Cartography M.Sc.

Master thesis

Cool Streets – Developing a Healthy Urban Route Planner

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Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master thesis entitled:

Cool Street - Developing a healthy Urban Route Planner

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Munich, 22.10.2022 Jiaying Xue

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Abstract

This study aims to find health-optimized navigation routes to minimize the adverse health impacts in urban regions. Synthetic data of AQI and temperature are generated and selected as costs to calculate the least polluted and coolest paths, respectively. Additionally, the cartographic design principles for interface and theories of visual attention required for symbol designs have been explored. The cartographic web interface has been created based on the principle of interactive web design, allowing users to interact by trying the functions, including route searching, route selection, and locating. A comprehensive user study has been carried out for usability and utility evaluation. Thirty participants were invited to complete the questionnaire. The quantitative analysis showed predominantly positive results on the assumptions of visual attention and the prototype's performance, while the qualitative results provided valuable ideas on the possible enhancement of the prototype. A self-assessment is conducted to verify whether the initial research objectives are fulfilled; the limitations of this study are discussed in terms of data used, routing algorithm, and user study, with a possible outlook for future work.

Key words: health-oriented routing, interactive web map, interface evaluation

Contents

List of Figures

List of Tables

1 Introduction

1.1 Motivation

As a large human settlement, city supports a large amount of population and human activities. Following unprecedented and rapid urbanization, over 50% of the world's population lives in cities. According to updated world urbanization prospects, this value is expected to boost to 66% (UN, 2015). However, intensifying urbanization leads to immense energy needs and severe environmental pressure (Lin & Zhu, 2018). Consequently, cities have been the hotspots of pollution and diseases, significantly undermining the satisfaction of life of their inhabitants (Galbrun et al., 2016). The growing city scale is accompanied by augmented human activities, switches in traffic mode, and increasing energy consumption (Lu et al., 2021). As one of the negative impacts, air pollution has especially caused broad attention globally (Wang et al., 2012).

Primary air pollutants are those transmitted into the atmosphere or those synthesized within the atmosphere, including sulfur dioxide, nitrogen dioxide, carbon monoxide, volatile organic compounds, ozone, and secondary particulate matter (PM) (WHO, 2021). Research has shown that exposure to urban air pollution leads to several adverse effects on human health. It has been proven to be associated with increased heart problem rates and mortality (Lü et al., 2015). Observations from 6488 participants were analyzed and found that residential exposure to fine PM might contribute to chronic impacts on cardiovascular disease (Viehmann et al., 2015). For vulnerable groups like the elderly and children, a clean air environment would be even more essential. Studies found that long-term exposure to air pollutants, including O3, PM10, and NO2, is remarkably related to lung function weakening in Children (Rojas-Martinez et al., 2007). Moreover, among major urban air pollutants, PM2.5 is the most related to allergic sickness in children (Lee et al., 2014). It was also indicated that exposure to traffic-related air pollution rises the danger of asthma hospitalization for elderlies, especially for people with past asthma (Andersen et al., 2012).

Apart from air pollution, urban regions face urban heat hazards caused by urbanization and industrialization. Urban heat islands are mainly caused by anthropogenic heat and vast amounts of heat produced by metropolitan structures because buildings and streets trap heat and thermal radiation and hamper air circulation (Rizwan et al., 2008). The heat from the two sources raises the temperatures in urban regions, compared to the surroundings, which is even worse in the cities with dense populations and large economic activities. Studies investigated the effects of heat risk on human health. Researchers from China found increased heat-related mortality in urban regions on hot summer days. They indicated that urban heat island is directly associated with worsening the adverse health effects of exposure to severe thermal environments (Tan et al., 2010). Besides the hazards caused by extreme heat waves, daily thermal comfort also plays a role in dweller health (Attema et al., 2015). Therefore, human thermal comfort is an important indicator of a healthy urban environment. However, as air pollution and heat are temporally and spatially uneven distributed, strategies have been implemented to mitigate the air pollution and heat to enhance pedestrian walkability and thermal comfort, including tree planting, shading of trees or buildings, and solar-reflective materials (Nasrollahi et al., 2020). As the idea of Smart City has drawn broader attention, strategies that cope with harsh city dilemmas to support optimized traveling and enhance residents' quality of life are strongly desired (Benevolo et al., 2016)Further than conventional navigation services, which commonly design the fastest, the least traffic, and the least expensive routing options, a more personalized and health-oriented routing application, especially for urban pedestrians and cyclists, is in high demand.

This thesis focuses on a navigation criterion that optimizes human comfort, health, and efficiency, by providing less polluted, more comfortable routes for walking, jogging, and cycling, with properly designed navigation interfaces and routing options. This will provide insights into more personalized navigation solutions and facilitate the goal of a smart city and healthy urban planning. Additionally, this thesis explores efficient interface visualization: surveys focus on users' attention distribution on map style, geometry visualization, and interface design are conducted to verify the balance between visual attention and distraction, ensuring the visual importance of healthier routing paths.

1.2 Research Objectives and Questions

This study will present health-optimal navigation options for pedestrians and cyclists to minimize pollution exposure while considering human comfort and travel efficiency. By integrating air quality, temperature, and street network datasets on a local scale, this thesis aims to develop a web application prototype in which users can select their navigation decision based on their preferences and demands. Besides, this research will test and analyze the effectiveness of the web prototype in terms of attention distribution, interface design, and user experience through a comprehensive user study. The objective will be further divided into the following three sub-objectives:

- To develop a web application prototype that helps find health-optimal paths in Munich. The prototype interface will contain interactive basemaps and features, including buttons, search boxes, checkboxes, etc. Customized cost and path-finding methods will be proposed to provide solutions that take effectiveness, health, and comfort into consideration, which is suitable for multiple scenarios.

- To investigate efficient means in health-related urban data visualization and map design for the interactive web interface. The outcome of web map design is supposed to balance the visual attention of different contents and match the theme of the map, which is easy for users to understand and operate.

- To evaluate the usability, applicability, and user experience through user study through a questionnaire. Surveys will be conducted to collect users' feedback and opinions about using the web application in terms of utility and usability.

To achieve the objectives above, research questions are separated into four phases. More specific research questions are proposed below.

1. **Background investigation:**
    a. What can be the proper methods for health-oriented routing?
    b. What can be the suitable ways to conduct the user study?
    c. What do the interfaces of other existing navigation applications look like?

2. **Data and algorithm:**
    d. What is the study area of this study?
    e. How is the data structured?
    f. How to generate health indicators properly?
    g. What are the weights for different routing options?
    h. What route-finding algorithm should this study apply?

3. **Visualization and map design**
    i. What are the principles of web map visualization?
    j. What does the web interface look like?
    k. What features should the interface include?
    l. Which color, style, and symbology are suitable for navigation routes visualization?

4. **Application evaluation**
    m. What are the possible methods and procedures to implement user study?
    n. How good are the visualization and interface design?
    o. How to analyze the results of the user study?
    p. How can this application be improved?

The hypothesis that runs through the whole study was that this web application is helpful and applicable in practice regarding learnability, effectiveness, and contentment. Differences in participants' performances in attention distribution can be observed in different cases.

1.3 Thesis Structure

This thesis consists of the following five chapters:

Introduction
This chapter mainly clarifies the motivations, hypothesis, and research objectives of this thesis. Detailed research questions in each phase and the general outline of this thesis are listed and explained.

Background information and Related works
In this chapter, previous related work will be reviewed and summarized. It introduces the existing approaches and applications in creating environment-related or user-specified routing solutions and summarizes feasible attention guide techniques to highlight desired map contents. It will also clarify the cartographic principles in map interface development and introduce the methods to conduct the user study and evaluate and analyze the results.

Methodology
This chapter concerns the research design. It specifies the methods for every research question above, including data processing, routing algorithm, and user study analysis in detail.

Results
The results of the prototype and user study are presented in this chapter. It contains the appearance outcome of the interface, the performance of routing prototype, and results of quantitative interpretation and thematic analysis of user study.

Discussion
This chapter will evaluate this study's outcome by verifying whether the research questions are answered and whether the research objectives are achieved. Challenges and limitations that appeared in prototype development, and user study will be discussed. Possible improvements and suggestions for further study will be put forward in the end.

Conclusion and Outlook
This is the last chapter that sums up the thesis. Key findings, the main constrains of this study in performance, together with the opportunities for future research are presented.

2 Background information and Related Works

This chapter provides an overview of relevant research on novel routing applications and background knowledge for visualization and interface design. It answers *Research Question 1* and provides theoretical guides for *Research Question 3*. This chapter is separated into five sections. The first section introduces the universal air quality index for measuring pollution levels. The second part shows previous studies and methods for customized routing applications, providing insights into determining routing weights or costs. The following section summarizes the cartographic principles for map design and interface design for routing applications, acting as guidance for visualization compared to existing navigation apps. The fourth section suggests suitable techniques for attention guiding, which helps improve the effectiveness of the application. The last section will review the existing user studies and interface evaluation methods to assess the application from users' feedback, followed by a brief conclusion.

2.1 Air Quality Index

Air quality is a measure of how clean or polluted the air is, which deteriorates with an increase in the concentration of pollutants and can be measured by near-road monitoring sensors for urban road networks (Baldauf et al., 2009). Air Quality Index (AQI) is a tool for identifying changes in the amount of air pollution (Nigam et al., 2015). There are different AQI systems across different countries and regions. Each standard has its definition and uses its hazard index based on pollutant concentration.

Common Air Quality Index (CAQI) is the AQI system used in some European countries, measuring the three major air pollutants with the scale of Very Low (0-25), Low (25-50), Medium (50-75), High (75-100) and Very High (> 100). It takes major pollutants of PM10, O_3, and NO_2 into consideration. Pollutants, including PM2.5, CO, and SO_2, are included in the calculation if available. CAQI considers the core pollutants for the calculation of the index. For urban environments, O_3, PM10, and NO_2 are mandatory components, with CO and SO_2 as supplementary components. For traffic sites, NO_2 and PM10 are mandatory, with CO as a supplementary component (Van den Elshout et al., 2008). A more widely used AQI developed by the United States Environmental Protection Agency ranges from 0 to 500, based on the concentrations of five major pollutants. Given that most websites prefer the US AQI system for displaying air quality levels in Germany, this thesis adopts the US standard in calculating AQI for the study area.

The US AQI has six categories, which are divided based on their impact on health. Level "Good" with a value of 0-50, "Moderate" with a range of 51-100, "Unhealthy for Sensitive Groups" with a range of 101-150, "Unhealth" with a range of 151-200, "Very Unhealthy" with range 201-300 and "Hazardous" with a range of 301-500 (*Figure 1.* Six categories of US AQ). The darker the color, the higher level of danger to health (ZAHMATkeSH et al., 2015). The major harmful pollutants involved in the computation are O_3, PM2.5, PM10, CO, SO_2, and NO_2. For each pollutant, a separate AQI is calculated by converting its concentration. The overall AQI for a particular area is represented by the highest AQI value among the five major *pollutions (Plaia & Ruggieri, 2011)*.

The AQI value for each pollutant is calculated by *Equation (1)*, where Cp is the measured concentration of the pollutant, BP_{hi} is the breakpoint that is over or equal to Cp and BP_{lo} is the breakpoint that is less or equal to Cp. I_{hi} and I_{lo} are the AQI value of BP_{hi} and BP_{lo}, respectively. *Table 1* shows the classification of concentrations of pollutants and AQI values.

$$AQI = \frac{I_{hi} - I_{lo}}{BP_{hi} - BP_{lo}} (Cp - BP_{lo}) + I_{lo} \tag{1}$$

Table 1. Breakpoints for the AQI

US AQI	O_3 (ppm)	PM10 (ug/m³)	PM2.5 (ug/m³)	CO (ppm)	SO_2 (ppb)	NO_2 (ppb)
0-50	0-0.054	0-54	0-12	0-4.4	0-35	0-53
51-100	0.055-0.07	55-154	12.1-35.4	4.5-9.4	36-75	54-100
101-150	0.071-0.085	155-254	35.5-55.4	9.5-12.4	76-185	101-360
151-200	0.086-0.105	255-354	55.5-150.4	12.5-15.4	186-304	361-649
201-300	0.106-0.2	355-424	150.5-250.4	15.5-30.4	305-604	650-1249
>300	>0.2	425-604	250.5-500.4	30.5-50.4	605-1004	1250-2049

Figure 1. Six categories of US AQI

2.2 Route Navigation

Previous studies into route navigation applications tend to concentrate on the utilitarian facets of traveling. Those systems were built to generate routes that minimize the travel cost in distance or time (Fu et al., 2006). Beyond traditional utilitarian attributes (i.e., distance and time), the urban route navigation system is switching to offer more dimensions in route recommendation (Siriaraya et al., 2020). More and more attention is being given to algorithms that recommend paths that underline user's enjoyment, well-being and safety, especially for pedestrians and cyclists, such as routes with higher aesthetic quality, less pollution, and a higher sense of security (Garvey et al., 2016). Golledge (1995) indicates the difference in navigation traits between drivers, pedestrians, and cyclists. Pedestrians and cyclists tend to have other route qualities further than shortness, such as comfortableness, attractiveness, and safety. This section reviews the academic articles about route navigation systems for quality-aware navigation, including their weighting function, route algorithms, highlights, and limitations.

2.2.1 Shortest Path Algorithm

Dijkstra's algorithm is one of the most famous algorithms for shortest pathfinding. It is also the first algorithm to use "shortest-first search strategy" (ZAHMATkeSH et al., 2015). It is an iterative algorithm to find the shortest path from a node to target nodes in the graph, generating the shortest route. Dijkstra's algorithm starts from the source node and assesses the whole graph to decide the shortest way between the source node and all the other nodes. Then the algorithm keeps track of the determined shortest path from the source node to other nodes and renews the distances iteratively if a shorter path is spotted. The node is marked as "visited" once the shortest path from the source node to the node has resolved. The process will terminate when all the nodes in the network have been labeled the status "visited". The shortest paths connecting the source node to all the other nodes are generated (Dijkstra, 1959). Because the weights of the edges need to be summed to determine the shortest path, the weights have to be positive. This thesis adopts Dijkstra's algorithm for wayfinding because the advantages of Dijkstra's algorithm include that it is applicable to both directed and undirected graphs, and the cost of each edge can be customized. Additionally, libraries of Dijkstra's algorithm are widely accessible in different programming languages and tools, which makes it possible to quickly implement shortest path analysis.

2.2.2 Health-oriented Route Navigation

Mahajan et al. (2019) came up with the CAR (Clean Air Routing) algorithm to create a route recommendation system that minimizes exposure to PM2.5. The open-source PM2.5 concentration data was interpolated spatially and temporally to produce air quality measurements for each time interval and location and combined with the street network. They assign weights at the intersections based on PM2.5 calculated value and used A* algorithm for pathfinding. They also develop a feedback session to collect users' opinions to monitor and improve the application's performance. The results suggest the CAR algorithm can reduce 17.1% of exposure on average, with an increased distance of 2.4%. Besides, assigning interpolation value to road segments, Müller and Voisard (2015) create a grid-based air quality layer. They came up with an approach to generate air quality adjusted routing using the Open Source Routing Machine (OSRM) and Berlin map data. Instead of assigning air pollution as a cost in each road segment or intersection, this research creates 1x1km grid of PM10 pollution. Results showing the air quality adjusted routes avoided the city center to reduce the total exposure. However, the route is around 22% longer than the shortest path; and the resolution for the PM10 emission grid is not fine enough to generate a route when the origin and destination are within one cell. Ramos et al. (2018) use an air quality sensor network to promote pollution-free routes according to the pollution in every zone in Madrid. They use IDW interpolation to interpolate the air pollution distribution in the study area and achieve to trace route in real-time. They developed a platform that can be used as a building service to help people be aware of the surrounding air quality. Similarly, Vairamuthu et al. present a pollution-based navigation system for citizens to reduce pollution exposure. They place sensors in the traveling zone and collect data in every 10 minutes. The value will be published to the cloud, where the rest of the processing will take place. The cloud is linked to mobile devices and will transmit the data to client side when required. Users could specify their threshold on the maximum pollution they are willing to tolerate. Lastly, the routing solution could be generated using Dijkstra's algorithms or Google API.

Different weighting functions of routing algorithms are introduced in this session as well. ZAHMATkeSH et al. (2015) compare the three navigation route calculation methods based on different parameters: distance only, AQI only, and both distance and AQI. After normalizing the parameters, the weight of AQI is double the weight of distance factor, which are 0.33 and 0.67, respectively. The results indicate that the combination of two parameters avoids the high influence on the route while balancing the efficiency. Sharker and Karimi (2014) introduce a weight function that calculates weight based on Air Pollution Exposure (APE), using geostatistical and non-geostatistical methods to derive APE. For the non-geostatistical method, inverse distance weighted (IDW) interpolation estimate the AQI for each road segment based on the observations at nearby stations. For the geostatistical method, Kriging interpolation is used to generate the AQI layer over the street network. Representative AQI is computed as the average AQI value over sample stations for the network segment. Instead of summing the AQI value of road segments together, it takes travel time into consideration when estimating the total air pollution exposure. The weight of each road segment is then calculated by multiplying the estimated time and AQI value. Another study (Steeneveld et al., 2017) developed a route planner for bicyclists and pedestrians in Amsterdam to reduce pollution and heat stress by using the pgRouting library and open-sourced network. The air pollution and temperature indicator are merged into one factor to represent the surrounding environment. The optimal route is computed by the Dijkstra algorithm, with air pollution and temperature as the cost to minimize. This study is a helpful case on using open-source libraries and data to build a customized routing planner. Similar to finding the cleanest air route in the urban environment, route navigation used for minimizing city heat stress also drew attention. Rußig and Bruns (2017) suggest an approach to decrease heat exposure in Karlsruhe city. It is said many daily activities can be done by walking, especially in European cities, such as buying groceries and going to the pharmacy. Through changes of different navigation routes or the time to conduct the navigation tasks, it is possible to reduce heat exposure and adverse health effects. Rather than using wide-ranging sensors, they combine fixed stations and remote sensing data in two steps, which are firstly to determine a walking path with minimum heat stress, and secondly to determine the best time to begin the travel in this path. Two parameters used in weight functions are distance along the edge and the heat exposure of the edge at a specific time. The weight value, therefore, is not fixed; it changes over time, which is one of the highlights of this study.

Except for those parameters from outside environments, researchers also explore other factors to deliver a more comprehensive health-optimal route navigation. Sharker et al. (2012) propose a novel weight for path segments to calculate health-oriented routes. Instead of only focusing on urban health indicators, this study also pays attention to the health conditions of pedestrians. They build a weighting model with detailed influencing variables, such as walkability, segment complexity, safety, distance, users' BMI, and walking speed. The overall cost is calculated by combining environmental and individual variables, which can then be used to derive a health-optimal route. This project shows an inspiring perspective to create a comprehensive weighting model for health-oriented route navigation by also considering personal factors. Another trip recommendation also considers individual physical information. Allemann and Raubal (2013) put forward a health-atlas platform, which serves as a navigation tool that integrates all possible transportation modes and recommends the healthiest path from the source to the target location. It is encouraging that recommended trip is displayed in real-time based on the underlying road network and public transit timetable. Additionally, a questionnaire-based empirical study is conducted to evaluate users' opinions regarding the healthiness of a trip among different user groups. Apart from information from individuals, more elements and factors can be extracted and taken into consideration. Wakamiya et al. (2019) focus on routes that are related to enjoyment in urban areas. Pleasure scores are extracted by the colors and objects from Google Street View images. They used the street layer in OpenStreetMap to build a road network and collected information from panoramic images in Google Street View to assign surrounding information to the nearby road segments. This article provides insights into the importance of the impacts of nearby surroundings when designing route navigation.

The routing algorithm of this paper will adopt the environmental indicators, i.e., air quality and heat as costing factors, to conduct route planning for pedestrians and cyclists without taking the user's health condition into account. Like most existing works, this study will also try to assign values to road segments and customize the weighting function for routing queries.

2.3 Map Design Principles

Apart from the accuracy and quality of weight functions and route algorithm, excellent visualization and design make a great map. This sub-chapter will introduce cartographic principles, visual variables, and interactive interface design for web mapping briefly.

2.3.1 Visual Variables

Map design is an artistic process of visual communication involving thoughtful thinking to convey the map's message through careful arrangement, symbol and color selection, and content aggregation (Otto et al., 2011). The symbol primitives of point, line, and area are the three fundamental representations of entities in maps. In various GIS applications, these representatives are known as marker, line, and polygon or called dot, dash, and patch (Robinson, 1960). More than half centuries of map-based study on perception, cognition, and semiotics, in other words, are how maps are viewed, interpreted, and ingrained with meanings – have been contained into the theory of cartographic representation. Among them, the identification of the visual variables can be considered one of the most important academic findings (Roth, 2012).

Through the variation of the basic visual variables, these fundamental visual representations can be differentiated to convey connections among or disparities between the data (Otto et al., 2011). Breaking down the map into its individual visual components helps diagnose and redefine ambiguous or polysemic map symbols, which enhances cartographic communication (Roth, 2017). The concept of visual variables is firstly proposed by Bertin (1967) and has a profound influence on cartography and data visualization. Despite its significant impact on the field of cartography, the consistent taxonomy of visual variable contents is still missing. *Figure 2* displays a set of 12 visual variables that incorporates remarkable attributes within cartography.

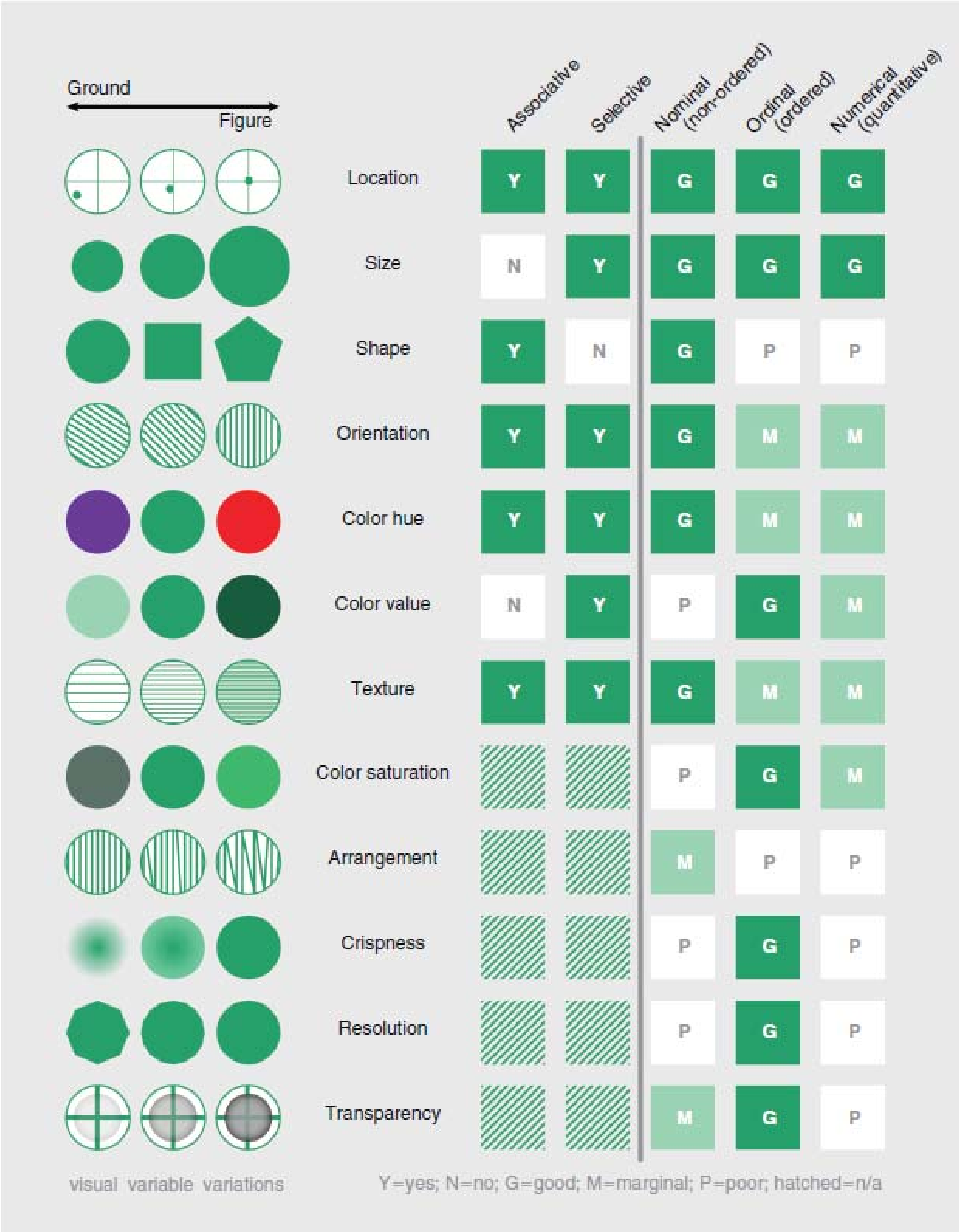


Figure 2 Visual variables adopted from Roth (2017).

Among them, the initial set of visual variables is demonstrated by Roth (2017). In cartographic design, *location* is given visual precedence over the others. It is used to depict the position of a map symbol relative to a spatial coordinate system.

Size is one of the primary visual variables and describes how much space the map symbol takes. *Shape* is an important variable used in qualitative point symbols. It describes the symbol outline. Rotation or direction of a symbol from the "normal" status is depicted by *orientation*. Perception of color relates to three attributes: color hue, value, and saturation. The main wavelength of the map symbol in the visible region of the electromagnetic spectrum is described by *color hue*. The *color value* of a map symbol represents the proportionate quantity of energy it emits or reflects. *Color saturation* also termed “chroma” or “purity”, indicates the map symbol’s spectral peaking over the visible spectrum. Considering the case of this thesis, which is to design an interactive map and line symbols for displaying navigation routes, visual variables like color hue, value, saturation, and size are given more attention.

2.3.2 Graphic Design Principles

Map symbols take many forms. Although people discern symbols differently, and it is nearly impossible to build up an approach for the usage of visual variables in cartographic production that is accurate and objective (Bláha & Štěrba, 2014), map readers seem to react to the visual variable system in a predictable mean. It allows map makers to develop map symbols for the majority groups of information, which can be understood and interpreted by readers as wanted (White, 2017). *Figure 3* lists common visual variables for point, line, and area features.

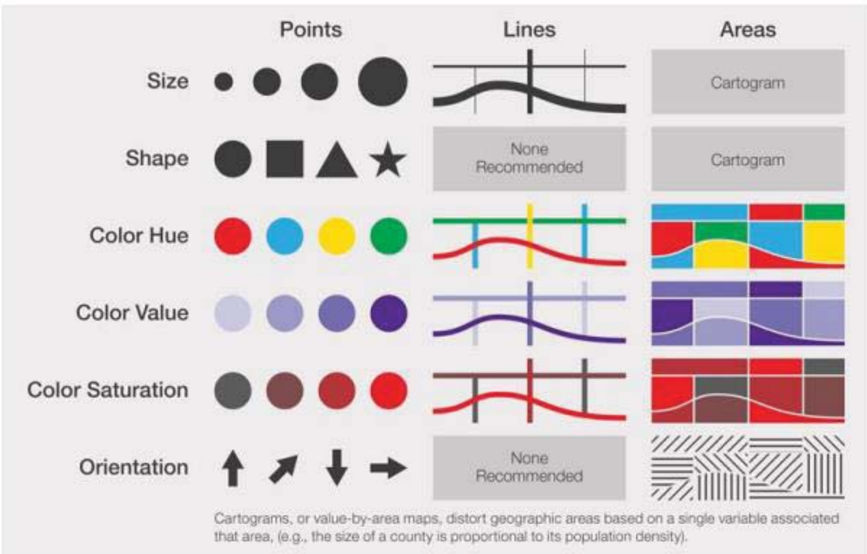


Figure 3. Common visual variables for point, line, and area adopted from White (2017).

