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# *Routi – A Novel Indoor Navigation Solution*

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Prof. Dr. Jan Borchers
Computer Science Department
RWTH Aachen University

*by*
*Lennart Stallmann*

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Prof. Dr. Ulrik Schroeder

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# Abstract

This bachelor thesis deals with the topic of Indoor Pedestrian Navigation. Research on this topic has focused mainly on geopositioning technology, particularly Real-Time Location Systems (RTLS) so far, which are expensive to set up and maintain. Other common technologies like Global Navigation Satellite Systems (GNSS), for example the Global Positioning System (GPS), are unreliable indoors. An alternative to the mentioned technologies are location based services (LBS) using Quick Response (QR) codes to georeference the user, when they scan them. In order to evaluate indoor navigation using QR codes, a prototype 'Routi' was implemented. In a user study at the Informatikzentrum (Computer Science Center, CSC) of RWTH Aachen University the prototype was evaluated. 13 participants solved tasks in scenarios, filled out a questionnaire and answered questions in an interview to provide feedback. The gathered information from the questionnaire and the interview were analysed in order to answer the three research questions: How can the information about the building and the route be represented, such that the user can identify their location and confidently reach their destination? What are the benefits and drawbacks of the proposed solution and how can it be improved? And last, is indoor navigation using QR codes a feasible alternative to Real-Time Location Services?

# Überblick

Diese Bachelorarbeit beschäftigt sich mit dem Thema der Navigation von Fußgängern innerhalb von Gebäuden. Forschung zu diesem Thema hat sich bisher vor allem auf Geopositionierungstechnik, vor allem Echtzeit- Lokalisierungssysteme (Real-Time Location Systems - RTLS) konzentriert, welche teuer einzurichten und zu unterhalten sind. Andere verbreitete Technologien, wie Globale Satellitennavigationssysteme (GNSS), z. B. das Globale Positionierungssystem (Global Positioning System - GPS), sind in Innenräumen unzuverlässig. Eine Alternative zu den genannten Technologien sind standortbezogene Dienste (LBS) unter Verwendung von Quick Response (QR)-Codes mit eindeutigen IDs, die Nutzende georefernziren können, sobald diese sie scannen. Um die Indoor-Navigation mit QR-Codes zu untersuchen, wurde ein Prototyp „Routi“ implementiert. In einer Nutzerbefragung am Informatikzentrum der RWTH Aachen wurde der Prototyp getestet. 13 Teilnehmende haben Aufgaben in verschiedenen Szenarien gelöst, einen Fragebogen ausgefüllt sowie Fragen in einem Interview beantwortet, um Feedback zu dem Prototypen zu geben. Die gesammelten Informationen aus dem Fragebogen und dem Interview wurden ausgewertet, um die drei Hauptforschungsfragen zu beantworten: Wie können die Informationen über das Gebäude und die Route so dargestellt werden, dass die Nutzenden ihren Standort identifizieren und sein Ziel sicher erreichen kann? Was sind die Vor- und Nachteile der vorgeschlagenen Lösung und wie kann sie verbessert werden? Und schließlich: Ist die Indoor-Navigation mit QR-Codes eine umsetzbare Alternative zu Echtzeit-Standortdiensten?

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This thesis could not have been accomplished, had it not been for the tireless work of the members of the free and open source software communities, who developed the technologies that form the basis for this prototype and the people offering their kind help with problems I encountered along the way.

I thank my participants for taking the time to evaluate the prototype and their valuable insights.

And last but not least, I thank all the people close to me, who supported me on the journey.

# Conventions

Throughout this thesis we use the following conventions:

- The thesis is written in British English.
- The first person is written in plural form.

Short excursuses are set off in coloured boxes.

**EXCURSUS:**
Excursuses are set off in orange boxes.

Where appropriate, paragraphs are summarized by one or two sentences that are positioned at the margin of the page.

This is a summary of a paragraph.

Source code and implementation symbols such as properties are written in `typewriter-style text`.

# Chapter 1

# Introduction

Challenges in Indoor Pedestrian Navigation

Navigating public buildings is often challenging for people, who have never been to them before. There are a multitude of conditions that lead to and worsen this fact for example complex building structures and unintuitive, inconsistent or outdated signage, which lead to a high cognitive load when navigating. In addition, visitors often only know what is at their destination, e.g. the person who owns the office where they have an appointment, but not where the office itself is located. Therefore, a mapping from meta data about a location to the location itself is required, which can introduce additional hurdles.

Early research on RLTS

While there has been substantial research on indoor pedestrian navigation since the early 2000s, it has for the most part focused on estimating the user's position using geopositioning technology, especially Real-Time Location Systems (RTLS) like Bluetooth Low Energy (BLE), Ultra-Wideband (UWB), or wireless LAN triangulation, which are expensive to setup and maintain. Lower-tech solutions on the other hand have been mostly explored in the early days of the field and studies have been conducted on technology that is considered outdated today.

Prototype Routi does not use ubiquitous positioning

We propose a solution to these problems by conceptualising and implementing 'Routi', a location based service (LBS) to aid indoor pedestrian navigation and wayfinding. Routi neither relies on RTLS technologies, nor Global Navigation Satellite Systems (GNSS) like the Global Positioning System

(GPS), which are unreliable indoors. Instead, it uses Quick Response (QR) codes that contain unique IDs, which can be resolved for their geoposition and thus allow the user to manually update their position by scanning them. This way, high accuracy can be achieved, while lowering operation costs to effectively 0.

Achieved work in this thesis

In prototype development, we first conceptualised a digital model of the Computer Science Center (CSC) building complex of RWTH Aachen University, where we would later conduct our user study. We developed a modification on the A* shortest path algorithm to integrate building meta data into wayfinding and implemented a web application for users to search for their destination and get detailed information for wayfinding on their own devices.

In a user study, we evaluate the working prototype and collect qualitative feedback in order to further improve it and make concrete suggestions as to how similar systems could be constructed and which information is most beneficial to users, in a system without ubiquitous positioning. We also evaluate QR codes as a low-tech alternative to RTLS.

Research Questions

We are particularly interested in the following research questions.

*RQ1* How can the information about the building and the route be represented, such that the user can identify their location and confidentially reach their destination?

*RQ2* What are the benefits and drawbacks of the proposed solution and how can it be improved?

*RQ3* Is indoor navigation using QR codes a feasible alternative to Real-Time Location Services?

## 1.1 Outline

The second chapter refers to Related Work, including Navigation Problems (2.1), Indoor Positioning Systems (2.2) and Route Planning (2.3). The challenges of route planning are discussed in detail in the following sub-chapters: Graph Algorithms (2.3.1), Modelling Indoor Spaces (2.3.2) and Generating Graphs (2.3.3).

The third chapter of this thesis describes the Design and Implementation of Routi. Section 3.1 explains the Refinement of the Navigation Problems, section 3.2 the Design Goals, section 3.3 the Technology Choices and section 3.4 the Building Model – The Graph of Connectivity. Section 3.4 is further devided into the sub-sections: The Topological Model (3.4.1), which contains information about Waypoints and Edges and The Context Model (3.4.2), which provides information about Rooms. Section 3.5 deals with the Search and 3.6 with QR Codes. Section 3.7 Wayfinding Algorithm focusses on A* Modification in 3.7.1. Section 3.8 User Interface addresses the Navigation Screen in 3.8.1, including the Navigation Overview and the Step-by-Step Navigation, and the Search Screen in 3.8.2. The last section in this chapter, section 3.9, describes the Administration Tool, which consists of the Graph Editor (3.9.1) and the Room Editor (3.9.2).

