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# Beyond efficiency: Designing Low-Emission and Experiential Tourists-Routes in Zurich

GEO 511 Master's Thesis

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A MASTER THESIS ON

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Master of Science

in

Geography: Geographical Information Science

by

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# Abstract

Urban navigation system shape how visitors experience a city, yet most routing tools prioritise efficiency over experiential quality. Growing tourism numbers set pressure on urban infrastructure, which leads to a need for sustainable and human-centred mobility solutions. Recent research emphasises experiential tourism and multimodal transport as key components of smart city strategies, but their integration into practical routing applications remains limited. This work addresses the challenge of designing a routing tool prototype that supports both sustainable mobility and meaningful tourist experiences. Here, it is shown that experience-oriented, multimodal city routes can be generated using an exact optimisation approach adapted from the Traveling Salesman Problem. Combined with locally grounded Points of Interest and user-centred design principles, the developed prototype demonstrated that dynamic-programming-based routing can feasibly optimise tourist itineraries. Focus lies on time constraints while prioritising scenic and culturally relevant paths rather than shortest-distance travel alone. This approach enables routes that encourage exploration and slower modes of transport. Beyond technical feasibility, usability feedback from tourists indicates that experiential routing is perceived as valuable and intuitive, suggesting that navigation tools can actively shape more sustainable and engaging travel behaviour. In a broader context, these findings demonstrate how algorithmic optimisation and human-centred design can be combined to support responsible urban tourism. This study shows how established optimisation methods can be translated into applied GIS solutions. The represented prototype serves as a foundation for future research on experience-driven navigation systems and highlights the potential of routing technologies. It influences not only how people move through cities, but how they perceive and engage with them.

**Keywords:** *Experience-oriented routing, Multimodal mobility, GIS, Traveling Salesman Problem, Tourist Trip Design Problem, User-centred design*

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# Chapter 1

# Introduction

For local residents of Zurich, a walk along the river Limmat between the main station and Bellevue is not necessarily part of their standard weekend routine. In their daily life, people often move around the area where they live and are more familiar with. Tourists, however, have a different perspective on the places they visit and, without local recommendations, struggle to find an enjoyable walking route without choosing the 'classic' path along the river Limmat. Based on these assumptions, this work aims to find evidence on how tourism patterns in a city, how it can be influenced by new tools, and what tools are already existing. This thesis explores an alternative approach to urban navigation that combines multimodal mobility with experiential route planning. Using Zurich as a case study, this study investigates how routing systems can support more sustainable and meaningful forms of city exploration.

## 1.1 Motivation

The presence of digital routing and navigation technologies has been demonstrated to have a positive correlation with the growth of urban tourism. These digital tools have a significant impact on how visitors navigate within a city and, in particular, how they experience it (Stankov and Gretzel 2020). Contemporary routing systems are designed to optimise routes according to efficiency criteria, such as travel time or distance. The motivation behind this research project is to encourage sustainable, social responsible and enjoyable tourist paths within urban areas. It is therefore proposed that experiential exploration of the urban environment is made easily accessible. Prior research highlights that tourists value routes and movements that offer scenic, cultural, or experiential qualities rather than serving only a functional way to get from one destination to another (Gavalas, Kasapakis, Pantziou, et al. 2016). This leads to a challenge that urban tourism places experience increasingly pressure on their transportation systems, public spaces and environmental sustainability. Butler (2015) notes that the long-standing tendency of tourists to maximise the number of visited places has intensified in modern urban contexts. This leads to a contribution of congestion and environmental strain. In cities like Zurich, with yearly rising visitor numbers, there is a demand for more intelligent and sustainable mobility solutions (**noauthor_stadt_nodate**). Within the broader framework of Tourism 4.0, explained later in this work, there are some challenges, which emphasises data-driven, interconnected navigational system while stressing the importance of human-centred and experience-oriented design (Stankov and Gretzel 2020). In parallel, multimodal mobility is identified as a key component of sustainable urban transport, enabling seamless integration of walking, cycling and public transport. This all, while supporting environmental and experiential goals (Joshi et al. 2024).

## 1.2 Research Questions

Based on the motivation outlined above, this thesis aims to investigate how digital routing systems can be designed to support more sustainable and experience-oriented urban tourism. Experiential tourism and multimodal mobility have been discussed in existing research, but their combined application within real-time urban routing system remains insufficiently explored. Especially, most navigation tools continue to prioritise efficiency-based criteria and lack to address experiential quality and environmental impact. Therefore, this thesis examines the potential of multimodal routing including sustainability goals as well as attractive and meaningful tourist experiences. The following research questions are formulated to address the identified gaps and to structure the research accordingly:

- **To what extent can a multimodal routing system that integrates walking, cycling, and public transport contribute to the reduction of $CO_2$ emissions while preserving or enhancing route attractiveness for tourists?** This question examines the environmental implications of multimodal routing in urban tourism and explores whether sustainable mobility choices can be promoted without diminishing the experiential quality of urban routes.
- **How can experiential and environmental criteria be incorporated into urban route planning in order to improve the quality of tourist experiences?** This research question addresses the challenge of translating qualitative aspects such as scenic value, cultural relevance, and environmental considerations into computable routing criteria that can inform navigation decisions.
- **Which types of data and algorithmic approaches are most suitable for identifying scenic and culturally meaningful urban routes in real-time routing applications?** This question focuses on the technical feasibility of experience-oriented routing, investigating data sources and algorithmic strategies that enable the identification and generation of attractive urban routes

within practical computational constraints.

The research questions thus form a structured framework for the design, implementation, and evaluation of the routing prototype developed in this thesis. The study commences with a comprehensive literature review, encompassing the tourism industry, the travelling salesman problem, user experience (UX) design, routing algorithms, and multimodality. In the Methodology chapter, the process of defining the prototype and the underlying rationale is elucidated. The subsequent section is concerned with the System Architecture, the prototype and, in particular, the algorithmic conception thereof. In order to elucidate the impact of the prototype, the chapter entitled 'Results' presents the findings that were obtained through the survey. In the penultimate chapter, entitled 'Discussion', the researchers reflect on the research question and highlight the limitations that were encountered. The conclusion is intended to summarise the thesis and its findings, while also presenting possible further work.

# Chapter 2

# Literature Review

This chapter provides a concise overview of the extant literature on the development of a routing tool guiding tourist not time-efficient but experiential-focused through Zurich.

The present research is based on the approach of Gavalas, Kasapakis, Pantziou, et al. (2016) entitled "Scenic Athens". Gavalas, Kasapakis, Pantziou, et al. (2016) developed a methodology for guiding tourists through Athens by foot, with the aim of connecting different points of interest along the proposed route. Users can select their initial and final locations, with the option to visit one or more attractions on the route. This figure shows how they designed their prototype:

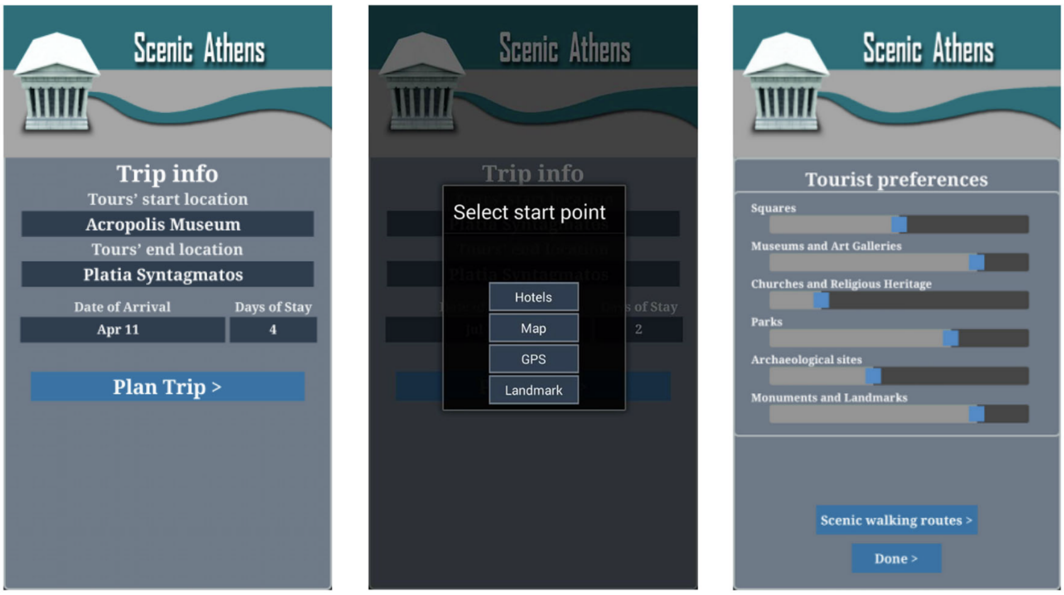



Figure 2.1: Prototype of the project Scenic Athens by Gavalas et al. (2016)

## 2.1 Tourism

Tourism is constructed with different influential factors. Each tourist seeks for something different. Therefore, this section aims to provide a overview on what is important for this project and which factors come into account to create a routing tool.

### 2.1.1 Trends and Changes in Tourism

This subsection examines trends and changes in tourism. It is evident that the tourism industry has undergone a transformation in recent years, deviating from its traditional trajectory. In order to keep up with this transformation, it is necessary to implement changes to the infrastructure, as well as to undertake a re-evaluation of the demands made by tourists. As Zhang et al. (2025) observe in their paper, there has been a shift in the focus of tourists. More concretely, they state that nowadays the focus lies on the personal experience and fulfilment of spiritual needs. This experiential shift has recently been conceptualised in tourism research as a move towards transformative tourism, where travel experiences are understood as catalysts for personal change rather than mere consumption of destinations. According to Pung, Gnoth, and Del Chiappa (2020), tourists increasingly seek meaningful experiences that provoke reflection, learning, and self-development, often leading to changes in values, attitudes, or behaviour. It is therefore imperative that informational products aimed at meeting the needs of tourists are developed based on the underlying assumption.Zhang et al. (2025) propose to implement a novel methodology for urban exploration. The proposed initiative should affect a transformation in the tourist perception of the city. From this perspective, the way tourists are guided through urban environments becomes highly relevant, as routing and information systems directly influence which encounters, cultural differences, and experiential stimuli tourists are exposed to, thereby shaping the overall quality and meaning of the experience (Pung, Gnoth, and Del Chiappa 2020). The **noauthor_edelweiss_2017** advertisement, which features the phrase "been there, done that", can be considered as an example of fast Traveling. As Butler (2015) asserts in his article, the tendency of tourists to visit as many places as possible has ancient origins. However, in the contemporary era, this tendency exerts a greater influence on the environment. The evolution of tourism is not solely attributable to technological advancements. Societal shifts also play a pivotal role in this transformation. The advent of social media has precipitated a new behaviour in the manner in which individuals document and share their travel experiences. The desire to showcase one's travels to friends and family has been expedited, as travellers seek to disseminate a comprehensive array of experiences. This phenomenon, as Butler (2015) notes, underscores the need for tourists to document their journeys in a more comprehensive way (Butler 2015).

Gavalas, Kasapakis, Pantziou, et al. (2016) explore, that time is often the most limiting resource for tourists, especially in urban environments with many possible activities and limited knowledge about navigation and transportation. Therefore, planning technologies and routing algorithms play a crucial role in shaping the tourist experience. Instead of only optimising shortest paths, future systems should prioritise personal preferences and experiential value (Gavalas, Konstantopoulos, et al. 2016).

### 2.1.2 The concept of Tourism 4.0

Urban destinations such as Zurich, the largest city in Switzerland, face increasing pressure on public transport, cultural sites and residential quality of life. Overnight stays in the city of Zurich exceeded four million in 2024 (Zürich 2024), indicating a renewed growth after the Covid-19 pandemic. This rise in tourist numbers requires the development of strategies for intelligent tourist management and improved mobility solutions. In this context, Tourism 4.0 is introduced as a conceptual and technological framework. It is helpful for addressing the increasing pressures on destination infrastructure through interoperable digital ecosystems and data-driven decision-making. Tourism 4.0 is characterised by the integration of technologies such as IoT, AI, big data analytics, and immersive interfaces. They try to create interconnected and phygital service environments that support both operational efficiency and enhanced visitor experiences (Stankov and Gretzel 2020). However, Stankov and Gretzel (2020) emphasise that such developments require a strong commitment to human-centered design to mitigate risks of technostress, information overload, and the potential depersonalisation of tourism encounters, which can otherwise undermine experiential value (Stankov and Gretzel 2020). Within this landscape, multimodal mobility emerges as a critical component of intelligent visitor management, facilitating seamless transitions across transportation modes and optimising resource allocation through real-time data integration. As argued in Joshi et al. (2024) article, multimodal systems prioritise interconnectivity, information integration, and user-centricity, enabling sustainable, efficient, and adaptable urban mobility solutions. The convergence of Tourism 4.0 principles with multimodal transport planning thus has the potential to support balanced visitor flows, reduce congestion, and reinforce urban quality of life, aligning technological innovation with socially and environmentally responsible destination management (Joshi et al. 2024).

## 2.2 Traveling Salesman Problem

Following subchapters introduce the Traveling salesman problem. To understand its relevance, the Traveling Salesman Problem is first explained and then it is linked to the Tourist Trip Design Problem, which is crucial for the development of the prototype of this work.