In contrast to texts or talks, maps are a visual medium that stimulates visual stimuli that generate various emotions in people. Comparing human communication using maps to other forms of communication is greatly different. Information is conveyed sequentially, with each sentence coming after the one before it, in both literature and spoken dialogues. Maps and other forms of graphic communication, however, present all the information at once (Otto et al., 2011). Therefore, great care should be given to how graphic elements look and are composed. All information is spatially connected and must be viewed as a whole on a map. According to Robinson (1995), the principles of map graphic design contain “legibility, visual contrast, and figure-ground perception”. Among them, legibility is considered the most essential principle, which highly relies on symbol size and density. Thus, looking for the proper balance between size and the number of symbols used is crucial for this thesis. Contrast is also an important factor for the visibility of a map. Appropriate contrast between graphic components can largely improve the visibility of the map, which can be realized by adjusting the size, color, or shape of a symbol. Figure-ground perception refers to a person's capacity to differentiate items from their surroundings. Based on the above reviews, in this thesis, the line symbol indicating the navigation route should be considered thoroughly with the size (i.e., line width), color, and contrast among different route options and basemaps, to properly emphasize the map content and catch the reader's attention.

2.3.3 Color Selection of Web Mapping

Color is considered the most significant visual variable that mainly describes qualitative variations. According to Lee and Qian (2004), color selection is vital in building impression since colors have sensibility and are associated with certain pictures or feelings. Variations in color dimensions, which are hue, value, and chroma, are the most effective tools for addressing or highlighting objects on the map (Otto et al., 2011). The meanings of the terms are explained in Table 2. Since the beginning of cartographic production, color has been crucial to the aesthetic interpretation of maps. As one of the visual variables, color seems to leave a stronger effect on map readers than the other variables. Evidence indicates that particular emotions may be aroused by certain colors, which affect users' behavior and decision significantly (Chesneau et al., 2005). Map contents with well-selected colors can be emphasized and distinguished effectively, while improper color design can negatively impact the perception of the information illustrated (Bláha & Štěrba, 2014). The perception of color has impacts on both physical and psychological aspects. Particular colors, such as the so-called warm color (red, yellow) and cold colors (blue), carry conscious or unconscious meanings (Otto et al., 2011). The majority of meanings arise from the various wavelengths that result in different times when the color reaches the eye: colors with long wavelengths, such as red and orange, are noticed earlier and look to be closer, yet colors with short wavelengths, like blue, are noticed later and seem to be farther (Otto et al., 2011).

Table 2. Definition of color hue, value, and saturation.

Hue	Describes color families, used to differentiate one from another	
Value	Relative lightness or darkness of a color	
Saturation	Intensity of a hue from gray tone (no saturation) to pure	

The readability of the map can be enhanced by proper usage and combination of colors. To reduce confusion and misunderstanding, some "color conventions" in cartography should be followed. The term "color convention" refers to the concept that some colors may stand for potential connotations. For example, green is normally associated with vegetation; blue is generally used for representing water-related entities. The commonly applied color conventions in graphic design are summarized in Table 3. It is more like application standards or recommended practices to specify color selection, which illustrates the common color usage (Grossman, 1992). ColorBrewer, as an online tool for color schema selection, is recommended by Harrower and

Brewer (2003). It guides mapmakers to determine the proper color schema for thematic maps and test maps together with a legend for multiple display environments.

Table 3. Color conventions (Grossman, 1992)

	Cartographic	Symbolic	Remarks
Blue	Hydrography (water), sky, cool	Advisory	Deeper saturations indicate greater depth, colder
Green	Vegetation	Go, good, on, safe, right, or starboard	Deeper saturations indicate heavier vegetation
Yellow/Tan	Dryness, medium temperature, medium elevation, lack of vegetation	Caution, standby, warning	
Brown	Land, mountains, warm		
Red	Important items, roads, cities, hot	Stop, bad, danger, off, warning, enemy, unsafe	Flashing red indicate emergency
White	Ice, high elevation	Neutral	

2.3.4 Cartographic Interaction

Cartographic interaction, as one of the crucial aspects of cartographic representation, is identified as the communication between the user and the map mediated through a computing device (Roth, 2012). The association between the three components is shown in *Figure 4.* Components of cartographic interactions.

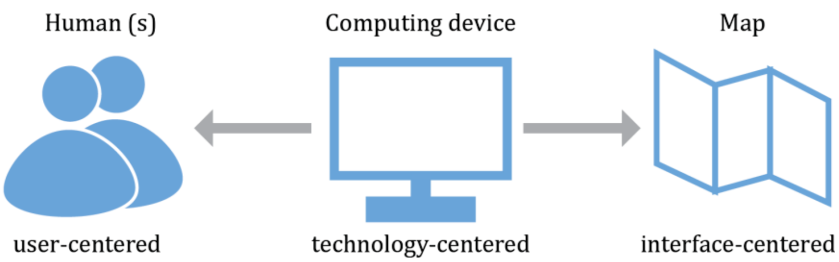


Figure 4. Components of cartographic interactions adopted from Roth (2015).

Both user and the map have the power to affect and make changes to each other. For example, readers request an updated map view through the map interface based on their objectives, which causes some sort of modification. Conversely, the modified and updated map interface is perceived and interpreted by the readers, which leads to some updates to the user's cognition towards map contents.

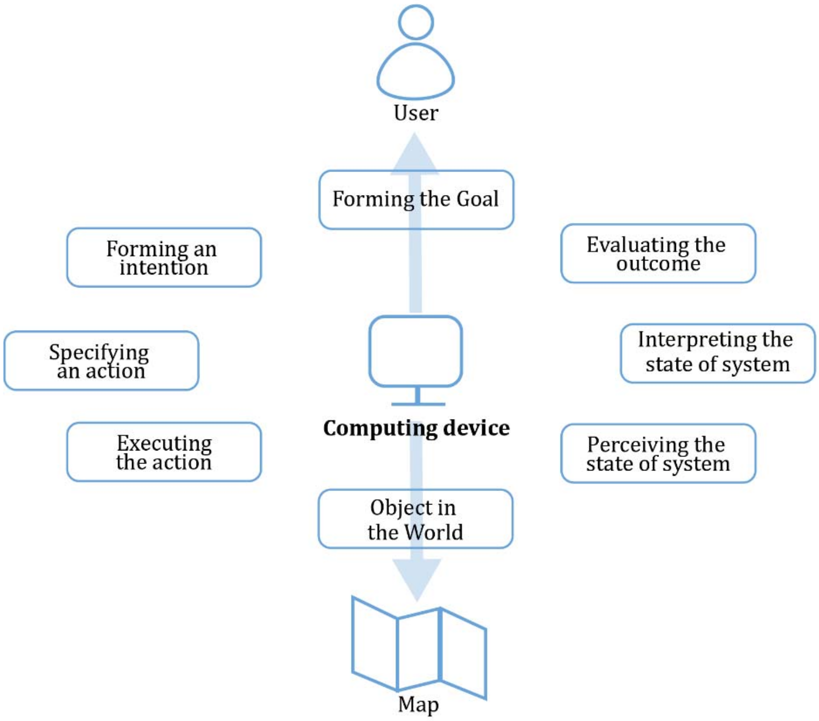


Figure 5. Stages of interaction adopted from Roth (2012).

To ensure the success of interactivity, Norman (1988) proposes an action model, which provides an idea of the process of cartographic engagement by categorizing it into seven measurable steps (*Figure 5*) under the context of *Figure 4*. The entire process includes (1) *framing a goal,* which determines an open-ended goal, (2) *figuring out the intention*, which determines close-ended objectives and tasks, (3) *specifying system function*, which acts as an operator, (4) *implementing the operator* through input devices, (5) *recognizing system condition*, results can be viewed through a display device (6) *explaining the system state*, which interprets the meaning of display results, and (7) *assessing the outcome*, which verifies if the initial goal is completed by matching the outcome to goal.

2.4 Attention-Guiding Techniques

It is necessary to achieve appropriate geovisualization and enable the suitable distribution of users' attention to accomplish effective information acquisition for map readers (Swienty, 2008). Attention-guiding geovisualization, according to Swienty et al. (2008), seeks to promote decision-making processes in geographic activities and deduce the reader's cognitive effort through quicker and more precise visual leading, as well as the following visual scanning to discover and pick relevant information. This sub-chapter reviews attention-guiding techniques in geovisualization to enable a faster and easier map reading process, especially for the case of wayfinding tasks.

There are two types of attention control, which are top-down (user-driven) and bottom-up (stimulus-driven) (Wolfe, 1994). Top-down activation is task-based, readers employ prior knowledge, current purpose, and prospects to gain a picture of what they are seeking and, accordingly, interpret geographic information in a derivable manner based on task-oriented purposes. In comparison, bottom-up activation leads people's attention automatically through sensory stimuli, allowing the user to anticipate where the associated information is placed. The interaction of the two activations determines how, where, and to which uses give attention in a certain visual environment to commence the cognitive process (Swienty et al., 2006). Wolfe and Horowitz (2004) review the current attributes that participate in attention guiding. Color, motion, orientation, and size the undoubted guiding attributes. And other attributes like luminance, shape, lighting direction, etc., are the possible guiding attributes. Hein et al. (2019) analyze the potential improvements in user performance under two standard guiding methods. It is shown that one of the most fundamental approaches of drawing visual attention is emphasizing the target object. Swienty (2008) further summarizes attention-guiding variables provided by ArcGIS for ordered data. It is shown for line symbol, color hue, color saturation, color value, and size are the four variables for attention-guiding design. The results show that users are easier attracted by objects with high contrast in color hue, value, and orientation in the map. Based on the theory of guiding attributes, Kurzhals et al. (2013) designed different variants to guide users to distribute attention evenly over the interesting objects in the video. They design the background into a static image to only provide contexture information, which gives more attention to objects and decrease the importance of the background. They also adjust objects to an equalized size to equalize the attention given to different objects. To test the influence on visual attention distribution, they conduct a comprehensive user study. Firstly, hypotheses are made, followed by a pilot study. Then participants are asked to accomplish some tasks, and their eye movements are recorded by eye trackers. Objective evaluation is determined by two ways. One is to quantify the distribution of attention by calculating the indicators based on eye movement characters. The other one calculates the performance score to measure effectiveness. Lastly, they collected subjective feedback from participants by filling out a questionnaire. The question design for the evaluation is quite inspiring for this: it contains questions from 6 aspects, including spatial context, interaction or relation between objects, attention distribution, effectiveness evaluation, effort used, and frustration level.

In this study, the top-down process is involved in leading the user to find and focus on the navigation routes. However, the bottom-up process is still essential for not distracting readers while providing enough geographic information for wayfinding. The route that deserves more attention should be highlighted. Additionally, the design principles, such as simplicity, visual hierarchy, and conciseness, should be considered as well when implementing attention-guiding geovisualizaiton. Inspired by the above research on cartographic principles and attention-guiding techniques, this study proposes two assumptions (1) basemap will affect the user's perception and attention distribution on the objects in the map, and (2) using combined visual variables is effective to guide user's attention. The effectiveness of visual attention guiding design and assumptions will be measured and verified by a questionnaire.

2.5 Evaluation of Interactive Map

Evaluation of the outcome is an essential stage to compare the results of interactive map with the originally expected outcome to verify if the initial goal and demands are reached (Roth, 2012). In the case of user-centered design, Roth et al. (2015) bring forward a set of evaluation methods that are categorized into three types based on the evaluator. *Expert-based methods* collect feedback and opinion from experienced consultants familiar with the interface design and evaluation. It is necessary that the evaluation knows little about the interface before evaluating it to ensure an unbiased view. *Theory-based methods* require self-assessment from the developer and designer. Theoretical frameworks via scientific study are used to ensure objectivity and rigor during the evaluation process. User-based methods focus on the evaluation results from a group of target users. Due to the constraints of time and cost, a small number of evaluators is sufficient.

User-centered design refers to map development that considers the user's demands and expectations to accomplish a successful and transparent interface design. For an effective user-centered design, the *target user* is the essential factor that deserves attention (Roth & Harrower, 2008). The requirements identified by target users are considered the initially desired functionalities, which serves as a baseline for the interactive map to compare (Roth et al., 2015). The success of an interface can be measured by two metrics: usability and utility. Usability indicates how easy it is to use the interface to implement desired tasks (Roth et al., 2015). There are five measures of usability proposed by Nielsen (1992), which have been adopted by Website Usability.gov:

I. **Learnability:** how fast can people grasp the interface without prior experience
II. **Efficiency:** how fast can people implement the desired tasks once getting familiar with the interface
III. **Memorability:** how well can people remember the operations and functions the next they pick up
IV. **Error frequency and severity:** how frequently people make mistakes and how severe the mistakes are
V. **Subjective satisfaction:** how much the user like the interface

Utility, on the other hand, depicts the usefulness for achieving the user's tasks (Grinstein et al., 2003). Roth et al. (2015) propose two common approaches to utility evaluation:

i. **Benchmark tasks:** user performance evaluation while using the interface
ii. **Analytical products:** hypotheses created, knowledge constructed, or decisions made when using the interface.

Andrienko et al. (2003) present an example of benchmark tasks that users have to implement using an interface. It is characterized into three parts, including (1) the cognitive operation, which refers to the user objectives for operating the task, (2) target searching, which seeks for the information under consideration, such as time, space, or attribute, and (3) search level, which serves as supplementary information content. Benchmark measures how correctly users answer the question provided to complete desired goals. The limitation of benchmark tasks, however, includes oversimplifying the interface that is applied in reality (Roth et al., 2015). For analytical products, North (2006) put forward five factors of insights used to assess the quality of thinking generated by an interactive mapping: (1) complex refers to the number of information items contained and how well they are combined, (2) deep describes the amount of time was used in building the insight (3) qualitative refers to the how exact is the insight, (4) unexpected describes how unique or fresh is the insight, and lastly (5) relevant clarifies how helpful is the insight to the application domain. Unlike benchmark tasks, this strategy assesses utility more accurately with how map interfaces are operated in practice, yet it faces more difficulties in measuring the correctness of the questions.

Therefore, user, utility, and usability are three essential components during interface evaluation: users interact with the map to determine possible useability problems and give suggestions for the utility in the next iterative version. The relationship between user, usability, and utility is shown in *Figure 6.*

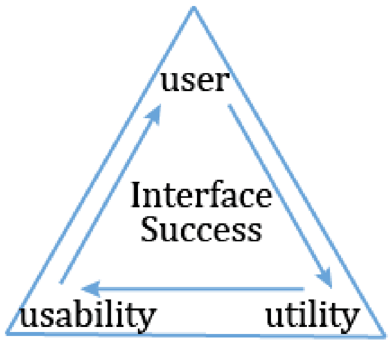


Figure 6. Interface success relationship adopted from Roth et al. (2015).

Following the "3 U" loop works, it is suggested to determine user demands and requirements first, then set utility thresholds that aim to solve the demands and requirements. The usability of the interface design can then be enhanced based on the utility thresholds, and eventually, the interface will be evaluated by starting a new "3 U" iteration.

In this thesis, a questionnaire will be designed to collect user feedback. The results of interface evaluation can be analyzed quantitatively or qualitatively. Quantitative testing is mainly in the form of multiple choices questions, which are mainly designed based on the form of a 5-point Likert-type scale, extending from "not at all" to "very much". The Likert scale is a method to measure personality traits and attitudinal quantitatively, which was developed by Likert and widely used in survey conduction Boone and Boone (2012). To measure the central tendency of the user's altitude, we cannot just calculate the mean value of Likert-type data since it is an ordinal measurement, and the average of agreement and disagreement does not make sense. Instead, descriptive and inferential statistics are two methods to analyze the Likert scale data (Boone & Boone, 2012). Descriptive statistics helps to get an overview impression of responses, which commonly employs the most frequent responses, i.e., mode and median, to represent tendency. Besides, the AttrakDiff method is used to measure how enjoyable the user experience when interacting with a product. The attractiveness of a product is determined through the combination of pragmatic and hedonic evaluations (Hassenzahl et al., 2003).

Qualitative methods are commonly used to find patterns. Thematic analysis will be executed to find patterns in what people write (Braun & Clarke, 2012). Thematic analysis is a structured approach for processing and interpreting what people think in a qualitative way. More than just summarizing the answers, the thematic analysis aims to identify and interpret themes, which are patterns in responses that make sense for the research (Maguire & Delahunt, 2017). According to Braun and Clarke (2006), the phases involved in qualitative thematic analysis include getting familiar with the dataset, identifying patterns, deriving themes, and creating a narrative.

2.6 Analysis of Existing Interactive Maps

There are many route navigation applications in the market. Although the main functions they provide are similar, there are still differences in terms of their main purpose, interface arrangement, basemap design, and route visualization. This paragraph selects and compares four widely used web navigation applications in terms of their design, visualization, and detailed functionalities. Statista counted the popular mapping apps for mobile devices in the US by downloads. It is shown Google Maps is the most downloaded navigation app, followed by another app called Waze. In this paragraph, Google Maps, Waze Map, Petal Maps, TomTom MyDrive, and OpenStreetMap are described since they provide a web version of services and have available data for routing in Munich. For each product, a screenshot with illustrations is provided to show both the general appearance of interface layout and map contents, basemap style, and navigation route visualization. To make the comparison more convincing and reduce the potential interference caused by different routing origins and destinations, the map center and zoom level are set to be similar; the starting and ending locations of the route for the four applications are the same, from Technische Universität München to Sendlinger Tor, at around 5pm on 29th September 2022.

In Google Maps, the typing box, together with the travel mode switcher, is located at the upper left corner of the interface (*Figure 7.* Interface and navigation route of Google Map*, A*), and the different route solutions and their direction guide are displayed in the lower left part (*Figure 7, B*). The layer controller is at the bottom left (*Figure 7, C*), while the zooming and locating controllers are located on lower left sides of the map (*Figure 7, D)*. The attraction selection buttons are placed at the top (*Figure 7, E*).

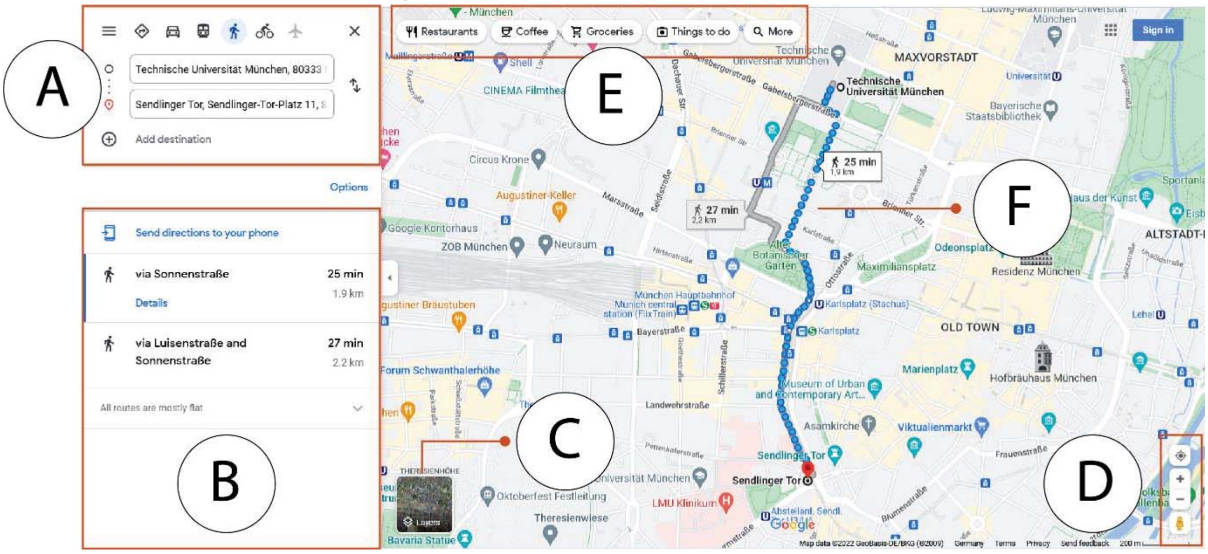
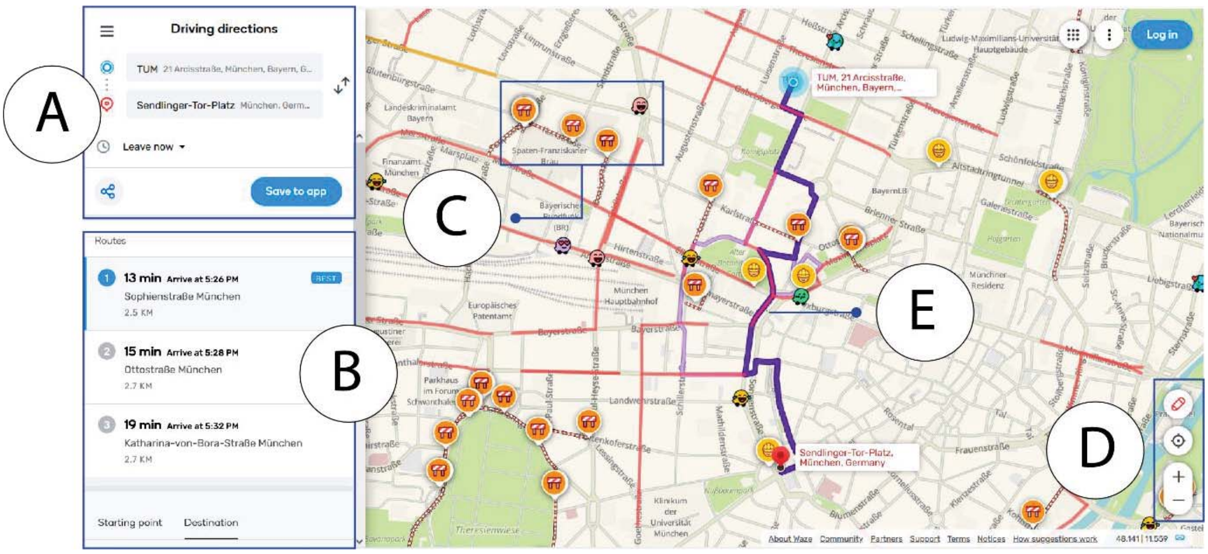


Figure 7. Interface and navigation route of Google Maps.
Access on 29th September 2022 5:22 pm.

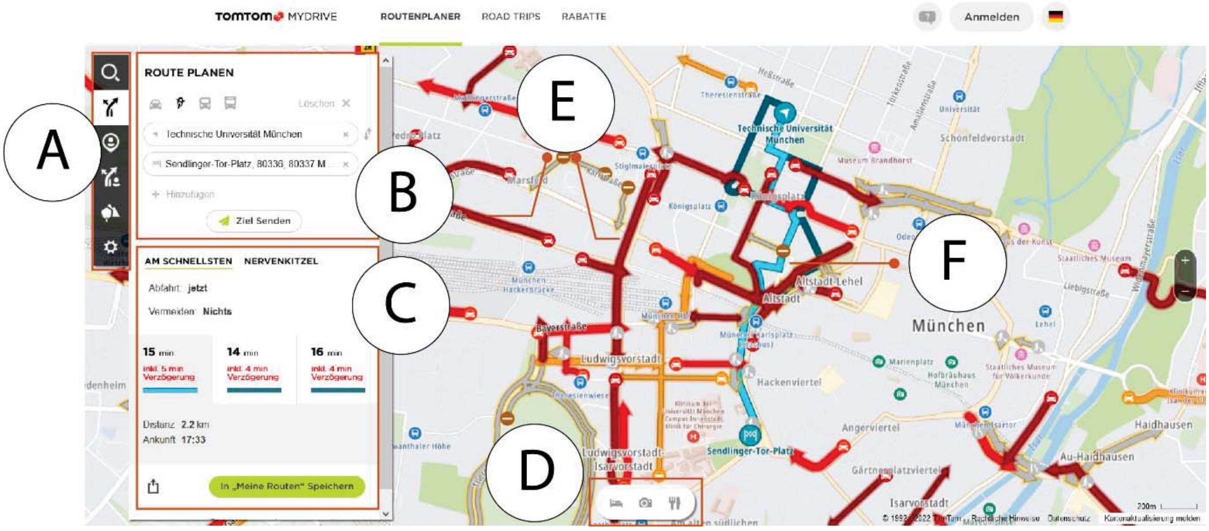
For the basemap, remarkable natural features like green areas and water are quite noticeable, while the road network is white in color. Busy and commercial areas, railway systems, famous landmarks, transportation stations as well as points of interest are also displayed. For visualizing navigation routes, Google Maps displays the most recommended (shortest solution by default) solution in blue, while the less recommended routes are in grey (*Figure 7, F*). For the travel mode of walking, the route is visualized as a dotted line, while for other travel modes, the route is displayed as a solid line. The destination is marked by a red marker, while the origin is represented by a dot. Both the origin and destination markers can be draggable to start a new routing.

Waze Map is a navigation that provides detailed traffic condition and real-time user sharing. Similarly, the typing box and route selection box are placed on the left (*Figure 8,* A and *Figure 8. Interface and navigation route of Waze Map Figure 8,* B), while the interface of Waze Map looks different from Google Maps at first glance. The base color of Waze Map is light yellow, while the road network is light grey, which makes the streets more noticeable. The zooming controller and editing button are placed in the bottom left corner. Under the same zoom level, Waze Map displays a sparser railway but a denser and more detailed, and noticeable road network. Unlike Google Map, Waze Map doesn't label landmarks, traffic stations, and point of interest. By default, the web interface shows real-time traffic conditions on certain road segments based on the congestion level. The darker the red, the worse the traffic condition. It also shows the notifications, including the closed roads, construction sites, and status of other wazers (*Figure 8, C*). For the route displaying, the best route (the shortest) is represented as a solid purple line (*Figure 8, E*), with the other options designed as light purple lines. By clicking on the route, the selected navigation route will be emphasized by turning into darker purple, while the unselected options become lighter. The destination is marked by a red marker, while the blue circle represents the starting location. The markers of origin and destination are not draggable, yet they are clickable to pop up the information about the two places.



[*Figure 8. Interface and navigation route of Waze Map*](#).
Access on 29th September 2022 5:16pm.

TomTom route planner focuses more on real-time traffic data: therefore, the arrows (*Figure 9, E*) that show the real-time traffic conditions and road condition have drawn the great attention of users. Different from the way Waze Map visualizes the traffic conditions, TomTom Route Planner uses enlarged arrows and distinct colors to illustrate the level of traffic congestion with directions. The condition of road segments and the causes of slow-moving traffic can be viewed by clicking the signs on the map. Important facilities, traffic stations, and points of interest are marked on the map. A slide menu is placed on the left (*Figure 9, A*), providing functions including searching, route planner, road tips, etc. The typing box and route selection box are placed in the left as well (*Figure 9, B and Figure 9, C*). The attraction selection buttons are put at the bottom of the map (*Figure 9, D*). However, there is no layer control on the page to switch basemap, and the details of the road network are lightened. The visual importance of the minor streets is reduced by decreasing the contract between roads and basemap. For navigation route design, it uses highlighted blue color for the most recommended route (the shortest route), while the less recommended option is in darker blue (*Figure 9, F*). The red arrows more or less interfere with the attention paid to the navigation route since they are partly overlaying on top of the route. Users can switch between various travel modes, and the distance and estimated time of arrival for each option will be provided. Although with different icons to represent, both origin and destination use markers in blue and draggable. More innovative than the other navigation applications, Tomtom Route Planner offers the option of "Thrills", which allows users to specify the level of steepness and curvedness of the route based on their preferences to increase more fun in traveling.



[*Figure 9. Interface and navigation route of TomTom RoutePlanner*.](#)
Access on 29th September 2022, 5:20pm.

Petal Maps is a navigation application based on TomTom. Different from other web navigation applications, Petal Maps puts a toolbar in the lower left of the map, which can be dragged up by clicking the buttons. Then the search box, travel mode switching, and direction guides are placed on the left (*Figure 10, A*). The layer controller and locating and zooming buttons are designed on the right side (*Figure 10, B and Figure 10, C*). Petal Maps designs road networks in light grey, using different thicknesses to represent importance. Points of interest, facilities and traffic stations are depicted on the map but designed in a less obvious way compared to TomTom MyDrive and Google Maps. For iconic buildings or places, Petal Maps uses bigger markers to label and draw more visual attention. The navigation route is displayed in blue (*Figure 10, D*), and in this case, it only provides one option for walking mode. The origin is marked by a blue dot, while the destination is shown as a red marker. Either of them is clickable or draggable.