The fourth chapter presents the User Study. Therefore the Methodology (4.1) and more precisely the Procedure (4.1.1) is outlined. The Study Design is described in 4.2, which includes the Usability Test (4.2.1) with the Scenarios, the Questionnaire (4.2.2) and the Interview (4.2.3). Section 4.3 refers to the Participants and 4.4 to the Limitations of this thesis.

The final chapter 5 contains the Analysis, including the Transcription (5.1), the Coding (5.2), a Thematic Analysis (5.3) and the Results (5.4) of the user study.

# Chapter 2

# Related Work

## 2.1 Navigation Problems

According to Downs and Stea [1977], navigation can be reduced to a set of navigation problems: orientation, route planning, track keeping and destination recognition, all of which also apply to indoor pedestrian navigation. Wayfinding applications should therefore aim to support their users in these areas.

## 2.2 Indoor Positioning Systems

Almost all Location Based Services (LBS) resolve the problem of orientation by utilising an Indoor Positioning System (IPS).

Current state of Indoor Positioning Systems

Research in LBS and indoor pedestrian navigation (often just indoor navigation) became established around the year 2000, when the first real-time location systems (RTLS) and carry-on devices, such as in pagers and phones as well as portable sensors became accessible [Maaß, 1997]. In early experiments, such as by Bahl and Venkata N. Padmanabhan [2000], radio frequency triangulation has been used to locate users indoors. This information could then be used to display georeferenced information such as wayfinding services, as demonstrated by Gilliéron and Merminod [2003]. In recent years, more elaborate RTLS have been developed [Davidson and Piché, 2017], the most promising being Wi-Fi fingerprinting [Retscher and Roth, 2017], Bluetooth Low Energy (BLE) [Huang et al., 2009] and Ultra Wideband (UWB) [Alarifi et al., 2016], which can achieve precision below 1 metre if sufficient coverage is guaranteed. Lam et al. [2016], Ettlinger et al. [2017] and Huang et al. [2018] propose systems combining these technologies with each other as well as inertial navigation systems that perform Pedestrian Dead Reckoning (PDR) to achieve even higher accuracy. Huang et al. also raised the issue, however, that the described sensor or beacon densities are often not feasible for scenarios where IPS are required due to high setup and maintenance complexity. Systems that are simpler and thus cheaper on the other hand would still lack the required accuracy.

Alternative positioning techniques using two-dimensional barcodes

Other solutions without RTLS technologies have been explored, for example by Ruppel and Gschwandtner [2009] and Mulloni et al. [2009] who used Quick Response (QR) codes to locate the user's device by calculating the distance to the code based on image processing techniques. Although these solutions received predominantly positive feedback, Nikander et al. [2013] estimated that the effort of manually scanning a QR code was to high for the user and thus the devices would need the ability to self-locate.

In the following years, no significant advances have been made in research on manual pedestrian positioning using QR codes. Instead, concepts on how such navigation systems could be implemented as well as reference implementations have been published for example by Raj et al. [2013] and Basiri et al. [2014], though user evaluation is largely missing.

## 2.3 Route Planning

### 2.3.1 Graph Algorithms

Generating a path from the current position to the destination can also be fully resolved by the LBS, provided that the data about the route endpoints is accessible. Graph algorithms are used to find a path that meets certain criteria based on the users' context [Huang et al., 2009], like being the shortest path or not leaving a building. In most systems, the context is disregarded though and a shortest path using Dijkstra's Algorithm [Dijkstra, 1959] or A* [Hart et al., 1968] is used.

### 2.3.2 Modelling Indoor Spaces

For those algorithms to solve shortest path problems, a proper model of the building complex in the form of a graph is required. As a model, by definition, is a reduction in information, different modelling approaches have been presented to serve a multitude of purposes based on the context requirements of the respective solution. The differences are especially prevalent in what nodes and edges represent in the graph. There is no consensus on how, for example rooms – especially large ones with complex geometry – or connections between places are best modeled. While there are standardisation approaches, for example IndoorGML by the Open Geospatial Consortium (OCG) [Lee et al., 2020] (first version [Lee et al., 2014]), implementations referencing the standard are lacking.

There is no agreed upon standard for modelling graphs. Two main approaches: Topological and Geo-Spatial Mapping

Goetz and Zipf [2011] provide an excellent overview over possible implementations, where space is discretised into the topology of rooms. This results in a graph that is easy to enrich with meta data and fast to query but not precise, due to the discretisation of space. Another approach presented by Steuer [2013] uses visibility graphs to trade the aforementioned benefits for exact geo-spatial shortest paths.

### 2.3.3 Generating Graphs

There is no agreed upon standard for information on building composition hindering graph generation

Information about a building can be available in a range of different formats. Some common representatives include (in increasing amount of detail): images of floor plans, floor plans as files with layers for distinct building features such as doors or walls, Computer-Aided Design (CAD) models of the building and Building Information Models (BIM). None of these formats are initially suitable for querying by shortest path algorithms and thus have to be converted – often involving extensive manual work, as there is no established standard for those models either. There have been attempts to automate as many parts of this process as possible by Nikander et al. [2013], but they make the assumption that the process can never be fully automated.

# Chapter 3

# Design and Implementation

## 3.1 Refinement of the Navigation Problems

During the development process, we decided on refining the navigation problems by Downs and Stea [1977] mentioned in Chapter 2.1 'Navigation Problems'.

Introduction of the new *course validation*, *error recovery* and *destination identification* Navigation Problems

When the user tries to navigate to their destination, they have to be able to validate that they are on the correct path (*course validation*) and, if an error occurs, be able to get back on track (*error recovery*). We also add the problem of *destination identification*, as the representation of the user's destination in the system does not necessarily have to match their mental model. This can lead to errors, when the user tries to enter their destination request into the system.

This classification was a guide throughout the development process to anticipate problems and counteract them by design.

## 3.2 Design Goals

The main contribution of this thesis is the design and implementation of the Routi prototype. Routi is an LBS that offers a wayfinding service to pedestrians with a focus on indoor navigation. Its core features include

- Loading the current position by scanning QR codes posted in the building
- Searching destinations by their meta data
- Calculating a shortest path while respecting the user's navigation requirements, such as avoiding stairs
- Displaying an overview map for the route and short information like building and floor for quick navigation by experienced users
- Navigating from the current position to the destination using step-by-step instructions displayed on a map that are manually advanced
- Recovering from errors easily by scanning another QR code to update the current position

## 3.3 Building Model – The Graph of Connectivity

Differences between the GOC and WIRG models

Most of the prototype's functionality is based on the graph of the building, which serves as foundational data structure. To enable location search and enrich the route with contextual information, we concluded that a topological graph, similar to the Weighted Indoor Routing Graph (WIRG) model suggested by Goetz and Zipf [2011] would be beneficial, as we could easily attach additional meta data to graph elements.

In Routi, the graph does however not only serve as a data store but is also used to display the route to the user. The coordinates of the individual waypoints must therefore be selected in such a way that a meaningful route is displayed when the edges of a path are overlaid onto a floor plan. Based on these additional requirements, we decided on modifying the WIRG model into what we call the *Graph of Connectivity* (GOC).

The GOC consists of two parts, the topological model that represents how spaces are connected to each other and the contextual model that contains meta data on these spaces. It is expected that the topological model changes seldom, as passages, rooms and their relative positions are mostly permanent. The context that describes what is located in a room, however, is expected to change more often – depending on the building complex even frequently. This separation of concerns [Dijkstra, 1982] has the benefit that updating meta data only needs access to one part of the graph, which could in some cases even be automated as explored in future work.