### 2.2.1 Traveling Salesman Problem Definition

As one of the most fundamental and extensively studies problems in combinatorial optimisation and operations research, the Traveling Salesman Problem (TSP) needs to be explained. In its classical formulation, the problem consists of determining the shortest possible closed path that visits each city (edge) in a given set exactly once and returns to the starting location. The TSP is computationally challenging and has served for decades as a benchmark problem for the development and evaluation of optimisation algorithms (Hahsler and Hornik 2008; Laporte 1992). TSP can be modelled on a complete weighted graph, where each vertex represents a city and each edge is associated with a distance or travel cost. The goal is to identify a minimum-cost Hamiltonian cycle, that is a cycle that visits every vertex exactly once (Laporte 1992). There are two types of distances, either symmetric, resulting in the symmetric TSP, or asymmetric, reflecting direction-dependent costs such as travel times or fares (Hahsler and Hornik 2008). In many practical applications, the distance matrix may also represent generalised costs rather than pure spatial distance. Computational complexity is one of the defining characteristics of the TSP. The number of feasible tours grows factorial with the number of cities, and the decision version of the problem is NP-complete. Consequently, no polynominal-time algorithm is known for solving the general TSP optimally, and exact solution methods become impractical for large instances (Laporte 1992). This fundamental difficulty has led to extensive research in the field of approximation algorithms, heuristics and metaheuristics, the aim of which is to achieve high-quality solutions within a reasonable computing time. The TSP finds wide application in various areas such as vehicle routing, manufacturing processes, circuit design, scheduling and data analysis (Hahsler and Hornik 2008). However, the classic TSP assumes that all locations must be visited and that the only optimisation criterion is to minimise travel costs. These assumptions limit its suitability for decision-making problems in tourism and personalised travel planning. This is because travellers usually select only a subset of the available attractions and try to maximise the experience value within time or budget constraints. This limitation motivates the extension of the TSP, which simplifies the requirement to visit all nodes. In particular, selective routing problems replace pure distance minimisation with profit-oriented goals, allowing the optimisation process to strike a balance between travel effort and cumulative profit. These generalisations form the conceptual basis for the orientation problem and, subsequently, for the tourist trip design problem, which are better suited to the behavioural and contextual characteristics of urban tourism scenarios (Hahsler and Hornik 2008; Laporte 1992).

### 2.2.2 Tourist Trip Design Problem

The Tourist Trip Design Problem (TTDP) represents a central optimisation challenge in intelligent visitor management, as it requires constructing personalised itineraries that balance visitor satisfaction with operational feasibility. The TTDP is fundamentally rooted in the Orienteering Problem (OP), in which an agent selects and sequences a subset of locations to maximise the accumulated profit within a constrained travel time budget (Vansteenwegen, Souffriau, and Oudheusden 2011). In its classical form, the OP assumes that attractions are continuously accessible and therefore abstracts temporal or contextual constraints. This formulation is appropriate for theoretical applications but inadequate for urban tourism settings, where attractions have heterogeneous opening hours, variable visit durations, and dynamic travel times. To capture such realities, research has expanded the OP to include time-window constraints, resulting in the Orienteering Problem with Time Windows (OPTW), in which visits must occur within specified temporal intervals to be valid (Gavalas, Kasapakis, Konstantopoulos, et al. 2017). The introduction of time windows drastically increases computational complexity, as feasible solutions must respect both spatial and temporal feasibility, often requiring iterative local search and metaheuristic approaches to avoid combinatorial explosion (e.g., tabu search, adaptive memory procedures, and iterated local search) (Vansteenwegen, Souffriau, and Oudheusden 2011). When multiple daily tours must be generated, the problem generalises further to the Team Orienteering Problem with Time Windows (TOPTW), which is widely applied in tourism itinerary planning and is considered one of the most challenging OP variants due to the need to distribute limited time resources across several routes while preventing redundant visits (Gavalas, Kasapakis, Konstantopoulos, et al. 2017).

Recent advancements demonstrate an evolution beyond point-based attraction modelling. While conventional TTDP solvers treat points of interest (POIs) as dimensionless nodes, empirical studies confirm that tourists value experiential movement, scenic walking opportunities, and the integration of multimodal mobility beyond shortest-path routing (Gavalas, Kasapakis, Konstantopoulos, et al. 2017). In response, Gavalas, Kasapakis, Konstantopoulos, et al. (2017) introduced the Mixed Team Orienteering Problem with Time Windows (MTOPTW), which assigns profit values not only to POIs but also to route segments, enabling the inclusion of scenic routes, pedestrian zones and culturally significant linear spaces within itinerary optimisation (Gavalas, Kasapakis, Pantziou, et al. 2016). This modelling paradigm supports a richer understanding of urban exploration, aligns with experiential tourism preferences, and enables planners to account for context-dependent value variation (e.g., market areas with daytime openings or river walks with peak aesthetic appeal during daylight hours) (Gavalas, Kasapakis, Konstantopoulos, et al. 2017). Solving MTOPTW requires sophisticated metaheuristic approaches such as iterated local search combined with graph preprocessing to maintain computational tractability while supporting real-time personalisation (Gavalas, Kasapakis, Konstantopoulos, et al. 2017). Thus, the progression from OP to OPTW, TOPTW and MTOPTW illustrates a shift from static, efficiency-driven routing models toward dynamic, context-aware and human-centric itinerary design. It sets TTDP research as a foundational component of Tourism 4.0 strategies for smart and sustainable visitor management in complex urban destinations.

## 2.3 UX Design

Modern routing involves more than algorithmic optimisation. Therefore, it requires a careful user experience (UX) that supports user perception, decision-making, and the environmental context. The design of routing interfaces has become central to how people understand, choose, and navigate routes. Parts of the design are determined by visual variables, web cartography and interaction design. All of this provides insights into how map interfaces can effectively guide users through spatial decision-making processes.

### 2.3.1 User-centred design and map comprehension

Web cartography has undergone a fundamental shift toward user-centred design (UCD) as interactive maps have become embedded in everyday digital systems. Tsou (2011) posits that UCD serves as a foundational paradigm for contemporary web mapping, asserting that contemporary cartographic interfaces must accord primacy to usability, intuitive interaction, and user task performance. It is argued by the author that the expansion of mobile platforms and APIs has created a "renaissance" in cartography. This renaissance has been driven not only by technological innovation, but also by a renewed focus on user needs, interface clarity, and public participation (Tsou 2011). This shift positions users not only as consumers of spatial information, but also as active participants whose cognitive processes, habits, and expectations shape cartographic design. The application of user-centred design in cartography is intricately linked with theories of cognitive psychology, encompassing spatial memory, mental maps and perceptual salience. According to Dang (2020), the effectiveness of mobile map design relies on considering cognitive maps, peripheral vision, and spatial memory. It determines how users recognise patterns, perceive routes and also recall locations (Dang 2020). Cognitive principles influence how map symbols are interpreted on small screens and under time pressure. Tsou (2011) mentions that web maps must support rapid interpretation through intuitive interface elements. Additionally, minimal cognitive loads and consistency between zoom levels and devices should be preserved (Dang 2020; Tsou 2011).

### 2.3.2 Visual variables as foundations of cartographic communication

Visual variables were introduced by Jaques Bertin as Garlandini and Fabrikant (2009) mention in their paper. Visual variables are widely recognised as core building bricks of cartographic symbolisation. Dang (2020) emphasises that variables such as colour, size, shape and value determine how effectively meaning and hierarchy are communicated in mobile interactive maps. Nikolova (2025) shows how the traditional approach can be extended by empirically testing visual variables within web-based, interactive environments, demonstrating that colour hue and size dominate in visual search performance, particularly when users must locate point symbols quickly. Bertin's categorisation has been historically influential as Garlandini and Fabrikant (2009) state. Much of this theory remains unvalidated empirically for decades, therefore their research proposes a perception-based evaluation. It investigates how visual variables support attention and change detection under controlled experimental conditions (Garlandini and Fabrikant 2009). They use the flickr paradigm and eye-movement data and test systematically size, colour value, colour hue and orientation as the chosen visual variables. Garlandini and Fabrikant (2009) demonstrate that size is the most efficient and most effective variable for detecting change, while orientation is consistently the least effective. This is particularly relevant for interactive routing interfaces, where users' ability to rapidly notice change, as updated congestions or route options, can directly influence decision-making.

Garlandini and Fabrikant (2009) empirically validate aspects of Bertin's implied ranking. Size shows strong selective, ordered, quantitative and dissociative characteristics. Thereby guiding attention more effectively than orientation. Their findings also emphasise the importance of pre-attentive processing. There, users do not consciously "read" symbols as much as they visually detect differences that "pop out". Effective visual design should, therefore, exploit perceptual salience rather than require cognitive interpretation (Garlandini and Fabrikant 2009). This reinforces Dang (2020)'s argument that cartographic interface design must align with cognitive processes and the constraints of mobile display environments. Garlandini and Fabrikant (2009)'s study strengthens together with Nikolova (2025)'s findings the empirical basis for choosing specific variables for certain tasks. Colour hue and size show an important effect for search and detection while orientation is stated as a weak visual variable for both detection and cognition. Colour value is stated to be useful, but less consistently dominant (Garlandini and Fabrikant 2009; Nikolova 2025). Importantly, these findings directly support UX and cartographic decisions regarding route emphasis, traffic highlighting and visual prioritisation in routing applications. Garlandini and Fabrikant (2009) also caution that visual salience competes across symbol sets. Too many similar or equally salient cues causes attention dispersion (Garlandini and Fabrikant 2009). Their results, in combination with Nikolova (2025)'s results, imply a UX rule for interactive routing maps: prioritise one dominant visual variable per task to preserve selective attention and reduce cognitive effort.

### 2.3.3 Visual Communication in Routing: Influencing Perception and Choice

One unique UX challenge presents the routing interface. Users must interpret spatial information quickly and accurately, sometimes under time pressure or environmental distraction (e.g. driving). Fuest et al. (2021) point out that effective route design requires clear visual communication of route characteristics, such as traffic congestion, temporal conditions and recommended paths. Their work highlights that users rarely optimise routes for social efficiency unless explicitly prompted to do so by the user interface (Fuest et al. 2021). Fuest et al. (2021) compare six design variants in a controlled experiment. Those variations represent congestion and recommend a preferred route. The following visual variables were used:

1. Colour hue (green/red)
2. Spacing (dash gaps)
3. Size (line width)
4. Symbols (car density)
5. Length distortion (perceptual shortening/lengthening)
6. Line distortion (smooth vs. jagged)

Fuest et al. (2021) found that most variants successfully shifted users towards the recommended route, especially at higher intensities. Symbols and length distortion are the most effective cues for having an impact on the choice of route. Less effective were line width and spacing, showing that some classical visual variables have limited influence in the routing context (Fuest et al. 2021). Users tended to choose the route that appeared faster, smoother, and more fluent, demonstrating how visual design can shape mental models of mobility. Fuest et al. (2021) take another note from cognitive psychology with regard to the focus on simplification of mental representations rather than geometric accuracy. Distortion techniques, such as simplifying a route or making it appear shorter, align with cognitive tendencies toward schematic maps, similar to subway diagrams. This suggests that carefully applied distortions can improve usability without misleading users (Fuest et al. 2021).

### 2.3.4 UX Principles for Designing Web-Based Routing Maps

As previously referenced, studies in cartography, cognitive psychology and UX design emphasise that effective routing maps must integrate visual communication principles and user-centred interface design. In traditional cartography, the emphasis is placed on the use of symbols and the accuracy of maps. In contrast, contemporary UX literature encompasses a wider range of concerns, including usability, intuitiveness, and accessibility. Integration of these perspectives is of critical importance for the field of routing applications, where users are required to make rapid decisions in the presence of visual load, movement, and time pressure. Hamidli (2023) describes UI/UX design as an essentially user-centred process, grounded in usability, visual clarity, accessibility, consistency, and feedback mechanisms. He points out that the reduction of cognitive effort should be provided by the interface which will lead to immediate and meaningful feedback. This maintains visual coherence, some principles that translate directly to routing contexts, where visual attention is strained by mobile usage, navigation tasks, and real-world distraction (Hamidli 2023). Across all reviewed work, five interconnected UX principles appear as particularly relevant to routing map design, which are discussed in the following sections.

#### Visual salience and perceptual efficiency

Garlandini and Fabrikant (2009) demonstrate that size and colour hue support rapid detection, while orientation is less effective. A similar statement is formulated by Nikolova (2025), who finds that colour and size significantly outperform shape and orientation in web-based visual search tasks. This means for routing interfaces that recommend routes should be encoded using perceptually dominant variables like colour or width. Additionally, critical traffic conditions should be visually salient and unnecessary stylistic variation should be avoided. These conclusions align with the UX principles of clarity and visual hierarchy as it is emphasised by Hamidli (2023), who notes that visual communication should be enabled immediate recognition of structure and meaning. Cartographic as well as UX literature underline both consistency of visual and interaction conventions. It has been argued that consistent colour systems, typography and iconography reduce cognitive load and strengthen usability (Hamidli 2023). Dang (2020) shows a similar approach, which underlines that consistent visual design helps users build mental models of spatial layouts and reinforces cognitive maps during navigation. Within routing maps, consistency means using stable meaning for colours, maintaining predictable button placement and avoiding sudden symbol or palette changes across zoom levels.

Routing applications require visual encoding specified for specific navigation tasks. This makes it different from general UI design, which prioritises ease of use (Hamidli 2023). UX literature highlights task efficiency, while experimental cartography studies identify the visual variables that best facilitate route comparison, directionality and congestion perception (Dang 2020; Hamidli 2023; Nikolova 2025). Fuest et al. (2021) demonstrate that route choices can be strongly influenced through visual encoding, especially through symbols and geometric distortions that make desirable routes appear shorter or visually smoother. To reflect Hamidli (2023)'s argument that UX design must always serve user goals rather than aesthetic concerns, following visual design aspects must align with task goals:

| | |
|---|---|
| **Comparison tasks** | colour hue, symbol density |
| **Attention tasks** | size variation |
| **Directional tasks** | line continuity and simplicity |

Minimalism and cognitive load can both be found in UX and cartography principles. Nikolova (2025) mentions to be careful with symbolic combinations, as they can exceed perceptual capacity. Garlandini and Fabrikant (2009) demonstrate that too many competing visual signals reduce pre-attentive detection efficiency. Hamidli (2023) frames this as simplicity, readability and feedback. These are the core UI principles, which reduce cognitive load and improve efficiency. Minimalism entails using one dominant cue per message and reduce background clutter. Another minimalism approach can be done through limiting symbol sets and simplifying geometry (Hamidli 2023; Nikolova 2025). Hamidli (2023) emphasises that UX design is an iterative process relying on user feedback, usability testing and continuous refinement. Tsou (2011) echoed his perspectives within cartography, arguing that modern map design requires iterative improvements based on real user behaviour and interface performance rather than static cartographic conventions.