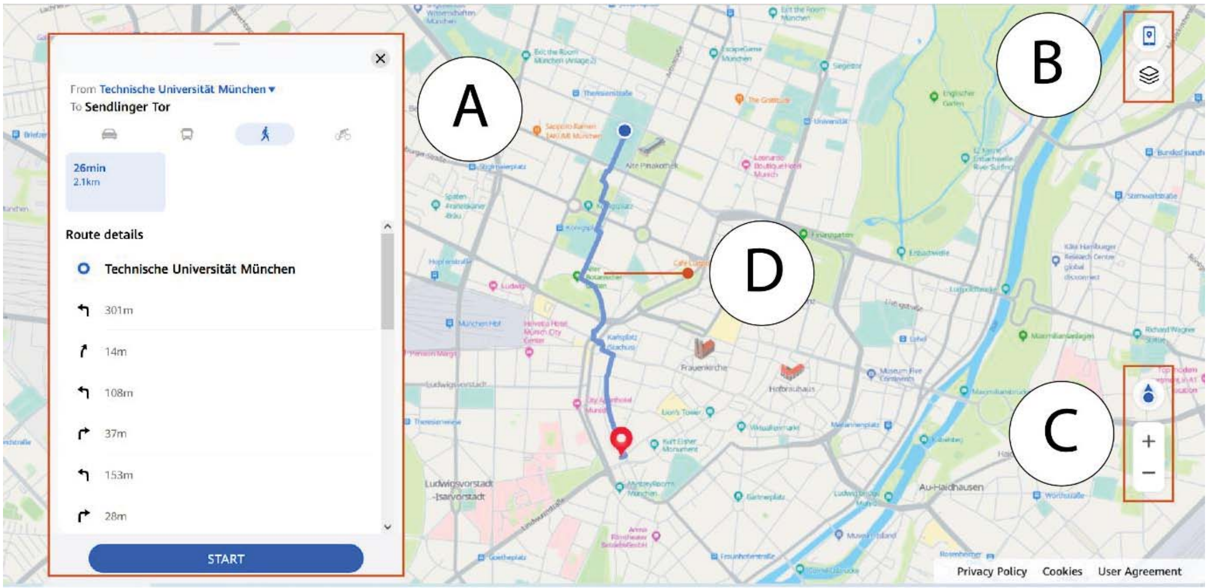


Figure 10. Interface and navigation route of Petal Maps.
Access on 29th September 2022, 5:03pm.

OpenStreetMap is a free and editable map; its interface is quite informative. It is not only designed for route navigation but also provides lots of geographic information. The search box is placed in the top left (*Figure 11*, A), while the direction guides are shown on the right (*Figure 11, B*). The layer controller, language switcher, and other editing or downloading functions are placed at the bottom left (*Figure 11, C*). The basemap of OpenStreetMap provides pretty complete building footprints, which is different from the other applications under a similar zoom level. The traffic network, including the streets, railways, and tramlines, are quite detailed and observable. Iconic places, traffic stations, and points of interest are sparsely marked under this zoom level. For navigation route visualization (*Figure 11, D*), OpenStreetMap firstly recommends the shortest path, which is designed as a blue purple line with transparency. The less recommended route is in a lighter color. The origin and destination are represented by green and red markers, respectively, both of which are draggable to launch new navigation.

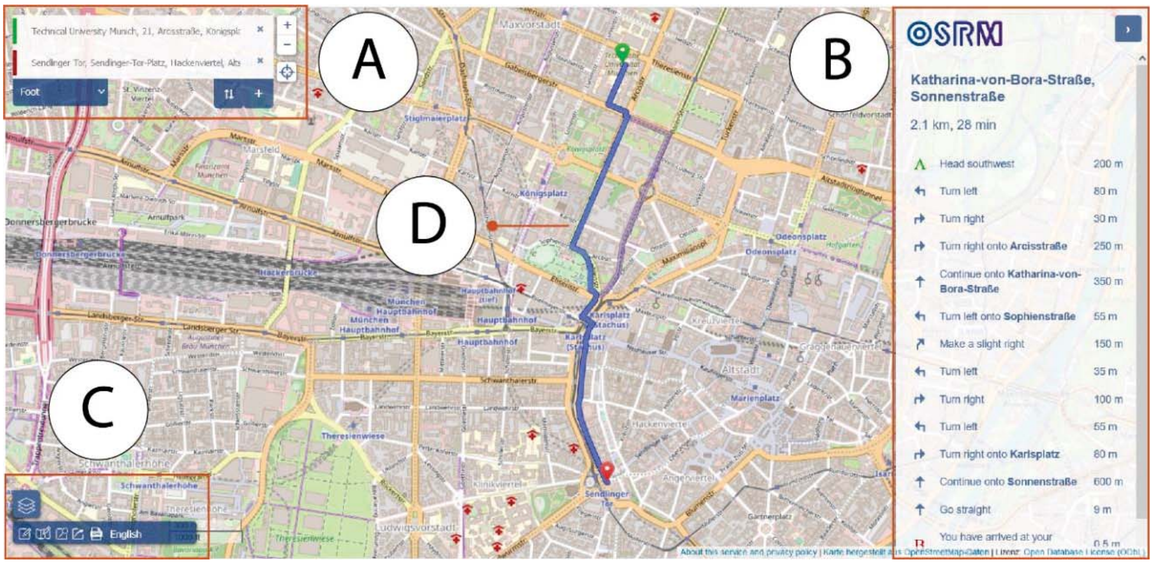


Figure 11. Interface and navigation route of OSRM

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To sum up, search boxes, layer controllers, and navigation routes are indispensable elements for the navigation interface despite different visualization or functional details. Different visualization techniques and styles can be adopted for mapping products with different target audiences and purposes.

2.7 Summary

This chapter answers Research Question 1. It presents ways of measuring air quality and determines US AQI to be the suitable standard for representing air quality in Munich. It figures out the suitable way to complete health-oriented navigation. Dijkstra's algorithm with health-oriented weighting functions is chosen as the ideal routing algorithm due to its ease of use and customization of costing factor. Wisely use of visual variables and attention-guiding techniques, including color, size, opacity, and contrast, is essential for a good map interface design, which provides insight for the implementation stage in Chapter 3. The roles and relations between the user, map, and devices are introduced, together with the procedure of conducting a user study. Lastly, popular existing navigation applications are compared to summarize the common traits and guide interface design.

3 Methodology

This chapter describes and explains the workflow, detailed methods, and tools used in this thesis and answers *Research Question 2*. It is divided into four sub-chapters: the first one clarifies the study area, synthetic data generation, and preprocessing. The second part explains the tools and steps of implementation of routing algorithms, the third sub-chapter addresses the principles and factors in interface design, and the last part describes the measures and procedures of user study, with a summary at the end.

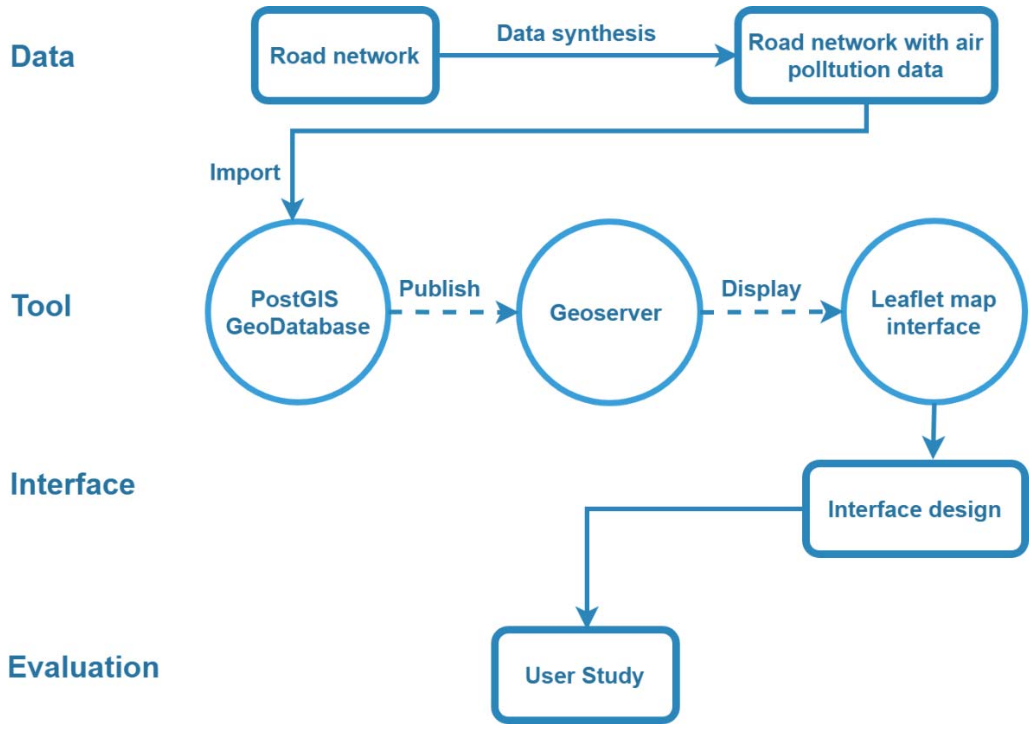


Figure 12. The workflow of methodology.

Figure 12 presents the workflow of this chapter: at the first stage, generated air pollution data, with the road network vector, will be imported into the Geo-Database. After creating the network and topology in the geo-database, the vector layer will be published into GeoServer. Then queried route will be fetched and eventually displayed in Leaflet interactive map from GeoServer. Different visualization factors will be considered for interface design, and lastly, the user study will be conducted through a questionnaire.

3.1 Data Synthesis and Preparation

The study area of this thesis is in the center of Munich city, with a more specific range from coordinate (11.512, 48.161) to (11.60, 48,127) (*Figure 13*). The road network of Munich is clipped from the OpenStreetMap data of Oberbayern, which can be freely downloaded from GEOFABRIK[1]. The road shapefile contains information on road code, class, name, direction, and speed limit. Since this thesis aims to design a web application mainly for pedestrians and cyclists, the roads that are drive-only, such as highways and trunks, can be filtered out to simplify the network.

In addition, the observed concentration of air pollutants, as well as ground temperature were sampled on 22 April 2022 by Climateflux[2] – a company offering platforms for data-driven and computational workflows for acquiring climate knowledge. The sample data contains 4583 records, the distribution of the sample points is shown in *Figure 13*: the sampling points are distributed along the main streets near Munich Center Station, the roads through the path, and the roads along the Isar river. The parameters collected include the coordinates of the sample points, temperature, humidity, and concentration of CO_2, PM10, PM25, and PM100.

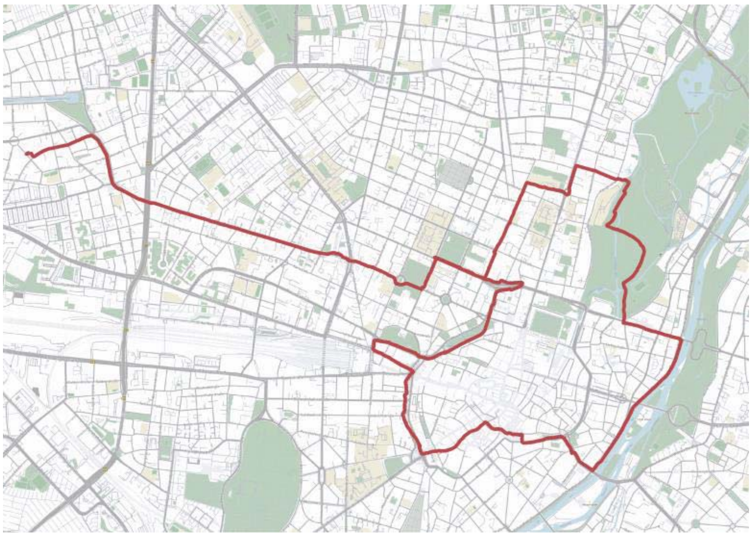


Figure 13. The distribution of sample data in Munich recorded by Climateflux on 22 April 2020.

However, the observed points are not distributed evenly within the study area, which leads to an inaccurate spatial interpolation result and, thus an inaccurate evaluation of the pollution level of the road network. To assign the air pollution value to road network, additional datasets are used to synthesize and calculate pollution indicators. The website Bayerisches Landesamt für Umwelt [3] provides current and historical air pollution hourly measurement data since 1980. According to the requirements in calculating US AQI, the measurement results of five major pollutants: O_3, PM2.5, PM10, CO, and SO_2, on the same date when the sample data is observed, are selected. The temperature and concentration range for each air pollutant during the day can then be derived from the dataset (*Table 4*). With the known concentration ranges, the corresponding AQI range for each pollutant can be calculated according to the breakpoint values provided in *Table 1* and *Equation (1) (Table 5)*.

[1] https://www.geofabrik.de/de/index.html
[2] https://www.climateflux.com/
[3] https://www.lfu.bayern.de/index.htm

Table 4. The ranges of pollutant concentrations

	O_3	PM2.5	PM10	CO	SO_2	Temperature
			μg/m³			°C
Min	19	2	2	200	2	21.13
Max	119	24	55	400	15	25.62

Table 5. Calculated Min and Max AQI value for each air pollutant

	AQI(O_3)	AQI(PM2.5)	AQI(PM10)	AQI(CO)	AQI(SO_2)
Min	**9.26**	8.3	0.93	1.98	7.49
Max	70.6	**76.06**	51.0	3.96	55.15

The overall AQI indicator is represented by the maximum value over the individual AQI values. Therefore, the lower limit of the overall AQI is extracted from the maximum value of the five minimum individual AQI values, which is 9.26; and the upper limit of the overall AQI is 76.06, which is represented by the biggest value among the maximum AQI value for each pollutant. Next, synthetic costing value for both the AQI indicator and temperature can be generated through the "Calculate Field" function for each road segment in ArcGIS Pro, which creates random numbers within the specified boundaries. To make a difference in cost factors, such as AQI value, temperature, and distance comparable and combinable, normalization of costing fields is necessary. Data normalization can be conducted through *Equation (2).* It shifts data values between 0 and 1 to eliminate the influence of inconsistent units and simplify the processing, which is commonly used for comparing and weighting.

$$N_i = \frac{X_i - (min(X))}{max(X) - min\,(x)} \tag{2}$$

After data generation and preparation, the road dataset is ready for more sophisticated analysis. The next step will explain procedures for implementing routing algorithms based on a local spatial database and customized costs.

3.2 Routing Algorithm

Dijkstra's routing algorithm is applied to determine the optimal path by minimizing the total cost from the origin to the destination. With the aim of creating health-oriented route paths, costs can be specified as pollution level or ground temperature. Three tools are mainly used in this study to achieve route querying, route publishing, and interactive visualization. The detailed procedures and techniques used for implementing the routing algorithm are demonstrated as follows:

- **PostgreSQL**

PostgreSQL is an open-source relational database system that uses and extends the SQL language, which serves as the primary data warehouse for web, mobile, geospatial, and analytics applications. It provides diverse open-source extension supports for spatial analysis and computation.

PostGIS, as one of the top extensions being installed, handles spatial data and allows location queries to be run in SQL. Additional geometry types and functions can be added to Postgres database through PostGIS, which makes spatial data management easier and faster. In this study, the road network of the study area, including all the textual information and geometry columns, is imported to Postgres database for further manipulating and querying. Apart from PostGIS, *pgRouting* is another open-source extension employed in this study to execute geospatial routing calculation. pgRouting library contains core features including All Pairs Shortest Path such as *Johnson's Algorithm*, *Floyd-Warshall Algorithm*, Shortest Path A*, Shortest Path Dijkstra, Driving Distance, K-Shortest Path, and Traveling Salesperson, etc. This thesis applies *Shortest Path Dijkstra* for calculating the desired route. The advantages of using the database routing method include (1) easy modification of data and attributes – data and attributes can directly be modified by using pgSQL or diverse clients, such as QGIS and ODBC, and it supports clients either from PCs or mobile devices, (2) instant data update – data changes can be updated instantaneously through the routing engine; thus there is no need for pre-calculation, (3) customized "cost" parameter – the cost for route navigation can be calculated dynamically through SQL and its value can be specified from multiple fields or tables. By using the two extensions, road shapefile with attributes of AQI and temperature can be imported into Postgres database as the relation for storing edge information of the network to further build topology relation and conduct routing algorithm.

Before creating network topology, nodes must be separated at every intersection to avoid ambiguity. *Figure 14* shows the challenges existing in building the network: if a line CD terminates in the middle of another line AB, and the junction C is not properly "noded" in line AB, then the line AB will not be separated by point C, which may lead to invalid network and incorrect routes. A completed "noded" network means that at every intersection in the road network, all the edges will be divided into separate road segments, as shown in *Figure 14b*.

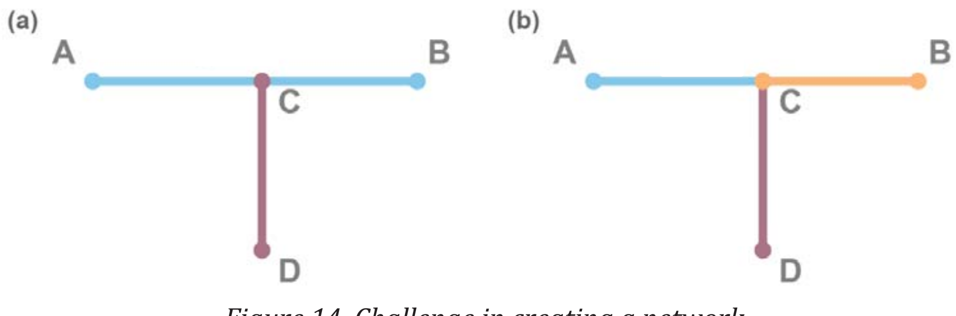


Figure 14. Challenge in creating a network.

In pgRouting, *pgr_nodeNetwork* is used to break all the edges into segments, and a new table will be created to store the nodes of the network. The tolerance for coincident points must be specified to decide multiple nodes within the tolerance are considered the same. Then the function *pgr_createTopology* is used to build network topology based on the geometry information. To accommodate the function, two extra columns, "*source*" and "*target,*" are added to the table. The tolerance is needed to specify the snapping tolerance of the disconnected segment. After creating network topology, since the newly generated table only contains the necessary columns, for example, the columns of id and geometry, it is necessary to copy useful attributes from the original table to the new noded table to determine traveling costs. In this case, distance, AQI indicator and temperature are used as costing factors respectively, in three different traveling modes. Thus, the field of distance, AQI indicator, and temperature will be either calculated from geometry or reproduced from the original table. Next, function *pgr_dijkstra* is used to select routes from network topology by specifying the cost filed, starting node, and ending node. *Figure 15(A)* shows an example of road segments selected by the query from node 1 to node 1000 and their visualization in the map (*Figure 15, C*). The results of the query list all the road segments between source and target nodes (*Figure 15, B*).

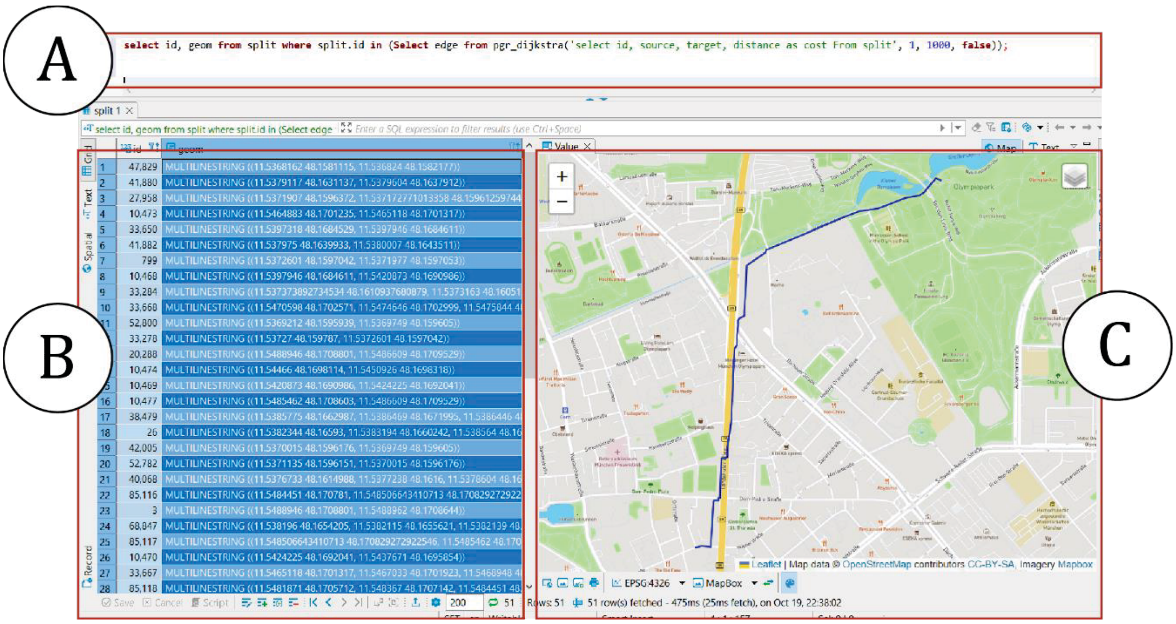


Figure 15. Example of route querying in Geodatabase.

- **GeoServer**

After succeeding in performing the query in the spatial database to find the optimal route, the next step is to publish the spatial data as well as the SQL query statement to a web server. GeoServer is an open-source web server for sharing geospatial data. It is designed for interoperability, and it allows users to access maps and data from a variety of formats to standard clients. In this thesis, GeoServer can connect to PostGIS database through the "Store" function to upload both edge and node files of the road network into GeoServer. Then GeoServer SQL views are created to execute a custom SQL query to create a new layer without the need to create a view in the database. Even more usefully, the SQL can be parametrized, the parameter values passed in along with a WMS or WFS request.

This study creates four SQL views in GeoServer. The first one searches and returns the nearest vertex in the network nodes to the point that the user marked. This query is the essential step to implement the routing algorithm because it corresponds the origin and destination to their closest vertexes respectively, which are the mandatory parameters for the pgr_dijkstra function. The other three SQL views are designed for different navigation purposes: the shortest path takes distance as cost and determines the shortest path between source and target nodes; the cleanest path aims to minimize the air pollution exposure during the travel; thus, it takes AQI value as costing factor and determines the least polluted path between the source and target nodes; coolest path, on the other hand, serves to find out the path has a lower ground temperature between the origin and destination. Users can specify the path between two points within the study area, based on their preference by requesting through GeoServer SQL views. The query results will be returned in the format of GeoJSON.

- **Web mapping technologies**

To display requested results in an interactive map, *Leaflet* is a convenient and efficient tool. Leaflet is an open-source JavaScript library for interactive maps, which is mobile-friendly and provides plentiful mapping features for map development. Leaflet maps are composed of tile layers along with browser support, default interactivity, panning, and zooming capabilities, with diverse plugins, simplicity, and high readability.

To display query results in web page, HTML, CSS, and JavaScript files are needed to design the interactive web interface. HTML refers to Hyper Text Markup Language, which is at the core of every web page. Instead of using programming language to perform functions, HTML helps to structure the page into different elements by tags. In this study, the HTML file defines the position of the map, search box, and buttons. It also defines the position and size of the canvas for displaying map legend as well as explanatory texts. While HTML is a markup language used to format a web page, CSS stands for Cascading Style Sheets, which determines how the HTML elements of a website should appear exactly on the front of the page. It is generally used to improve the appearance of a web map and make the web look more presentable and attractive for end use by designing thoughtful CSS styles. Good usage of CSS is the essential step to creating a neat and readable map interface. In this case, the CSS file dictates the ratio of the map, absolute position, background color and stroke style of the search bar, color and line style of legend, and the color and detailed design for checkboxes.

Compared to HTML and CSS, JavaScript is a more sophisticated programming language, which is normally used to control the behavior of different elements and add interactivity to the website. For web development, JavaScript is widely used to modify website content and make it respond in different ways to user's actions. In this thesis, the JavaScript file defines variables to add map layers and clarify map view as well as the basic functions like zooming, locating, and layer switching. To implement the routing task, text contents that the user typed into searching forms are fetched as starting and ending addresses. To get the corresponding coordinates of the address that the user submitted, the function for geocoding is necessary. Nominatim, an open-source geocoder, is used to search corresponding coordinates by name and address based on OpenStreetMap data. The response results include the osm type, latlon coordinates, street name, city, state, country, postcode, etc. Based on this scenario, coordinates are adequate to add markers in the map page to represent the start and end location and to derive the nearest vertex in the road network by requesting URLs through SQL view in GeoServer. Similarly, requesting URLs for different routing algorithms can be sent to get the paths and displayed on the map by adding extra layers based on the status of the corresponding check box.

By combining the three tools and the procedures above, a basic route navigation application is formed. It supports simple interactivities and allows users to place markers on the map by entering addresses and generating routes between the two markers. However, to achieve a more effective visual design for attention guiding and the aesthetic goal of interactive map, a more the delicate and detailed user interface is needed.

3.3 *Map Interface* Design

Summaries from the existing web navigation application show that the main components of the web interface are the background map, searching area and map controllers, and navigation routes. Since this prototype aims to serve people regardless of age, gender, and occupation, it is essential to make the interface and operation simple and straightforward. This section will address the elements of the map interface developing from the above four perspectives.

3.3.1 Basemap Design

Mapbox[1] is an ideal provider of basemap for the web interfaces. It provides traffic and movement data, navigation and geocoding function, and logistics services. More important, Mapbox Studio[2] highly supports map customization over the color and label of each layer, which allows the design of various background maps that are suitable for different navigation scenarios and to test the effectiveness of different basemap designs. In this study, four basemaps are customized using Mapbox Studio: three of them are for daily mode, and one is for dark mode.

The first map is adapted from the Mapbox Streets style, which has rich color components and detailed road networks. The overview of *Basemap I* and its main color components are shown in *Figure 16*. Comparing *Basemap I* with other navigation products, the natural features like water bodies and vegetations are represented by blue and green with higher saturation. Roads are designed into white lines, while railways and underground lines are represented by a thinner grey line. Different areas are represented in different colors based on their purposes, for instance, light yellow for commercial areas, magenta for hospitals, and brown for schools. Public transport stations, road and place labels, and points of interest are marked using different symbols, colors, and sizes. Generally, this design depicts the urban features in a clear and distinguishable way.

[1] https://www.mapbox.com/
[2] https://www.mapbox.com/mapbox-studio

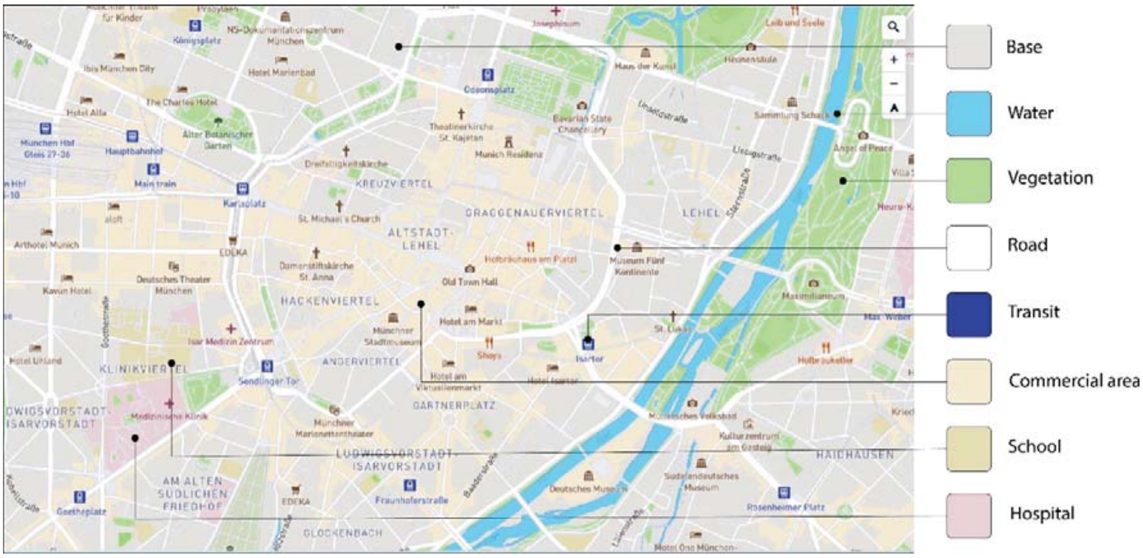


Figure 16. Overview of Basemap I and its main color components.

However, holding the purpose of promoting health-oriented navigation routes and the attention guiding techniques in mind, the underlying background map is better to be understated to make the routes stand out. The *Basemap II* is then designed to reduce the visual importance of the underlying map (*Figure 17*).