### 3.3.1 The Topological Model

Usage of nodes and edges

Similar to Goetz and Zipf [2011], we distinguish between places 'one can be in' that we call *waypoints* and represent in the graph using nodes and the connections between those places represented by edges.

#### Waypoints

Waypoints are a discretisation of space and either represent a room, part of a room or an outside place, such that all relevant locations can be mapped to at least one waypoint. Accordingly, a room can be represented using multiple waypoints, if it is required by its complex geometry, see Chapter 3.3.2 'Rooms'

Waypoint coordinates

Waypoint positions are given by EPSG:3857[1] geodetic (sometimes 'geographical') coordinates in latitude and longitude and a floor number. A geodetic Coordinate Refer-

[1] https://epsg.org/crs_3857/WGS-84-Pseudo-Mercator.html

ence System (CRS) has been chosen, as planar CRS, which are used by other authors, such as Nikander et al. [2013] need to be projected onto a geodetic CRS when outside navigation between building should be supported in addition to indoor navigation. For the simplicity of prototyping, we sampled geodetical coordinates directly to avoid this issue.

The area of a waypoint

In cellular building models like the IndoorGML standard proposed by Lee et al. [2020], being inside a room is equivalent to one's position being inside the two- or three-dimensional polytope of the room. Although waypoints also represent spaces, our abstraction does not specify an area or volume and therefore does not allow such precise calculations. Instead, in Routi, the user is considered to be 'approximately at the waypoint' that is closest to them with respect to Vincenty's formula Vincenty [1975], while avoiding non-traversable objects like walls. This inaccuracy is acceptable, as there is no situation where a mapping from a coordinate-floor pair to a waypoint would be necessary. At the same time, the effort in sampling waypoints and storing them is greatly reduced.

#### Edges

Edges model connectivity between waypoints

In the GOC, there is a directed edge from node A to node B, if and only if one can traverse from the waypoint of node A to the waypoint of node B in a straight line, where doors and floor changes are allowed. Traversability can therefore be defined as a transitive and reflexive binary relation on waypoints. In the WIRG model, edges are undirected, as most pairs of connected nodes have equal meta data for both traversability directions. We chose directed edges however, as crucial traversability information is often only relevant for one direction. For example, door closing times generally only apply to entering a room, while leaving is possible at any time. This way, we significantly simplify attaching meta data to edges.

Edge properties for wayfinding

For the wayfinding algorithm to find a route that matches the user's context like reduced mobility, it needs to access meta data on the traversability between waypoints. All edges have a `distance` property, storing the Vincenty distance [Vincenty, 1975] between its waypoints. It is used as the edge weight in the wayfinding algorithm described in Chapter 3.6 'Wayfinding Algorithm' to find shortest paths. Goetz and Zipf [2011] propose a differentiation between edge weight and distance in order to take navigation preferences into account and to penalise undesirable edges. While this approach is promising, it has not been implemented here in order to keep the prototype simple. Other properties included are whether the edge is traversable by wheelchair or at which times it is not traversable, for example because the door it represents is locked. Arbitrary strings can be attached as `additionalInfo` to be displayed to the user, when they reach the edge.

Floor changes are modeled using edges

Floor changes, for example by stairs or lifts are modeled using edges that have a `floor` property value of `null`. For lifts, this means implicitly, that the `distance` is equal to 0, which is why the current algorithm prefers lifts in most cases.

### 3.3.2 The Context Model

#### Rooms

Representation of room meta data in the GOC

To make locations at the building searchable, context in form of room meta data has to be related to waypoints. For simplicity, we decided to include the data as room nodes and attach them to all of their waypoint nodes directly, using room edges, that are ignored when determining traversability. It might, however, be more effective to relate room identifiers to meta data outside the graph, especially when integrating with external systems that manage room meta data. By isolating the room data from waypoints, we achieve separation of concerns, which is particularly advantageous for generalisation, as room meta data can vary tremendously depending on the building type.

To allow effective querying by the user, we impose minimal structure on context data to both allow filtering and attaching arbitrary meta data. The `RoomCategory` enumerated type assigns the room to a group such as 'female restrooms' and the `searchTerms` property holds a list of arbitrary keyword strings that describe the object, like the names of people working in an office. Using an enumerated type has the additional benefit that the values can easily be localised.

Unlike Yuan and Schneider [2010], not all pairs of waypoints in a room that can be traversed in a straight line are connected in our model. While this can lead to sub-optimal shortest paths, in the real world these differences are marginal, so reducing the number of edges is justified. Similar to the WIRG approach, we add auxiliary waypoints to avoid obstacles, but we also introduce them to simplify the subgraphs in spaces.

Regarding outside points of interest (POI) like bus stops, we made the unconventional design decision to assign their waypoints a virtual room that holds the meta data. In the future, it might be necessary to introduce a dedicated POI type, but for the prototype, this was a sufficient workaround.

## 3.4 Search

Room properties are queried using Fuzzy Search

A major goal for the Routi prototype is to provide effective search tools to query room meta data and thus make both self-localisation based on a known room and destination identification as defined in Chapter 3.1 'Refinement of the Navigation Problems' easy. The user is presented with a search box that applies Fuzzy Search based on the Levenshtein distance [Levenshtein, 1966] between the search text and all available `searchTerms`, `displayNames` and `roomNames` and displays all matching rooms. This way, typing errors do not affect the search results in most cases and the user might be able to find a room with just partial information. Adding relevant `searchTerms` increases room identification success.

In addition to text search, the user can also use filters to reduce the rooms to a `RoomCategory`.

## 3.5 QR Codes

As established in Chapter 2.2 'Indoor Positioning Systems' RTLS still have tremendous problems, especially the cost-precision trade off. A major goal of this thesis is to evaluate whether QR-code-based localisation, which has been explored in the earlier days of the field, is a viable alternative today. We assume that due to the abundance of QR codes today [Ozkaya et al., 2015], users are more familiar with them and interaction feels natural and effortless.

Advantages of QR codes

QR codes in our system contain URLs to the Routi website including a unique location argument. This allows us to display a relevant, user friendly interface without requiring a download that might be undesirable due to download time. We can also position the user precisely, as scanning a QR code requires relative closeness and line of sight, so while the location estimation might be off by a few metres, we can safely assume that the user is in the room indicated by the location argument in the code.

QR codes area also more privacy friendly than RTLS or GNSS, as the position cannot be monitored continuously and there are no other service providers that could access the information. Also, the user can be confident that no tracking software is installed on their device, as Routi runs as a web app.

Oppose to RTLS, deploying a QR code based solution is simple, cheap and low maintenance as the only requirements are identifying relevant locations, printing the QR codes and sticking them to a wall, where in RTLS complex sensory/beacon systems have to be deployed, maintained and powered, which might require constructional work.

We decided to include the `nodeID` that uniquely identifies a GOC waypoint node in the URL to allow a direct mapping from QR code to position in the GOC.

## 3.6 Wayfinding Algorithm

Given a start and destination in the GOC, finding a traversable path between them, as defined in Chapter 3.3.1 'Edges' can be reduced to finding a path between their waypoint nodes. We implemented a custom modification of the efficient A* shortest path algorithm by Hart et al. [1968] to additionally take the context of the user into account.

### 3.6.1 A* Modification

We use the Vincenty distance [Vincenty, 1975] as the heuristic for the A* algorithmic base, as it can be calculated quickly for each pair of waypoint nodes and is admissible. Our modification concerns which edges can be expanded. When navigating buildings, some paths that might be traversable by other people or at other times, might not be available to the current user. We express this algorithmically by limiting the set of edges that can be expanded.