## 2.4 Routing algorithms

### 2.4.1 Dijkstra-Algorithm

Route-planning must be efficient as a foundational requirement in modern navigation systems, transportation platforms, and logistic optimisation. Computing the shortest or least-cost path between two points in a network is essential for real-time decision making and minimising travel time, cost, and fuel consumption. Therefore, Dijkstra algorithm, introduced by Edsger W. Dijkstra, remains one of the most widely used and influential algorithm for solving the single-source shortest path problem in weighted graphs (Javaid 2013; *Routing-Algorithmen: Definition & Typen | StudySmarter* 2025). The algorithm delivers deterministic and optimal results for routing tools and navigation devices. Despite its original calculation, it is possible to be adapted and, especially for large-scale real-world networks, it continues to enhance (Fan and Shi 2010). The core principle of the Dijkstra algorithm is the assignment of each node a label pair (pj, dj) where d(j) is the shortest known distance from the source to node j and p(j) is the predecessor node on that path. The algorithm starts with labelling the source node with distance 0 and all others with $\infty$. Afterwards, it progressively finalises the nodes with the minimum temporary distance until all nodes are processed (Javaid 2013). The benefit of this algorithm for routing is the optimal path selection. It always finds the mathematically shortest or lowest-cost path. The deterministic performance show the same results each time and it does not vary between runs. Additionally, the local next-hop visibility is an advantage as routing tables can only store the next step rather than full paths which improves simplicity (Javaid 2013). However, this step requires substantial memory and processing time for larger networks because it searches exhaustively without geographic or topological constraints. Especially for real-time routing in a lager city-scale transportation network, processing time can be a limitation (Fan and Shi 2010). As mentioned before, the Dijkstra algorithm is suitable for further development. As Fan and Shi (2010) stated in their paper, practical challenges for large road networks can be improved. The original adjacency matrix wastes memory by storing many zero and $\infty$ values. The improved version uses an adjacency list, significantly reducing storage volume and redundancy, particularly in sparse graphs. Another improvement approach is the restricted searching area. Recognising that shortest paths in real world networks tend to follow the direction between start and destination, the improved method restricts search to a defined rectangular region rather than a circular full-network search.

Dijkstra algorithm is the classical foundation for computing the single-source shortest path in weighted graphs. It systematically expands the shortest distance from a starting point, progressively selecting the next closest vertex and updating paths until the shortest path to all reachable nodes is known. Its deterministic behaviour and ability to guarantee optimal path choices have led to widespread adoption in a variety of domains including logistics, computer networks and road navigation.

## 2.5 Multimodality

Creating a route commonly takes more than just one mode of transportation. If one intends to use public transport, they still need to walk to the stations from their current location or they need the route to change the station. Therefore, there is a need to introduce multimodality in routing algorithms. Classical shortest-path algorithms such as Dijkstra assume single underlying graph structure and static edge weights, but multimodal environments consist of heterogeneous networks that have to be integrated in a coherent representation (Liu 2011).

### 2.5.1 Concept of Multimodal Routing

Timetable validity, synchronisation between services, possible missed transfers and the path within stations make the public transit routing significantly more complex than road routing. Routing therefore cannot be solved solely by distance minimisation, but must reason over time-dependent availability of edges (Joshi et al. 2024). Mobility systems bring a dynamic nature, such as disruptions or timetable changes. This further increases complexity and prevents static optimality assumptions.

### 2.5.2 Multi-criteria Aspects

Multiple criteria need to be taken into account when a route is calculated. Tourists rarely optimise solely for travel time, but consider additional aspects such as number of transfers, walking distance, but also comfort and qualitative factors. Therefore, there is no unique optimal solution but Pareto set of trade-off, which will be discussed in a later chapter (Abdellaoui et al. 2025). To improve a tourist's experience, recent approaches explicitly include reliability and context like availability of shared vehicles and arrival punctuality. However, multimodal routing comes with the central challenge of the representation and coupling of different transport networks. Liu (2011) introduced the Plug-and-Play Multimodal Graph Set, where each transport mode is represented as a separate network and connected through formalised mode-switching nodes. This leads to a structured modelling of access restrictions, transfer rules as well as mode changes. Another challenge is the performance. High-performance GIS implementations avoid storing multimodal networks as relational tables due to inefficient join operations. Therefore, a binary adjacency structure is proposed to return turn restrictions and Z-levels (bridges, tunnels) to support multimodal routing at scale (**noauthor_pdf_2025**).

### 2.5.3 Personalised and Experiential Routing

Multimodality is not only a technical challenge, it also reflects user preferences and travel behaviour. In tourism scenarios, optimality is not defined by minimal travel time, but by experiential quality, scenic value, cultural interest, and walking enjoyment (Gavalas, Kasapakis, Pantziou, et al. 2016). The Scenic Athens system introduces the idea that walking routes itself can be treated as valuable edges rather than merely transitions. Therefore, routes can be expanded beyond nodes (POIs) to meaningful paths. Their approach to integrate scenic walking segments helps the system to explicitly enable multimodality between cognitive, emotional and spatial dimensions of urban movement. This goes beyond traditional algorithms, as they do not model cognitive or emotional dimensions.

### 2.5.4 Multimodality in Smart Cities

In Joshi et al. (2024)'s work, they positioned multimodality within a much broader context of urban sustainability. The environmental impact and the smart-city planning can be considered for multimodal routing. Urban Odyssey interprets multimodal routing as strategic multi-objective decision-making problem for sustainable and efficient transport systems rather than merely a shortest path-problem. It highlights integration of different modes and emerging factors such as ecological impact accessibility and urban resilience (Joshi et al. 2024).

### 2.5.5 Algorithmic Approaches

Classical shortest-path algorithms such as Dijkstra were designed for static networks in which edges represent direct costs, typically travel time or distance. In public transport networks, however, each edge is time dependent and valid only according to the corresponding timetable. As soon as transfers, arrival times, departure times and waiting times must be evaluated repeatedly, classical graph-based algorithms scale poorly. This is since every connection attempt requires evaluating many edges under time constraints (Javaid 2013). Therefore it leads to large computational overhead, especially in large metropolitan networks with dense public transport services. Consequently, a number of dedicated approaches have been developed to overcome the limitations of repeated edge relaxations and time-dependent re-evaluation (Abdellaoui et al. 2025; *Routing-Algorithmen: Definition & Typen | StudyS-*

*marter* 2025).

### RAPTOR Framework

A prominent example of such a specialised algorithm is the Round-based Public Transit Routing (RAPTOR) framework (Delling, Pajor, and Werneck n.d.). RAPTOR fundamentally departs from classical shortest-path formulations. Instead of traversing a weighted graph using priority queues, RAPTOR operates on timetable data and processes the network in discrete rounds. Each round corresponds to journeys with an increasing number of transfers. In every round, only stops whose arrival time can be improved are updated, thereby avoiding unnecessary work and achieving significantly better performance than graph-based approaches in large networks. Since each round represents a fixed transfer count, RAPTOR naturally supports multi-criteria optimisation, most notably the joint optimisation of arrival time and number of transfers (Delling, Pajor, and Werneck n.d.). In practice, this enables the extraction of efficient Pareto-optimal journey sets without requiring explicit enumeration of all possible paths.

### Pareto-optimal routing

In order to plan a route within a city, certain factors must be specified as constraints, as otherwise there are countless possible routes.This is a well-known problematic in the transportation-routing thematic. To approach this nearly unsolvable problem, Weng et al. (2021)'s approach can be used. They found a solution to extract meaningful routes based on multiple criteria (Weng et al. 2021). Weng et al. (2021) highlighted that certain constraints must be set to reduce the number of potential routes. To address this, they applied the concept of the Pareto set, which identifies routes that are Pareto-optimal, meaning that no other route can improve one objective (e.g., travel time) without worsening another (e.g., number of transfers). This approach effectively reduces the set of feasible routes by eliminating those that are dominated, in example, not optimal under any trade-off between the considered criteria.

# Chapter 3

# Methodology

This chapter describes the methodological approach adopted in this work. It outlines the overall research design, the survey-based data collection process, and the conceptual development of the routing algorithm. OpenTripPlanner was initially analysed as a potential framework to support multimodal routing. However, its complexity and limited suitability for the envisaged scenic scoring approach led to the decision to build a custom prototype instead. The chapter therefore explains how "scenic" was defined in the context of this thesis, how relevant points of interest (POIs) and user insights were collected, and why a dynamic-programming formulation of the travelling salesman problem (TSP) with bitmasks was selected as the conceptual core of the routing logic. Finally, the methodological setup for the usability evaluation with tourists in Zurich is outlined.

## 3.1 Research Design

The overall logic behind this work follows a user-centred design approach. The study is structured as a two-phase, mixed-method process to obtain direct user feedback and locally grounded content. In both phases, surveys were employed as the central data collection method. In the first phase, an exploratory survey was conducted to gather domain-relevant content by asking local residents to suggest POIs and areas they considered meaningful for visitors. In the second phase, a usability-focused survey was carried out to evaluate the prototype developed on the basis of these POIs. This structure ensures that both the content and the evaluation of the routing tool are informed by real user input rather than hypothetical data.

## 3.2 Definition of "scenic"

Gavalas, Kasapakis, Pantziou, et al. (2016) use the word "scenic" as equivalent for experiential walking rather than efficient movement. Tourists prefer indirect or roundabout routes because they allow exploration and discovery. In a rewritten version, Gavalas, Kasapakis, Konstantopoulos, et al. (2017) use scenic in relation of market areas, architectural tours, natural and seaside walks as well as senic neighbourhoods. This leads to following definition for this work:

> Scenic elements in tourism refer to urban or natural paths, areas, or segments that are experienced as enjoyable, aesthetically or culturally significant, and worth traversing in their own right, enabling experiential engagement rather than merely functional navigation.

## 3.3 Survey Design

In this section the two surveys are explained. They are conducted as part of the research process to support the development and evaluation of the routing tool. The first survey investigated local perspectives to identify relevant POIs for visitors in the region. The second survey focused on assessing the usability and user experience of the routing tool prototype, which was developed based on insights obtained from the initial survey. Together, these surveys enabled a user-centred research approach that informed both the content and functional design of the tool.

This leads to a two-phases process. In the first phase, an exploratory survey to gather domain-relevant content was conducted. During the second phase, the focus lied on the usability evaluation of the prototype using the content from phase one. Therefore, it is ensured that the evaluation was grounded in realistic use cases and reflected genuine local knowledge rather than hypothetical data.

### 3.3.1 First survey: Finding POIs

The objective of the present survey was to provide local residents with a means of expressing their opinions. The objective of the survey was to gather insights from local residents regarding places they deem to be significant or valuable for visitors. These insights were necessary to create an authentic and representative dataset for the routing system. The participants were local residents, either from the city itself or from the agglomeration. The subjects were required to provide details regarding their place of residence, with a view to establishing a contextual framework for the discussion of their proximity to the metropolis. The survey was disseminated through university group chats, family members and house chats, with the recommendation that it be circulated further afield. Due to the anonymous nature of the survey, it was not possible to calculate an average age or determine precise origins of the participants. Initially, the survey was completed by 27 individuals; however, only 15 of these individuals proceeded to submit their results. The 15 results obtained were utilised for subsequent analyses. The participants were instructed to first select a POI within the city of Zurich. The placement of a pin on the map, within the geographical boundaries of the city, is a potential option. The subsequent query sought to substantiate their selection. The question was designed to assist in the classification of motivations for visiting the POI, and to potentially assign it a relative importance. The process was then repeated with an area of interest. Subsequently, the subjects were required to specify their place of residence. The survey was conducted in German, as it was hypothesised that the local population speaks German. The survey period commenced midway through August and concluded midway through November. Two distinct waves of commitments were observed; the initial wave transpired following the primary distribution in August, while the subsequent wave occurred in November prior to a critical juncture.

The resultant data set was then subjected to an analysis using the POIs for the routing tool. The results were stored in a .csv file using ArcGIS Survey123 Collaborate. During the survey period, it was possible to continuously monitor the results on the ArcGIS website. The description facilitates the visualisation of the POI in the tool, thereby enhancing the user experience.

### 3.3.2 Usability Survey

The objective of the second survey was to assess the usability and practical value of the routing prototype developed in the preceding phase, and to gather feedback from individuals actively engaged in exploring the city. The aim was to evaluate the prototype under realistic usage conditions and to determine whether it supported tourists in planning an enriching and meaningful city experience. The participants consisted of tourists visiting Zurich who were approached in person at Bürkliplatz, one of the city's central transport and activity spots. In contrast to the first survey, the focus was placed on visitors rather than residents in order to obtain insights from individuals with an external perspective and with a genuine need for navigational support. The survey was conducted using a personal tablet, on which participants first interacted with the routing prototype and subsequently completed the questionnaire. Some tourists scanned the QR-Code of the survey and filled it out later in the day. The survey was structured into two thematic sections. The first section contained contextual and demographic questions designed to establish a framework for understanding the participant's background, including their familiarity with digital navigation tools and city trip planning. A single-choice question was included to ascertain their general experience level with planning urban itineraries. These questions were required to provide contextualisation for the subsequent evaluation of usability. Following this initial section, participants were instructed to actively interact with the prototype by creating a personalised route. Upon conclusion of their interaction, they completed the second section of the survey, which was designed to evaluate the usability and user experience of the tool. The questions focused on first impressions, ease of learning, clarity of the interface and any difficulties encountered during use. Open-ended formats were intentionally employed in order to obtain qualitative responses that could provide insights into areas for improvement and potential redesign. The survey was conducted during a single sampling period and was completed by five participants. Due to the direct personal recruitment process, monitoring demographic characteristics beyond the contextual questions was not feasible. The survey was implemented using the ArcGIS Survey123 platform to ensure systematic data capture and reliable storage. The collected responses served as a qualitative foundation for assessing the strengths and weaknesses of the prototype and for identifying opportunities for further development.

## 3.4 Data collection

Various sources were considered as possible frameworks for the prototype. Since the idea was to make the tool as accessible as possible, open source tools served as starting points. Therefore, the first prototype was initially based on Open Trip Planner. Building on the knowledge gained from OTP, however, a different method was ultimately used to embed the algorithm in a prototype.