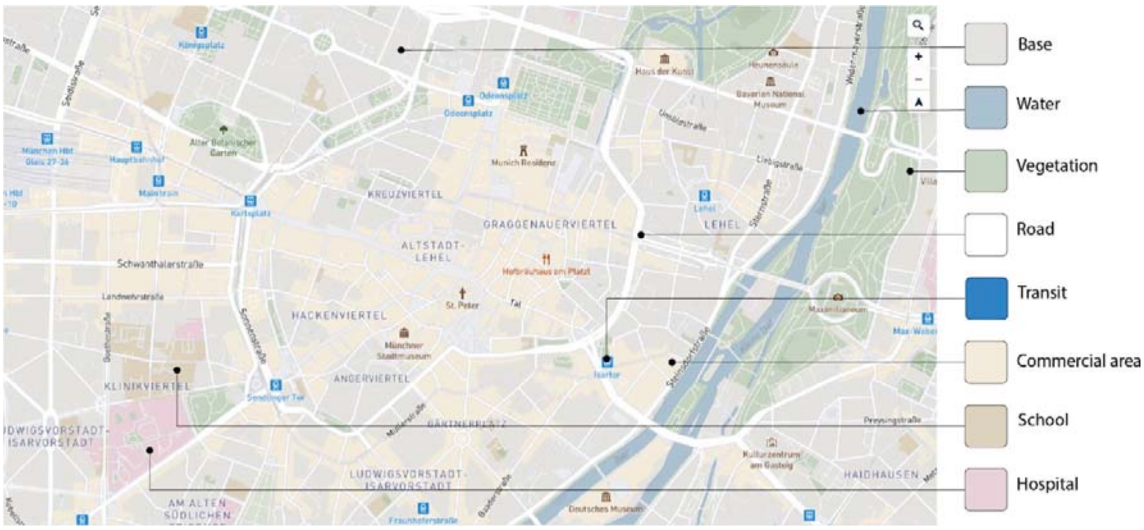


Figure 17. Overview of Basemap II and its main color components.

Basemap II is also adapted from Mapbox Street template with modifications to its color scheme. It keeps the original colors and design of area classification and traffic network while it greatly reduces the saturation of rivers and vegetations. What's more, it changes the hue of labels of the underground station and reduces the density of labels of points of interest, appearing to decrease the visual crowdedness. Although the profile of the *Basemap II* looks plainer, it still provides the necessary information to support navigation purposes. Its understated visualization can help increase the contrast between background and line objects, which allows users to focus more on the routing lines.

Since strong contrast between objects and background helps to attract the user's attention, does it mean the plainer the underlying map, the better to display the routes for wayfinding? To answer this question, *Basemap III* is designed to test its potential in navigation applicaitons (*Figure 18*). The base color of *Basemap III* is white. The road network is visualized in light grey. Although the water and vegetation are still represented by blue and green, the saturation is quite low, which makes the natural features less salient compared to the base color. Different land use like commercial area, hospital, and education are not marked out. The density of the points of interest is further sparser than the *Basemap II*, and the visibility of the railway is very low due to the thinner and lighter symbol design for rail lines. All the labels, symbols, and texts for transport stations, points of interest, place names, and road names are consistent with the color gray. Despite the neat and clear appearance of this map to display line features, it may face the challenge that the street network is not well visible in some regions. For instance, the roads pass through the vegetation. Besides, it may lose some spatial information that is useful for wayfinding in practice.

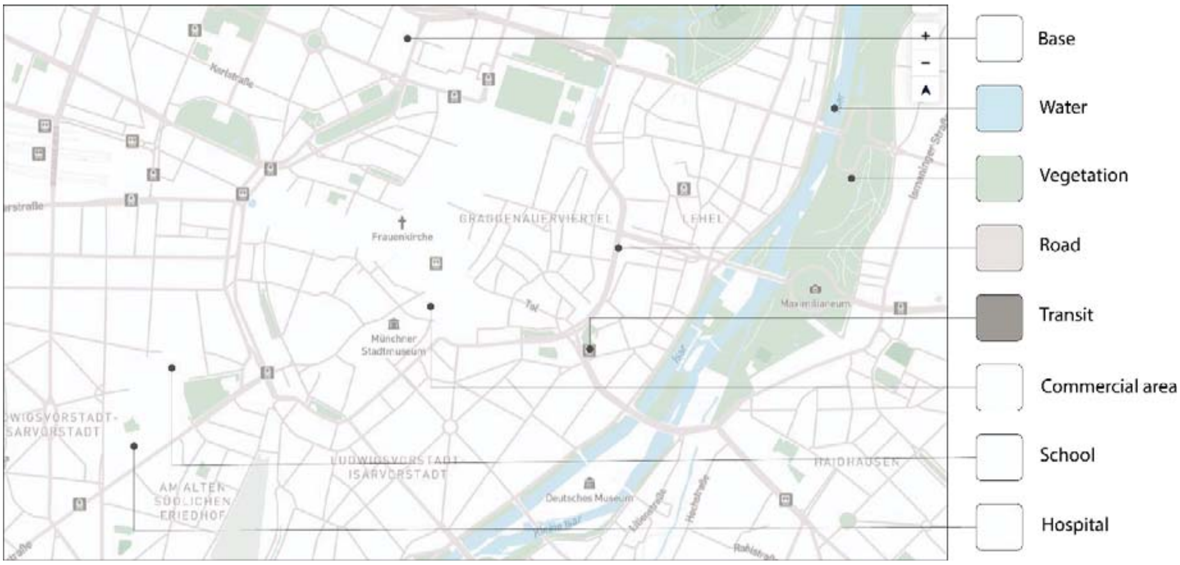


Figure 18. Overview of Basemap III and its main color components.

Figure 19. Overview of Basemap IV and its main color components.

Basemap IV for night mode and its color components are provided in *Figure 19* for comparison. It adapts the Mapbox Studio Navigation Night template. Different land uses are classified out by different colors. Road networks, labels and symbols of stations or points of interest, and natural features are quite distinguishable, while the visibility of railways is relatively low. The *Basemap IV* may result in different visual effects on emphasizing navigation routes due to the different visual contrast. Specific visual effects of using a dark background map are going to be tested out by a detailed user study.

3.3.2 Map Elements

After the determination of the background maps, other elements are ready to be added to the interface. The map elements considered in this study are search boxes, controllers, and a legend. Similar to the majority of existing navigation applications, the search box (*Figure 20a*) is placed in the upper left corner, containing the typing form to fetch the address that the user submitted. Under the typing boxes, travel mode checkboxes are provided to the user. Instead of allowing the user to choose different means of transport, the travel mode in this application stands for the preferences of different routes, i.e., cleanest, coolest, or shortest path. The corresponding path will show up or hide in the map when the user ticks or unticks one certain checkbox. Therefore, a legend is desired to illustrate and differentiate different routes (*Figure 20b*).

Besides, some other map controllers are desired for a user-friendly interface design. The layer controller, as one of the most practical and frequently used controllers, is going to be placed in the lower left corner. By clicking the layer controller, the user can easily choose and switch the underlying map based on application scenarios or aesthetic preferences. Additionally, locating button and zooming buttons are positioned on the left of the map, right on top of the layer controller. Locating button allows user to locate their current location once it is given permission, which is also a common and practical feature of navigation applications. Zooming buttons serve as an auxiliary controller that allow the user to zoom in or out by buttons (*Figure 20c*).

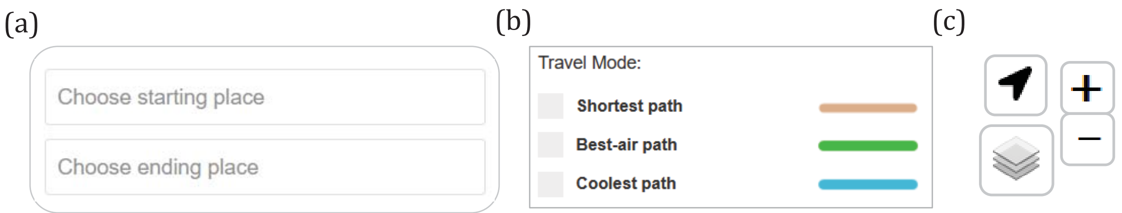


Figure 20. Map elements of the interface.

3.3.3 Route design

Routes displaying would be the core part of a navigation application. How to visualize paths in a readable, effective, and attractive way is always a challenge for map designers. This section will explain the design logic of the three routes based on the theories of color, attention guiding, and interaction.

The commonly used color used to visualize the navigation route is blue, with additional colors like orange or red to indicate traffic conditions along the route; the alternative paths are widely represented by the lines with the same hue but lower saturation. However, to display and differentiate different routes in the map interface at the same time, different colors and line styles should be employed in this study. Based on color perception and convention, blue is a typical representative of cold color, which is highly associated with the feeling of cool. According to such emotional connection, this study thus applies blue to represent the coolest path. Similarly, the green color evokes feelings of nature, health, and safe. Therefore, it would be a rational choice to represent the cleanest path with the least health impact by air pollution. The shortest path, on the other hand, in some graph analysis, is designed as a red line. However, red is an emotionally intense color that demands lots of attention. It indicates danger, emergency, and caution, which is widely used in cartography for highlighting and emphasizing. Instead of using red color for the shortest path directly, a less conspicuous color or symbol design is desired to achieve the study goal of promoting health-oriented paths. The following measures can be considered to reduce the visual importance of the shortest path or enlarge the attraction of the other two.

Color is considered the most powerful visual variable to guide attention and distinguish objects. Making good use of color can effectively ease the map reading process and lead the user to focus on the parts that deserve more attention. Since green and blue are considered the suitable colors to represent the cleanest and coolest paths due to the associated conventional meanings, color choice for the shortest path should avoid using green and blue or similar colors to prevent ambiguity. On the contrary of straight using attention-seizing colors like orange and red, adjustments on the saturation, hue, or value may help to reduce the visual salience while keeping the distinctiveness.

Figure 21a provides a set of color selections for displaying the three routes over a background map. The three routes have the same line thickness. The shortest path is visualized in red (hue is around 10°), with a low saturation (around 30), to make it more muted. The cleanest route and blue paths are visualized in green (hue is around 120) and blue (hue is around 193), respectively, with relative higher saturation (around 80) to increase visual salience. Apart from that, factors like opacity and thickness can also be employed together. Opacity is one of the visual variables that help to reduce the visual importance by undermining opacity. Similarly, visual importance can be affected by the thickness of the line symbols: the thicker object attracts more users' attention since it takes up more space. *Figure 21b* thus shows the ultimate line symbol legend after the route query for the three routes: color, opacity, and thickness are combined to further address the health-oriented paths. Both the cleanest and coolest employ thicker lines with an opacity of 0.95, while the shortest path is of the opacity of 0.8. Like most of navigation applications, users are allowed to click one of the routing options to fully concentrate on it. The visual importance of the selected path will be then significantly enhanced, while the rest of the routes will be much less important. In this thesis, *Figure 21c* gives an example, showing the symbol design after the cleanest path is picked by user.

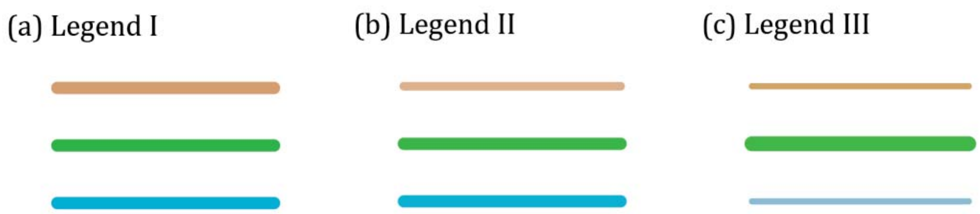


Figure 21. Legends for line symbols.

Summarizing and combining the above visualization techniques, the cleanest and coolest paths can be given more weight in line thickness over the shortest path, and they can be displayed with higher saturation colors and opacity to stress the visual importance. The effectiveness of navigation route design in practice will be evaluated through a user survey.

Another feature that deserves consideration during route design, is its interactivity. Like many navigation products, this application designs the markers to be draggable: Two markers in different colors representing origin and destination, respectively, will appear after the user finish the address typing, which allows the users to drag and drop them to any place inside the study area. Navigation routes that connect the two markers will be updated once the user drags the markers. Additionally, the different routing options are clickable and can be added or removed based on the user's preferences. After clicking on the desired route, the selected route will be highlighted, while the two will become less conspicuous due to reduced line thickness and color saturation. Throughout the above process, the map interface is equipped with the necessary functions for route navigation. Hence, the following section will focus on the flow and measures on user study to evaluate the effectiveness of interface design.

3.4 User Study

Identifying a map as a "good" map has been a challenge for a cartographer for a long time. According to Brychtova and Coltekin (2016), the quality of a map is determined by a variety of elements, including empirical evidence-based design decisions, the map's suitability for its intended purpose, and whether it suits its target user. Additionally, the background of the target user is another element deciding the quality of the map. People with different academic backgrounds, map-using familiarities, and ages may lead to different results of map quality evaluations subjectively. To resolve such personal diversities, user-centered usability evaluations are widely conducted to measure the efficiency, effectiveness, and user experience based on the user performance.

3.4.1 Questionnaire Design

The online questionnaire was designed by Google Forms, which allows for designing surveys in different forms. As mentioned in chapter 2, the questionnaire can be analyzed by two approaches, i.e., qualitative and quantitative analysis.

For Likert-type questions, bar charts can be created to visualize the distribution of responses for each question. For inference statistics, this study uses chi-square to verify whether the hypothesis holds. Users' responses to AttrakDiff can be visualized an into line chart to view users' impressions toward this prototype. Qualitative questions are open and text-based, asking the user's subjective insights, findings, or challenges about using the product. To conduct thematic analysis, particular pattern in the transcript can be coded first. Then reviewing the codes with associated scripts helps to better understand how the codes can connect. The theme can be created by grouping codes, and the narrative of interpreted analysis can be added in the end.

The user study was conducted face-to-face, allowing the users to interact with the interface personally. Participants' special reactions or comments toward the survey question and the interface were observed. The collection of user feedback lasted for a week, from 08.10.2022 to 15.10.2022.

3.4.2 Participants

Since the application aims to provide routing options for health-oriented purposes, it should target all social groups, regardless of age, gender, and background. Since advanced understanding and techniques in mapping software are not necessary for this user study, the questionnaire was thus distributed mainly among students without background preferences to verify its general applicability. Around 30 participants are expected to take part in the evaluation since it is a recommended sample size to obtain valid quantitative results of user study (Budiu & Moran, 2021).

3.4.3 Procedure

The common criteria used for usability assessment were proposed by Nielsen (1992)which are learnability, efficiency, memorability, error frequency and severity and subjective satisfaction. In this study, learnability, efficiency, and satisfaction are placed as higher priorities, while memorability and error frequency are not considered since participants are supposed to interact with the application for once, and there is no standard to classify user's operation as a "mistake."

The survey was carried out on my laptop, with a screen size of 14 inches, under a similar lighting environment and screen brightness: participants viewed the map interface and answered survey questions under indoor lighting conditions during the daytime. Such a consistent viewing environment helps avoid the interference of inconsistent outside variables to ensure the accuracy of survey results. Participants were asked to fill out the questions following the flow one by one. The entire experiment is composed of seven sections, including the introduction and consent, general information collection, visual attention, thematic relevance, interface interaction, interface evaluation, and user experience. *Figure 22* shows the questions under each sector. The complete questionnaire is attached in Appendix A.1.

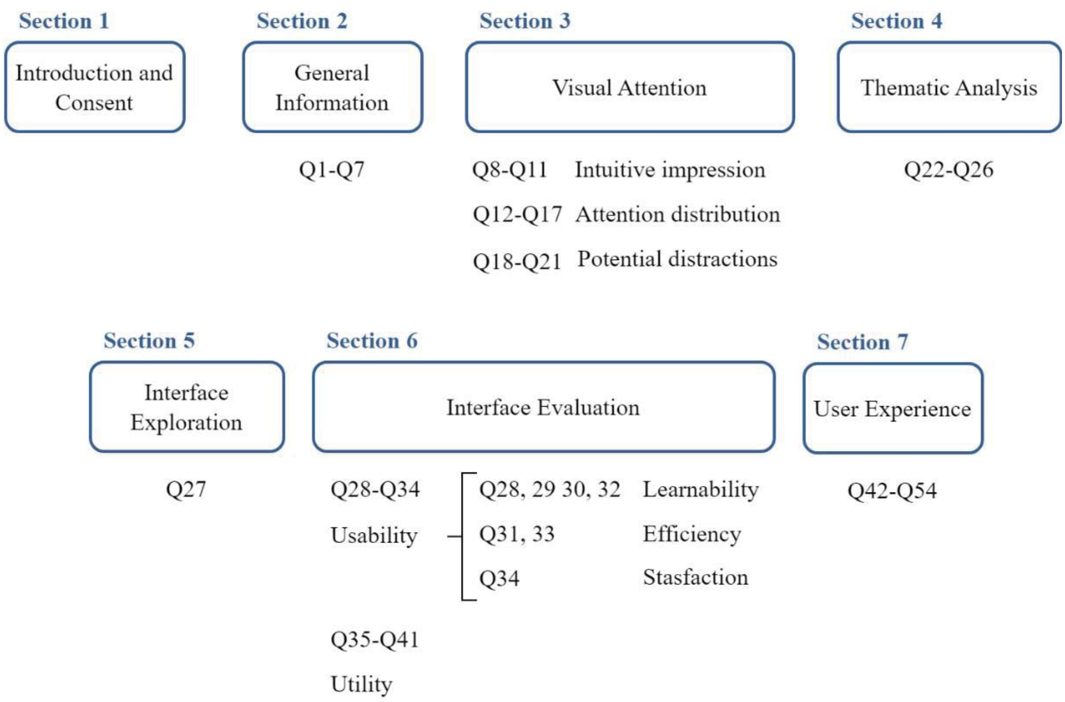


Figure 22. Questions for each section

Introduction and Consent

This section presents the basic idea of the application and study to participants to ensure users understand the purpose and usage of this study correctly. Besides, a consent form was provided to seek participants' agreement on volunteer participation in this survey and the consent of survey data usage. Users can continue the survey by ticking "Yes, I agree."

General Information

This section collected basic information about participants. It collected personal questions like age (Q1), gender(Q4), the current level of education (Q2), field of study (Q3), behavior frequency investigation, i.e., frequency of using web application for navigation (Q5), and questions about the study area, for example, whether the participants are living or once lived in Munich (Q6), and their familiarity with Munich city (Q7). Potential patterns may be derived from answers to this section, showing the disparities in user preferences in interface design among people with various education backgrounds or different familiarities with either Munich city or web applications.

Visual Attention

In this section, participants were asked to select the route that they noticed first, based on their intuitive impression (Q8 – Q11). Four static maps are visualized with the same origin and destination and visualization of routes but different in basemap designs, which aims to test the visual attention of different route operations with various underlying maps. Then another set of static maps are prepared to figure out how visual variables affect visual attention distribution over maps (Q12-Q17). Participants were required to answer the questions by choosing the path that received more attention. For this set of questions, the underlying maps are fixed, while the path symbol designs are different in color, opacity, or thickness. Additionally, a set of questions for testing distractive map elements are designed at the end of this section (Q18-21). Participants are supposed to select the potential elements that may interfere with the user's visual focus on the navigation routes. A variety of static maps are provided, showing possible factors that may distract the user's attention, including similar color design of basemap, dense symbols of POIs, underlying road network, labels of road or place, etc. Users are allowed to select multiple factors by ticking the check boxes or specifying possible factors that are unlisted.

Thematic Relevance

The objective of this section is to verify the readability of the interface by measuring whether the color or symbol design can be easily understood by most of the participants. Firstly, users are asked to enter the ideal colors that are best to represent the "cleanest," "coolest" and the "shortest" routes(Q22). The answer to this open question can give insights into color usage and its associated meanings, which can be used to evaluate whether the color design in this application is intuitive or not. Then two legend designs are shown to ask participants' opinions on the intuitiveness of the legend design (Q23) by Likert scale from strongly disagree to strongly agree. Then a static map showing two markers with different colors is provided, asking users to choose which one represents the origin based on their prior experience or intuition (Q24). After making the decision, the user would rate the intuitiveness of the marker design, where they were told the red marker stands for the destination and the blue marker stands for the origin (Q25). Then, participants were asked to rate the different basemaps based on how well they satisfy the practical demands of pedestrians and cyclists as a map for navigation (Q26).

Interface Interaction

Participants were given around 5 minutes to freely explore the map application interface in this section. Users were told the applicable regions in Munich city that support route finding. Participants can obtain an impression of the interface's usability, interact with different functions such as address typing and layer switching, view basemap designs in different zoom levels with more details, and examine whether the interface is understandable. Users may encounter some difficulties or confusion in using the application or come up with inventive ideas or suggestions that may improve the interface design or contents to make it more attractive or comprehensive. Subjective experience and evaluation of using the application will be assessed in the following sections based on the interface exploration. In the end, the functions that participants interacted with were asked (Q27) to investigate the popularity, in other words, the importance of different functions.

User Evaluation

In this section, user evaluation is divided into two sub-sections, which are usability and utility study. Both studies asked the user to select his or her agreement extent towards the given seven statements on the Likert scale from strongly disagree to strongly agree. For usability study, the learnability attribute tests how quickly a user can know how to use the interface without previous knowledge. It was assessed by Q28, Q29, Q30, and Q32, stating "It is very easy to understand and use to find a healthier path," "A support of a technical person is needed to be able to use the map", "Some detailed help or tutorial are required to be able to use the map", and "Some background knowledge of using interactive maps is necessary to be able to use the map". The efficiency attribute was verified by Q31 and Q33 to evaluate how fast and clear user can accomplish the desired tasks once getting to know about the interface. The statements were designed as "Many people will be able to learn to use the map quickly" and "I was often confused about where to click or where to look when using the map." The satisfaction of the user was examined by the statement: "The visual design of the application is well done" (Q34), to test whether participants like the interface.

Afterward, the utility study asked users a set of questions based on the usefulness of the application. Q35, Q36, and Q37 investigated the applicability and user's interests in the prototype by the statements: "I would like to use the map often," "It is an application of my interest," and "It would be applicable for the users who want to have health-oriented routes." The practicality and effectiveness were tested by Q38 and Q39, saying, "The features or functions should be added into routing application like Google Map", and "It has expected functions for health-oriented routing." The effectiveness of interface design was assessed by Q40 and Q41, saying, "It has necessary visualizations to understand," and "Different paths are visualized in a proper way."

User Experience

The last session collects the user's subjective feedback on user experiences and impressions of this application. The emotion of participants was collected by Q42: "How discouraged were you when using the map?", with answers ranging from "Not at all discouraged" to "Extremely discouraged." Extra features that may make the application more engaging and attractive were listed in Q43, to investigate users' interests in route applications. Five possible options with illustrations, including a layer of real-time air quality data over the road network, a layer of real-time surface temperature, expected time of arrival for each route, the amount of reduction on air pollution exposure, when choosing the "cleanest" path, and the amount of reduction on heat exposure, when choosing the "coolest" path were provided. Users can either select the option they are interested in by ticking the check boxes or add additional unlisted features.

After that, participants' impressions of the web application were surveyed based on antonym adjective pairs. Users were required to select a number as the answer for each question to represent the extent that they agreed with adjectives. Number Ten questions (Q44-Q53) were provided to assess this application comprehensively. The adjective pairs are: "unpleasant – pleasant," "conventional – inventive," "unprofessional – professional," "impractical – practical," "ugly – attractive," "confusing – clearly structured," "complicated – simple," "unpresentable – presentable," "unruly – manageable," and "boring – interesting." Lastly, users were asked to share their suggestions, questions, or ideas on how to improve the application without any constraints before they finally submitted the form (Q54).

3.5 Summary

This chapter describes detailed procedures and methods for study implementation. Firstly, the study area is introduced, together with the data generation and processing methods. Synthetic air pollutant concentrations and temperature were produced by random function based on the observed value ranges for each segment to determine the health attributes of the road network. Secondly, thorough steps of network creation, route finding algorithms, routes displaying, as well as the software and tools engaged were explained in detail. Road network and additional attributes were stored in Postgres geodatabase, and the desired route could be queried from GeoServer SQL View and then displayed on the interface. The third part describes the factors considered in interface design. It introduces the four basemaps used in this study and the placements of other map elements like the layer controller and buttons. Then the visualizations of different routes were illustrated to explain how to highlight health-related paths by adjusting and manipulating visual variables. Lastly, the procedures for conducting the user study were illustrated. Questions about interface evaluation and user experience were summarized.

4 Results

This chapter shows the principal results of the route algorithm implementation, interface design, route visualization, and user study, demonstrating how the research objectives were addressed and answering the research question 4k and 4l. Subchapter 4.1 describes the outcome of the prototype, displaying the design of the interface and map layout. Subchapter 4.2, on the other hand, illustrates the evaluation of results from the user study.

4.1 User Interface

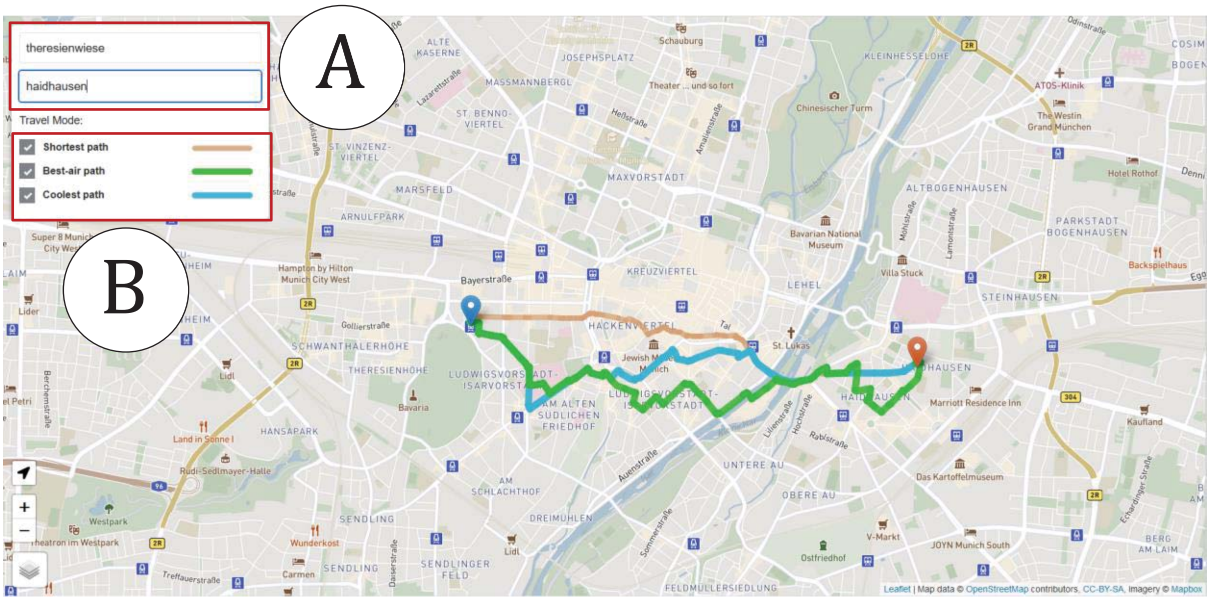
The interface of the prototype based on HTML, CSS, and JavaScript is developed, containing a basemap, search boxes, travel mode switcher, and other map buttons. The general appearance of the interface is shown below (*Figure 23*):

Figure 23. The initial user interface of the application.

The interface uses *Basemap II* as the initial underlying map by default since it is considered a compromise design to balance visual importance and necessary map contents: the main colors used are less notable for increasing the visual contrast to navigation routes. At the same time, it includes details such as landuse classification, road network, or labels of POIs for pedestrians and cyclists. The interface is centered in the city center of Munich, at the coordinates of (48.137, 11.567), covering the main study area of this application with a zoom level of 14. Searching boxes, travel mode selector, as well as legend, are placed in the left upper corner (*Figure 23, A)*, while the locating and zooming buttons and layer controller are placed at the bottom of the left side (*Figure 23*Figure 23*, B*).

To accomplish the path-finding purpose, user can type the address of origin and destination in the search boxes, and the markers representing the starting and ending points will show up after submitting their addresses by pressing enter (*Figure 24a, A*), where red marker represents the destination, and blue marker represents the origin. By ticking the checkboxes to add different routing options between the original and the destination, the corresponding route will appear (*Figure 24*a, *B*). Both markers are draggable and allow the user to drag and drop them at desired positions within in study area. Then updated routes connecting new origin and destination will be derived and displayed. The address input boxes will be empty after dragging either one of the markers. Users can click one specific route to focus on, the chosen path will be emphasized by a more conspicuous symbol design like brighter color, yet the unchosen routes will become less salient with thinner line stroke and duller color (*Figure 24b, C*).