Edges are excluded from being expanded if at least one of the following criteria is true:

1. The edge is marked as `isTemporarilyNotTraversable` for example due to construction work
2. The edge is currently not traversable, meaning that the time of querying and 30 minutes in the future both lie in the interval between the properties `traversableStarting` and `notTraversableStarting` of the edge
3. The edge is marked as `isNotTraversableByWheelchair` and the user has indicated that they would like to avoid stairs

Proof that the modification finds a suitable shortest path if it exists

This modification does not violate the admissibility of the heuristic function, as it is equivalent to finding a shortest path in GOC′, where the respective edges are removed from GOC. Also, the algorithm still returns a shortest path. Let

$P$ be a shortest path in GOC and $Q$ be a shortest path in GOC′. Let us assume for contradiction, that $Q$ is shorter than $P$. Obviously, $Q$ is also contained in GOC but as it is shorter than $P$, $P$ cannot be a shortest path in GOC. Therefore the assumption must be false and thus there can never be a shorter path in a graph by removing edges. This implies that the heuristic is admissible under the modification.

It can be possible however, that the algorithm does not find a path between the start and destination waypoint nodes. Either because there is none in the GOC or because the additional restrictions do not allow traversal. In this case, the search is repeated with one by one relaxed criteria unless a path is found. An appropriate warning message is then attached to the returned route for each criterion that had to be relaxed to find that path.

1. Is not traversable in 30 minutes
2. Is not traversable right now
3. `isNotTraversableByWheelchair`
4. `isNotTraversableTemporarily`

If the algorithm still does not find a route, the start and end-point are marked on the map for the user to find their way on their own.

This algorithm ensures that there is always relevant information returned to the user, even if they might not be able to take the path. In some cases though, another person could help them to take stairs, unlock a door or similar, such that they would be able to get to their destination anyway.

While this algorithmic expansion has been implemented and should increase usability, it could not be evaluated in the user study, due to technical complications. Therefore, the modifications had to be removed and a plain A* implementation has been used.

## 3.7 User Interface

### 3.7.1 Navigation Screen

In navigation, maps are an effective way to communicate location based information to the user [Huang et al., 2018]. We therefore constructed a georeferenced building map by overlaying a floor plan image we received from the building administration over map tiles provided by the OpenStreetMap Foundation[2]. The route calculated by the wayfinding algorithm is displayed on this map.

#### Navigation Overview

There are two navigation modes proposed in Routi. When the route is first calculated, an overview is displayed that contains the entire route on the building map, markers for the user's current and destination position and markers for floor changes that indicate where and to which floor to change. Additionally, there is a box with information to help users that are already acquainted to the building complex, listing the destination building name and floor as well as the route length and estimated walking time.

#### Step-by-Step Navigation

Path Segments

In step-by-step navigation, the route is partitioned into path segments. Those segments are sets of consecutive edges that end at the end of rooms and buildings, on floor changes or when there is contextual information attached to an edge. Each of these segments is considered a 'step' and displayed as a line connecting the coordinates of the waypoints in the segment in order. Each segment can be focussed on individually, highlighting it in green, zooming the current map selection to fit and rotating it so that the average direction of all lines, weighted by their length, points upwards. The user can focus the next and previous

[2] https://osmfoundation.org

segment by tapping the respective buttons. In step-by-step mode, only the path segments between the previous and next floor change are displayed. Segments from other floors would display on floor plan features of this floor, which could be irritating, especially as the architecture does not necessarily have to be identical, which could lead to path segments through walls. Previous segments are displayed in grey, subsequent segments in blue.

Floor Changes

Floor changes are represented using floor change markers, as in the navigation overview. Additionally, there is a banner indicating the vertical direction and number of the floor, to which the user should change. Advancing to a segment on another floor loads the respective floor plan and displays the corresponding path segments.

Information Banners

Similar banners appear, when there is contextual information attached to an edge in the current segment, like closing times for doors or `additionalInfo` strings. Furthermore, a marker is displayed on the respective line to georeference that information.

Destination Recognition

When the end of the route is selected as current segment, a confetti animation is played to signify that the user has reached their destination.

Lost

When the user gets lost on the way, they can scan a QR code to update their position and effectively start a new navigation from their current position.

### 3.7.2 Search Screen

We implemented a robust search feature to allow users to find their destinations easily as described in Chapter 3.4 'Search'. The search screen displays a list of the found rooms with a title, room number, the `RoomCategory`, an icon for each `RoomCategory` and the list of related `searchTerms`. `searchTerms` that match the query are printed in bold to indicate why a room was found. This should make it easier to recognise false positives and support the decision as to which room should be selected for navigation if the name of the room does not match what the user expects.

To make the search responsive, room meta data is cached locally on website load.

Filters

The filter chips are generated based on the values of the `RoomCategory` enumerated value. Only one filter can be selected at a time, which can be deselected either by being tapped or by tapping the filter remove icon. If that icon is tapped when no filter is selected, the filter chips are highlighted to indicate that they can be used to filter rooms. If the text field is empty, all rooms that match the active filter are displayed, otherwise they are filtered according to the search text.

Help when no rooms are found

When the search does not find a room, help information is displayed offering multiple options, depending on the search context. If a filter is selected, the `RoomCategory` is reported, to signify that the user is only searching a subset of rooms. The presented options are buttons that guide the user to the required UI element or perform the action:

- Removing the selected filter (if one is selected)
- Searching in a room category (if no filter is selected)
- Reformulating the query (if not empty)
- Scanning a QR code (when searching start rooms)

## 3.8 Administration Tool

To construct the GOC, a data collection tool had to be implemented. As the *Admin Tool* is also implemented in Flutter[3] it can be accessed on multiple platforms, of which a desktop environment was the primary design target. The Admin Tool consists of two parts, the graph editor and the room editor. Data can be exported to and imported from a JSON[4] file in a custom format.

[3] https://flutter.dev
[4] https://datatracker.ietf.org/doc/html/rfc7159

### 3.8.1 Graph Editor

The graph editor shows an excerpt from the OSM that contains the building complex for which the GOC is created. The floor plans of all buildings are overlaid over the building outlines and can be swapped by the floor selection. When clicking on the map, a new waypoint with pre-filled meta data on `buildingID`, `floor` and `coordinates` is created. To link the waypoint to its room, the room number has to be added manually by reading it from the floor plan. The text fields also recognise values that do not match the syntax of the building (e. g. rooms on the first floor not having a '1' in the hundreds place), prohibit saving and display a helpful warning. While clicking on the map is not an accurate way to assign coordinates to waypoints, the relative position to rooms on the floor plan and to other waypoints is primarily important as this is what is displayed to the user. Therefore, this imprecision is tolerable.

Selecting two waypoints allows the user to create directed traversability edges and add meta data to them. The edge and node editor use colour to indicate which marker and lines on the map correspond to which waypoints and connectivity edges.

The node and edge editor also display a border if there are unsaved changes and allow to delete the selected objects, where nodes can only be deleted, when there are no edges connected to them. Nodes can also be moved.

### 3.8.2 Room Editor

For each room indicated by waypoints from the graph editor, a room object is created automatically, which can be enriched by meta data, including the `displayName`, `RoomCategory` and `searchTerms`. Common search terms include names of people, institutions and abbreviations related to the room. Rooms can also be marked as interesting or as done editing for data collection purposes. If there are unsaved changes, the rooms are highlighted, deletion is only possible, once all waypoint nodes related to them are deleted.

All rooms can be searched by `buildingID`, `floor`, `roomID` and filtered by `RoomCategory` and values of interesting and hide done.

