within a dataset and can manifest as a single mode, multiple modes (as in bimodal or multimodal distributions), or in some cases, there may be no mode at all if no value repeats. It is particularly valuable for categorical data where the primary interest is in identifying the most commonly occurring category or response. Within satisfaction surveys, the mode illustrates the satisfaction rating that appears most frequently. One of the drawbacks of relying on the mode is that it may not effectively characterize the data's central tendency if the most frequent value is not significantly common, or if the data has several modes (Lawless 2013).

Based on the descriptive analysis of satisfaction scores across the age groups the results are displayed on Table 5.1. According to the table, 19-30 age group showed high satisfaction, with most respondents rating the satisfaction as 4. The average satisfaction closely aligns with the median and mode, indicating a consistent satisfaction level across respondents. In 31-50 age group although the sample size is small (only 2 responses), the average satisfaction is slightly higher than the younger group, at 4.5. Both the median and mode reflect a high level of satisfaction, but with such a small sample, these results should be interpreted with caution. 51 and over age group had a slightly lower average satisfaction of 3.67, though the median satisfaction remained at 4, similar to the younger groups. The lower average suggests a slightly broader range of satisfaction levels in this group.

Age Group	**Mean Satisfaction**	**Median Satisfaction**	**Mode Satisfaction**
19-30	4.11	4.0	4
31-50	4.5	4.5	4
51 and over	3.67	4.0	4

TABLE 5.1: Descriptive statistics of satisfaction scores across age groups

The descriptive statistics suggest that while there's a generally high level of satisfaction across age groups, there may be a slight decrease in satisfaction among the oldest age group. However, the small sample sizes, especially in the 31-50 and 51 and over age groups, limit the robustness of these conclusions. To gain more insights and strengthen these findings, it would be beneficial to collect more responses, especially from the underrepresented age groups. This would allow for a more reliable analysis and potentially enable more nuanced understanding of satisfaction across different demographics.

Chapter 6

Conclusion

In the contemporary landscape, where digital maps and applications play a pivotal role in guiding visitors through various environments, the demand for enhancements in user experience and interactivity has become increasingly pronounced. This master's thesis delves into the realm of location-based interactive mobile web map applications, presenting a comprehensive exploration aimed at augmenting visitor experiences through careful attention to user interests and the incorporation of modern design principles.

Embarking on this research journey, the thesis initially identifies the existing gaps within the domain of current location-based map applications. A significant observation was the overwhelming influx of information presented to users through a constrained user interface, coupled with a noticeable lack of interactivity. To address these challenges, the thesis advocates for the deployment of a modern user interface (UI) design, enriched with various algorithms and tools to foster enhanced interactivity.

The core of the proposed solution lies in its ability to dynamically adapt to users' historical interactions and preferences. By analyzing which Points of Interest (POIs) a user engages with and their preferred categories, alongside leveraging data on users' movements and directions, the application intelligently tailors POI suggestions. This personalized approach ensures that users are presented with recommendations that not only match their interests but also align with their navigational trajectory, thereby elevating the overall experience.

A crucial component of this research involved evaluating the application's adherence to modern UI design principles and its overall usability. Through the implementation of a questionnaire distributed across various age groups, the study gleaned valuable insights into users' perceptions of the application's design and functionality. The feedback confirmed that the application's UI elements and panels corresponded well with contemporary design expectations, underscoring the effectiveness of the modern design approach adopted.

However, the evaluation shows also areas for potential enhancement, particularly concerning the application's performance across diverse mobile devices and browsers. This feedback underscores the importance of cross-platform compatibility and optimization, highlighting the need for ongoing refinements to ensure the application's robustness and accessibility across the broad spectrum of user devices.

In conclusion, this thesis has significantly contributed to the field of digital mapping and visitor guidance systems by demonstrating the potential of leveraging advanced technology to devise solutions that are both engaging and highly personalized. The research underscores the critical importance of user-centered design and interactivity in the development of location-based applications, setting a foundation for future innovations in this rapidly evolving domain. As the digital landscape continues to expand, the insights and methodologies presented in this thesis offer a valuable blueprint for enhancing visitor experiences through the strategic integration of modern design and personalized interactivity.

Appendix A

Structure of Directory

```
├── index.html
├── index.js
├── package-lock.json
├── package.json
├── postcss.config.js
└── public
    └── assets
        ├── data
        │   ├── POIs.geojson
        │   ├── boundary.js
        │   ├── outsideBoundary.js
        │   ├── route1.geojson
        │   └── route2.geojson
        └── icons
            ├── building.svg
            ├── favicon.ico
            ├── info.svg
            ├── location_on.svg
            ├── memorial.svg
            ├── monument.svg
            ├── n-user-location.svg
            ├── plant.svg
            ├── restaurant.svg
            ├── sprinkler.svg
            ├── theater.svg
            ├── viewpoint.svg
            └── wc.svg
```

```
│    └── images
│         ├── osm_basemap.png
│         ├── poi
│         ├── route1.png
│         ├── route2.png
│         └── satellite_basemap.png
└── src
     └── components
          ├── detail-panel
          │    ├── detail-panel.css
          │    └── detail-panel.js
          ├── feedback-panel
          │    ├── feedback-panel.css
          │    └── feedback-panel.js
          ├── filter-panel
          │    ├── filter-panel.css
          │    └── filter-panel.js
          ├── map
          │    ├── helpers
          │    │    ├── calculateTrendDirection.js
          │    │    ├── createPois.js
          │    │    ├── createRoutes.js
          │    │    ├── getUserLocation.js
          │    │    ├── globalState.js
          │    │    ├── mapPrimitives.js
          │    │    ├── shadowOutside.js
          │    │    ├── updateNearbyMarkers.js
          │    │    ├── updateNearbyOfRoutes.js
          │    │    └── weighting.js
          │    ├── map.css
          │    └── map.js
          ├── navbar-bottom
          │    ├── navbar-bottom.css
          │    └── navbar-bottom.js
          └── query-panel
               ├── query-panel.css
               └── query-panel.js
```

```
│   │   ├── route-panel
│   │   │   ├── route-panel.css
│   │   │   └── route-panel.js
│   │   └── sidebar-menu
│   │       ├── sidebar-menu.css
│   │       └── sidebar-menu.js
│   └── translations.js
├── style.css
├── tailwind.config.js
└── yarn.lock
```

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