(a)



(b)

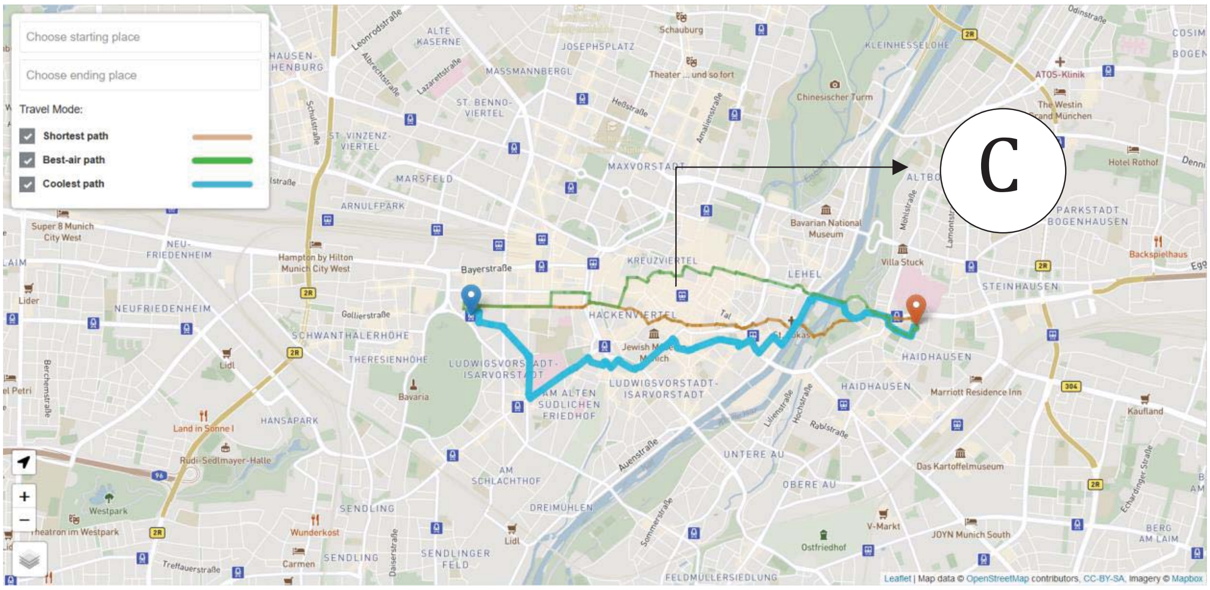


Figure 24. The user interface for route finding

The interface supports the user to switch between different layers. Except for the four designs of basemap introduced in chapter 3.3, Mapbox Satellite layer is also provided as a standard configuration of a navigation application. The user is also allowed to press the locating button to access his or her current position if permission is given.

4.2 Results of User Study

This section evaluates the result of the user study described in chapter 3.4. There are 30 participants took part in the study to fill out the questionnaire in total. Generally, the majority of the feedback were positive and inspiring. Quantitative analysis with charts or diagrams will be conducted for quantitative questions. On the other hand, for open questions, the thematic analysis will be applied to group users' answers and find patterns from what people write.

4.2.1 General Information

The statistics of demographic information such as age, gender, and educational background are shown as follows. Due to the reason that the questionnaires were mainly distributed in student dormitories, and the age distribution of participants was uneven (*Figure 25*a). Almost all the users were between 20 to 29 years old. On the other hand, the gender of participants was distributed more evenly: 16 female and 14 male users took part in the user study and completed the questionnaire (*Figure 25b)*.

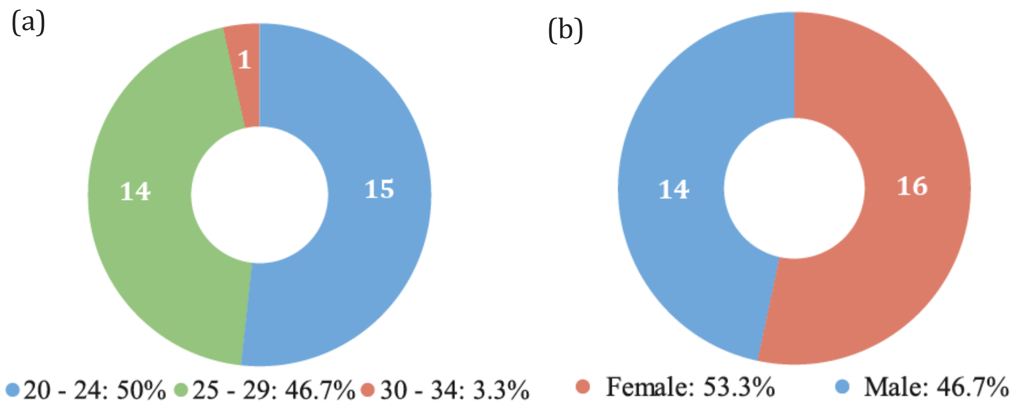


Figure 25. Gender and Age of participant.

For the current level of education, 43% of the participants were master's students with an undergraduate degree, another 53% of the users did have a postgraduate degree, and one participant was an undergraduate student with a high school degree (*Figure 26a*). The fields of study of participants showed rich diversity: the majority of the participants were studying Engineering, and the rest of the participants were majoring in Computer Science or Mathematics, Science, Architecture, Language, Law, Health Science, Chemistry, and Communication (*Figure 26b*).

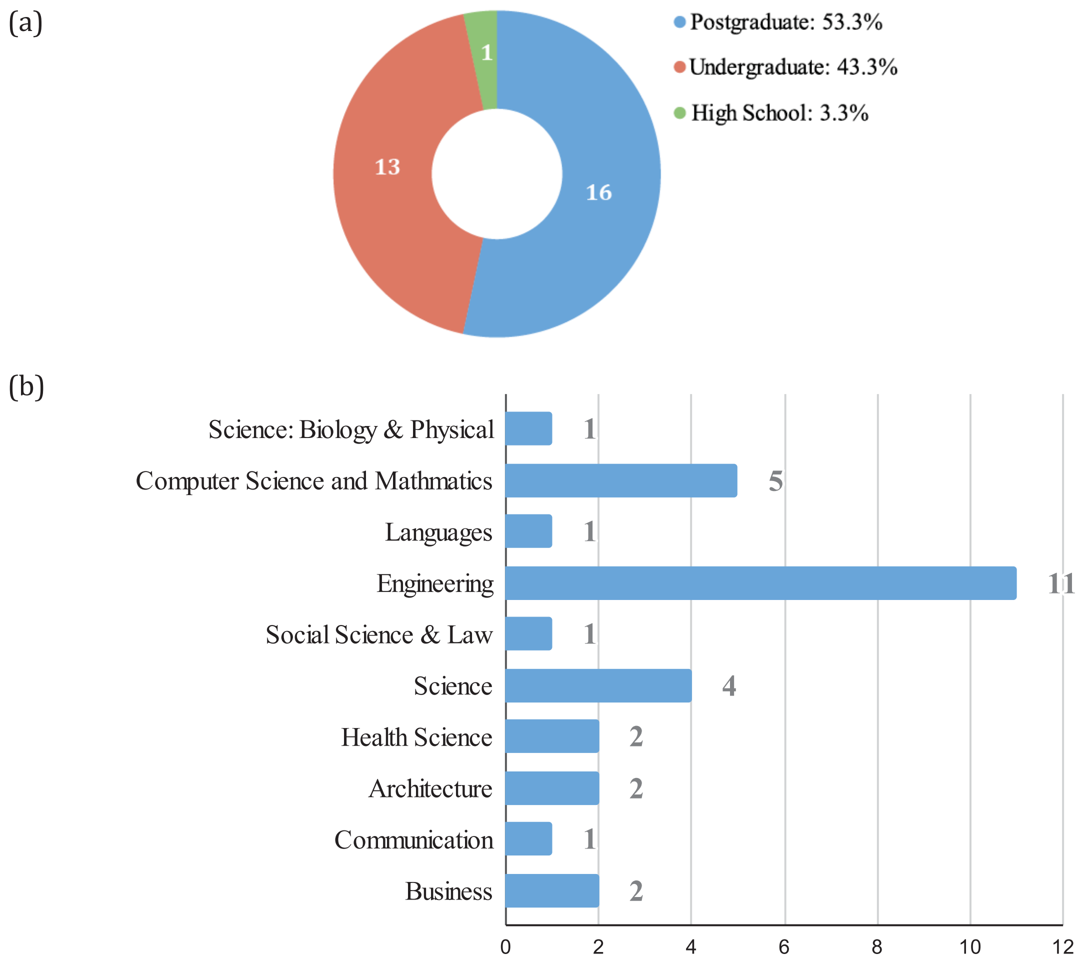


Figure 26. Education level and background of participants.

Figure 27 and *Figure 28* display the investigation results on the frequency of using web navigation applications and familiarity with the study area. It was indicated that over half of the users claimed that they used web navigation products quite often (twice a week or more). Most of them once lived or were living in Munich city at that moment when the survey conducted, which was expected with regard of the target audience.

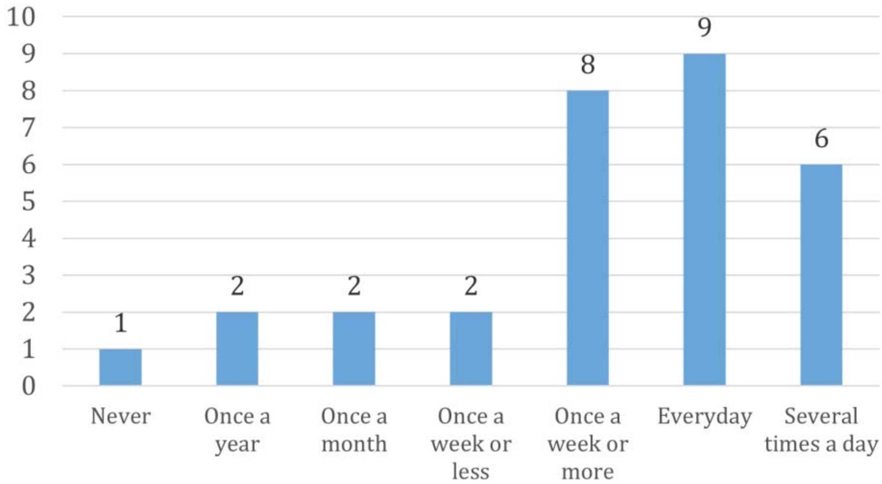
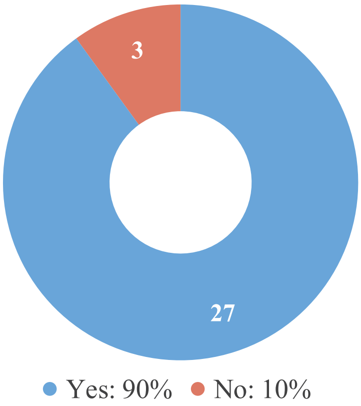


Figure 27. Frequency of using web navigation applications

(a)



(b)

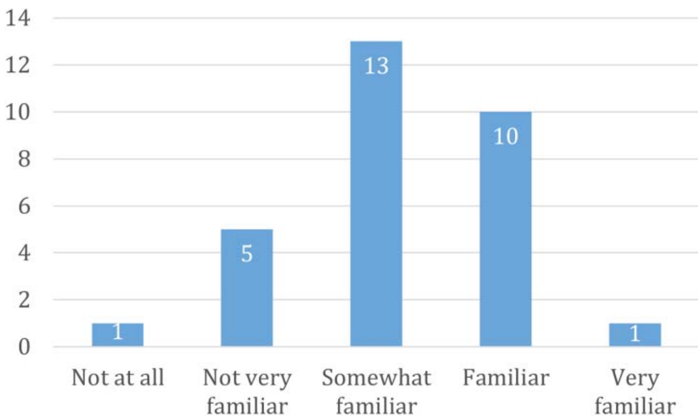
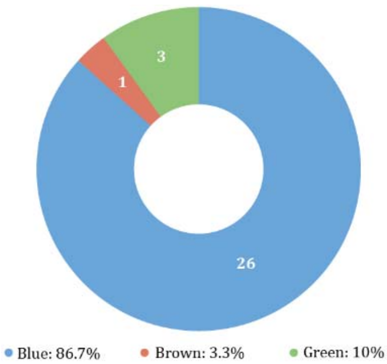


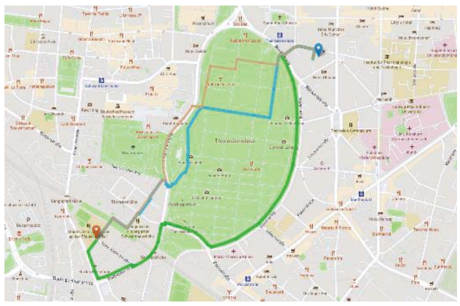
Figure 28. Familiarity with Munich City

4.2.2 Visual Attention

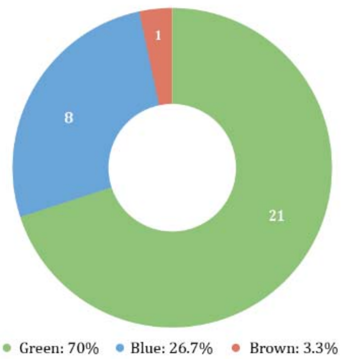
The results of this section were quite inspiring and worth pondering. Answers from Set I indicated the observable impacts of underlying backgrounds. The corresponding results for each static map are seen in *Figure 29*. For *Basemap II and Basemap III*, over 65% of the users first noticed the "cleanest" path, i.e., the green path (*Figure 29b and c*), while in the case of *Basemap I* (*Figure 29a) nearly 87%* of the users were attracted by the blue path. Similar patterns also appeared in dark mode (*Figure 29d)*: the majority of the user firstly noticed the blue path.

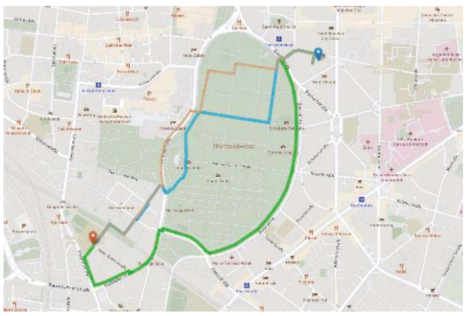
(a)





(b)





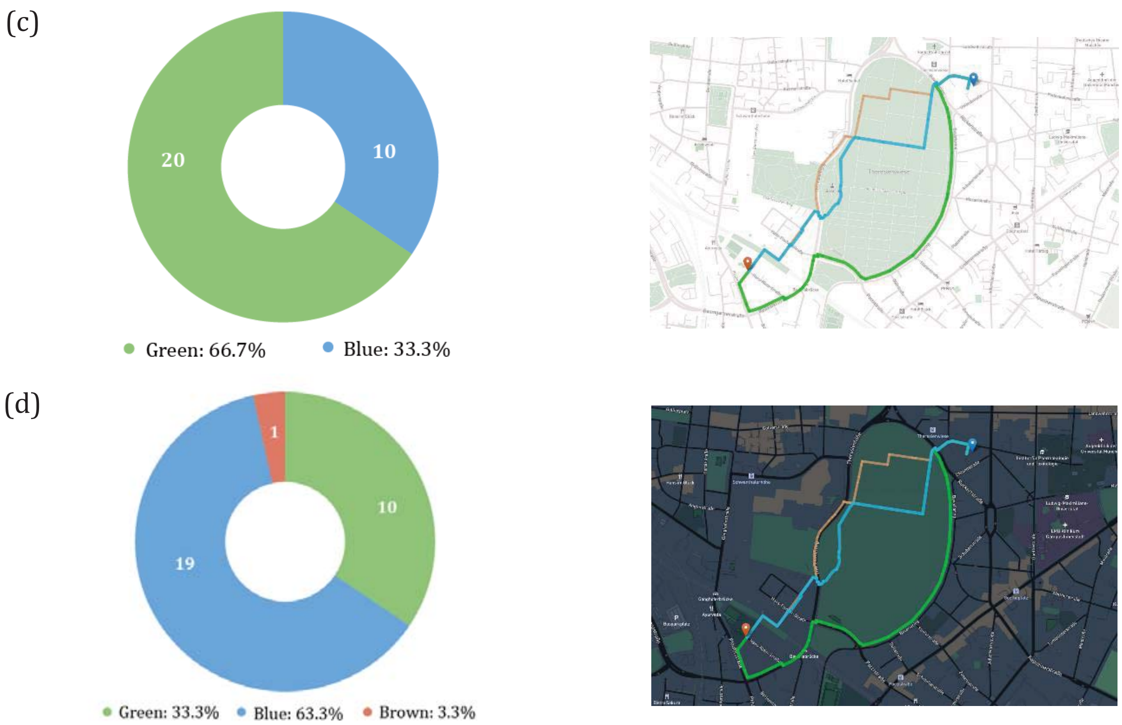


Figure 29. Impacts of basemap on visual attention

Although the above static map cannot guarantee that the user's choice of route is absolutely fair due to the diversities of routes in positions and lengths, which inevitably affected the user's perception, it still certified the assumption proposed in *Chapter 3* that basemap design indeed played a role in guiding user's visual attention and influencing user's choices. In cases where the visual importance of the background map is diminished (Q8 and Q10), the user's preattention may probably fall on the objects that occupy more spatial extents, i.e., green path. On the contrary, in the case where the basemap was given more importance (Q11) or changed the contrasts between objects and background (Q9), the user tended to notice the path with the biggest contrast to the background. Since the green path shown in the example was around a park, which was also represented by green, the blue path looks more salient.

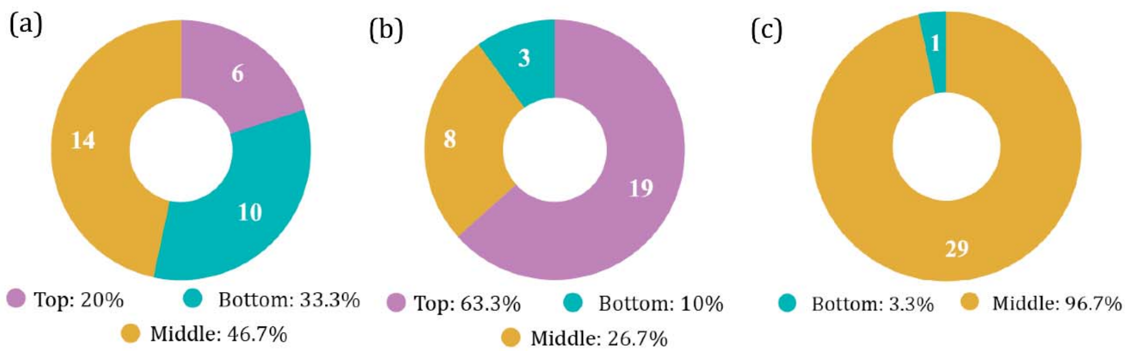


Figure 30. Statistics results of Question 12 to Question 14.

The results of question Set II showed how visual variables guide and manipulate visual attention by asking where they allocated most of their attention. Q12 designed line symbols with different colors but the same thickness and opacity, and none of the three routes overwhelmingly captured the attentions of users: *Figure 30a* shows that around half (46.7%) of users gave their attention to the middle path, and 33.3% of the users were more attracted by the bottom path, while 20% of participants said the top one is more attractive. *Figure 30b* and *Figure 30c* applied the same color of three routes yet made changes in line opacity and thickness. The charts show that 63.3% of the users selected the one with the highest opacity, and almost all the users (96.7%) chose the middle line with the biggest thickness, showing the great effects on attention capture. After that, *Figure 31* shows the user's selection under the cases where a particular travel route was selected and addressed by the users, in which color, opacity, and thickness were combined in line symbol design. It is suggested that in the three cases, over 90% of the participants decisively selected the paths that were emphasized, which indicated the superiority of using combined visual variables to make map contents more notable and verified assumption II raised in *Chapter 3*.

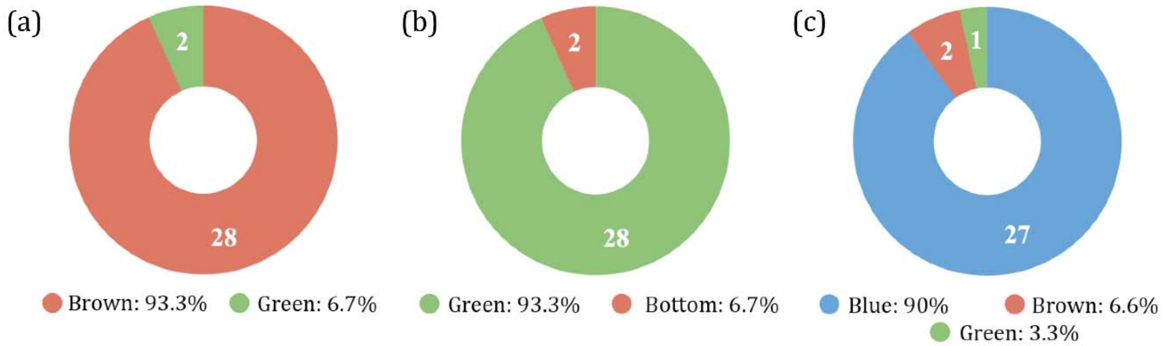
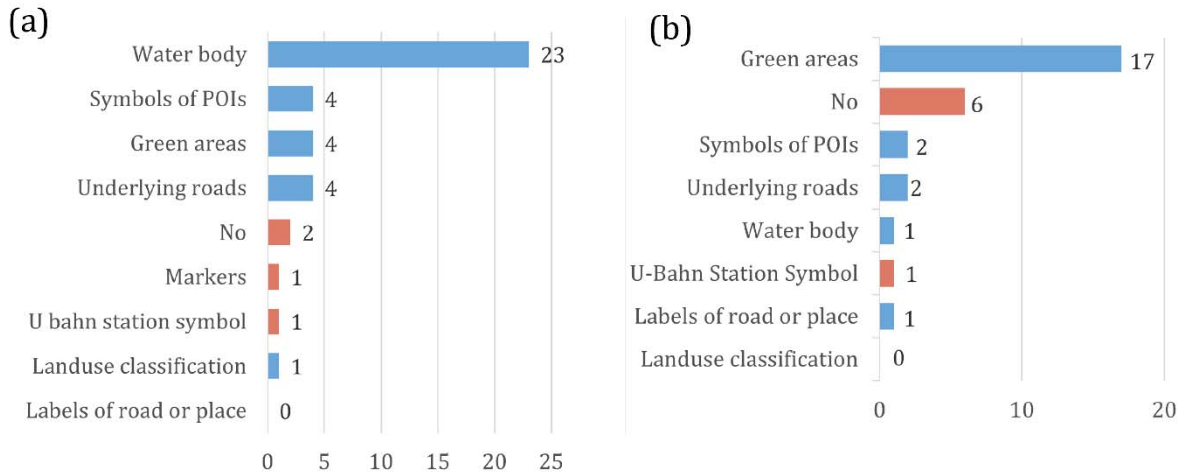


Figure 31. statistic results for Question 15 to Question 17.

Investigations on potential distractions of map reading were shown in the following diagram. Users were allowed to select multiple elements that may distract their attention and add more items based on their definitions of distraction. Although strong tendencies existed in users' choices in some cases, there were still huge individual differences in the answers.



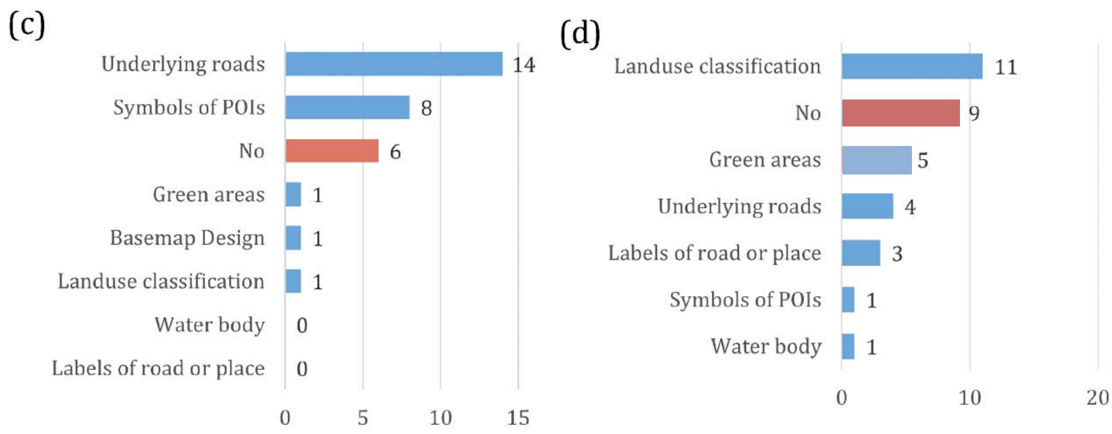


Figure 32. Results from Question 18 to 21, on distractive map contents

*Figure 32*a shows the user's responses on the static map, where the "coolest" route is along the riverbank, with a similar color. Most of the participants classified "water body" as a distraction that interfered with their attention on the path due to the similar colors. The red bars were the answers written by users. Some opinions, however, said underlying road networks, symbols of POIs and U-bahn stations, and green areas caught their attention while viewing the route. One user considered the landuse classification in the background map as a distraction, and two users claimed nothing bothered them at all. One answer that the user wrote said the marker design also caught his attention when viewing the map. *Figure 32b* shows the results of another static map, where the "cleanest" green path is near a green area. The chart shows that over 50% of the participants believed the "Green area" was a visual distraction because of its visual importance. Besides, two users chose the "Underlying roads" as a distraction, and one user selected "Water body" as the distraction. There were four participants said they were affected by the name labels of places or roads, or symbols of POIs or U-bahn stations, while six of them said nothing distracted their attention. In the next case in *Figure 32c,* dominant choices went to "Underlaying roads" and "Symbols of POIs" since the road color was similar to the path's, and the dense distribution of POIs and U-bahn Stations over the map extent. And six comments from users said there were no visual distractions. *Figure 32d* shows the results of over dark basemap. Around 37% of the participants took "Landuse classification" as distractions, while 30% of the users wrote "no distraction". For the rest of the selection, five took green areas as disturbing factors, four classified labels and symbols as distractions, and three answers went to "Underlying roads".

The results indicate how other map contents affect the user's focus. Some objects like natural features, road networks, and POIs distribution help to give users hints to better recognize surrounding environments and locate themselves in practice. However, those contents should not be indifferentiable from navigation routes or cause much visual confusion when developing the interface.

4.2.3 Thematic Relevance

This section shows participants' attitudes on the intuitiveness of the color design. Q23 collects the user's answers on the desired colors for three routes, respectively. Except for one invalid answer with only one color written, there are 29 valid answers. *Figure 33* lists the results of participants' preference for route colors.

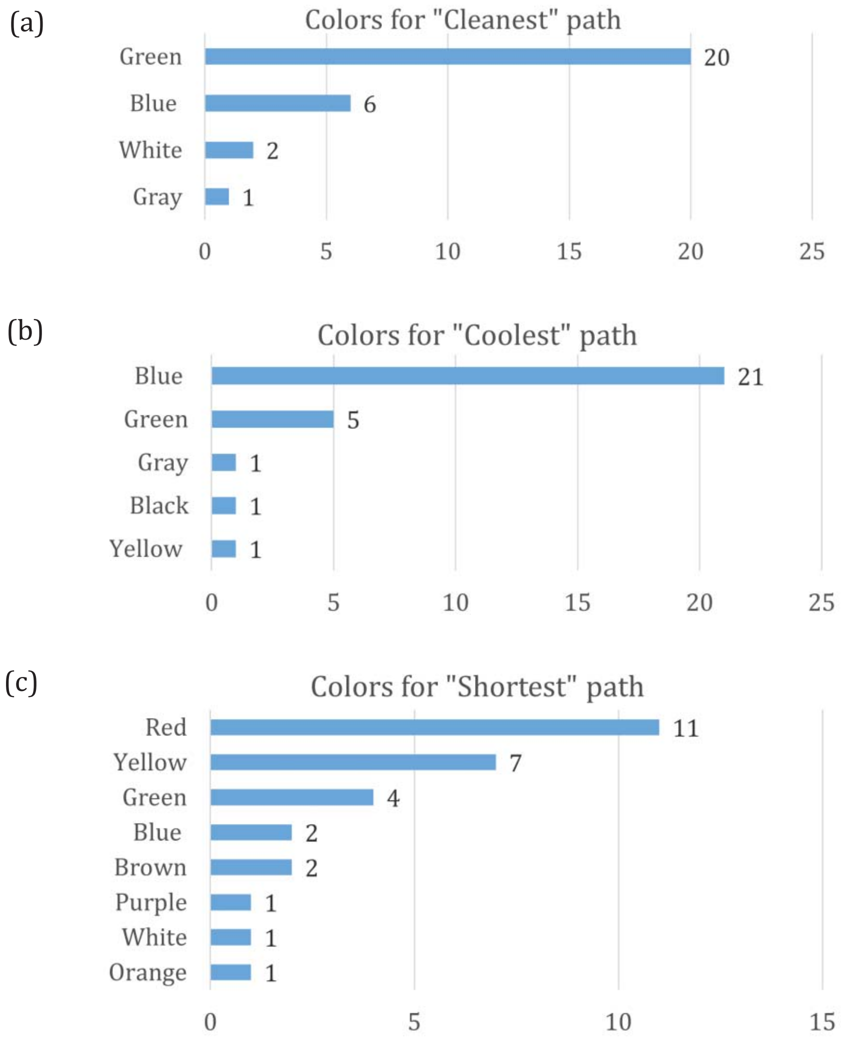


Figure 33. User's preferences for the "Cleanest", "Coolest", and the "Shortest" path.