# Chapter 4

# User Study

A major goal of this thesis is to investigate how indoor navigation applications that do not rely on RTLS can be constructed, such that they are beneficial to their users. Therefore we wanted to gather data from practical use of the prototype, to evaluate the concrete strategies that were implemented. We were especially interested in usability problems in the participants' interaction with QR codes, the user interface of the prototype and whether there were apparent issues in the overall design as established in chapter 3 'Design and Implementation'.

We conducted a user study, where participants would be presented with scenarios in which they needed to go to a room. After the scenarios, the participants filled out a questionnaire and participated in an interview to report their experiences and give feedback.

To evaluate the data, we focussed on qualitative research methods, especially Thematic Analysis as proposed by Braun and and Clarke [2006].

## 4.1 Methodology

### 4.1.1 Procedure

The study was structured in 4 phases: The introduction (~5-10 min), a usability test, comprised of a set of 7 scenarios for the participant to complete (~20-40 min), a questionnaire (~10-15 min) and a semi-structured interview (~10-40 min). Most trials took 50-75 minutes, though there were 3 outliers that took more time in the semi-structured interview. There was enough time for each participant to take as long as they needed, both in the trials and the interview.

When the participant arrived, they were greeted, thanked for their willingness to participate and given an overview of what they would be doing. They also signed a consent form and were able to ask any questions. When they were ready to start, they were presented with a scenario, where they would need to navigate to a room. They were allowed to use any aids, such as present signage and prior knowledge of the building but the researcher explicitly pointed out a QR code before the first scenario and explained that the prototype that should be evaluated could be accessed by scanning the QR code. As there were technical difficulties on some devices, the participants were in those cases offered a smartphone by the researcher. After completing all scenarios, they were asked to answer the questionnaire to collect socio demographic data, information on navigation application use and ratings for usability, likeability and cognitive load. Finally, there was a semi-structured interview to assess how they perceived the prototype, discover problems, gather feedback and opinions.

## 4.2 Study Design

### 4.2.1 Usability Test

The usability test was carried out at the *Informatikzentrum* (Computer Science Center, CSC) of the RWTH Aachen University, due to its availability and high structural complexity. University campuses are a typical environment for wayfinding LBS [Gilliéron and Merminod, 2003], [Nikander et al., 2013], emulating an authentic area of application. To further increase external validity, participants were allowed to use any navigation aids available to them, including signage and prior knowledge of the building complex.

Participants were instructed to find their way independently of the researcher and to utter their thought process according to the Thinking-Aloud method, presented by Lewis [1982]. At the beginning of each scenario, participants received minimal information on the room they needed to seek. They were then followed by the researcher, who took notes on interesting behaviour and utterances and assigned them the next scenario on completion.

**Scenarios**

The scenarios were designed to produce typical challenges in navigating public buildings. The participants had to find different types of rooms, were given incomplete or erroneous information and had to find rooms based on different types of meta data. This was done to achieve a broad spectrum of situations in which potential problems could be observed.

A list of scenarios, their descriptions and intended problems can be found in Appendix A 'SCENARIOS'.

### 4.2.2 Questionnaire

The questionnaire was conducted to collect quantitative and socio-demographic data that is used to contextualise the qualitative results. As all participants were fluent in German, the questionnaire was held in German. The questionnaire can be found in Appendix B 'QUESTIONNAIRE'.

We measured the usability of the system using the System Usability Scale (SUS) proposed by Brooke [1986]. It

SUS questionnaire for usability evaluation has been chosen for being well-established and reliable in measuring software system reliability [Lewis, 2018] and being short compared to other questionnaires like the Usefulness, Satisfaction, and Ease of Use (USE) questionnaire [Lund, 2001]. It also does not requiring a license like the Software Usability Measurement Inventory (SUMI) [Kirakowski, 1995] or the Questionnaire for User Interface Satisfaction (QUIS) [Chin et al., 1988], which would otherwise have fulfilled our requirements towards reliability. There are multiple German translations available, which have been evaluated by Brix et al. [2023]. We chose the translation by Reinhardt et al. [2013] (cited in Brix et al. [2023] as by 'Rummel B.') for its closeness to the original wording and methodical construction.

Other measured variables include the cognitive load in completing the scenarios as suggested by Paas [1992], the likeability of the system and the technological exploratory tendency of the participants, all but the first of which are represented using seven-point Likert Scales [Likert, 1932] that allow to calculating means due to being a pseudo-equidistant ordinal measure.

### 4.2.3 Interview

The semi-structured interview has been conducted to allow the participants to report their experiences and problems, give feedback and utter their opinions regarding interaction with the system. Additionally, the interviewer can ask for clarifications and explore interesting topics in further detail [Lazar et al., 2017].

The interview guide can be found in Appendix C 'INTERVIEW GUIDE'.

## 4.3 Participants

The target population for this study is defined as the set of all people, who visit public buildings and need navigation help. As this population is unknown and thus the chances of selecting an individual are unknown, a non-probability sampling method had to be chosen [Gravetter et al., 2021]. While quota sampling with quotas for age, prior knowledge of the test building and technical literacy would have been preferable, convenience sampling had been chosen due to resource constraints. The implications are discussed in Chapter 4.4 'Limitations'.

$n = 13$ participants were recruited to take part in the study. While no proper sampling method was used, we tried to include male ($n = 5$) and female ($n = 8$) participants and also both people that were well acquainted with the test building ($n = 7$), as well as unfamiliar with most locations ($n = 6$) to guarantee input from these groups.

## 4.4 Limitations

Sample is not representative of the target population

A group that has not been included in the sample, is people who have never been to the CSC. This poses a major limitation on generalisation and restricts findings to people, who are at least vaguely familiar with the building complex. However, as usability research is mainly concerned with improving a system and not making general statements about users [Wixon, 2003], [Lazar et al., 2017], this does not invalidate the findings. Routi is in an early prototype stage and the feedback that has been provided by the participants can be used to further improve it. However, the flaws in sampling have lead to the third research questions not being able to be answered.

*RQ3* Is indoor navigation using QR codes a feasible alternative to Real-Time Location Services?

Suboptimal questions asked in semi-structured interview

Furthermore, as we had not received adequate interview training, some suboptimal situations occurred, e.g. when the interviewer asked suggestive or dichotomous questions or interrupted the participant. These incidents are noted in the interview transcripts and special care was taken when analysing the responses to these questions.

Data is coded by a single person

As the data is coded by just one person, there is potentially low reliability in how codes are assigned.

# Chapter 5

# Analysis

We collected three categories of data on each participant. The study notes that have been taken by the researcher during the trials reflect their observations, for example regarding behaviour and utterances of the participant and problems that occurred. These notes have primarily been used as reference material for asking questions in the interview and adding context in the transcripts. Second, some quantitative measures have been collected in the questionnaire as described in Chapter 4.2.2 'Questionnaire' to contextualise the findings in the interview. Third, the coded interviews serve as the basis for the thematic analysis [Braun and and Clarke, 2006].

## 5.1 Transcription

All interviews have been recorded with the consent of the participants. They have been pre-transcribed locally, on our own hardware using the Whisper model by OpenAI [Radford et al., 2022]. As the pre-transcriptions contained a lot of errors and no speaker recognition, all transcriptions have been edited for clarity and context and explicitly validated by hand. Edits include:

- Cleaning up recognition errors

- Adding punctuation
- Adding speakers
- Removing filler words and false starts if they hinder understanding
- Anonymising names of people
- Adding notes to further clarify meaning or make corrections ('Anmerkung', 'Anm.'), based on the study notes by the researcher

## 5.2 Coding

We used an emergent coding strategy to assign codes to participant utterances in the interview transcripts according to inductive thematic analysis developed by Braun and and Clarke [2006]. Each interview has been coded twice to increase reliability. The coding manual [Lazar et al., 2017] can be found in Appendix D 'CODING MANUAL'.