### 3.4.1 Open Trip Planner

Although OpenTripPlanner (OTP) was initially explored as a potential routing framework, its internal complexity and lack of direct support for scenic scoring led to the development of a custom solution. Therefore, OTP informed the conceptual understanding of multimodal routing while the final prototype was implemented independently. OTP is an open-source routing framework specifically designed for multimodal route planning with a focus on public transport. It combines different modes of transport such as walking, cycling, car sharing and public transport in an integrated routing process. OTP directly accesses data from OpenStreetMap (OSM) and timetable data in General Transit Feed Specification (GTFS) format. OSM provides the geographical infrastructure such as paths, road routes and elevation profiles, while GTFS maps the time-related information of public transport. By combining this data in an intermodal way, OTP enables highly flexible and realistic navigation. The architecture of OTP is based on a modular structure. Its central components are the Graph Builder, which generates a routing graph from OSM and GTFS data, and the Routing Engine, which calculates routes using various algorithms such as Dijkstra or A*. The generated graph can then be queried via an API based on Java and Spring, which offers both REST and web-based interfaces. This clear separation between data preparation and routing logic facilitates modular expansion and the integration of new functions (CH Open 2022; OpenStreetMap US 2016; *OpenTripPlanner - creating and querying your own multi-modal route planner*

2025).

Since the project is being developed entirely openly on GitHub, there are many possibilities for expansion. The open code base allows routing parameters, evaluation logic, or additional modes of transport to be flexibly integrated. This allows developers to implement their own optimization criteria, such as ecological assessments, accessibility, cost efficiency or, as in this project was planned 'scenic scores' to evaluate routes according to their scenic appeal rather than purely on distance or travel time. By adjusting the weighting in the routing algorithm, alternative route strategies can be developed without having to completely change the core architecture. There are currently two main version lines, with this project based on version 2.8.0. Version 2.x introduces significant enhancements over 1.x, particularly in the handling of complex public transport networks and routing performance. The active open-source community promotes continuous enhancements and offers extensive documentation, issue tracking and exchange opportunities, making OTP a stable foundation for your own research and development projects. This leads to many different ways of documentations in the code base itself. Getting an overview which module is connected with another tis a time-consuming and complex task, especially since knowhow on graph coding is needed. Overall, OpenTripPlanner offers great potential for scientific and practical further development, particularly in the context of innovative mobility applications, thanks to its flexible structure, open architecture and use of open data sources. However, a deep knowhow in each module is needed.

### 3.4.2 Data sources

The spatial routing information used in the prototype was obtained through the Google Directions API, which provides route geometry in the form of encoded polylines. These polylines were subsequently processed and integrated into the custom routing logic. In addition, the POI dataset was entirely collected through the exploratory survey and supplemented with manually created input parameters, as no suitable open scenic datasets were available.

## 3.5 Conceptual Algorithm Choice

To provide a meaningful, user-centred routing solution for tourists, the routing problem can be conceptualised as a variant of the classical Travelling Salesman Problem (TSP). For example, generating a route that visits multiple POIs within a realistic time budget is a typical instance of the TSP, where the goal is to visit several locations while respecting a constraint on time. The TSP framework is appropriate because the goal is to find an order in which a user visits a subset of POIs so as to maximise "value", in this case the number of POIs. This all, while respecting a contraint like the available timeframe.

However, a full TSP on all possible POIs is intractable for large numbers. Since tourists routes typically involve a moderate number of POIs (around 5-30), an exact approach remains feasible. To address state explosion and ensure practicability, a dynamic-programming (DP) method based on bitmasking was chosen. This approach is widely used for moderate-size TSP instances and can guarantee an optimal solution under the defined constraints.

### 3.5.1 Bitmasks and dynamic-programming

A bitmask uses a binary number in which each bit corresponds to a POI, i.e. bit = 1 means visited and bit = 0 means not yet visited. This allows representing any subset of POIs in a fixed-size integer (or integer array), which is computationally efficient. Therefore, bitmask provide a compact representation of visited sets. Since each subset of POIs corresponds to one mask value, the DP can iterate systematically over all subsets and build up partial solutions by expanding visited sets one POI at a time. This avoids redundant recomputation and ensures that all possible subsets are considered, thus, the result is an efficient state-space enumeration (GeeksforGeeks 2025). Exactness in moderate-size instances is given through time and memory limits performed by bitmask-DP. This provides a robust option over heuristics. It becomes straightforward to integrate additional constraints into the state transitions, like total time budget or mandatory start or end point. This, because each DP state can carry the accumulated cost/time along with the visited set. This matches exactly the requirement of a tourists routing tool.

### 3.5.2 Conceptual description of the DP-bitmask approach

- **State definition:** Each DP state represents a subset of visited POIs (encoded as a bitmask) and the index of the last visited POI. The value stored in the state corresponds to the minimal travel time required to visit this subset and end at the last POI.
- **Initialisation:** States that contain only a single visited POI are initialised with the travel time from the start location to that POI.
- **Transition:** From a given state, the algorithm considers adding any POI that has not yet been visited. For each such candidate, a new state is created (with an updated bitmask and last index), and the corresponding travel time is updated if it improves upon an existing value.
- **Constraint handling:** Transitions are only allowed if the accumulated travel time remains within the user-defined time budget, taking into account both intermediate legs and, if required, the return leg to the end location.
- **Solution extraction:** After all reachable states have been processed, the algorithm selects the state that visits the largest number of POIs (or yields the highest total “scenic” value) while still

satisfying the time constraint. Among solutions with the same number of POIs, the one with the lowest travel time is preferred. The final route is reconstructed by backtracking through the recorded predecessor states.

The detailed implementation can be found in the following chapter where the OrienteeringSolver, the main logic of the routing tool, is described. Given that the prototype's purpose is to generate optimal or near-optimal city tours tailored to a tourists time budget and POI preferences, the bitmask-DP TSP algorithm provides a solid, explainable and deterministic foundation. It balances computational efficiency with exactness, and allows easy adaption (**noauthor_travelling_nodate**). POIs can be added or removed, cost functions can incorporate multimodal transport, walking versus bicycle versus transit, and constraints like time budget, start and end points can be enforced directly. As such, this approach supports a reproducible, transparent and user-centred routing design.

# Chapter 4

# System Architecture for the Routing Tool

This chapter summarises the building process of the prototype for the routing tool. It outlines the development process, explaining the technologies used, and justifies the architectural decisions made. The chapter is divided in two sections. Firstly, the backend structure, which contains the routing logic and data handling, secondly, the frontend layer, which provides the user interface for interacting with the tool. The system follows a client-server architecture, where the backend process requests and performs route calculations, while the frontend visualises the results and manages user input.

## 4.1 System Overview

The prototype follows a client-server architecture, as shown in this figure. The backend exposes REST endpoints that receive user input (start, end, time budget and transport modes). The backend also performs route computation and returns the route geometry. The frontend renders the resulting route on a map and enables user interaction.

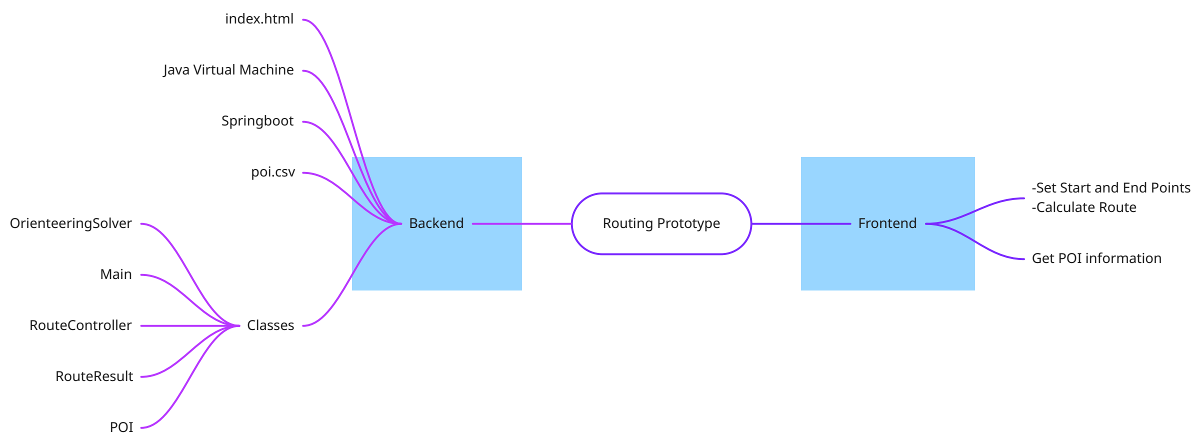



Figure 4.1: System Architecture of the routing prototype

## 4.2 Building the Backend

The backend forms the core of the routing tool by handling data processing operations, executing routing algorithms and providing REST endpoints for communication with the frontend. The backend was implemented using Java in combination with the Spring Boot framework. This choice was based on performance, scalability and reliable integration with external services.

### 4.2.1 The use of Java

The main logic is built on multiple Java which work together as so called classes. The initial development was conducted within OpenTripPlanner (OTP) framework, whose classes are implemented in Java. For prototyping, OTP's project structure was adopted in order to benefit from existing tool architecture conventions. However, as the requirements of this thesis evolved, the solution diverged substantially from OTP functionality. Consequently, the final implementation forms an independent web application developed in Java. Only the initial structure and conceptual starting point were derived from OTP. The resulting framework is functionally and technically separate. As the application requires high computational performance, Java provides a compiled execution model and its mature ecosystem for high-performance server-side processing.

### 4.2.2 Backend Classes and Responsibilities

The prototype contains multiple so called classes, which work together to function as web application. The heart class of the prototype is the OrienteeringSolver, which contains the routing logic and is explained in the following chapter.

**Orienteering Solver**

The routing logic is implemented in the OrienteeringSolver class. It performs four main tasks:

1. Precalculating travel times
2. Constructing multimodal edges
3. Running the DP-based solver using bitmasks
4. Reconstructing routes for visualisation

As describe in the Methodology chapter, the routing algorithm is formulated as a bitmask-based dynamic programming solution to as TSP-like problem. To have an approach to solve the TSP, it is important to set constraints and a main goal. The target is to maximise the amount visited POIs. One constraint hereby is time, as there should be a certain time budget given by the prototype user. The problem is modelled as a fulfilled graph, where the nodes correspond as POIs (inclusive start and end point) and the edges are the travelling time. The main code is split in four different phases. Prior to the initiation of the path algorithm, the system performs a calculation of the travel times between all node pairs. This component is characterised by its high computational demands, owing to the integration of external APIs and multimodal logic. A special feature of the implementation is that an edge between two nodes A and B is not static. The solver dynamically calculates the minium of two options:

- **Unimodal (Direct):** A $\rightarrow$ B (e.g., only bike or only walking via Google Maps API).
- **Multimodal (Intermodal):** A $\rightarrow$ $\text{Station}_{\text{Start}}$ $\rightarrow$ $\text{Station}_{\text{End}}$ $\rightarrow$ B.
  In this case, the solver iterates over all available station pairs (considering bike and dock availability).
  The cost function is defined as:

$$t_{\text{total}} = t_{\text{walk1}} + t_{\text{bike}} + t_{\text{walk2}} + t_{\text{transit}}$$

This ensures that the algorithm makes locally optimised decisions for each section (so called 'greedy' at edge level) before global route optimisation begins.

The next step is the actual approach to solve the routing problem. It is an exact algorithm for instances from small to middle size, which is typical for touristic routes. The dynamic programming state is defined as dp[mask][last], where:

- Mask is a bitmask indicating the subset of POIs that have already been visited. For example, a binary mask of 101 denotes that POI 0 and POI 2 have been visited.
- Last represents the index of the most recently visited POI.

The value stored in dp[mask][last] corresponds to the minimum travel time required to visit all POIs encoded in *mask* and to end at POI *last.*

**Initialisation:** The initial states are defined as:

$$\mathrm{dp}[1 \ll i][i] = \mathrm{cost}(\mathrm{Start}, \mathrm{POI}_i),$$

which represents the travel cost from the starting point to the first visited POI.

**State Transition:** For each reachable state, the algorithm extends the current partial route by selecting a new POI *next* that has not yet been visited:

$$\mathrm{dp}[\mathrm{mask} \mid (1 \ll \mathrm{next})][\mathrm{next}] = \min\Big(\mathrm{dp}[\mathrm{mask} \mid (1 \ll \mathrm{next})][\mathrm{next}],\ \mathrm{dp}[\mathrm{mask}][\mathrm{last}] + \mathrm{cost}(\mathrm{last}, \mathrm{next})\Big).$$

This transition is only executed if the accumulated travel time plus the travel time to the next POI does not exceed the maximum allowable time budget:

$$\mathrm{dp}[\mathrm{mask}][\mathrm{last}] + \mathrm{cost}(\mathrm{last}, \mathrm{next}) \leq T_{\max}.$$

In the next step the optimal route is selected. After the dp-table is filled, the best solution must be extracted. The algorithm follows a hierarchical prioritisation:

1. **Primary objective:** Maximise the number of visited POIs, i.e., maximise Integer.bitCount(mask).
2. **Secondary objective:** Minimise the total travel time among solutions that visit the same number of POIs.
3. **Feasibility validation:** Each candidate solution is evaluated to ensure that the return path from the last visited POI to the final destination lies within the allowed time budget:

$$\mathrm{TotalTime} = \mathrm{dp}[\mathrm{mask}][\mathrm{last}] + \mathrm{cost}(\mathrm{last}, \mathrm{End}) \leq T_{\max}.$$

This implementation provides an exact solution for the given POI set while allowing multimodal travel time optimisation within the defined time constraints.

The final step in the process is the visualisation stage. As is often the case in such scenarios, this element is frequently underestimated. However, given that, as in the initial step, the edges were constructed in an abstract manner, it is imperative to reconstruct the physical and realistic routes. Therefore, the employment of a parent matrix as a helper function is necessary in order to retrace the route from the optimal end result to the initial point. Moreover, the utilisation of polylines from the Google

API is evident. It has been demonstrated that a multimodal edge can be formed by combining three segments (walking, biking, walking). Consequently, utilising Google Polyline alone may not be sufficient. It is therefore necessary to define an additional helper function with the purpose of decoding the encoded polyline of each segment into a list of coordinates. Subsequently, the entirety of the double coordinates is eliminated, prior to the encoding of the complete list as a single polyline string for the purpose of visualisation in the frontend.

The OrienteeringSolver combines an exact solution approach to the orienteering problem based on dynamic programming with flexible, multimodal edge weighting. By encapsulating the station logic in the cost calculation of the edges, the complexity of the graph remains limited to the number of POIs (N), while at the same time determining the optimal combination of walking and bike sharing for each section. This enables precise route planning under tight time constraints.

### 4.2.3 Spring Boot

Spring Boot is an open-source framework for Java development which helps to create a stand-alone and productive web application. It brings the application to run through predefined Starters. It is an extension of the Java spring framework itself. Both used together provides an robust platform for a Java-based software (Deinhard 2025). It is the base infrastructure for an application to spare the developers focus on the development of the application rather than the infrastructure of it.