It is indicated that green and blue were the most popular two colors associated with the themes of health and cooling. For the route with the best air quality, the majority of (66.7%) users would like it to be green and, 20% of participants preferred it was in blue. Some other colors, like white and grey, were proposed by the other three users, saying white or light grey indicates cleanliness and pureness for them. Conversely, for the coolest path, the most popular color was blue (70%), while the second favored option was green (16.7%). Other desired colors, like yellow, gray, and black, were mentioned. Although answers for the shortest path were quite diverse, most of the users chose the warm colors for it: 63.3%of users in total decided to represent the shortest path in red, yellow, or orange, and red is the most popular option among them. Besides, brown, blue, green, purple, and white were mentioned as well.

Reviewing the answers from users, it is found that most of the users (73.3%) agreed to employ colors with different hues to represent different paths. However, some participants did choose colors with the same hue but different saturations or opacity to represent two or three different paths. For example, one user expected both the cleanest and coolest routes should be in blue while the shortest path in yellow. Another one wrote, “blue for the cleanest route, and green for the coolest and the shortest,” which was opposed to another answer that said, “green for the cleanest, and blue for the coolest and the shortest.” One answer specified particular green to represent three routes. It wrote “forest green for the cleanest route, lime green for the coolest, and green for the shortest.” Complete proposals for participants can be found in Appendix A.2.

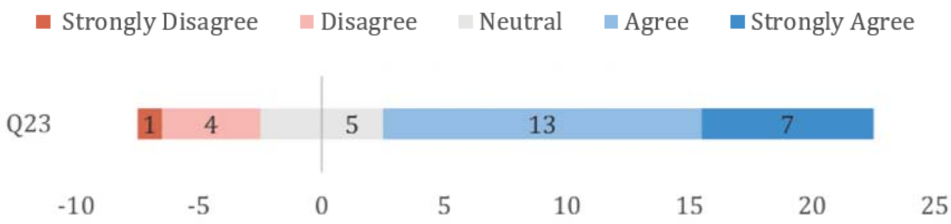


Figure 34. User’s agreements to legend design (Q23).

Figure 34 shows people’s agreement on the set of route color designs. The schema employed green for the cleanest path and blue for the coolest path and used dull orange or brown to represent the shortest path respectively. Results show that 5 people remained neutral, 5 disagreed with the design in general, and 20 users expressed positive attitudes towards the color design. The p-value of the chi-square test, in this case, is around 0.0027, which is less than the significant value α (α=0.05), indicating the null hypothesis can be rejected, and the patterns on the user’s altitude are not random.

Figure 35 shows the user’s feedback on marker colors. 70% of the users considered the blue marker represented the starting point, and 63.3% of the participants stated the marker color matched their expectations and intuitiveness. The p-value of the user’s intuitiveness is 0.0186 (< 0.05). Therefore, the null hypothesis can be discarded.

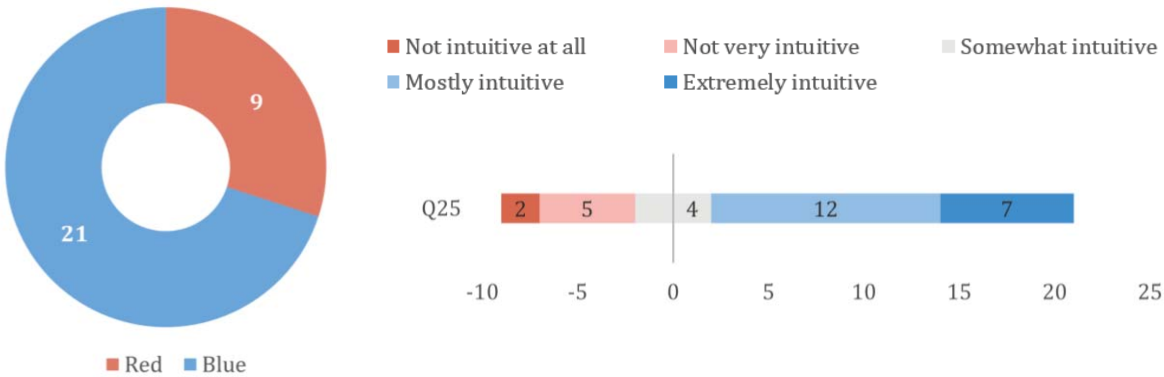


Figure 35. User’s agreement on marker color design.

Lastly, the user's ranking on basemap design for pedestrians and cyclists is shown in *Figure 36.* It is quite clear that the *Basemap III* was favored most by half of the users to be the most suitable basemap for pedestrians and cyclists due to its vividity, and the *Basemap III* was the least popular one since it was "too plain" and lacked necessary contents. Over 50% of the participants rated *Basemap II* as the second liked basemap, and 33% of the participants gave the third-best basemap to the dark one.

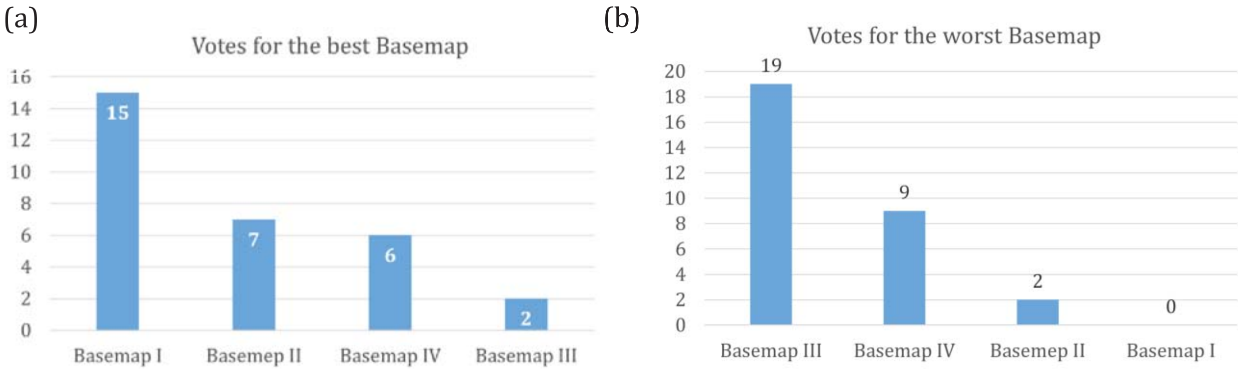


Figure 36. Results of basemap rating.

4.2.4 Interface Interaction

Every participant was given around 5 minutes to explore the interface freely. Their expectations, strategies for interacting, and challenges faced are qualitatively described and explained in this section.

The majority of the participants viewed, panned, and zoomed the basemap when first introduced to the interface. Then they would try to type the address of their interests in the search boxes, which could take some time because the geocoding requires a completely correct address without autocomplete function. Around 7 of the participants tried to obtain the starting and ending locations by clicking the places in the map directly or by clicking the locating button to access the current location. After the routes were displayed, generally, the users would zoom in or out to view the routes better. Some of the participants could find out the markers were movable, and they would drag the marker to different places to check how the routes changed and how fast the update would be. Some of them also would try to turn on and off certain routing layers to compare. They probably tried to switch to a different basemap by layer controller and tried to click the locating button. After users were familiar with the interface, they were asked to continue the rest of the survey.

4.2.5 Interface Evaluations

This section shows the subjective evaluation of the prototype in terms of usability and utility. The answers were collected in the form of the Likert scale. There is no fixed or standard way of analyzing and visualizing Likert data (Petrillo et al., 2011). Commonly, Likert data can be visualized in any one of the following forms: simple bar chat, stacked bar chart, diverging bars with neutrals separate, and diverging bars with neutrals split. In this section, the results will be illustrated in the form of diverging bars with neutrals split to make it easy to see the general shapes of agreement and disagreement.

Learnability is one aspect of usability evaluation; users must be able to use a new application quickly without any prior experience. Four statements were designed to examine the learnability:

Q28: It is very easy to understand and use to find healthier paths.
Q29: A support of a technical person is needed to be able to use the map.
Q30: Some detailed help or tutorial is required to be able to use the map.
Q32: Some background knowledge of using interactive maps is necessary to be able to use the map.

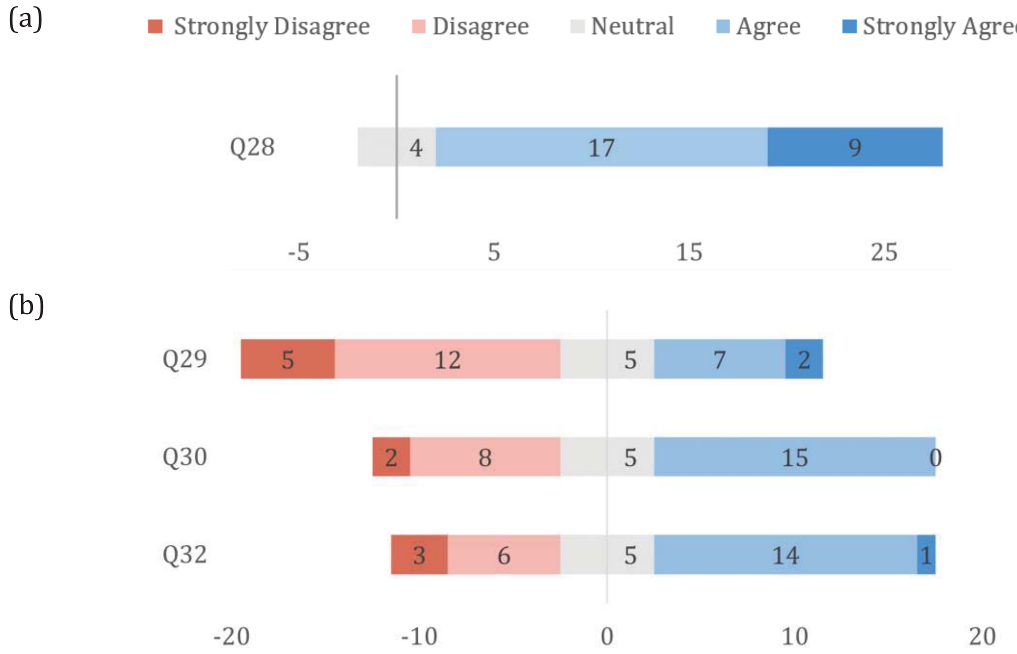


Figure 37. Distribution of answers for Q28, Q29, Q30, and Q32.

The scale distribution of Q28 *(Figure 37a)* shows that except for the four users holding neutral atitudes. All the participants agree that this prototype is simple to use. The p-value significantly less than 0.05 ($p < 0.00001$), which rejected the null hypothesis that the above pattern randomly appeares. The other questions, on the other hand, reflected user's demands to have an instruction to guide users to use the prototype. For Q30, half of the users supposed it is necessary to have an information page or brief introduction for them to better understand the use of the application. Prior experience and knowledge about how to use interactive interface like Google Maps or Bing Map were considered important for users to get started quickly.

The efficiency attribute was examined by Q31 and Q33 to evaluate how fast users can complete desired tasks through the interface:

Q31: Many people will be able to conduct the route-finding task quickly.
Q33: I was often confused about where to click or where to look when using the map.

Distribution results can be seen in *Figure 38.* The patterns from the distributions of the two answers are quite strong and obvious, particularly for Q31. It is found that 29 out of 30 participants agree that users can implement route finding tasks fast through this route planner, with a p-value significantly less than 0.05. Besides, two-thirds of the users disagreed with the statement in Q33, showing the majority of the users did not encounter big challenges when using the route planner. The p-value of the result of Q33 is 0.006, which discards the null hypothesis and indicates the validity of the distribution pattern.

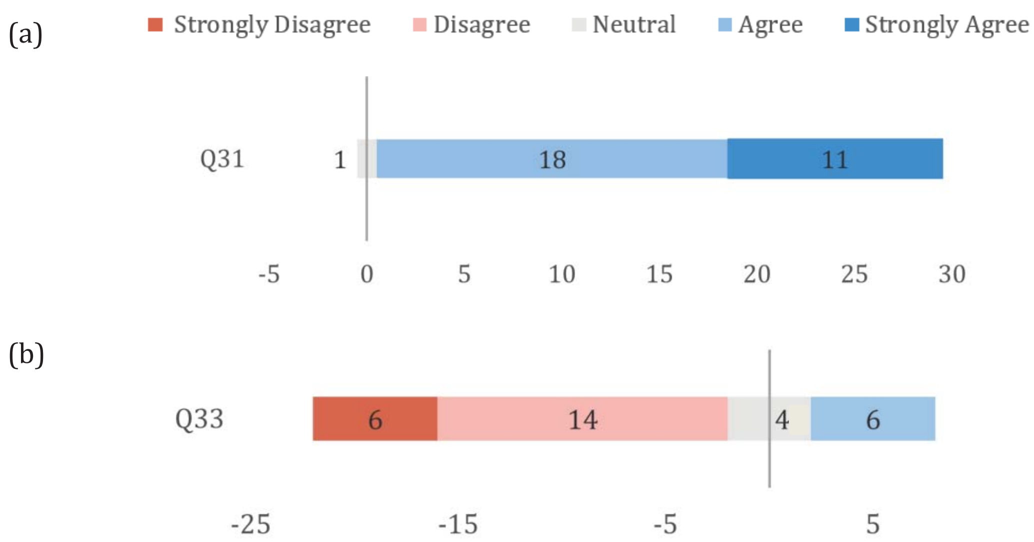


Figure 38. Distributions of answer Q31 and Q33, for efficiency testing

Figure 39 illustrates the users' opinions on the appearance of the application in general by asking the question: Q34: The visual design of the application is well done. The distribution shows 76.7% of the users gave positive feedback towards the interface appearance, with the p-value significantly less than 0.05.

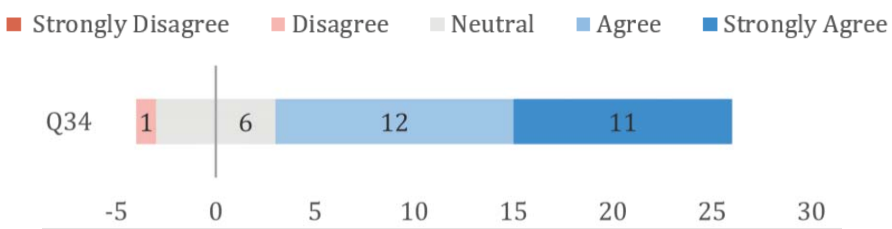


Figure 39. The distribution of answers Q34, for satisfaction testing.

The usefulness of the prototype was examined by Questions 35 to 41. Among them, Q35, Q36, and Q37 examined user's interest and applicability of the application:

Q35: I would like to use the map often.
Q36: It is an application of my interest.
Q37: It would be applicable to the users who want to have health-oriented routes.

The practicality was verified by question Q38 and Q39:

Q38: The features or functions should be added to routing applications like Google Maps.
Q39: It has expected functions for health-oriented routing.

Lastly, the effectiveness of design and visualization was examined by Q40 and Q41:

Q40: It has necessary visualizations to understand
Q41: Different paths are visualized in a proper way.

The results of the distribution of the Likert scale are displayed in *Figure 40*, using diverging bar plot with alignment at the neutral part. By viewing the distribution patterns, we can get a general overview of users' opinions on the utility of this application.

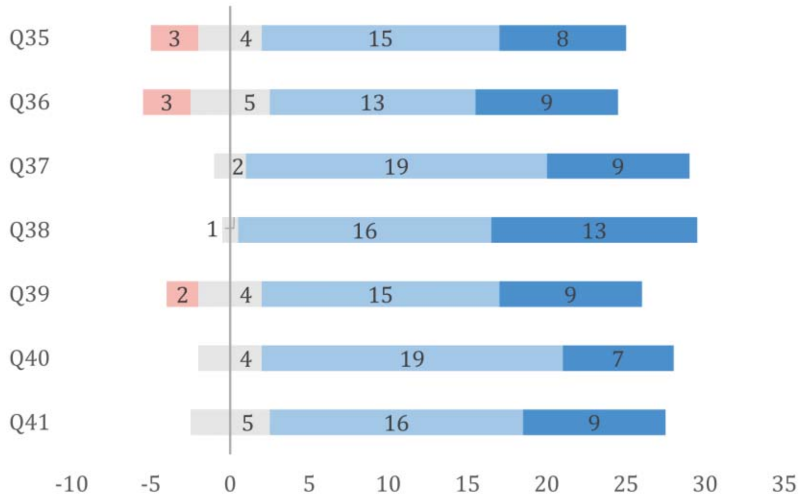


Figure 40. Distributions of answers Q35 to Q41.

It was found most of the answers fell on the positive side, indicating the utility of this prototype generally satisfied the user's expectations. The p-value of the above set of questions is 1.91×10^{-35}. Therefore, the alternative hypothesis that the feedback of the utility test is positive is verified.

4.2.6 User Experience

This last section of questionnaire results shows participants' subjective impressions of this application in general. User's emotion while using the application was collected by Question 42, and the statistics show that 83.3% of the users did not feel discouraged when using the map. Q43 investigated potential features that might be liked by users. The chart below (*Figure 41*) shows the user's choices of favored features.

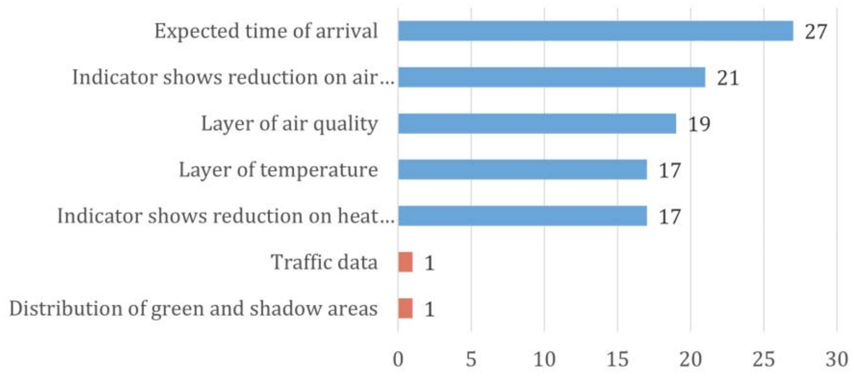


Figure 41. Results of Q43, about additional desired map features.

From the given options, the expected time of arrival for each route was the most wanted feature. According to some participants, "it helps to give better ideas on the traveling time and effect for each route," and "it shows the time cost of health-oriented paths." The idea of adding an indicator showing how much air pollution exposure can be avoided by choosing the cleanest path was also favored by 70% of the users because "it makes the health-oriented options more motivational and appealing". Except for the given features, there were two inspiring features proposed by users. One user would like to add real-time traffic data for reference since streets with heavy traffic are generally associated with higher air pollution. Another one mentioned adding the distribution of green and shadow areas, which would be helpful for pedestrians and cyclists to choose a pleasant traveling environment while reducing adverse health impacts.

Next, users' ratings on their impressions are shown below. For Q44 to Q53, Attrakdiff was used to investigate users' feelings from both pragmatic and ease of use (hedonic) aspects. Ten pairs of antonyms of adjectives were listed, and asked users to select the agreement extent between adjective pairs, which is closest to describing their feeling towards the product. The average value of each factor was calculated and illustrated in *Figure 42.* It is found that all the ratings on this application are positive from the standpoints of pragmatic, hedonic, and attractive qualities, which indicates this application was regarded as a pleasant, inventive, and practical product that was liked by the majority of the participants.

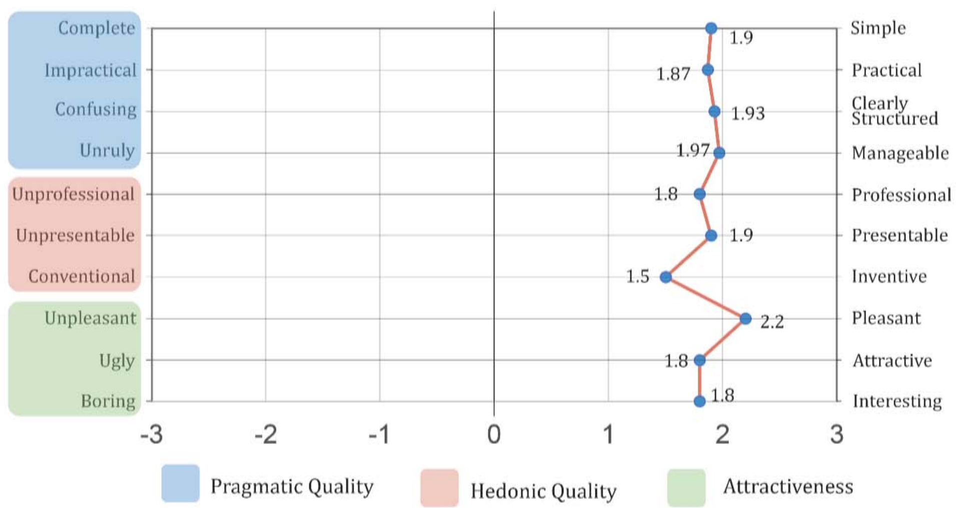


Figure 42. Answers of Q44 to Q53, for user's impressions

For the last open question on how to make the application better, thematic analysis was implemented. The crucial step of thematic analysis is the determination of themes. After getting familiar with the data collected, themes can be defined. Each theme is supposed to be a word or short statement, which groups at least two topics the users mentioned. Thirty responses were grouped into six themes based on the common keywords mentioned to analyze the patterns and meanings of what people thought (*Table 6*).

Table 6. Thematic analysis for Q54.

Theme	**Example quotes**	**No.of people mentioned**
Interface function	"I would like to have fuzzy match available, instead of typing the whole exact address name" "Vague input or autocorrection for address inputting" "Improve the accuracy of geocoding" "It would be better to zoom to the routes after submission"	13
Symbol design	"Using the same marker symbol for origin and destination sometimes cause confusion" "Light blue is closely tied to cleanliness in Germany. Personally, I would suggest a lighter blue for the coolest path." "Emphasis on the importance of layer controller"	6
Personal altitude	"Graphic design, or just use dark mode as its most pleasing and interesting." "While the map is very inventive and not something I have already encountered, it doesn't meet my personal interest and is kind of niche."	2
Desired feature	"I would add expected time of arrival" "It would be more practical and attractive if some photos for attractions and the corresponding reviews from pedestrians be highlighted on the map" "Add direction guides for navigation, and add different mode of travelling, like walking or cycling" "Add information or reminder of stairway"	12

User instruction	"A short guidance would be nice to show what functions are usable. For now, it's a bit hard to figure out that the route is clickable, and the points are draggable." "Need to specify the intended user group" "More explanations on route planning" "Add hints to guide the new users"	5
Outlook	"I wanted it on Google Map," "I would make it a collaboration with already existing map app" "It's better to combine with the google map or others."	4

Under the theme of interface function, among the functions provided in the interface, most of the comments went to the geocoding results and address typing form. Responses reflected the insufficiency in related function design. Suggestions from participants that the combination of address inputting and direct clicking and zooming map to queried routes are valuable to make the prototype more user-friendly and mature. Demands on more accurate geocoding results indicating Nominativ may not be the ideal geocoder in the study area of Munich. The theme of symbol design shows different aesthetic or perception preferences in map reading. Although the majority of the users agreed with the line and point symbol design in general, some users were still confused when using the interface. It is indicated a clearer symbol design that decreases ambiguity and confusion is highly needed. The theme of desired features provides inspiring and appealing attributes to make the prototype more comprehensive: it was mentioned by users to add direction guides after picking a wanted navigation path, like many navigation apps. Other recommendations like adding a reminder of the stairway, integrating of slope dataset, and adding surrounding attractions the considered user's health condition and potential interests into consideration, which may make the prototype safer and more attractive to use in practice. Additionally, few users mentioned the necessity of having guidance for new users to explain the intended purpose and available functions. Although most participants considered the prototype easy to operate and understand in the quantitative test, it seemed to cause confusion as to what the prototype was for and what each path represented. In the theme of outlook, users expressed their expectations on this health-oriented route planner can be broadly used. Responses suggested to combine it with existing commercial navigation apps for the concern of health.

4.3 Summary

In this chapter, the outcome of the interactive map application was demonstrated. It supports multiple travel modes, layer switching, locating, and dynamic route-finding functions within study areas. The user study received 30 responses within one week, and the feedbacks from surveying were positive in general. Evaluation of visual attention of interface design was conducted to illustrate the assumptions that basemap and symbol design played a role in attention distribution and that the interface and symbol designs are effective in guiding user's attention to health-oriented or heighted paths.

The usability of the prototype was examined by three attributes using the Likert scale – learnability, efficiency, and satisfaction. The results were analyzed quantitatively by chi-square test and verified that majority of the participants thought the application was easy to use. However, prior knowledge of using interactive maps was considered necessary to use this prototype easily, with a lot of demands from users to provide an introductory page on how to get familiar with this application quickly. For the utility of this prototype, responses from the Likert scale proved that majority of the users agreed that this prototype had expected functions and was applicable in reality. Users' subjective impressions and emotions were measured by AttrakDiff. The results showed that the average points for all the descriptions were positive, indicating this prototype was favored by participants generally. Additionally, users' suggestions on how to improve the application were summarized qualitatively, showing diverse opinions on symbol design, interface function improvements, the addition of useful features, and further outlooks.

5 Discussion

As listed in Chapter 1, this thesis aims to develop a application prototype that focus on healthy routing in urban regions. To verify whether the research objectives are reached, and whether all the research questions were answered sufficiently, this chapter conducts an overall assessment to discuss and compare the outcomes with the expected performance one by one. Afterward, the limitations of the prototype and user study are listed, followed by possible improvements and suggestions for future study.

5.1 Overall Evaluation

Prototype development

One of the main objectives of this study is to develop an application prototype to find the health-oriented paths in Munich, which is supposed to adopt a health-related routing algorithm and be integrated with necessary navigation features. This initial goal was fulfilled by the following stages. Chapter 2.1 and chapter 2.2 reviewed previous related research to provide a theoretical basis for building novel navigation applications and answered research questions a and b. AQI and temperature were selected as two health indicators, and Dijkstra's algorithm with customized cost was used for route planning. Chapter 3.1 and chapter 3.2 detailed the process of data preparation and algorithm implementation, which answered research question 2. Synthetic data was generated over the study area and assigned to the road segment. Then topology network was created for the route queries. PostgreSQL, GeoServer, and Leaflet were combined for route querying and displaying. The outcome of the prototype interface and its functions was illustrated in chapter 4.1. It consisted of basemap layers, locating buttons, the search box, and a travel mode switcher. It allows users to drag the marker to get updated routes dynamically.

Interface visualization

Another sub-objective of this thesis is to effectively design a web interface, which serves the theme of the prototype and can well balance the visual attention of different map contents. Chapter 2.3 introduced the cartographic principles in interactive map design, including the visual variables, color selection about line symbols, arrangement of map elements, and components in the interaction process. Chapter 2.4, on the other hand, provided knowledge on attention-guiding techniques, and chapter 2.6 showed the existing web mapping navigation applications to compare the different visualization styles and details. Research questions 1c and 2 were thus answered. Inspired by the given information, in chapter 3.3, the interface was decided to address the importance of health-oriented paths by giving them more visual importance and reducing the salience of basemap. Multiple basemap designs were provided to users to freely select the desired one based on their demands. In chapter 4, the appearance of the interface was shown, and the results of the user study indicated that the interface design, including the route visualizations, was helpful for distributing attention over the health-related path, and the interface, in general, was favored by participants.