## 5.3 Results

Participant knowledge of the CSC

To contextualise the results, it is important to take the limitations as described in Chapter 4.4 into account, especially the fact that the sample only included participants, who had been to the CSC at least 5 times before. 46% of the participants (AC: 6) stated that they were usually in the same, few places in the building complex and 31% of the participants (AC: 4) indicated that they knew almost all relevant places and buildings. 23% reported, that they knew the CSC very well. Also see Figure 5.1

Ease of Wayfinding

We also asked them about how easy they find their ways at the CSC, see Table 5.2. There was a fairly even distribution of In all cases but P3's, wayfinding became easier when asking people for help.

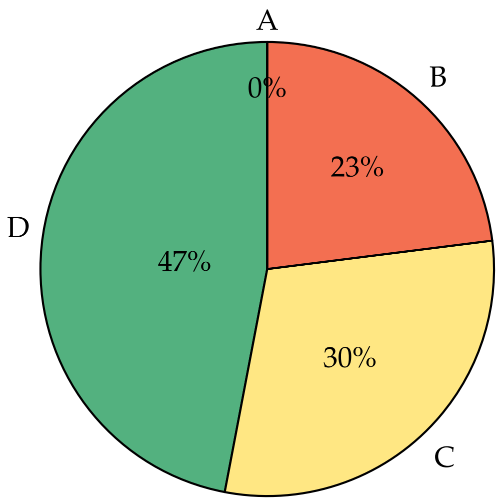



**Figure 5.1:**
A: 'I (almost) don't know my way around' (AC: 0)
B: 'I am usually in the same, few places' (AC: 3)
C: 'I know most relevant places and building' (AC: 4)
D: 'I know the Computer Science Center very well' (AC: 6)

| Participant | Without asking other people | When asking other people |
|---|---|---|
| P1 | 7 | Not necessary so far |
| P2 | 2 | 4 |
| P3 | 5 | 3 |
| P4 | 2 | 5 |
| P5 | 1 | 7 |
| P6 | 7 | Not necessary so far |
| P7 | 6 | Not necessary so far |
| P8 | 7 | Not necessary so far |
| P9 | 2 | 4 |
| P10 | 5 | 6 |
| P11 | 3 | 6 |
| P12 | 5 | 6 |
| P13 | 6 | Not necessary so far |

**Table 5.2:** 'I find my way around the CSC well'.
Agreement measured on a seven-point Likert scale
Colors for visualisation only

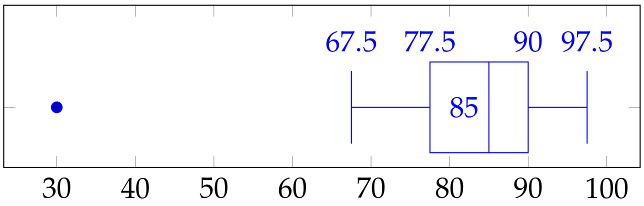



**Figure 5.3:** SUS Score
Values 0-100
Participant scores are plotted

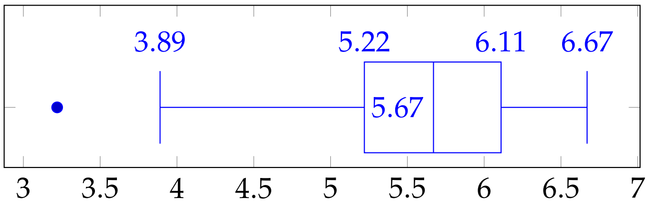



**Figure 5.4:** Likeability
Likert Scale 1-7
Participant means are plotted

### 5.3.1 Quantitative Data Analysis

SUS Rating

To measure the usability of the Routi system, we employed the System Usability Scale proposed by Brooke [1986] as described in Chapter 4.2.2 'Questionnaire'. Routi achieved a median SUS score of 85.00, which according to the curved grading scale by Lewis and Sauro [2018] lies in the 96-100 percentile range, rewarding Routi the highest grade 'A+'. This indicates excellent usability, as rated by participants from the recruited sample. Also see Figure 5.3.

Likeability

We also measured likeability, as high likeability is helpful in fostering adoption. Participants rated Routi with a likeability score of 5.67 (median of participant means) on a Likert scale from 1 to 7, yielding a slightly positive result. Also see Figure 5.4.

Cognitive Load

Another important factor for technology adoption is cognitive, as low cognitive load increases user satisfaction [Schmutz et al., 2009]. We used a standard test, developed by Paas [1992] and measured a median of 3 on a Likert scale

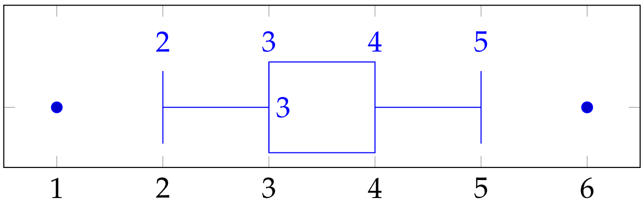



**Figure 5.5:** Cognitive Load
Likert Scale 1-9
Participant responses are plotted

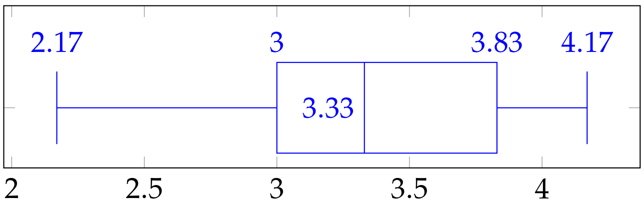



**Figure 5.6:** Technical Exploratory Tendency
Likert Scale 1-5
Participant means are plotted

from 1 to 9. This indicates low to medium cognitive load on the users. Also see Figure 5.5.

Technical Exploratory Tendency

We decided to measure the construct of technical exploratory tendency, to contextualise interview data and investigate relationships with other variables. We could, however, not observe significant correlations with other variables. Also see Figure 5.6

## 5.4 Thematic Analysis

We conducted an inductive thematic analysis as introduced by Braun and and Clarke [2006] on the coded interview transcripts and defined a main theme with subthemes.

### 5.4.1 Navigation Apps are a Necessary Evil

Our participants seemed to generally prefer navigating without navigation systems when they felt confident in their ability to reach their destinations on their own. This includes Routi, but also other LBS like Apple Maps.

*'I followed the route segment as far as I could see it. But when I understood it, I stopped using it.' – Participant 4*
*"Ich bin jetzt mal dem Pfeil [Anm. dem Routensegment], soweit ich ihn gesehen habe, nachgelaufen. Aber dann habe ich es auch mehr benutzt als ich es verstanden habe." – Versuchsperson 4*

*About Apple Maps: '[...] usually, I just select the destination and choose the streets to walk myself' – Participant 4*
*Über Apple Maps: "[...] meistens habe ich nur einfach das Ziel und gucke selber welche Straßen ich jetzt dahin laufe." – Versuchsperson 4*

*'To be honest, I think that I have not discovered all features. I actually don't know... There were some more buttons [the "Next" buttons], but I did not use them all. [...] because I could manage myself and did not have a reason to experiment.' – Participant 7 "Ich habe ehrlich gesagt das Gefühl, dass ich nicht alle Features erkundet habe. Ich weiß tatsächlich gerade gar nicht... Es gab da noch mehr Buttons unten [Anm. "Weiter" Knöpfe], aber ich habe die eigentlich alle nicht genutzt. [...] Weil ich so klar gekommen bin und keinen Grund hatte da irgendwas zu testen." – Versuchsperson 7*

We assume that any interaction demands mental capacity, users from our sample like to save. This is especially prevalent in new applications, which require learning. Additionally, using a system, especially inputting information, requires time.