## 4.3 Building the Frontend

The visualisation of the route, the respective points of interests and the users input are all provided by a single HTML document. It evaluates the JSON responses returned by the backend and renders them directly in an interactive web interface.

### 4.3.1 HTML file

The main index.html follows its own clear architecture and acts as the entry point for the entire frontend. The structural layout is defined using HTML5, which provides the necessary container elements such as the sidebar, form components and the map container through semantic markup. In this way, the browser is able to construct a coherent Document Object Model (DOM) that serves as the basis for interaction and visualisation.

The visual styling and layout behaviour are implemented using CSS3, including responsive properties that determine the positioning of the sidebar and the design of markers and interface components. Although part of the styling derives from Leaflet default, additional CSS rules are declared directly in the file to ensure a consistent design language.

Java Script forms the central interaction layer of the system. It handles form submission, manages user input, triggers API requests to the backend, and controls the interaction with the map. All functional logic , form coordinate selection to event-based interaction with the map, it is encapsulated in JavaScript functions.

Leaflet is the primary Geographic Information System (GIS) framework. Beyond providing stylistic defaults, Leaflet is responsible for rendering the base map tiles, creating polylines, and managing geospatial layers and markers. Through these capabilities, it becomes the core mapping engine on which the entire visualisation is built.

Finally, the Mapbox Polyline library is included as a supporting component to decode encoded route geometries, as the backend returns Google-style encoded polyline strings. These coordinates must be decoded into latitude-longitude pairs before they can be interpreted and drawn by Leaflet.

### Layout

The frontend is structured into three principal areas that are reflected directly in the DOM. First, the app-container functions as the overarching wrapper and defines a horizontally aligned layout using Flexbox, thus presenting the application in a two-column design. Second, the sidebar contains all user-oriented interaction elements, such as form fields for start and end coordinates, travel mode selection, and route duration. It also displays the computed results and a list of visited POIs once the backend response is processed. The third area is the map container, which hosts the Leaflet instance and enables interactive geospatial interaction, such as visualising start and end points, the computed route, and navigable map events.

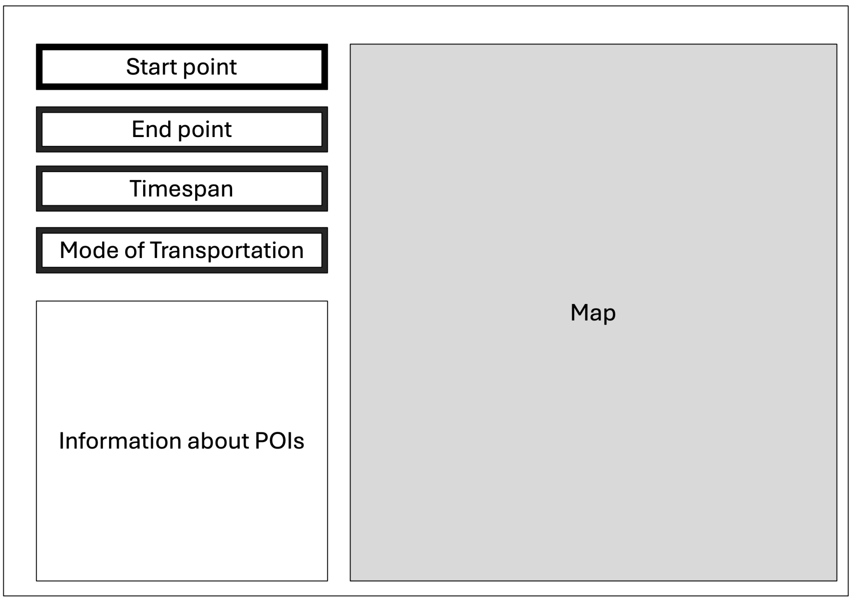



Figure 4.2: Initial idea of the layout of the website.

**Functionality**

The functionality of the frontend follows a clear structure that begins with the initialisation of the Leaflet map. It then culminates in the visualisation of the calculated route and its related POIs. When the page is loaded, a Leaflet instance is created and centred on a predefined location. The base map tiles are retrieved from OpenStreetMap and are directly added as a tile layer. From this point onward, all map-related operations as adding layers, drawing polylines, placing markers or opening pop-ups, are applied to this map instance. User input can be done manually by entering coordinates into text fields or interactively by selection points on the map. When the user activates the map-picking mode, the corresponding button registers a click event, and the next click on the map is interpreted either as start or end location. The selected coordinates are automatically inserted into the respective input field and a corresponding marker is placed on the map. This creates a seamless coupling between form-based input and spatial interaction. Upon submission of the form, the input values are collected and transformed into a JSON request body. It contains the start and end coordinates, the selected travel mode, and the maximum travel time. This request is sent synchronously to the backend using the Fetch API. Once the backend responds with a route description, the encoded geometry is decoded using the Mapbox Polyline library and transformed into latitude-longitude pairs, so that Leaflet can interpret it. The resulting coordinate list is then displayed as a polyline on the map, and the viewport is adjusted to the spatial extent of the computed route. Furthermore, the response can contain additional information as the description of the visited POIs. These POIs are inserted as a separate markers into a layer and are associated with interactive actions. Selecting a POI marker or clicking the corresponding entry in the result list triggers a pop-up window displaying the descriptive information received from the backend. This modal design separates semantic information from the cartographic representation, while it still allows the user to contextualise geographic locations in an intuitive way.

### 4.3.2 Deployment on Virtual Machine

To be able to evaluate the prototype independent of a local development environment, the complete system was deployed on a Microsoft Azure virtual machine running Ubuntu Linux. After building the backend application as a .war archive using Maven, the application was deployed on the server. Maven was known from OTP as their application is built with it. Therefore the knowledge was reused and implemented for the new prototype. The Azure server has Apache Tomcat running, whereas the .war file could deployed directly on the server. To ensure full accessibility through the public Internet, a reverse proxy was configured using Ngix, which forwards incoming HTTP request to the running Tomcat instance. Furthermore, it was necessary to install the suitable Java version, so the application ca be ran. The .war file can now be started as a service and it starts as soon as the Virtual Machine is running. This setup allowed test users to interact with the system remotely and enabled a realistic evaluation scenario using real network conditions rather than relying solely on local execution.

# Chapter 5

# Results

This chapter presents the empirical results which were obtained throughout the development and evaluation of the routing prototype for the tourist exploration in the city of Zurich. The findings derive from two principal sources, the collection of POIs contributed by local residents and the usability evaluation conducted with tourists. Together, these outcomes provide the basis for assessing the prototype's functionality, data integration and suitability as navigation and recommendation tool. It begins by outlying the results of the POI collection survey, followed by the integration of the collected data into the prototype. This is done with a particular emphasis on design choices and visual variables. This includes the representation of POIs, the applied colour scheme and cartographic backgrounds. Additionally, the prototype's look is introduced and some of its functionality, like pop-up windows. The section also reports on the implemented interaction mechanics that shape how users navigate the interface. Lastly, the chapter presents the results of the usability survey conducted with tourists. This evaluation captures first-hand impressions of the prototype's clarity, learnability and practical value for city exploration.

## 5.1 Survey POI Collection

To build an authentic and representative dataset for the routing tool, the first survey was designed to collect suggestions for POIs from local residents. A total of 27 individuals opened the survey and 15 completed it and submitted their responses. There cannot be made a precise statement about demographic characteristics like age or place of origin, as the survey was in an anonymous format. However, the available information confirmed that participants resided either within the city of Zurich or in the surrounding agglomeration. The responses produced a collection of 15 POIs, each accompanied by textual description. Some of those entries described a personal story, some of them mentioned a fact about the location. Across the submitted entries, POIs covered a variety of categories, including cultural and historical sites (Polyterrasse), natural or recreational locations (Saffa-Insel), neighbourhoods of particular atmosphere or interest (Altstadt, Cafe du bonheur), or spaces valued for local charm or insider recommendations (Swiss Life Arena, Letten). All results can be found in the following figure:

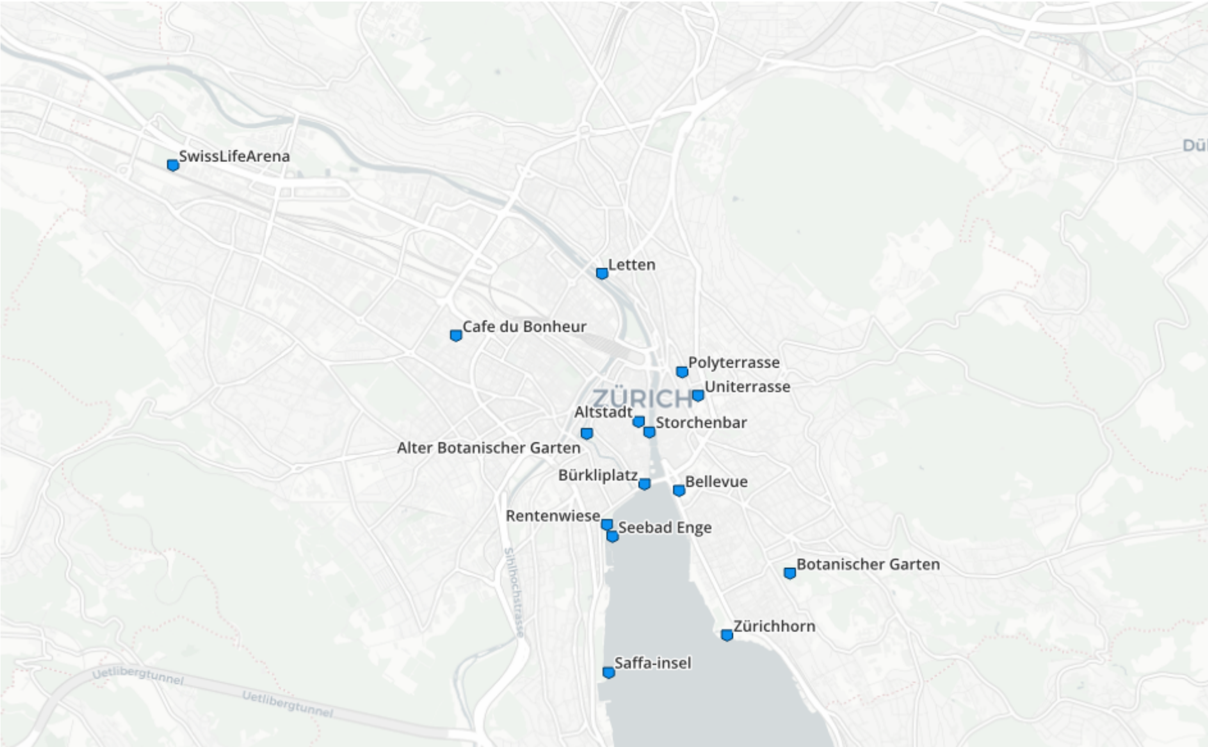



Figure 5.1: All collected POIs in Zurich

The provided description often highlighted the reasons behind the choices, such as aesthetic appeal, personal recommendations, perceived importance for visitors, or the presence of notable landmarks or views. These explanations facilitated the later classification of POIs within the routing system. In addition to the POI selection, participants were instructed to identify a broader area of interest within Zurich. This step provided further insight into districts and zones considered relevant by local residents. The survey remained active during 3 months until mid November. Submission patterns showed two distinct peaks, one immediately after the distribution and the second one before the planned analysis deadlines. This temporal pattern did not influence the content requirements but reflects the distribution dynamics of the survey.

## 5.2 Prototype Data Integration

As described in the methodology chapter, the survey responses were exported as a spreadsheet via ArcGIS Survey123. This file could be directly integrated into the prototype's codebase, enabling a seamless workflow during development. Whenever new or corrected POI submission became available, the dataset could be replaced and reloaded without requiring structural adjustments to the tool, as long as the name of the file remained the same. For each POI entry there is a unique ObjectID, a descriptive name and geographic coordinates stored in the EPSG:4326 format, as defined by the Survey123 default settings. These fields represented the core attributes used within the prototype. The coordiantes served as spatial input for route computation and map visualisation, while the POI names were integrated into labelling, pop-up windows, and the ordered list of visited POIs presented in the user interface. The POIs were further processed within the OrienteeringSolver, the routing component explained in the System Architecture chapter. During computation, the solver accessed the POI dataset to determine which locations were feasible to visit within a user-defined time frame. The integration of the dataset into the solver ensured that the routing process was directly informed by the contributions gathered from local residents. In this way, the POIs moved beyond a static list and became embedded in the functional logic of the prototype.

## 5.3 Processing the Data for route generation

The final prototype is capable of dynamically evaluating and selecting POIs based on a combination of constraints given by the user. The central factors considered during route generation include the spatial relationship between POIs and the route corridor, the available time frame and the selected mode of transportation. Each POI is checked by the algorithm whether it lies within a feasible distance from the evolving route and whether sufficient time remains to extend the itinerary to incorporate the location. Only when these conditions are met is a POI integrated into the final route. Users must specify both a start point and an end point. These can be entered manually, selected directly on the map or generated using the current device location, if enabled. The routing algorithm then constructs a path that connects these two points while optimising the visitable POIs under the constraint of the selected duration. The tool additionally offers two travel modes, walking or cycling, which influence the route geometry and travel speeds, as Google's Routing API differentiates between transportation types. When the user initiates route calculation, the prototype returns two key outputs. First, a visual representation of the route on the map and a summarised textual list in the side panel. All POIs included in the computed route are highlighted on the map using a distinct icon. Simultaneously, the side panel displays the total route duration, the start time and a chronological list of all visited POIs. This list is scrollable, allowing users to explore longer routes with multiple stops. Each POI remains clickable on the map, presenting a pop-up window with the full resident provided description. Through this integration of spatial data, algorithmic logic and visual communication, the POIs provided by locals are transformed into an actionable, personalised route.

### 5.3.1 Design and Visual Variables

To design the prototype the principles of user-centred design and perceptually effective cartographic communication were used as guidelines, as outlined in the literature review. The objective was to create an interface that supports rapid comprehension, intuitive interaction, and minimal cognitive load for tourists navigating an unfamiliar city. The visual integration of POIs, routes and interface elements was therefore shaped by established UX principles such as visual salience, hierarchy, simplicity and consistency (Hamidli 2023; Tsou 2011). At the same time, the implementation drew on cartographic theories of visual variables, which served as foundational framework for symbol design and the spatial representation of information (Dang 2020; Garlandini and Fabrikant 2009). In the following subsection, the key visual and interaction design components of the prototype are presented. These elements reflect the final state of the application and demonstrate how the theoretical design principles were applied in practice.