User study

The last sub-objective is to evaluate the usability and performance of the prototype by the user study. Chapter 2.5 provides the basic measures of product evaluation, which answered the research question m. The user study was conducted in the form of questionnaire, with 30 participants took part in. The questionnaire observed users' behaviors and perceptions about visual attention, investigated users' opinions on the symbol and basemap design, collected feedback on usability and utility testing, and asked for participants' suggestions for potential improvements. The results of surveying were analyzed quantitatively to indicate that most users were satisfied with the interface, which also answered research questions n and o. Additionally, qualitative analysis was conducted to answer research question p and summarize the user's ideas on how to make the prototype better.

To sum up, the initial objectives and all the research questions were fulfilled and answered by the previous chapters. However, some limitations exist in the methodology and user study, and some aspects may deserve to be improved in further study.

5.2 Challenges and Limitations

5.2.1 Prototype developing

The challenges in developing the prototype can be discussed from the perspectives of data and algorithm. Datasets mainly involved in the prototype development are the shapefile road network and observed and generated environment data. Although the open-source road data have adequate details in name, class, and speed limit, it doesn't provide complete information on the direction. This may cause inaccuracy because some streets are one-way only. Another data limitation of this thesis is the generation of air pollution data. Despite the concentration value of each pollutant and temperature of the road segment being within the appropriate ranges derived from observed raw data, the randomly assigned values may fail to reflect the actual pattern because the spatial attributes of the road segment are not taken into consideration. For instance, for a road near a green area or with less traffic, the air quality of it is more likely to be better than the roads with heavy traffic. Therefore, the pollution distribution may possess certain spatial patterns, for example, better air quality in suburban regions and worst air conditions in busier regions. However, in this case, the potential spatial patterns were erased since every segment was treated equally and assigned value randomly. Another issue with the environmental data is timeliness. The raw dataset employed in this study was observed more than two years ago, and more recent observations may need to make the prototype more precise.

Besidesthe data, the limitations may also come from the routing algorithm employed. Since this study applied AQI value, temperature, and distance as costing factors for three routes, it failed to consider the relationships among the three factors. As one article reviewed in chapter 2 mentioned, the traveling time of pedestrians and cyclists is closely associated with travel distance, and the pollution or heat exposure also depends on how long you are exposed to them. Hence, distance is an essential factor that needs to be considered even though when deriving health-related routes. A more reasonable weighting function could be created that aims to minimize the product of traveling time and AQI value or temperature.

5.2.2 User study

The limitations of the user study can be mainly analyzed in terms of method, participants, and question design. The user study of this thesis is based on a questionnaire survey, the results of which are highly dependent on participants' subjective judgments. For questions investigating visual attention distribution and potential distractions, sometimes users struggle to capture their first visual impression, which may cause inaccuracy in survey responses. As reviewed in chapter 2, many studies applied both objective and subjective methods to conduct user evaluations. Eye tracking is one of the widely used ways to capture user's attention by following eye movements. A task-based method is also a common way for objective assessment via measuring the time user cost of completing certain tasks. Therefore, the lack of objective assessment may result in bias in the responses and influent the accuracy of the result analysis.

Besides, the participants who took part in the survey were not randomly selected. Almost all the participants were university students between the ages of 20 to 30. The group of participants was relatively young and educated and likely had prior experience with interactive map products. This limitation in surveyed people may reflect in the patterns of responses, which lacks the persuasiveness to represent all groups of people: even though most participants held supportive attitude towards this prototype and thought it was simple to operate and understand, there is no conclusion of generality that can be drew.

Another factor that may affect the survey results was the question design. Static maps with different visualization styles were provided, asking users to select the path that captured the most attention. The aim of those questions was to test the attention distribution over line with different symbol design or test the effects of visual variables. However, it was hard to control the irrelevant variables exactly the same. For example, the three routes were different in spatial positions and with different lengths, which caused biases in the user's perception. The middle path, or the longest path tended to capture more attention from participants.

6 Conclusion and outlook

This study aims to promote a health-oriented route planner to help users find the healthier paths through the city by employing proper visualization and attention-guiding techniques. This study created an interactive application prototype as an output, which targets pedestrians and cyclists to minimize the negative health impacts. The interactive interface supports the route query by routing algorithm and visualizes the routing paths in a well-addressed way by the theories of attention guiding. A user study was implemented to examine the effectiveness of interface design and the usability of the prototype. The qualitative and quantitative results of the questionnaire analysis verified the usefulness of applicability of this prototype to some extent. It can be summarized that the prototype performed well in terms of learnability, efficiency, and user satisfaction, while answers made by some participants indicate the demands of providing introductory information for better understanding.

While the user study ended with predominantly positive results, there is still room to enhance the performance of this prototype in the future. For the development aspect, features like adding markers by clicking would be practical for users to start the route-finding task. Zooming to the navigation targets, adding expected time of arrival, and providing direction guides are seemed to be highly demanded attributes as well. Besides, as the previous work mentioned in Chapter 2, individuals' health conditions also can be considered and integrated into the routing algorithm for a more comprehensive study.

Summing up, this thesis develops a prototype for searching and emphasizing healthier navigation options for urban citizens, offering insights into future related research. This is believed to have a positive impact on a healthy urban environment in the long run.

A. Appendix

A.1 Questionnaire

A.1.1 Introduction and Consent

Hello!

You are invited to participate in this online survey on evaluation of interface design for health-oriented route planner. This is a part of the Master Thesis conducted by Jiaying Xue, from M.Sc. Cartography programme at Technische Universität München. The thesis is titled **"Cool Street – Developing a healthy Urban Route Planner".**

PURPOSE

The purpose of this research is to develop a prototype of web application to find **healthier** routes in Munich for **pedestrians and cyclists**, to **minimize the health impacts of urban air pollution and surface heat during navigation.** This survey will ask you to explore the interface and collect your feedback on interface design, usability and experience. This survey should take 20 minutes of your time approximately to complete.

PARTICIPATION

- Your participation in this survey is **voluntary** and you may, anytime, refuse to take part in this research
- All the information you submit is **anonymous**, and all the information is stored and used solely for the purpose of this thesis.
- If you have any question about the survey, please contact researcher, Jiaying Xue.

CONSENT

By clicking "I agree", I agree and affirm that:

- I have read and understood the purpose of the information stated above
- I voluntarily give my consent to participate in this study.

◯ No, I do not agree
◯ Yes, I agree

A.1.2 General Information

1. How old are you?

- ◯ Younger than 15 years old
- ◯ 15 to 19 years old
- ◯ 20 to 24 years old
- ◯ 25 to 29 years old
- ◯ 30 to 34 years old
- ◯ 35 to 39 years old
- ◯ 40 to 44 years old
- ◯ 45 to 49 years old
- ◯ 50 to 54 years old
- ◯ 55 to 59 years old
- ◯ 60 years or old

2. What is your current level of education?

- ◯ High School
- ◯ Undergraduate
- ◯ Postgraduate
- ◯ PhD

3. What is your area of study?

- ◯ Agriculture & Natural Resources Conservation
- ◯ Architecture
- ◯ Area, Ethic, & Multidisciplinary Studies
- ◯ Arts
- ◯ Business
- ◯ Communication
- ◯ Community, Family & Personal Services
- ◯ Computer Science & Mathematics
- ◯ Education
- ◯ Engineering
- ◯ Engineering Technology & Drafting
- ◯ Languages
- ◯ Health Science
- ◯ Philosophy, Religion & Theology
- ◯ Science
- ◯ Social Science & Law

4. What is your gender?

- ◯ Female
- ◯ Male
- ◯ Other ________

5. How often do you use web mapping applications for navigation?

◯ Never
◯ Once a year
◯ Once a month
◯ Once a week or less
◯ Twice a week or more
◯ Everyday
◯ Several times a day

6. Do you currently live or have you ever lived in the city of Munich?

◯ Yes
◯ No

7. How familiar are you familiar with the city of Munich?

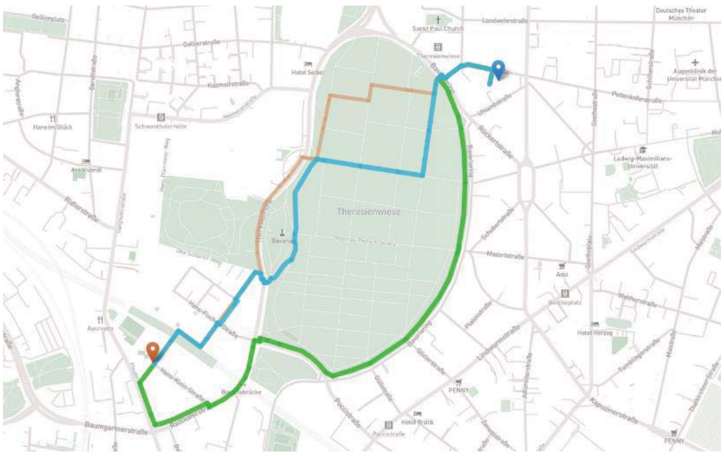
◯ Not at all ◯ Not very familiar ◯ Somewhat familiar ◯ Familiar ◯ Very familiar

A.1.3 Visual Attention

Set I

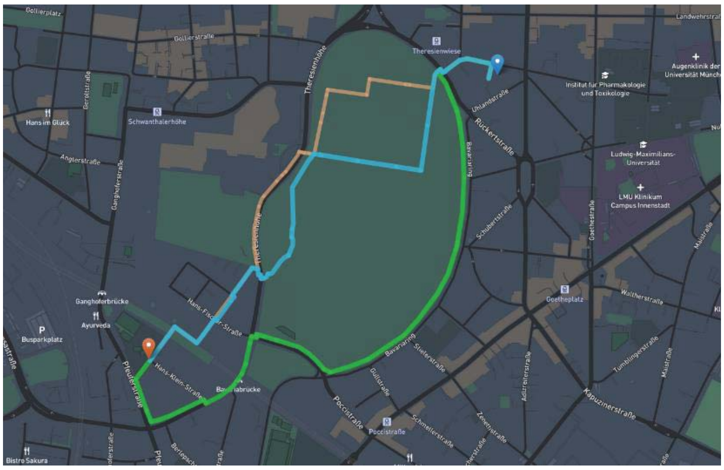
Look at the maps below and select which path do you notice at first glance?

8.



◯ The green path
◯ The blue path
◯ The brown path

9.

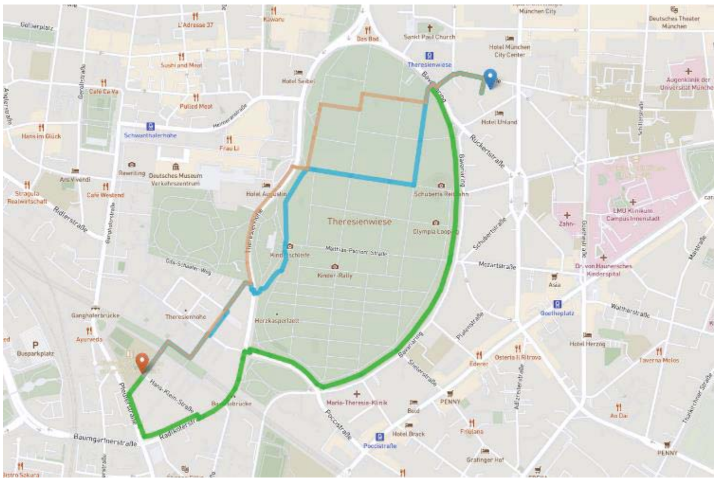


◯ The green path

◯ The blue path

◯ The brown path

10.

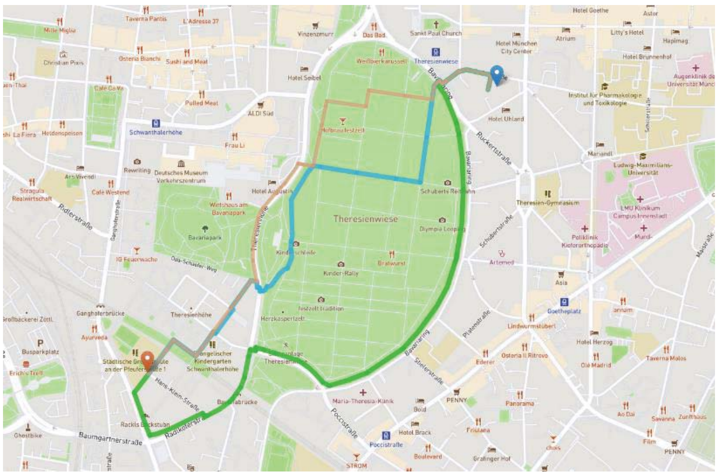


◯ The green path

◯ The blue path

◯ The brown path

11.



◯The green path

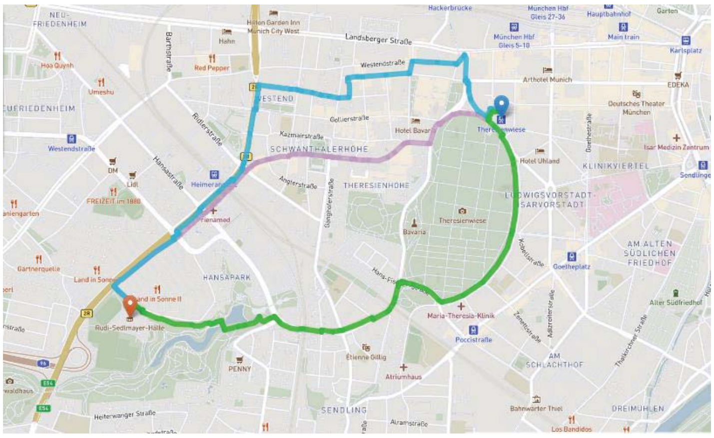
◯ The blue path

◯The brown path

Set II

Which path grab you more attention?

12.

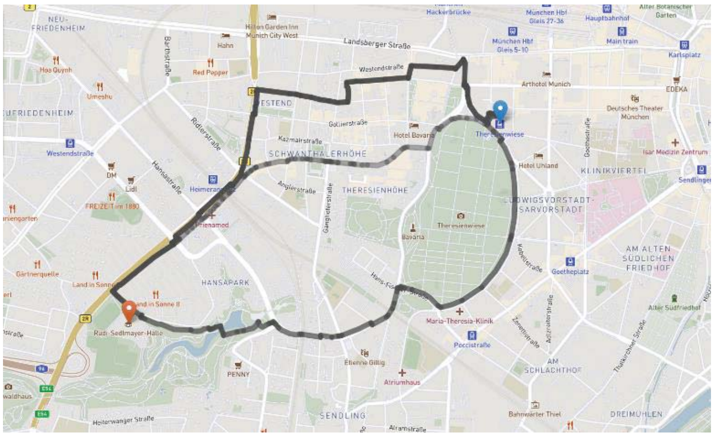


◯ The top one

◯ The middle one

◯ The bottom one

13.

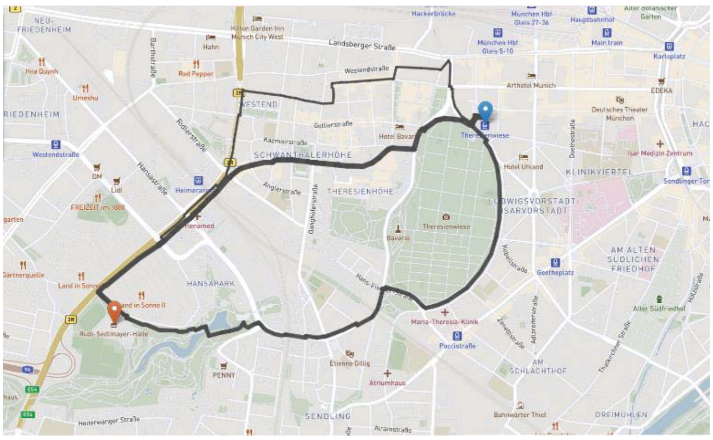


◯ The top one

◯ The middle one

◯ The bottom one

14.

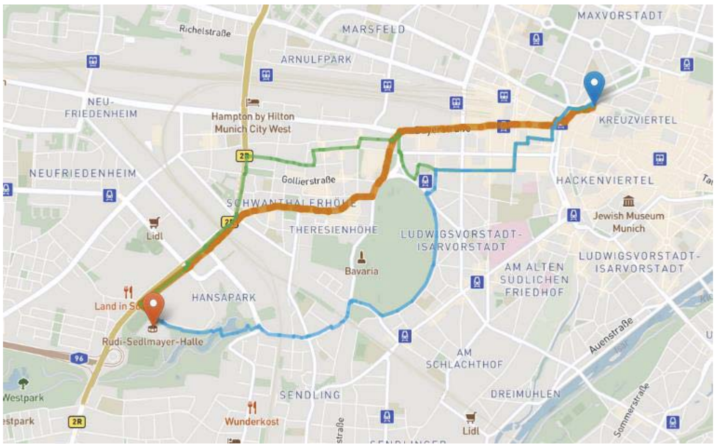


◯ The top one

◯ The middle one

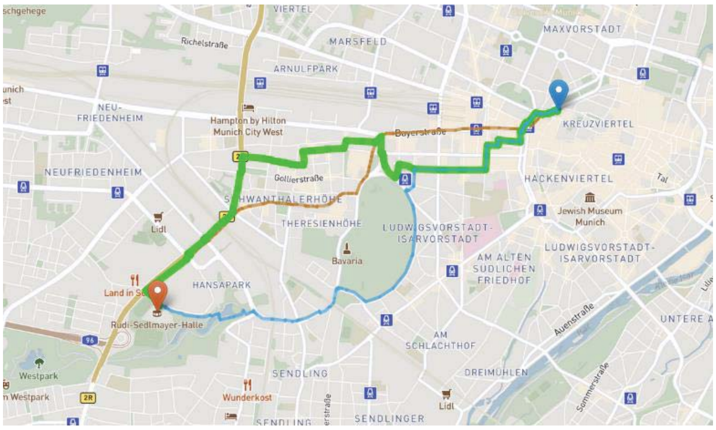
◯ The bottom one

15.



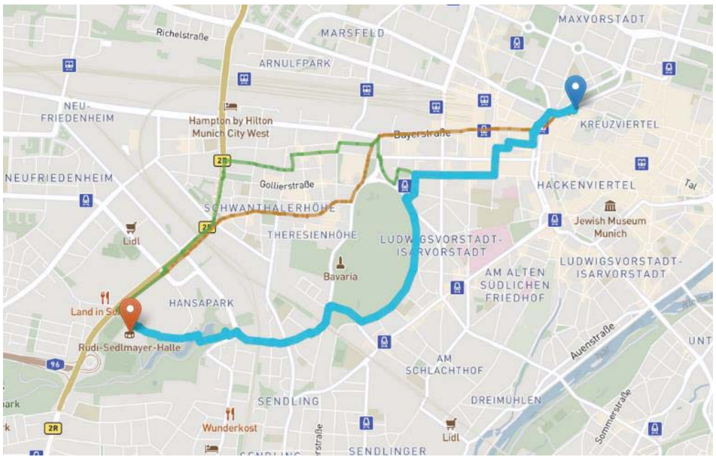
- ◯ The top one
- ◯ The middle one
- ◯ The bottom one

16.



- ◯ The top one
- ◯ The middle one
- ◯ The bottom one

17.



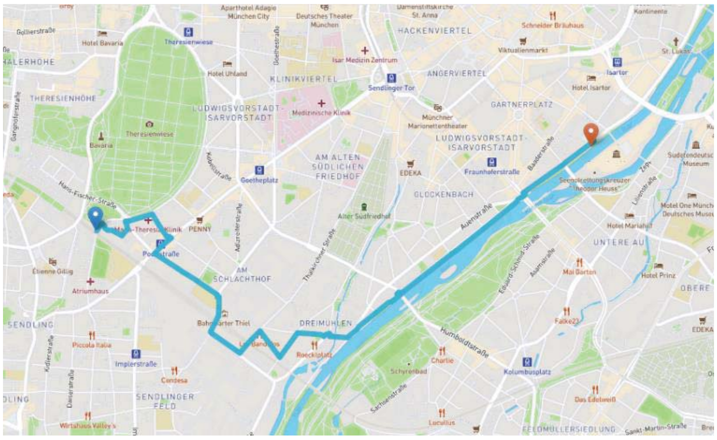
- ◯ The top one
- ◯ The middle one
- ◯ The bottom one

Set III

What may distract you from focusing on the routes?

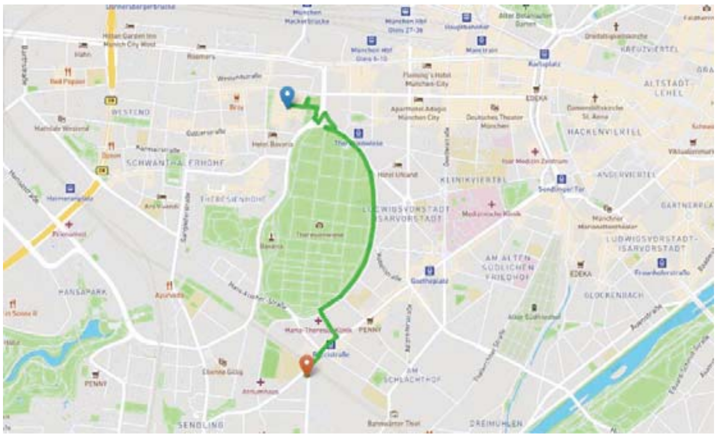
*POI: stands for point of interest – a specific point location that may be useful and interesting. For example: hotel, restaurant, grocery store, etc.

18.



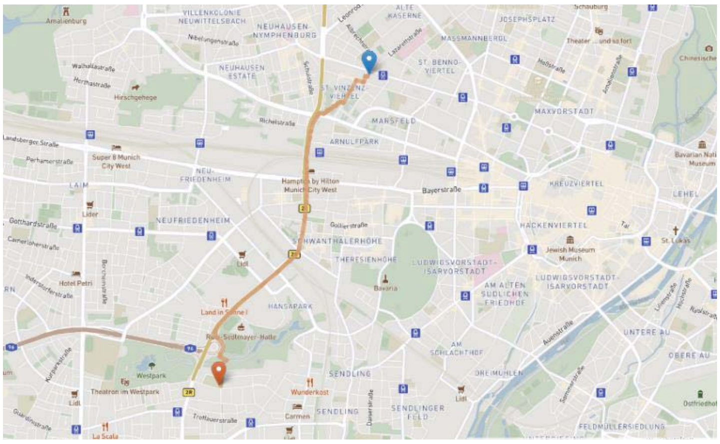
☐ Underlying roads
☐ Green areas
☐ Water body
☐ Landuse classification
☐ Symbols of POIs
☐ Name labels of road or place
☐ Other ________

19.



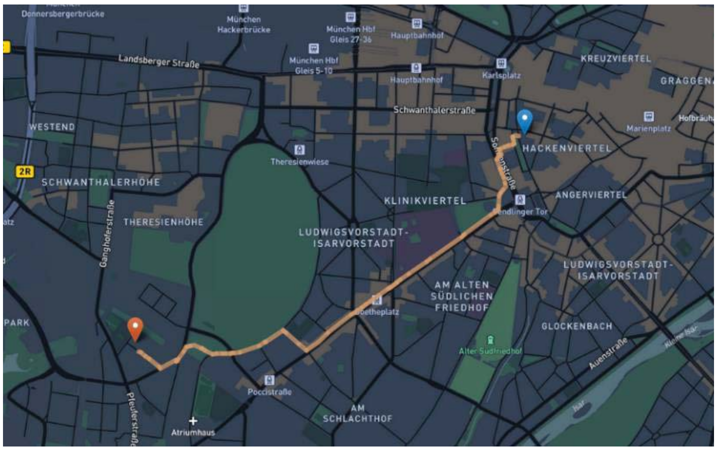
☐ Underlying roads
☐ Green areas
☐ Water body
☐ Landuse classification
☐ Symbols of POIs
☐ Name labels of road or place
☐ Other ________

20.



☐ Underlying roads
☐ Green areas
☐ Water body
☐ Landuse classification
☐ Symbols of POIs
☐ Name labels of road or place
☐ Other ________

21.



☐ Underlying roads
☐ Green areas
☐ Water body
☐ Landuse classification
☐ Symbols of POIs
☐ Name labels of road or place
☐ Other ________

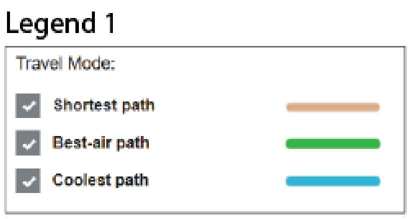
A.1.4 Thematic Relevance

22. Which color do you think is the best to represent "cleanest", "coolest", and "shortest" path respectively?

Please type the colors below:

____________________, ____________________, ______________________.

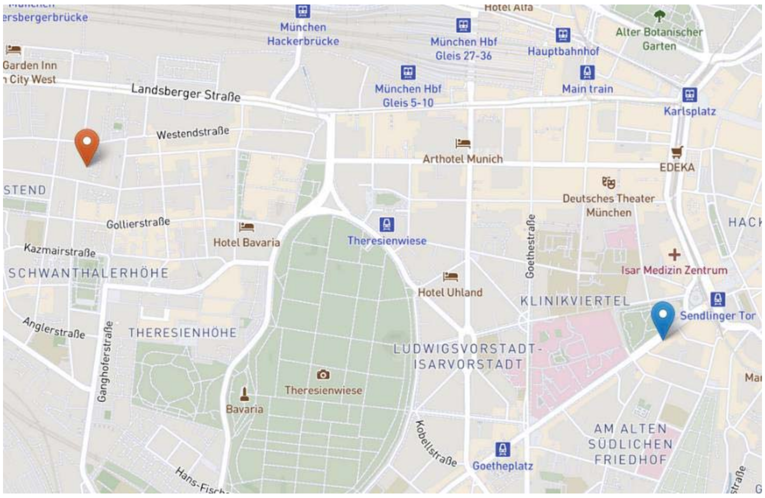
23. How do you agree with color design shown in the legend for the three routes?



Legend 1:

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

Q24. Which marker do you think represents the starting points?



◯ Red

◯ Blue

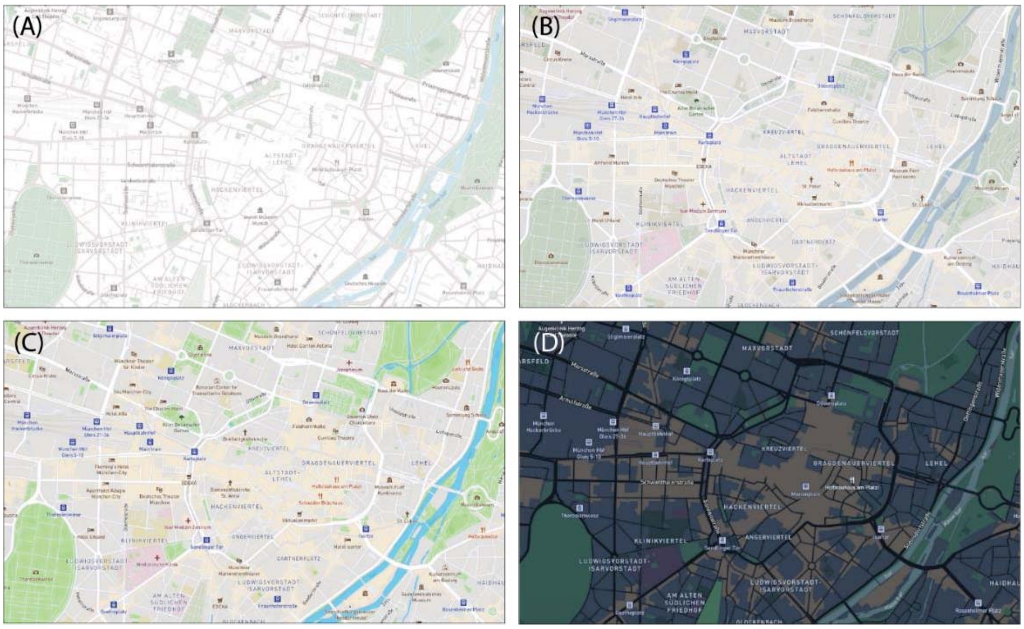
25. How intuitive are the marker colors for origin and destination?