*'And I thought, it would take more time to start the app than to just walk there. Hence, I just walked there.' – Participant 8*
*"Und ich fand, das würde länger dauern, die App anzumachen, anstatt einfach dahin zu laufen. Deswegen bin ich einfach dahin gelaufen." – Versuchsperson 8*

For designing wayfinding systems, this means that ease of is a major factor in adaptability. Also, alternative systems besides digital solutions should be developed to support users that renounce them.

# Chapter 6

# Summary and Future Work

This thesis provides an implementation that aims to explore the usage of QR codes and their ability to replace RLTS technologies in user positioning. Results from the evaluation suggest that while the prototype has potential to server as a platform on which this hypothesis can be evaluated, there are still tremendous improvements required, especially with respect to performance, to separate feedback on the modeled solution from usability feedback.

In the future, another user study with a sample more representative of the target population should be conducted. Another topic of interest is integration with facility management software to both automatically extract floor plans and enrich them with dynamic meta data.

# Appendix A

# SCENARIOS

A list of the scenarios the participants had to complete and the challenge each should create. We were interested in how the participant would behave in these situations.

**'You have an appointment with a friend in the library.'**
The library cannot be found by a room filter, therefore the participant must utilise the search field.

**'You have a job interview at the COMSYS chair.'**
Chairs can be found by the room filter. Also, it might be possible that the user does not know how to spell 'COMSYS'.

**'You have a tutorial at UMIC.'**
The UMIC is not located within the CSC complex. Participants must trust Routi to identify the correct room to actually go there.

**'You have an appointment with Professor PROFESSOR NAME.'**
There are no offices of people in Routi. The participant must recognise that walking to the chair secretariat is required.

**'You have a lecture in lecture hall 2.'**
The lecture halls are not named 'lecture hall' but 'AH<number>'. The participant must select a room filter to find them.

**'You need to deliver a parcel to Dr. WRONG PRONUNCIATION.'**
The name of the person to which the artificial parcel should be delivered is wrong, there is no person registered in the system with this name, because there is a superfluous letter, which could have been placed there accidentally by the sender. We were interested in how the participant would react to this.

**'You have a seminar at b-it.'**
There are 3 seminar rooms, whose names contain 'b-it'.

# Appendix B

# QUESTIONNAIRE

This is the export from the survey tool SoSci Survey[1]

Question 4 and 7 are displayed with an error. The radio button in the second row should be labelled:

- Question 4: “War nicht der Fall”
- Question 7: “Bisher nicht nötig”

[1] https://www.soscisurvey.de/en/index

**Seite 01**
VP Nummer

**1. Sie sollten diese Seite nicht sehen können. Bitte melden Sie sich bei Ihrer Versuchsleitung.**

VP Nummer [ ]

**Seite 02**
Intro

Vielen Dank, dass Sie bis hier an der Studie teilgenommen haben!

Nun möchte ich Sie bitten, diesen Fragebogen auszufüllen. Es gibt keine richtigen oder falschen Antworten, allein Ihre Meinung und Ihre persönlichen Erfahrungen zählen. Dabei werden Ihre Antworten pseudonym gespeichert und sind nicht zu Ihnen zurückverfolgbar. Es geht darum das System zu testen, das heißt, ich versuche möglichst viele Probleme zu identifizieren.

Der Fragebogen wird ca. 10-15 Minuten in Anspruch nehmen. Wenn Sie eine Pause benötigen oder den Fragebogen abbrechen wollen, ist dies jederzeit möglich, ohne dass Ihnen daraus Nachteile entstehen.

Ich möchte Sie bitten, den Fragebogen möglichst selbstständig auszufüllen, wenn Sie aber eine Verständnisfrage oder ähnliches haben, können Sie sich gerne an mich wenden.

Sie können jetzt unten auf "Weiter" klicken, um den Fragebogen zu starten.

**Seite 03**

**2. Die mentale Anstrengung, die ich in die Lösung der Aufgaben gesteckt habe war**

- ◯ Sehr, sehr gering
- ◯ Sehr gering
- ◯ Gering
- ◯ Eher gering
- ◯ Weder gering, noch hoch
- ◯ Eher hoch
- ◯ Hoch
- ◯ Sehr hoch
- ◯ Sehr, sehr hoch

**Seite 04**
Likability

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | teils-teils | Stimme eher zu | Stimme zu | Stimme völlig zu |
|---|---|---|---|---|---|---|---|
| Ich habe das System nur widerwillig genutzt. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich hätte es vorgezogen ein alternatives System zu verwenden. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Das System entspricht meinen Anforderungen. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Mit dem System zu Interagieren war mühsam. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich hatte das Bedürfnis aufzuhören das System zu benutzen. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Das System zu benutzen war frustrierend. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich mochte es, das System zu benutzen. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich würde das System Freundinnen und Freunden empfehlen. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich würde das System gerne in öffentlichen Gebäuden nutzen können | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

**Seite 05**
Navigation

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | teils-teils | Stimme eher zu | Stimme zu | Stimme völlig zu |
|---|---|---|---|---|---|---|---|
| Live-Standortbestimmung, wie auch immer sie technisch umgesetzt würde, würde es im Vergleich zu dem aktuellen Ansatz signifikant einfacher machen einen Weg zu finden. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich fühle mich wohl damit die Standortbestimmungsdienste (zum Beispiel GPS) auf meinem Smartphone zu aktivieren. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich finde es störend QR-Codes zu scannen, um meine Position zu laden. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich finde es intuitiv meine Position zu laden, in dem ich einen QR-Code scanne. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Manuell in Routi auf „Weiter“ zu tippen ist störend. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich kann meine aktuelle Position auf der Karte identifizieren. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich kann überprüfen, ob meine tatsächliche Position und die, die Routi bestimmt hat übereinstimmen. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

**3. Bei dieser Frage geht es um die Raumsuche auf der Website, nicht um das Ablaufen der Route.**

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | teils-teils | Stimme eher zu | Stimme zu | Stimme völlig zu |
|---|---|---|---|---|---|---|---|
| Es ist einfach meinen Zielraum über die Suchleiste zu finden. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Die Raumkategorien helfen mir meinen Zielraum schneller zu finden. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Es wird klar kommuniziert, warum ungewollte Räume von der Raumsuche gefunden werden. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**4. Bei dieser Frage geht es um die gelaufene Route.**

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | teils-teils | Stimme eher zu | Stimme zu | Stimme völlig zu |
|---|---|---|---|---|---|---|---|
| Es ist einfach dem Weg zu folgen, den das System vorschlägt. | ○ | ○ | ○ | ○ ○ | ○ | ○ | ○ |
| Die Optionen, um den richtigen Weg wiederzufinden, nachdem man sich verlaufen hat sind hilfreich. | ○ | ○ | ○ | ○ ○ | ○ | ○ | ○ |
| Es ist einfach die Navigation wieder aufzunehmen, nachdem man falsch abgebogen ist. | ○ | ○ | ○ | ○ ○ | ○ | ○ | ○ |
| Es ist eindeutig, wann und wo man die Etagen wechseln muss. | ○ | ○ | ○ | ○ ○ | ○ | ○ | ○ |

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | teils-teils | Stimme eher zu | Stimme zu | Stimme völlig zu |
|---|---|---|---|---|---|---|---|
| Es ist einfach zu erkennen, wenn man sein Ziel erreicht hat. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |