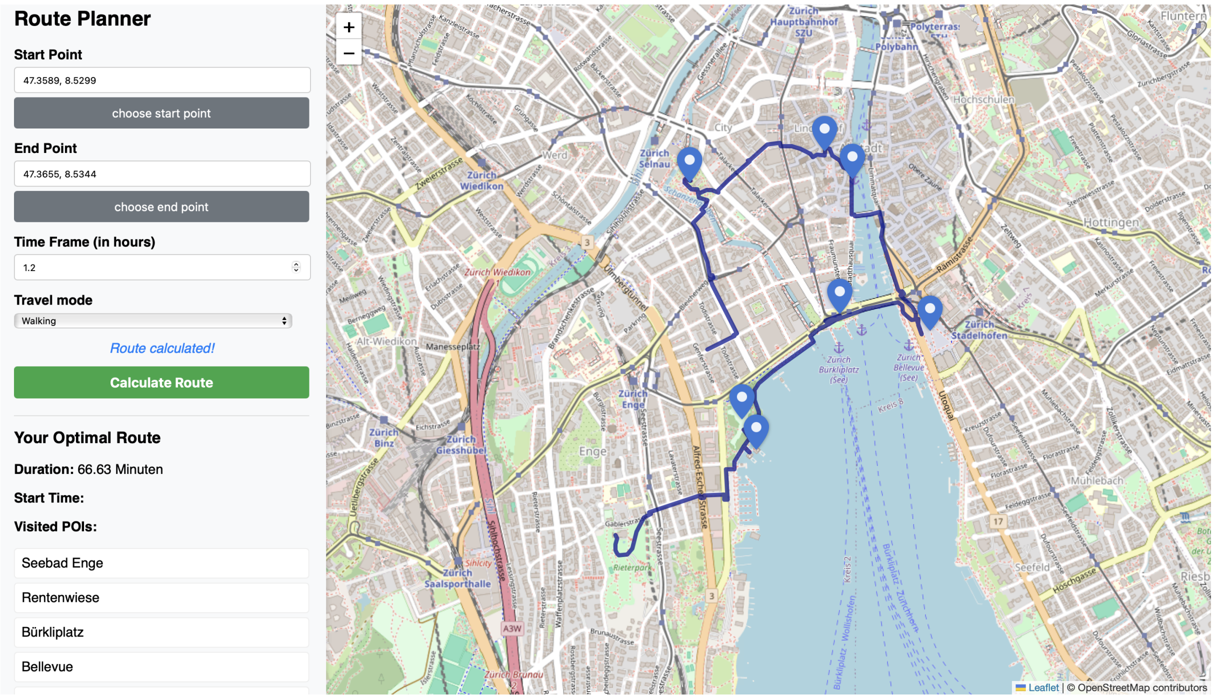



Figure 5.2: User interface of the prototype.

#### Visual representation of POIs

All POIs collected through the survey appeared as point symbols on the map and were integrated into the prototype using a red circular marker with a white check-mark during the evaluation period. After some feedback, the POI symbol changed to a more neutral symbol as it is known from Google maps or OSM.

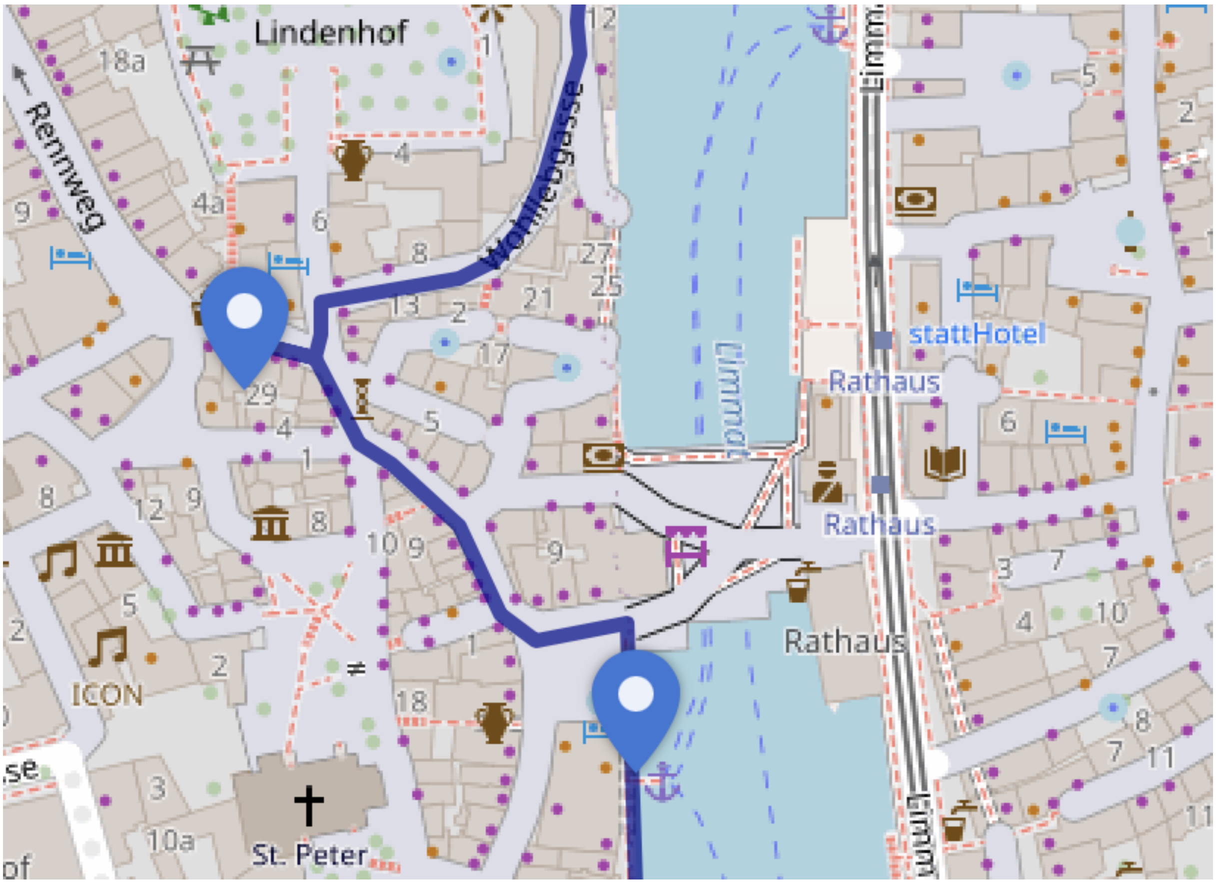



Figure 5.3: Pin symbol for POIs.

This design decision reflects findings from cartographic research, which emphasises colour hue and size as particularly effective visual variable for rapid search and detection (Garlandini and Fabrikant 2009; Nikolova 2025). The blue hue provides strong perceptual contrast against the predominantly green and grey tones of the OpenStreetMap base map, ensuring that POIs remain immediately recognisable even in visually dense urban regions. The POI markers are uniform in shape and size, which aligns with UX principles regarding symbolic consistency and cognitive efficiency (Hamidli 2023). This prevents the dispersion of visual attention that would otherwise occur with too many symbol variations (Garlandini and Fabrikant 2009). Each marker is interactive, thus, clicking on it reveals a pop-up window containing the full local-provided description, including personal comments, historical references or subjective motivations for choosing the location. The pop-up thereby serves as a bridge between the qualitative content gathered in the first survey and its integration within the spatial interface. As tourists typically seek contextual information during route planning, this approach supports user comprehension while keeping the map surface visually uncluttered.

### Colour scheme and background layers

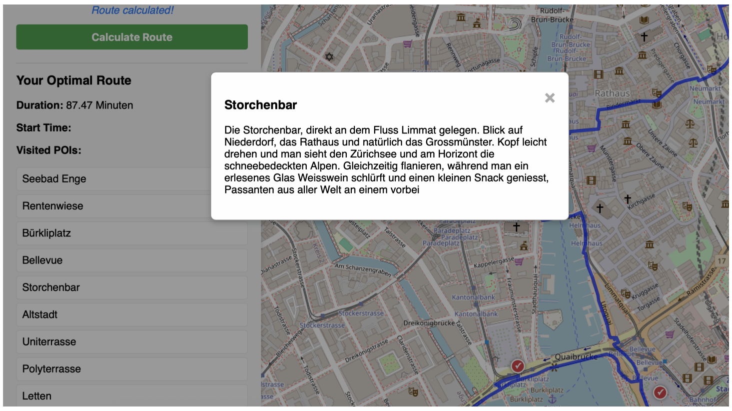
The prototype uses the standard OpenStreetMap (OSM) raster tiles as the base map. This choice was motivated by considerations of clarity, familiarity and detail. OSM's colour palette, characterised by soft greens, pale yellows and light greys, provides a balanced visual background. This does not compete with the more salient overlay elements. According to Dang (2020), maintaining contrast between base layers and thematic overlays is essential for reducing cognitive load and optimising visual hierarchy. The POIs and route line use saturated colours (red for POIs and blue for the route), which stand out clearly from the muted base map. This reflects the recommendation by Hamidli (2023) that routing interfaces should rely on a limited number of strong cues to preserve visual coherence and user focus. It also corresponds with empirical findings suggesting that colour hue is one of the most efficient variables for guiding user attention during map interpretation (Nikolova 2025).

### Route visualisation

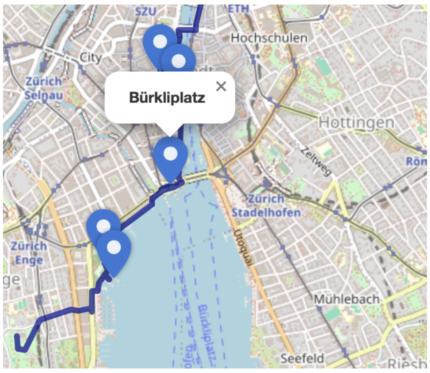
When the route is calculated, it is visible as a bold blue polyline on the map. The use of single continuous line follows principles of simplicity and directional clarity. These are crucial for navigation tasks as Fuest et al. (2021) stated. The chosen line thickness ensures that the route remains visible without obscuring underlying streets, enabling users to maintain situational awareness of the urban environment. The colour blue was selected for its high contrast with both the lighter blue POI markers and the light-coloured base map. Research on visual communication in routing emphasises recommended routes should be using perceptually dominant variables (Fuest et al. 2021). Like Google Maps and Apple Maps, the prototype's route colour was intentionally chosen to be visually prominent yet non invasive. Unlike experimental variants such as width variation or dashed spacing, which Fuest et al. (2021) mentions to be less influential in user decision-making, the continuous blue line supports fluent interpretation and reduces distraction. Each recalculation replaces the previous polyline and updates the sequence of POIs in the side panel, what makes the route visualisation dynamic. This supports the UX principle of immediate feedback, which allows users to directly observe the consequences of their input (Hamidli 2023).

### Labels, Pop-up Windows and visual hierarchy

The POIs are not labelled directly on the map to avoid textual clutter. This follows recommendations in UX and cartographic literature which caution against overloading the user's perceptual field. Particularly on map interfaces where spatial density is high, as it happens to occur in cities (Nikolova 2025). Instead, textual information is displayed in two situations. First, inside the pop-up when a POI marker is clicked, the contextual descriptions are displayed. Secondly, when the user clicks on one of the visited POIs, which are in the side panel listed, another pop-up provides information. This dual system maintains a clear visual hierarchy. The map provides spatial context, while the route gives navigational structure and the side panel works as delivery of structured semantic information. As Dang (2020) notes, effective map interfaces separate spatial perception from textual interpretation to support cognitive clarity. The pop-up windows serve an important UX function by presenting the qualitative descriptions provided by locals. Therefore, they act as an interpretative interface between raw geographic data and user meaning-making. This supports user-centred design principles by enabling users to form subjective impressions of locations rather than relying solely on graphical cues.




(a) Example of one pop-up window containing POI description.




(b) POI with name pop-up window.

Figure 5.4: Examples of POI pop-up windows in the frontend interface.

### Interaction design

The design of the prototype to interact is deliberately minimalistic. Users begin by defining a start point and an end point. This can be done by either entering coordinates, selecting their current location or clicking directly on the map. This direct-manipulation approach aligns with UCD principles, which emphasises intuitive actions and minimal instruction (Tsou 2011). To provide visual feedback immediately to the user when a point on the map is selected, labelled markers appear (Start or End). Feedback mechanisms are essential for reducing cognitive uncertainty and improving usability (Hamidli 2023). Once the route is computed, a confirmation message, "Route calculated", appears at the the bottom of the user's given parameters. The updated list of visited POIs appears simultaneously in the side panel. It reflects the UX principle of reducing decision complexity by guiding users through a structured sequence of task. It also reduces cognitive load, as users are not confronted with unnecessary options at early stages of the process (Hamidli 2023).

## 5.4 Survey Prototype Evaluation

To assess the usability, clarity and how the usefulness of the routing tool from the perspective of tourist is perceived, a prototype evaluation survey was conducted. In total, eight participants completed the survey after interacting with the prototype. All participants first explored the tool by creating a personalised route before answering a series of contextual and usability-focused questions. The collected responses provide qualitative insights into user expectations, interaction behaviour and overall impressions of the interface.

### 5.4.1 Participant Context and Prior Experience

The first question was about the initial plans and intentions for the day in Zurich of the participants. The responses gave an insight of the variety and a range of typical tourist activities, including sightseeing, casual exploration, walking through the city and visiting well-known landmarks. This confirms that the evaluation comes close to a real-world scenario, as participants were actively engaged in exploring the city at the time of the survey. Prior experience with route planning were conducted from the participants. They reported having used a variety of existing tools, most commonly general-purpose navigation applications such as Google Maps or transportation application like SBB mobile. Levels of experience with planning city trips varied, ranging from occasional planners to participants who described themselves as experienced. Due to this diversity, the prototype was evaluated by users with differing levels of familiarity with digital navigation tools.