(Blue marker stands for origin; red marker stands for destination)

◯ Not intuitive at all
◯ Not very intuitive
◯ Somewhat intuitive
◯ Mostly intuitive
◯ Extremely intuitive

26. How will you rate the following basemaps as navigation maps for pedestrians and cyclists?

Please order them from the best (1st) to worst (4th).



	1st	2nd	3rd	4th
Map (A)	◯	◯	◯	◯

Map (B)	◯	◯	◯	◯
Map (C)	◯	◯	◯	◯
Map (D)	◯	◯	◯	◯

A.1.5 Interface Exploration

Feel free to explore and use the inface.

27. Which features have you interacted with?

☐ Location typing box
☐ Travel mode switch
☐ Layer controller
☐ Draggable markers
☐ Clickable paths
☐ Location button
☐ Other __________

A.1.6 Interface Evaluation

Usability Study

To what extend do you agree with the following statement

28. It is very easy to understand and use to find healthier paths.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

29. A support of a technical person is needed to be able to use the map.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

30. Some detailed help or tutorial are required to be able to use the map.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

31. Many people will be able to conduct the route-finding task quickly.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

32. Some background knowledge of using interactive maps is necessary to be able to use the map.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

33. I was often confused about where to click or where to look when using the map.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

34. The visual design of the application is well done.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

Utility Study

To what extend do you agree with the following statement.

35. I would like to use the map often.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

36. It is an application of my interest.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

37. It would be applicable for the users who want to have health-oriented routes.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

38. The features or functions should be added into routing application like Google Map.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

39. It has expected functions for health-oriented routing.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

40. It has necessary visualizations to understand.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

41. Different paths are visualized in a proper way.

◯ Strongly disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly agree

A.1.7 User Experience

42. How discouraged were you when using the map?

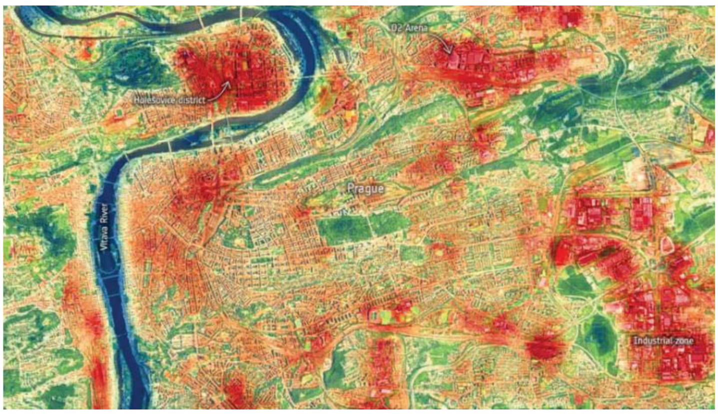
◯ Not at all discouraged ◯ ◯ Neutral ◯ ◯ Extremely discouraged

43. What other elements would you like to add to make the interface more engaging?

☐ Layer of real-time air quality data over road network, for example:

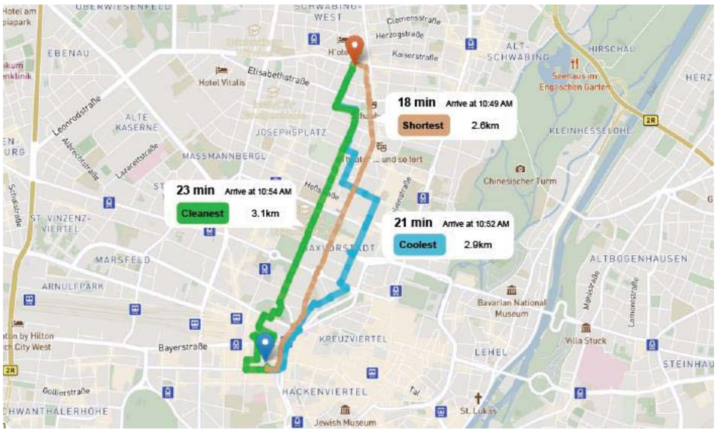
(Source: https://www.google.com/earth/outreach/special-projects/air-quality/)

☐ Layer of real-time surface temperature, for example:

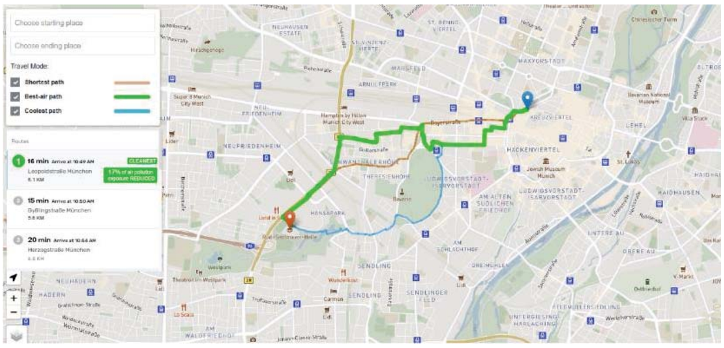


(Source: https://www.esa.int/ESA_Multimedia/Images/2022/07/Land-surface_temperature_in_Prague_on_18_June_2022)

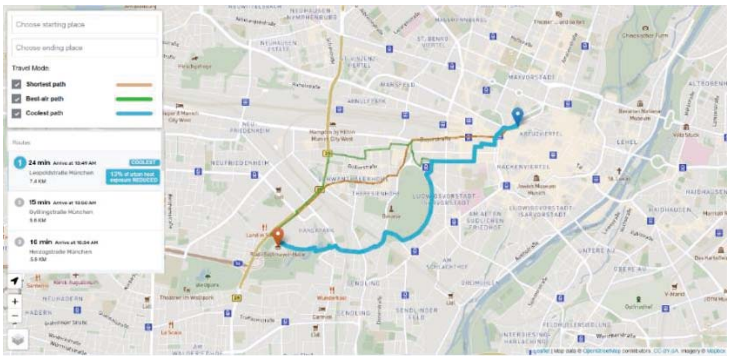
☐ Expected time of arrival for each route, for example:



☐ The amount of reduction on air pollution exposure, when choosing the "cleanest" path, for example:



☐ The amount of reduction on heat exposure, when choosing the "coolest" path



☐ Other ________________

What is your impression on this Prototype?
Score the map from the following perspectives

44.

Unpleasant ○ ○ ○ ○ ○ ○ ○ Pleasant

45.

Conventional ○ ○ ○ ○ ○ ○ ○ Inventive

46.

Unprofessional ○ ○ ○ ○ ○ ○ ○ Professional

47.

Impractical ○ ○ ○ ○ ○ ○ ○ Practical

48.

Ugly ○ ○ ○ ○ ○ ○ ○ Attractive

49.

Confusing ○ ○ ○ ○ ○ ○ ○ Clearly structured

50.

Complicated ○ ○ ○ ○ ○ ○ ○ Simple

51.

Unpresentable ○ ○ ○ ○ ○ ○ ○ Presentable

52.

Unruly ○ ○ ○ ○ ○ ○ ○ Manageable

53.

Boring ○ ○ ○ ○ ○ ○ ○ Interesting

54. How would you like to improve the Application?

____

____

A.2 Questionnaire Answers

Table 1. Answers to Question 1.

	< 20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	>60
Q1	0	15	14	1	0	0	0	0	0	0

Table 2. Answers to Question 2.

	High School	Undergraduate	Postgraduate	PhD
Q2	1	13	16	0

Table 3. Answers to Question 3.

	Q3
Engineering	11
Computer Science & Mathematics	5
Science	4
Architecture	2
Business	2
Health Science	2
Communication	1
language	1
Social Science & Law	1
Science: Biology & Physics	1

Table 4. Answers to Question 4

	Female	Male	Other
Q4	16	14	0

Table 5. Answers to Question 5.

	Never	Once a year	Once a month	Once a week or less	Twice a week or more	Everyday	Several times a day
Q5	1	2	2	2	8	9	6

Table 7. Answers to Question 6.

	Yes	No
Q6	27	3

Table 8. Answers to Question 7.

	Not at all	Not very familiar	Somewhat familiar	Familiar	Very Familiar
Q7	1	5	13	10	1

Table 9. Answers to Question 8,9,10 and 11.

	The green path	The blue path	The brown path
Q8	20	10	0
Q9	10	19	1
Q10	21	8	1
Q11	3	26	1

Table 10. Answers to Question 12,13, and 14.

	The top path	The middle path	The bottom path
Q12	4	17	9
Q13	19	8	3
Q14	0	29	1

Table 11. Answers to Question 15,16, and 17.

	The green path	The blue path	The brown path
Q15	2	0	28
Q16	28	0	2
Q17	1	27	2

Table 12. Answers to Question 18,19,20, and 21.

<table>
<tr><th colspan="2"></th><th>Q18</th><th>Q19</th><th>Q20</th><th>Q21</th></tr>
<tr><td colspan="2">Underlying roads</td><td>4</td><td>2</td><td>14</td><td>4</td></tr>
<tr><td colspan="2">Green areas</td><td>4</td><td>17</td><td>1</td><td>5</td></tr>
<tr><td colspan="2">Water Body</td><td>23</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td colspan="2">Landuse Classification</td><td>1</td><td>0</td><td>1</td><td>11</td></tr>
<tr><td colspan="2">Symbols of POIs</td><td>4</td><td>2</td><td>8</td><td>1</td></tr>
<tr><td colspan="2">Labels of road/places</td><td>0</td><td>1</td><td>0</td><td>3</td></tr>
<tr><td rowspan="3">Other</td><td>No distraction</td><td>4</td><td>6</td><td>6</td><td>9</td></tr>
<tr><td>Symbols of U-Bahn station:</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>Basemaps</td><td>0</td><td>0</td><td>1</td><td>0</td></tr>
</table>

Table 13. Answers to Question 22.

Mention

Proposal	Cleanest path	Coolest path	Shortest Path	Count
1	Green	Blue	Red	6
2	Green	Blue	Yellow	5
3	Green	Yellow	Red	1
4	Forest green	Lime green	Green	1
5	Blue	Gray	Red	1
6	Blue	Blue	Brown	1
7	Blue	Blue	Yellow	1
8	Blue	Green	Green	1
9	Green	Blue	Orange	1
10	Gray	Green	Red	1
11	Green	Blue	white	1
12	Green	Blue	Blue	1
13	Green	Black	Red	1
14	Green	Blue	Brown	1
15	Green	Blue	Green	1
16	Green	Blue	Purple	1
17	Blue	Green	Yellow	1
18	Blue	Lighter blue	Green	1
19	White	Blue	Red	1
20	White	Green	Blue	1

Table 14. Answers to Question 23.

Q23	Strongly disagree	disagree	Neutral	Agree	Strongly agree
Legend 1	1	4	5	13	7

Table 15. Answers to Question 24.

	Red marker	Blue marker
Q24	21	7

Table 16. Answers to Question 25.

	Not at all intuitive	Not very intuitive	Somewhat intuitive	Mostly intuitive	Extremely intuitive
Q25	2	5	4	12	7

Table 17. Answers to Question 26.

Q26	1st	2nd	3rd	4th

Map (A)	2	2	7	19
Map (B)	7	14	7	2
Map (C)	0	15	10	5
Map (D)	6	4	11	9

Table 18. Answers to Question 27.

Location typing box	28
Travel mode switcher	24
Layer controller	27
Draggable markers	27
Clickable paths	21
Locating button	23

Table 19. Answers to Question 28 to Question 34.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Q28	0	0	4	17	9
Q29	5	12	5	7	1
Q30	2	8	5	15	0
Q31	0	0	1	18	11
Q32	3	6	5	14	2
Q33	6	14	4	6	0
Q34	0	1	6	12	11

Table 20. Answers to Question 35 to Question 41.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Q35	0	3	4	15	8
Q36	0	3	5	13	9
Q37	0	0	2	19	9
Q38	0	0	1	16	13
Q39	0	2	4	15	9
Q40	6	0	4	19	7
Q41	0	0	5	16	9

Table 21. Answers to Question 42.

	Not at all discouraged	Not very discouraged	Somewhat discouraged	Discouraged	Extremely discouraged
Q42	11	14	3	2	0

Table 22. Answers to Question 43.

Layer of real-time air quality data over road network		19
Layer of real-time surface temperature		17
Expected time of arrival for each road		27
The amount of reduction on air pollution exposure, when choosing the cleanest path		21
The amount of reduction on heat exposure, when choosing the cleanest path		17
Other	Layers of slope and stairway	1
	Layers of green area and shadow distribution	1
	Layer of traffic data	1

Table 23. Answers to Questions 44 to 53.

	1	2	3	4	5	6	7
Q44	0	0	0	1	6	9	14
Q45	0	2	0	4	5	13	6
Q46	0	0	0	4	8	8	10
Q47	0	0	1	4	4	10	11
Q48	0	0	0	6	4	10	10
Q49	0	0	1	3	5	9	12
Q50	0	0	1	4	5	7	13
Q51	0	0	0	4	3	15	8
Q52	0	0	0	1	7	14	8
Q53	0	0	1	3	5	13	8

Table 24. Answers to Question 54.

Mention

1	Zoom to the paths when submit the form
2	• Autocomplete for locations • Different marker symbols for better differentiation of start location and target • Small preview of the layer controller when choosing between the layers (like Google Map)
3	More explanations on route planning
4	Vague input/ autocorrection for address inputting.
5	Different colors for the paths. Light blue is closely tied to cleanliness in Germany. Personally, I would suggest a lighter blue for the coolest path. While the map is very inventive and not something I have already encountered, it does not meet my personal interest and is kind of niche. An option to edit the maps for pedestrians and cyclists would be helpful as these groups have different ways of moving through the city, especially the Metro and Busses. Good idea, which is well thought out, even though the project still needs a finishing touch.

6	It would be more practical and attractive if some photos for attractions and the corresponding reviews from pedestrians be highlighted on the map, since it's mainly aimed for people who take a walk. The user group would have a relaxing mindset other than people who go to work or school, so they may be more interested in sightseeing.
7	It would be better if the map includes more information about the presented routes. For example, users can have an overview of the planned trips in advance and the differences of choosing different routes. The user would find the map easier to use if it had similar settings and symbols' positions as the existed popular maps such as Google map or Apple map.
8	It would be better to zoom to the routes after submission, because sometimes the marker and routes are outside current map view, caused a little confusion
9	I would like to have some additional data that will help me choose between the way options- such as how polluted it is the shortest road in comparison to the cleanest and so on.
10	It's better to combine with the google map or others.
11	Using the same marker symbol for origin and destination sometimes cause confusion, would be better to create color indication or legend, to correspond color and meaning. Besides, it would be more user friendly if it allows user to click the map to select origin and destination
12	Improve the accuracy of geocoding
13	Add information or reminder of stairway
14	When querying the address, I would like to have fuzzy match available, instead of typing the whole exact address name. A short guidance would be nice to show what functions are usable. For now, it's a bit hard to figure out that the route is clickable, and the points are draggable.
15	Add direction guide for navigation, and add different mode of travelling, like walking or cycling
16	Emphasis on the importance of layer controller
17	It is nicer if this app relates to other main map for more convenience.
18	Graphic design, or just use dark mode as its most pleasing and interesting
19	Maybe add more information about the real time road situation, like somewhere is quite crowded.
20	Add travel modes for walking and cycling. Add arrow to indicate direction
21	Add expected travel time of each route, add traffic condition. It would be better to select location by clicking on the map page.
22	Add hints to guide the new users
23	For coolest and cleanest routes, I think it would be better to have time limitation.

24	Zoom to the path selected and show direction guide.
25	I would make it a collaboration with already existing map app; for the clean air one maybe some insights how much better your air will be compared to the other roads
26	I would add expected time of arrival.
27	Add spent time, add arrow to show the direction, hint steep on the map, day light on/off button, orientation correction
28	The traffic or the crowd could also be notified.
29	Need to specify the intended user group
30	I want it on Google maps

References:

Allemann, D., & Raubal, M. (2013). Towards health-optimal routing in urban areas. Proceedings of the Second ACM SIGSPATIAL International Workshop on the Use of GIS in Public Health,

Andersen, Z. J., Bønnelykke, K., Hvidberg, M., Jensen, S. S., Ketzel, M., Loft, S., Sørensen, M., Tjønneland, A., Overvad, K., & Raaschou-Nielsen, O. (2012). Long-term exposure to air pollution and asthma hospitalisations in older adults: a cohort study. *Thorax*, *67*(1), 6-11.

Andrienko, N., Andrienko, G., & Gatalsky, P. (2003). Exploratory spatio-temporal visualization: an analytical review. *Journal of Visual Languages & Computing*, *14*(6), 503-541.

Attema, J., Heusinkveld, B. G., Ronda, R. J., Steeneveld, G.-J., & Holtslag, A. A. (2015). Summer in the city: Forecasting and mapping human thermal comfort in urban areas. 2015 IEEE 11th International Conference on e-Science,

Baldauf, R., Watkins, N., Heist, D., Bailey, C., Rowley, P., & Shores, R. (2009). Near-road air quality monitoring: factors affecting network design and interpretation of data. *Air Quality, Atmosphere & Health*, *2*(1), 1-9.

Benevolo, C., Dameri, R. P., & D'auria, B. (2016). Smart mobility in smart city. In *Empowering organizations* (pp. 13-28). Springer.

Bláha, J. D., & Štěrba, Z. (2014). Colour contrast in cartographic works using the principles of Johannes Itten. *The Cartographic Journal*, *51*(3), 203-213.

Boone, H. N., & Boone, D. A. (2012). Analyzing likert data. *Journal of extension*, *50*(2), 1-5.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Braun, V., & Clarke, V. (2012). *Thematic analysis*. American Psychological Association.

Brychtova, A., & Coltekin, A. (2016). An empirical user study for measuring the influence of colour distance and font size in map reading using eye tracking. *The Cartographic Journal*, *53*(3), 202-212.

Budiu, R., & Moran, K. (2021). How Many Participants for Quantitative Usability Studies: A Summary of Sample-Size Recommendations. *Nielsen Normal Group*.

Chesneau, E., Ruas, A., & Bonin, O. (2005). Colour Contrasts Analysis For A Better Legibility Of Graphic Signs For Risk Maps. in'Proc. of the International Cartographic Conference: Mapping Approaches Into A Changing World, A Coruna,

Dijkstra, E. W. (1959). A note on two problems in connexion with graphs. *Numerische mathematik*, *1*(1), 269-271.

Fu, L., Sun, D., & Rilett, L. R. (2006). Heuristic shortest path algorithms for transportation applications: State of the art. *Computers & Operations Research*, *33*(11), 3324-3343.

Galbrun, E., Pelechrinis, K., & Terzi, E. (2016). Urban navigation beyond shortest route: The case of safe paths. *Information Systems*, *57*, 160-171.

Garvey, M., Das, N., Su, J., Natraj, M., & Verma, B. (2016). Passage: A travel safety assistant with safe path recommendations for pedestrians. Companion Publication of the 21st International Conference on Intelligent User Interfaces,

Golledge, R. G. (1995). Path selection and route preference in human navigation: A progress report. International conference on spatial information theory,

Grinstein, G., Kobsa, A., Plaisant, C., Shneiderman, B., & Stasko, J. T. (2003). Which comes first, usability or utility? Visualization Conference, IEEE,

Grossman, J. (1992). Color conventions and application standards. In *Color in electronic displays* (pp. 209-218). Springer.

Harrower, M., & Brewer, C. A. (2003). ColorBrewer. org: an online tool for selecting colour schemes for maps. *The Cartographic Journal*, *40*(1), 27-37.

Hassenzahl, M., Burmester, M., & Koller, F. (2003). AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. In *Mensch & computer 2003* (pp. 187-196). Springer.

Hein, P., Bernhagen, M., & Bullinger, A. C. (2019). Improving Visual Attention Guiding by Differentiation between Fine and Coarse Navigation. 2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games),

Kurzhals, K., Höferlin, M., & Weiskopf, D. (2013). Evaluation of attention-guiding video visualization. Computer graphics forum,

Lee, J.-H., & Qian, W. (2004). Color your feeling. In *Recent Advances in Design and Decision Support Systems in Architecture and Urban Planning* (pp. 113-125). Springer.

Lee, J. Y., Lee, S. B., & Bae, G. N. (2014). A review of the association between air pollutant exposure and allergic diseases in children. *Atmospheric Pollution Research*, *5*(4), 616-629.

Lin, B., & Zhu, J. (2018). Changes in urban air quality during urbanization in China. *Journal of Cleaner Production*, *188*, 312-321. https://doi.org/10.1016/j.jclepro.2018.03.293

Lu, J., Li, B., Li, H., & Al-Barakani, A. (2021). Expansion of city scale, traffic modes, traffic congestion, and air pollution. *Cities*, *108*, 102974.

Lü, J., Liang, L., Feng, Y., Li, R., & Liu, Y. (2015). Air pollution exposure and physical activity in China: current knowledge, public health implications, and future research needs. *International journal of environmental research and public health*, *12*(11), 14887-14897.

Maguire, M., & Delahunt, B. (2017). Doing a thematic analysis: A practical, step-by-step guide for learning and teaching scholars. *All Ireland Journal of Higher Education*, *9*(3).

Mahajan, S., Tang, Y.-S., Wu, D.-Y., Tsai, T.-C., & Chen, L.-J. (2019). Car: The clean air routing algorithm for path navigation with minimal pm2. 5 exposure on the move. *IEEE Access*, *7*, 147373-147382.

Müller, S., & Voisard, A. (2015). Air quality adjusted routing for cyclists and pedestrians. Proceedings of the 1st ACM SIGSPATIAL International Workshop on the Use of GIS in Emergency Management,

Nasrollahi, N., Ghosouri, A., Khodakarami, J., & Taleghani, M. (2020). Heat-mitigation strategies to improve pedestrian thermal comfort in urban environments: A review. *Sustainability*, *12*(23), 10000.

Nielsen, J. (1992). The usability engineering life cycle. *Computer*, *25*(3), 12-22.

Nigam, S., Rao, B., Kumar, N., & Mhaisalkar, V. (2015). Air quality index-A comparative study for assessing the status of air quality. *Research Journal of Engineering and Technology*, *6*(2), 267-274.

Norman, D. A. (1988). OF EVERYDAY THINGS. In: New York City, NY, USA: Doubleday.

North, C. (2006). Toward measuring visualization insight. *IEEE computer graphics and applications*, *26*(3), 6-9.

Otto, J.-C., Gustavsson, M., & Geilhausen, M. (2011). Cartography: design, symbolisation and visualisation of geomorphological maps. In *Developments in earth surface processes* (Vol. 15, pp. 253-295). Elsevier.

Petrillo, F., Spritzer, A. S., Freitas, C. M. D. S., & Pimenta, M. S. (2011). Interactive analysis of Likert scale data using a multichart visualization tool. *IHC+ CLIHC*, *67*.

Plaia, A., & Ruggieri, M. (2011). Air quality indices: a review. *Reviews in Environmental Science and Bio/Technology*, *10*(2), 165-179.

Ramos, F., Trilles, S., Muñoz, A., & Huerta, J. (2018). Promoting pollution-free routes in smart cities using air quality sensor networks. *Sensors*, *18*(8), 2507.

Rizwan, A. M., Dennis, L. Y., & Chunho, L. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of environmental sciences*, *20*(1), 120-128.

Robinson, A. H. (1960). Elements of cartography. *Soil Science*, *90*(2), 147.

Robinson, A. H. (1995). Elements of cartography//Review. *Cartographica*, *32*(3), 58.

Rojas-Martinez, R., Perez-Padilla, R., Olaiz-Fernandez, G., Mendoza-Alvarado, L., Moreno-Macias, H., Fortoul, T., McDonnell, W., Loomis, D., & Romieu, I. (2007). Lung function growth in children with long-term exposure to air pollutants in Mexico City. *American journal of respiratory and critical care medicine*, *176*(4), 377-384.

Roth, R. E. (2012). Cartographic interaction primitives: Framework and synthesis. *The Cartographic Journal*, *49*(4), 376-395.

Roth, R. E. (2015). Interactivity and cartography: A contemporary perspective on user interface and user experience design from geospatial professionals. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *50*(2), 94-115.

Roth, R. E. (2017). Visual variables. *International encyclopedia of geography: People, the earth, environment and technology*, 1-11.

Roth, R. E., & Harrower, M. (2008). Addressing map interface usability: Learning from the lakeshore nature preserve interactive map. *Cartographic Perspectives*(60), 46-66.

Roth, R. E., Ross, K. S., & MacEachren, A. M. (2015). User-centered design for interactive maps: A case study in crime analysis. *ISPRS International Journal of Geo-Information*, *4*(1), 262-301.

Rußig, J., & Bruns, J. (2017). Reducing individual heat stress through path planning. *GI_Forum*, *1*, 327-340.

Sharker, M. H., & Karimi, H. A. (2014). Computing least air pollution exposure routes. *International Journal of Geographical Information Science*, *28*(2), 343-362.

Sharker, M. H., Karimi, H. A., & Zgibor, J. C. (2012). Health-optimal routing in pedestrian navigation services. Proceedings of the First ACM SIGSPATIAL International Workshop on Use of GIS in Public Health,

Siriaraya, P., Wang, Y., Zhang, Y., Wakamiya, S., Jeszenszky, P., Kawai, Y., & Jatowt, A. (2020). Beyond the shortest route: A survey on quality-aware route navigation for pedestrians. *IEEE Access*, *8*, 135569-135590.

Steeneveld, G.-J., Vreugdenhil, L., van der Molen, M., & Ligtenberg, A. (2017). Development of a Healthy Urban Route Planner for cyclists and pedestrians in Amsterdam. Societal Geo-innovation. Selected Papers of the 20th AGILE Conference on Geographic Information Science,

Swienty, O. (2008). *Attention-Guiding Geovisualisation* Technische Universität München].

Swienty, O., Reichenbacher, T., Reppermund, S., & Zihl, J. (2008). The role of relevance and cognition in attention-guiding geovisualisation. *The Cartographic Journal*, *45*(3), 227-238.

Swienty, O., Zhang, M., & Reichenbacher, T. (2006). Attention guiding visualization of geospatial information. Geoinformatics 2006: Geospatial Information Technology,

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A. J., & Li, F. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. *International journal of biometeorology*, *54*(1), 75-84.

UN, D. (2015). World urbanization prospects: The 2014 revision. *United Nations Department of Economics and Social Affairs, Population Division: New York, NY, USA*, *41*.

Vairamuthu, S., Ojha, I., Soni, A., & Varshney, K. Pollution based Navigation System for Metropolitan Cities.

Van den Elshout, S., Léger, K., & Nussio, F. (2008). Comparing urban air quality in Europe in real time: A review of existing air quality indices and the proposal of a common alternative. *Environment International*, *34*(5), 720-726.

Viehmann, A., Hertel, S., Fuks, K., Eisele, L., Moebus, S., Möhlenkamp, S., Nonnemacher, M., Jakobs, H., Erbel, R., & Jöckel, K.-H. (2015). Long-term residential exposure to urban air pollution, and repeated measures of systemic blood markers of inflammation and coagulation. *Occupational and environmental medicine*, *72*(9), 656-663.

Wakamiya, S., Siriaraya, P., Zhang, Y., Kawai, Y., Aramaki, E., & Jatowt, A. (2019). Pleasant route suggestion based on color and object rates. Proceedings of the Twelfth ACM International Conference on Web Search and Data Mining,

Wang, Q., Yuan, X., Ma, C., Zhang, Z., & Zuo, J. (2012). Research on the impact assessment of urbanization on air environment with urban environmental entropy model: a case study. *Stochastic environmental research and risk assessment*, *26*(3), 443-450.

White, T. (2017). Symbolization and the visual variables. *The Geographic Information Science & Technology Body of Knowledge, 2nd ed.; UCGIS: Ithaca, NY, USA*.

WHO. (2021). *WHO global air quality guidelines: particulate matter (PM2. 5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization.

Wolfe, J. M. (1994). Guided search 2.0 a revised model of visual search. *Psychonomic bulletin & review*, *1*(2), 202-238.

Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nature reviews neuroscience*, *5*(6), 495-501.

ZAHMATkeSH, H., SABeR, M., & MAlekPoUR, M. (2015). A new method for urban travel rout planning based on air pollution sensor data. *Curr World Environ*, *10*, 699-704.