### 5.4.2 First impressions of the prototype

The survey revealed a predominantly positive first impression. Several responses described the tool as clear, intuitive, or interesting, particularly in comparison to conventional navigation applications. Some participants noted that the focus on POIs rather than purely on efficiency made the tool feel more exploratory and better suited for tourism-oriented use cases. Some answers indicated initial uncertainty, mainly regarding the understanding of the handling of the tool itself. At first glance, the available interaction did not directly explain itself. However, this uncertainty was generally resolved once participants began interacting with the interface.

### 5.4.3 Ease of Learning and Route Creation

Participants were explicitly asked whether it was clear how to start using the tool and how easy or difficult it was to create a route. Selecting start and end points and generating a route was for most participants understandable without external explanation. The presence of clearly labelled buttons and visual feedback on the map supported this process. The task of creating a route was generally described as easy or manageable, even for users with limited prior experience in route planning. Some participants noted that the process became clearer through direct interaction, suggesting that the interface supports learnability through exploration rather than relying solely on instructions.

### 5.4.4 Encountered Problems and Difficulties

Despite the overall positive evaluation of the interaction, participants also reported several issues and points of contention. They were primarily concerned about which interaction steps were required first. There was a minor confusion regarding the input options and the limited feedback when unexpected results occurred. Nonetheless, theses issues did not prevent participants from completing the task but indicate areas where clearer guidance or additional feedback mechanisms could improve the user experience. Importantly, no critical errors of failures were reported that would render the tool unusable.

### 5.4.5 Evaluation of generated routes, layout and visual clarity

After completing the task of creating a route, participants were asked whether the generated routes met their expectations. Most respondents indicated that the suggested routes aligned well with their intentions for exploring the city. The inclusion of multiple POIs along the coherent path was frequently perceived as useful, particularly for visitors unfamiliar with Zurich. Some participants wished that suggested route would be described more detailed, for example by adapting more strongly to personal preferences or by offering additional contextual information. Nevertheless, the routes were generally regarded as realistic and appropriate for the given time frame. Also the layout and structure of the interface was positively assessed by the majority. The separation between the map view and the information panel was perceived as logical, allowing users to both visualise the route spatially and review the list of visited POIs in parallel. The interface was received as structured, clear and not overly cluttered. The combination of map-based interaction and textual information supported different ways of understanding the route. No participants reported difficulties related to visual overload, suggesting that the applied design principles successfully limited cognitive load.

### 5.4.6 Overall assessment

In the final question of the survey, participants were asked whether they would use the tool again. Most respondents answered affirmatively, stating they would consider using it again. Particularly, in a tourism context or when a city is explored for the first time, they stated the tool as helpful. Reasons for potential reuse included the focus on local POIs, the exploratory nature of the routes and the simplicity of the interface. Participants who expressed reservations typically referenced desired improvements rather than fundamental flaws, indicating that the concept itself was perceived as valuable. The usability survey results indicate that the routing prototype was generally perceived as intuitive, visually clear and useful for tourist-oriented route planning. Participants were able to complete the core task of generating a route and they reported positive impressions of both the interface and the route suggestions. Opportunities for improvement, particularly in terms of interaction guidance and feedback clarity, were revealed through the gathered feedback. The results obtained provide a qualitative foundation for the subsequent assessment of the prototype's feasibility and usability, a topic which will be further examined in the following Discussion chapter.

### 5.4.7 Online accessibility

To facilitate reproducibility and interactive exploration of the results, a web-based application was deployed and is temporarily accessible as Web application (available until completion of this thesis and for few months thereafter). The full source code will be made publicly available via GitLab at GitLab UZH.

# Chapter 6

# Discussion

In order to plan a route within a city, certain factors must be specified as constraints, as otherwise there are countless possible routes. It is a well-known problematic in the transportation-routing thematic. To approach this nearly impossible to solve problem, there is a paper from Weng et al. (2021) where they found a solution to extract meaningful routes based on multiple criteria.

Transit route planning in urban transit networks poses several challenges, as there are often many alternative routes to the same destination. Weng et al. (2021) highlight that certain constraints must be set to reduce the number of potential routes. To address this, they apply the concept of the Pareto set, which identifies routes that are Pareto-optimal, meaning that no other route can improve one objective (e.g., travel time) without worsening another (e.g., number of transfers). This approach effectively reduces the set of feasible routes by eliminating those that are dominated, in example, not optimal under any trade-off between the considered criteria.

## 6.1 Reflection on Research Question

Several methodological and technical decisions were revisited and adapted during the development of the routing prototype, resulting in a final system that differs in important ways from the initial conceptual vision. Emerged from practical constraints, performance considerations, and the iterative nature of user-centred system development, changes were not directly provoked by design choices. Within this context, the research questions formulated at the outset of the thesis provide a useful framework for reflecting on what the prototype ultimately achieves, where it falls short, and how its contributions should be interpreted. While not all aspects of the original research agenda could be fully realised within the scope of a master thesis, the developed prototype offers several insights into the feasibility of experience-oriented and sustainability-aware routing in an urban tourism context. The following subsections discuss each research question in turn, linking empirical and technical outcomes of the project back to the theoretical perspectives as they were introduced in the literature review.

### 6.1.1 Multimodal Routing, Sustainability, and $CO_2$ Reduction

"To what extent can multimodal routing system (walking, biking, public transport) reduce $CO_2$ emissions while preserving or enhancing route attractiveness for tourists?" as first research question was used as guideline to develop the prototype. Sustainability is primarily address implicitly through the prioritisation of low-emission transport modes, particularly walking and cycling. Routing logic encourages combinations of walking and shared bicycle use and limits reliance on motorised transport, as it is defined through the prototypes design. This aligns with existing research research that identifies multimodality as a key enabler of sustainable urban mobility, particularly in tourism contexts where travel distances are relatively short and flexibility is high (Joshi et al. 2024; Gavalas, Konstantopoulos, et al. 2016). It is important to note that the prototype does not calculate or visualise $CO_2$ emissions explicitly. Instead, emission reduction is inferred from modal choice, an approach that is common in early-stage or conceptual routing tools but limits the precision of sustainability assessments. This presents a deliberate trade-off between computational complexity and conceptual clarity. While direct emission modelling would provide more robust quantitative evidence, the current implementation still supports the broader goal of promoting environmentally friendly behaviour by only making low-emission routes attractive and accessible. Out of a tourists perspective, the integration of walking and cycling also contributes to experiential quality. Slow mobility allows for greater sensory engagement with the urban environment. It also aligns with the shift away from efficiency-driven travel that has been criticised in tourism literature (Butler 2015). Therefore, sustainability and experiential value are not treated as competing objectives but as mutually reinforcing design principles. The findings suggests that multimodal routing can support sustainability goals without necessarily downgrade he attractiveness of tourist routes. Although, further empirical validation with larger user samples would be required to confirm behavioural effects.

### 6.1.2 Integrating Experiential and Environmental Criteria

The second research question addressed how experiential and environmental criteria can be incorporated into urban route planning in order to improve the quality of tourist experiences. Experiential value is in thesis defined through the concept of "scenic" routing, which prioritises routes that pass through locally values points of interests and meaningful urban areas rather than strictly minimising travel time or distance. The collected POIs of local residents were used to reflect an attempt to ground scenic value in lived experience rather than purely algorithmic approaches. This proposal is consistent with the work of Gavalas, Konstantopoulos, et al. (2016), Gavalas, Kasapakis, Pantziou, et al. (2016), and Gavalas, Kasapakis, Konstantopoulos, et al. (2017), who points out that routes themselves can hold experiential value independent of destination points. By embedding POIs and their manly qualitative descriptions, apart from the very short noticed descriptions, into the routing logic,the prototype moves beyond traditional node-based optimisation. It acknowledges the importance of narrative, atmosphere, and discovery in urban tourism. At the same time, this method highlights a key challenge discussed in the literature, naming the subjectivity of experiential qualities, which are difficult to translate into computable metrics. The incorporation of environmental criteria is more indirect, primarily through the selection of transport modes and the assessment of route feasibility, as opposed to the utilisation of explicit environmental scoring. This pragmatic design decision stemmed from the absence of open and fine-grained datasets that could reliably quantify scenic or environmental quality at the street-segment level for Zurich. Consequently, environmental considerations are integrated at the level of system design rather than algorithmic optimisation. Whilst this does limit analytical precision, it demonstrates that experience-oriented routing can be implemented using relatively simple data structures, provided that qualitative inputs are meaningfully integrated.

### 6.1.3 Data and Algorithmic Choices for Real-Time Routing

The third research question lied focus on identifying suitable data sources and algorithmic approaches for generating scenic and culturally meaningful routes in real-time applications. The choice of dynamic programming approach based on bitmasking reflects a conscious decision to prioritise exact solutions for moderately size problem instances over heuristic scalability. This approach provides deterministic and transparent results, which can be clearly explained and reproduced. Here must be mentioned, that this only applies, when it is given that typical tourist routes involve a limited number of POIs. At the same time, the performance implications of this choice are significant. Computational cost increases exponentially with the number of POIs, which directly affects response time and limits scalability. This trade-off mirrors challenges identified in the literature on the Tourist Trip Design Problem, where exact methods offer high-quality solutions but struggle with real-time constraints in larger networks (Gavalas, Kasapakis, Konstantopoulos, et al. 2017). The prototype therefore positions itself closer to a research-oriented and exploratory system rather than a fully scalable commercial navigation tool. Additionally, the initial exploration of OpenTripPlanner illustrates this tension particularly well. While OTP offers robust multimodal routing capabilities, its complexity and architectural rigidity made it difficult to integrate custom scenic scoring logic within the scope of this project. The advantage of OTP is the pre-configured connection to public transport data. The integration of public transport as mode was omitted, as this would have added even more complexity, which would have completely negated the performance. at least in this format in which the prototype is currently set up. The decision to develop an independent web application ultimately enabled greater methodological flexibility, but at the cost of performance optimisations and established routing efficiencies. This reflects a broader insight of the thesis: integrating experiential criteria into routing systems often requires sacrificing some degree of computational efficiency in favour of conceptual clarity and design control.

## 6.2 Visualisation and User Experience

For routing applications, visualisation plays a central role, as it directly shapes how users perceive, interpret, and evaluate suggested routes. In the context of experience-oriented tourism, visual design is not merely a matter of aesthetic presentation but a decisive factor in guiding behaviour, attention, and expectations. The visualisation choices made in the developed prototype therefore ensures critical discussion, particularly with regard to cartographic design, symbolisation of points of interest, and linguistic consistency.

### 6.2.1 Base map and Cartographic Choices

OpenStreetMap is used as underlying base map of the routing prototype, rendered through the Leaflet library. The use of OPenStreetMap aligns with the open and transparent philosophy of the project, as it enables reproducibility and avoids dependence on proprietary mapping platforms. From a cartographic perspective, OpenStreetMap provides a high level of spatial detail, particularly for pedestrian and cycling infrastructure, which is essential for multimodal routing in an urban environment. This supports user-centred navigation through visible green spaces, walking path and secondary streets. These are elements that are often under-represented in car-oriented map designs. In this regard, the choice of OpenStreetMap corresponds well with the objectives of sustainable and experiential routing and reflects recommendations from web cartography literature that emphasises openness, adaptability and contextual richness (Tsou 2011).

### 6.2.2 POI Symbolisation and the "Been There, Done That" Problem

Next to the advantages of the visualisation, there are also some issues regarding the symbols of the POIs. The visualisation of the points of interest reveals a tension between usability conventions and the conceptual goals of the project. In the state of the evaluation period, POIs were represented using checkmark-style icons. While such symbols are commonly associated with completion, confirmation, or task fulfilment, their use in a tourism routing context introduces unintended semantic associations. Specifically, checkmarks evoke the idea of having "completed" or "checked off" a location, which closely aligns with achievement-oriented and efficiency-driven travel behaviour. This symbolism directly contradicts the project's intention to move away from the "been there, done that" mentality that characterises fast and checklist-based tourism. Symbols are not neutral transfers of information rather they actively shape cognitive framing and decision-making, at least from a user experience perspective. Garlandini and Fabrikant (2009) demonstrate that users tend to interpret symbols pre-attentively, assigning meaning before conscious reflection occurs. As a result, the current symbolisation of POIs can unconsciously lead users to perceive the route as a sequence of tasks to be completed rather than an open exploration of the urban space. This observation is consistent with the findings of Fuest et al. (2021), which show that visual design elements can significantly influence users' route choice and perception, even if the underlying route characteristics remain unchanged. Therefore, after the evaluation, the symbol was adjusted again to create a concise but not overly influential effect.

### 6.2.3 Language Inconsistency as UX issue

Linguistic consistency is another visualisation related issue. The POIs and their descriptive texts were collected in German, as the survey targeted local residents of Zurich. They provided their answers in German as well, and as the prototype directly processes this data, the description and the POIs names are in German. However, the user interface of the routing tool is designed in English, reflecting the assumed primary user group of international tourists. This results in a mixed-language interface in which spatial elements and system controls are presented in English, while POI descriptions are in German. Such inconsistency increases cognitive load and can disrupt the flow of interaction. According to UX design principles, consistency across interface elements is crucial for reducing cognitive effort and supporting intuitive interaction (Dang 2020; Hamidli 2023). This language mix also highlights a methodological tension inherent in the project. The use of locally sourced POIs was a deliberate design decision intended to ground the routing experience in authentic, local-based knowledge rather than generic tourist data. It can be an option to translate these descriptions but it would risk losing nuances, cultural references, or informal expressions that contribute to their experiential value. Consequently, the language inconsistency can be understood not only as limitation but also as a by-product of prioritising authenticity over interface uniformity. It is a trade-off, which illustrates another challenge in experience-oriented system design. The balance of the variety of qualitative, locally grounded content is difficult to design while regarding the usability requirements of a diverse, international user base. In general, the visualisation choices in the prototype show how strongly cartographic and interface design decisions are intertwined with conceptual goals. The use of OpenStreetMap as a clean, map-centred interface supports experiential and sustainable navigation, while the current symbolisation and language setup partially undermine these intentions. Such findings are indications of the implementation of arguments from UX and cartography literature. Visual design will be treated as an integral part of the routing logic and not as a second level added after technical implementation. In future developments, visualisation should therefore be considered a central design element in order to actively support the slow but exploratory and experience-oriented format of city tourism.

## 6.3 System Performance and Computational Trade-offs

The performance of the prototype represents another trade-off, as the integration of multimodal logic, experiential criteria, and exact optimisation methods introduces substantial computational overhead. Unlike commercial navigation systems that prioritise fast response time through heuristic or precomputed routing strategies, the prototype deliberately favours transparency and optimality for small to medium-sized problem instances. This design choice has direct implications for user experience and system responsiveness.

### 6.3.1 Routing Time and User Expectations

There is an observed average waiting time of around 30 to 40 seconds per route request, depending on the mode and the time frame given. It is primarily attributable to the algorithmic design choices. The dynamic programming approach with bitmasking guarantees optimal solutions but exhibits exponential growth in computational complexity as the number of POIs increases. In the context of the Tourist Trip Design Problem, similar limitations have been documented, where exact methods provide high-quality results but are not scalable to large, real-time networks (Gavalas, Kasapakis, Konstantopoulos, et al. 2017; Vansteenwegen, Souffriau, and Oudheusden 2011). From a research perspective, this trade-off is acceptable, as the prototype targets realistic tourism scenarios with a limited number of POIs rather than city-scale routing.

### 6.3.2 PubliBike (GBFS) Integration Issues

The utilisation of external data sources has been identified as a contributing factor to performance limitations. Despite the successful establishment of a technical connection to the PubliBike GBFS interface, access to station data during runtime remains unfeasible. This issue is likely attributable to API rate limitations or other restrictive query parameters. The introduction of these measures was intended to reduce the overall computational load. As is also the case in the literature on multimodal routing, the real-time integration of shared mobility services is defined as a bottleneck for system performance and robustness (Joshi et al. 2024). Consequently, the multimodal logic of the prototype remains largely theoretical, thereby constraining its practical applicability despite its conceptual correctness.

### 6.3.3 Google API Routing Constraints

The walking and cycling segments are estimated to have certain travel-time, both handled via the Google Directions API, provide a stable and widely used time predictions. However, the routing does not explicitly prioritise bicycle-friendly infrastructure, relying instead on general path availability. This reflects a common simplification in routing systems that optimise for travel time rather than infrastructural suitability (Liu 2011). While no routing conflicts were observed during testing, this design choice introduces a structural risk that highlights the tension between computational simplicity and infrastructural accuracy.

## 6.4 Methodological and Technical Limitations

Despite the conceptual contributions of the developed routing prototype, various methodological and technical limitations must be taken into account. This does not invalidate the result, but the findings must be contextualised. The exploratory scope of this work highlights areas that should be refined in the future. A significant methodological limitation concerns the database used to represent the experience and landscape value. The sights were recorded through an exploratory survey of locals, which resulted in a relatively small and subjective data set. Although this approach is in line with user-centred and participatory design principles as explained by Tsou (2011), it limits the generalisability of the results. The perception of landscape is inherently subjective and culturally influenced, which means that the selected POIs reflect specific local perspectives rather than a comprehensive or statistically representative sample of the attractiveness of cities. In addition, there is a seasonal bias due to the timing of the data collection. The POIs were collected in late summer and autumn, a time when outdoor areas such as lake shores and meadows are perceived as more attractive than in darker seasons. Another example of seasonality is the POI 'Swiss Life Arena', which is only of interest during the ice hockey season or for certain events. Seasonal conditions such as daylight hours, weather, vegetation and temperatures influence the behaviour of tourists and their spatial preferences (Butler 2015). As a result, the collected POIs and their descriptions may be overrepresented in the routes, which limits the transferability of the results to winter or off-season tourism. Dependence on external APIs leads to additional limitations. The inability to consistently retrieve data on bicycle rental stations from the PubliBike GBFS interface limits the practical implementation of multimodal routing. Furthermore, travel time calculations based on the Google Directions API do not explicitly consider bicycle restrictions or bicycle-priority infrastructure, which can lead to inaccuracies in route planning. Such simplifications are common in multimodal routing research, where the integration of heterogeneous data sources often requires trade-offs between accuracy and system performance (Joshi et al. 2024; Liu 2011). The evaluation of the prototype is limited by a small sample size in terms of user-friendliness. The survey was conducted by directly approaching individuals, which means that it does not provide a neutral basis. The qualitative user study provided valuable insights into the clarity of the user interface, but does not allow for statistically sound conclusions about user behaviour or satisfaction. These limitations are therefore consistent with the exploratory nature of design-oriented research and reflect the iterative development process, as emphasised in the literature on UX and web cartography (Hamidli 2023). Taken together, these limitations emphasise that the developed routing prototype is best interpreted as an experimental and research-oriented system. Its value lies more in demonstrating the feasibility and impact of integrating experiential, sustainable and multimodal criteria into urban routing than in providing a universally applicable navigation solution.

# Chapter 7

# Conclusion

This thesis explored how urban routing systems can move beyond efficiency-driven navigation towards more sustainable and experience-oriented tourist exploration. Zurich as a case study was ideal to develop a prototype routing tool that integrates multimodal mobility with experiential criteria, operationalised through locally collected POIs and dynamic-programming-based routing algorithm.

Demonstrated by the results, the technical feasibility to generate personalised tourist routes that prioritise experiential value is given. It is shown that time constraints and multimodal travel options still can be respected. By modelling the routing problem as a variant of the Tourist Trip Design Problem and implementing a bitmask-based dynamic programming approach, the prototype was able to compute optimal or near-optimal city routes for moderate numbers of POIs. This confirms that exact algorithmic approaches remain practical for typical tourist scenarios and can provide transparent and reproducible routing decisions.

This work highlights beyond the technical implementation the importance of user-centred design in routing applications. The exploratory survey with local residents enabled the creation of an authentic POI dataset grounded in lived urban knowledge. This, while the usability evaluation with tourists provided qualitative insights into interface clarity, learnability, and perceived usefulness. Although the evaluation sample was small, feedback indicated that users valued the idea of experiential routing and appreciated routes that encouraged exploration rather than merely optimising for speed.

From a conceptual perspective, this thesis contributes to ongoing discussions in Tourism 4.0 and smart mobility by demonstrating how experiential and environmental criteria can be embedded into routing logic. A shift from node-based attraction planning toward route-based urban experiences is illustrated by the prototype. Walking segments, neighbourhoods, and transitions themselves become meaningful components of the journey. In doing so, the project aligns with broader goals of sustainable tourism by encouraging slower modes of transport and potentially distributing visitor flows more evenly across the city.

However, several limitations must be acknowledged. The prototype relies on a small, manually collected POI dataset and external routing APIs, which constraints scalability and reproducibility. The usability study involved only a limited number of participants, preventing statistically robust conclusions. Furthermore, real-time transit data, dynamic disruptions, and explicit $CO_2$ calculations were not fully implemented, while multimodal routing was conceptually integrated.

Future work could address these limitations by handling larger and more diverse datasets or integrating real-time public transport feeds. Extending the optimisation criteria to explicitly include environmental indicators such as estimated emission could also be worked on in the future. Additional UX iterations and larger user studies would help refine interface design and validate experiential benefits more clearly. Moreover, replacing external routing services with fully open-source solutions and expanding scenic scoring to include contextual data, like greenery, noise levels, crowd density, would further strengthen the system.

Overall, this thesis demonstrates that routing can be reimagined as an experience-shaping practise, not merely a problem of optimisation. Experience-oriented routing represents a promising step toward more humane, flexible, and meaningful urban navigation systems.

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## Appendix A

# Appendix

### A.1 Usability Survey Results

## Usability Survey Results

### Question 1

What is your first impression?

| Participant | Response |
|---|---|
| 1 | Great tool to plan a day in zurich, easy and userfriendly |
| 2 | I really like it, because I can freely choose a location on the map or select my current location.<br><br>The best thing is that I'm able to set time - so I have an idea on what locations (route) fits best to my schedule. |
| 3 | It was only in German. I understand it but for Tourists English might be needed. |
| 4 | Looks like a handy tool but not fully developed yet. the interface looks quite raw. |
| 5 | It seems very practical that, firstly, exciting places are suggested and, secondly, an efficient route is created right away. This could save a lot of time in planning. |
| 6 | It is nice. I like that I get a little explanation for each point, even though it was in german. |
| 7 | looks a bit rough on the edges, but easy and intuitive to use, has all the necessary functions for basic trip planning |
| 8 | Simple and with a good overview |

### Question 2

Was it clear how to start using the tool? Why or why not?

| Participant | Response |
|---|---|
| 1 | yes it was quite easy to navtigate on the laptop, took some time to calculate the route |
| 2 | It was very clear - the buttons are labeled accordingly to their functions. Within the drop down menu I can choose my mode of transportation. I would say, using the routing tool feels obvious. |
| 3 | Yes, but I wanted to insert a name into the start and end field which was not oossible somehow. So I selected on the map. |

| | |
|---|---|
| 4 | Yeah, i'd say so. The instructions where quite clear. |
| 5 | Yes, it was. Because everything is presented very clearly and is well labeled. |
| 6 | Yes it was clear how to start the tool. Because it was named starting point and was on the top of the site. |
| 7 | it's pretty straight forward, well described and the function to use your current location as a starting point is a nice extra |
| 8 | Yes, the only confusing thing was the different languages..parts are in english and parts in german |

## Question 3

How easy or difficult was it to accomplish creating a route?

| Participant | Response |
|---|---|
| 1 | very easy |
| 2 | It was very easy and clear to me. I would say it's not difficult at all.<br>Also when I didn't selected a end point, I received an error message clearly stating, that no end point was set - very clear for a user. |
| 3 | A bit difficult because of using it on the phone. |
| 4 | Not difficult at all |
| 5 | Really easy. |
| 6 | It was easy with giving just the timeframe and starting/ending point. |
| 7 | very easy, no problems |
| 8 | very easy, it worked by first attempt |

## Question 4

What are problems you were facing while using the tool?

| Participant | Response |
|---|---|
| 1 | It doesnt pay attention to the season or weather neither to the openingtime of the POIs. |
| 2 | No problems really, only the creation of a certain route took long time compared to the other routes. |

| | |
|---|---|
| 3 | Turning the phone around so that everything fits (done on an iphone 15). |
| 4 | I was using it on a mobile device, so the map wasn't visable at first. |
| 5 | No problems. |
| 6 | I would like to take out some points of the route which I may already visited or are not for the season at the moment (like Letten in Winter). I would like to give preferences in what I am interested like museum, architecture, bar ect. Or I would like to have more time specific points like Christmas markets in winter, swimming places in summer ect. |
| 7 | the loading time for generating a route was rather long, was not sure if it's still loading or just stopped working |
| 8 | no problems at all, only the christmas markets are not included, that would have been nice |

## Question 5

Did the generated routes meet your expectations? Why or why not?

| Participant | Response |
|---|---|
| 1 | Yes it was a realistic Route during this time, although it does probably not include time to spend there at the different POIs only the way between the points.<br>Also it would be cool to get the Infos from Google maps, when clicking on the POIs eg. Opening Times, Link to the website. |
| 2 | It meets my expectations because it does exactly what it should do. As a tourist with a limited time frame, I want to see as much as possible in terms of sights. Therefore I really like it! |
| 3 | It seemed very nice, cool that you can give a time and then it kinda fills your given time frame nicely!<br><br>The texts about the points along the route were very different in style and writing and how much info they give - I would generalise that. |

| | |
|---|---|
| 4 | Yes it did. I estimate my timeframe is matched quite well. |
| 5 | Yes, partly. I’m still missing a tool where you can choose your preferred genres and remove places you’re not interested in. |
| 6 | I liked the route I took me through nice places and I really liked the explanation of each point. Maybe I would be nice if it is giving information about the Kilometer length or some information about the altitude differences on the route. |
| 7 | the generated routes definitely met my expectations |
| 8 | Yes, and we actually needed less time than calculated by the tool, it was cool to take some routes, we wouldn't have taken otherwise |

## Question 6

How would you describe the layout and structure of the interface?

| Participant | Response |
|---|---|
| 1 | Clean and userfriendly |
| 2 | Clear and user friendly and not overloaded. One directly understands the purpose of the tool. I only would recommend changing the title "route planner" because if someone misses the context (for instance by requesting the page directly) it could be maybe misunderstood and perceived as a tool for public transportation or route in general. |
| 3 | In general userfriendly, except language and selecting on map on the phone |
| 4 | Looks raw and quite simple |
| 5 | I thought the interface was great overall. My only points would be the ones mentioned above. |
| 6 | I like the layout and simplicity of the interface. It is very clear. I would also like different icon depending on the Place like a bar is a little drink, or good view is a binaculars. |
| 7 | as said before it looks a bit rough but still usable.<br>things that i would like to be added: |

| | |
|---|---|
| | - a loading bar for the generation of the route,<br>- a numbered list of the POI's with corresponding numbered points on the map (not just checkmarks)<br>- an adaptation for mobile usage (an app etc.)<br>- an option to save and/or export your generated routes |
| 8 | it is clean and userfriendly, a good overlook on the map |

## Question 7

To end the survey: Would you use this tool again? Why or why not?

| Participant | Response |
|---|---|
| 1 | Yes, I would, especialy if I would go to Zurich again with a friend that hasn't been here. |
| 2 | Sure, because when someone plans a city trip, most of the time it's difficult to find out if it's possible to get to several sights with a specific timeframe. With the route planner I know what can I see based on my personal time making my city trip extremely efficient in terms of time spend planning but also visiting - I have got the feeling that I saw the most important things based on my available time.<br><br>Unfortunately not available for other cities. |
| 3 | Yes I can imagine using it also in other cities! |
| 4 | Yeah maybe i would. Would be nice to have more options when it comes to ways of transport, like buses for example |
| 5 | Yes, I could see myself using it when needed on efficient city trips to save time. |
| 6 | Yes, if I could choose more between categories I am interested in for sure! |
| 7 | i would definitely use it again, just because it is so easy to use and it takes a lot of the planning load of your shoulders. |
| 8 | yes we would, also in other cities |

# Copyright Statement

Personal declaration: I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis. The AI models Gemini (Google), ChatGPT (OpenAI) and DeepL Write were used as follows:

- Brainstorming, error finding and performance issues with ChatGPT for the implemented application code
- Layout the thesis using latex with ChatGPT
- Set up the virtual environment and deploy the prototype with Gemini
- Stylistic improvements of this text with DeepL Write

Signature: L. Hürlimann

Zürich, Schweiz, January 2026 Larissa Hürlimann