**5. Wie häufig sind Sie bereits im Informatikzentrum gewesen?**

- ○ Noch nie
- ○ Bis zu 3 mal
- ○ 3-5 mal
- ○ Häufiger als 5 mal

**6. Wie gut kennen Sie sich am Informatikzentrum aus?**

- ○ Ich kenne mich (fast) gar nicht aus
- ○ Ich bin üblicherweise an den gleichen, wenigen Orten
- ○ Ich kenne die meisten relevanten Orte und Gebäude
- ○ Ich kenne das Informatikzentrum sehr gut



PHP-Code

```
if(value('CS01') != 1) {
    question('CS03');
} else {
    goToPage('Likability');
}
```

question('CS03')

**7. Ich finde mich am Informatikzentrum gut zurecht.**

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | teils-teils | Stimme eher zu | Stimme zu | Stimme völlig zu |
|---|---|---|---|---|---|---|---|
| Ohne andere Menschen zu Fragen | ○ | ○ | ○ | ○ ○ | ○ | ○ | ○ |
| Wenn ich andere Menschen frage | ○ | ○ | ○ | ○ ○ | ○ | ○ | ○ |



**8. „Das System" bezieht sich hier sowohl auf die Website, als auch auf die Interaktion mit den QR-Codes.**

| | Stimme überhaupt nicht zu | | | | Stimme voll zu |
|---|---|---|---|---|---|
| Ich denke, dass ich das System gerne häufig benutzen würde. | ○ | ○ | ○ | ○ | ○ |
| Ich fand das System unnötig komplex. | ○ | ○ | ○ | ○ | ○ |
| Ich fand das System einfach zu benutzen. | ○ | ○ | ○ | ○ | ○ |
| Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können. | ○ | ○ | ○ | ○ | ○ |
| Ich fand, die verschiedenen Funktionen in diesem System waren gut integriert. | ○ | ○ | ○ | ○ | ○ |
| Ich denke, das System enthielt zu viele Inkonsistenzen. | ○ | ○ | ○ | ○ | ○ |
| Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit diesem System sehr schnell lernen. | ○ | ○ | ○ | ○ | ○ |
| Ich fand das System sehr umständlich zu nutzen. | ○ | ○ | ○ | ○ | ○ |
| Ich fühlte mich bei der Benutzung des Systems sehr sicher. | ○ | ○ | ○ | ○ | ○ |
| Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden. | ○ | ○ | ○ | ○ | ○ |

Wenn Sie ihre Daten angeben, können daraus wertvollere Erkenntnisse gezogen werden, als wenn Sie darauf verzichten. Die Angabe ist freiwillig und es entstehen Ihnen keine Nachteile, wenn Sie darauf verzichten.

**9. Wie alt sind Sie?**

Alter in Jahren [ ]

**10. Was machen Sie beruflich? Falls Sie hauptberuflich studieren, geben Sie bitte ihren aktuellen Studiengang an.**

Beruf/Studiengang [ ]

**11. Wie lange interagieren Sie durchschnittlich mit Ihrem Smartphone?**
**Wenn Sie beispielsweise 30 Minuten ein Hörbuch aussuchen und danach 2 Stunden ein Hörbuch hören gelten 30 Minuten als Interaktionszeit.**

- ◯ Ich benutze kein Smartphone
- ◯ 0-2 Stunden pro Woche
- ◯ 2-4 Stunden pro Woche
- ◯ 1-2 Stunden pro Tag
- ◯ 2-3 Stunden pro Tag
- ◯ 3-4 Stunden pro Tag
- ◯ Mehr als 4 Stunden pro Tag

| | Stimme überhaupt nicht zu | Stimme eher nicht zu | Teils-teils | Stimme eher zu | Stimme völlig zu |
|---|---|---|---|---|---|
| Ich mag es neue Technologien auszuprobieren. | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich bevorzuge es, die Anleitung zu lesen, bevor ich anfange eine neue Technologie zu benutzen. | ◯ | ◯ | ◯ | ◯ | ◯ |
| Es ist wahrscheinlicher, dass ich eine neue Technologie ausprobieren, wenn sie mir von jemandem empfohlen wird, den ich kenne. | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich bevorzuge es eine Technologie erklärt zu bekommen anstatt sie auf eigene Faust zu erkunden. | ◯ | ◯ | ◯ | ◯ | ◯ |
| Normalerweise verstehe ich Technologien, die ich neu ausprobiere schnell. | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ich fühle mich wohl neue Technologien auszuprobieren. | ◯ | ◯ | ◯ | ◯ | ◯ |



**12. Wie häufig verwenden Sie die genannten digitalen Navigationsdienste?**

| | Sehr selten | | | | Sehr häufig | Nie / Kenne ich nicht |
|---|---|---|---|---|---|---|
| DB Navigator App | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Deutsche Bahn Reiseauskunft (Website) | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Google Maps | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| naveo | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| movA | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Apple Maps | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Waze | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| komoot | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Open Street Maps (OSM) | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Navi im Auto | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Andere | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |



Wählen Sie für jeden Dienst aus, für welche Art von Fortbewegung Sie ihn nutzen.

PHP-Code

```
if (value('NT01_01') >= 1) {
    question('NT02');
}

if (value('NT01_02') >= 1) {
    question('NT03');
}

if (value('NT01_03') >= 1) {
    question('NT04');
}

if (value('NT01_04') >= 1) {
    question('NT05');
}

if (value('NT01_05') >= 1) {
    question('NT06');
}

if (value('NT01_06') >= 1) {
    question('NT07');
}

if (value('NT01_07') >= 1) {
    question('NT08');
}

if (value('NT01_08') >= 1) {
    question('NT12');
}

if (value('NT01_09') >= 1) {
    question('NT09');
}

if (value('NT01_10') >= 1) {
    question('NT10');
}

$answer_count = 0;
$item_count = 9;
$question = 'NT01';

for ($i=1; $i<=$item_count; $i++) {
    $id = id($question, $i); // => NT_01
    if (value($id) >= 1) {
        $answer_count++;
    }
}

if($item_count == 0) {
    goToPage('CSC');
}
```

question('NT02')

**13. DB Navigator App**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT03')

**14. Deutsche Bahn Reiseauskunft (Website)**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT04')

**15. Google Maps**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT05')

**16. naveo**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT06')

**17. movA**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT07')

**18. Apple Maps**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT08')

**19. Waze**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT12')

**20. komoot**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT09')

**21. Open Street Maps (OSM)**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

question('NT10')

**22. Navi im Auto**

Wählen Sie alle zutreffenden Optionen aus.

- ☐ Laufen
- ☐ Rad fahren
- ☐ Auto fahren
- ☐ Öffentlicher Personennahverkehr (Bus, Straßenbahn...)
- ☐ Züge

**Letzte Seite**

## Vielen Dank für Ihre Teilnahme!

Wir möchten uns ganz herzlich für Ihre Mithilfe bedanken.

Ihre Antworten wurden gespeichert, Sie können das Browser-Fenster nun schließen.

# Appendix C

# INTERVIEW GUIDE

- Describe your experiences with Routi
- Did you encounter any problems?
- Do you use other navigation applications? Explain differences.
- Have you been frustrated in the trials?
- Have you encountered features that did not work?
- Where there situations where you did not understand Routi or vice versa?
- Were there specific features that proved especially useful?
- Were unnecessary features?
- Do you have suggestions for improvements that would make you more efficient?
- Would you like to see any quality of life improvements?
- Do you think, Routi is useful for regular and inexperienced users?
- Do you have anything else to add?

# Appendix D

# CODING MANUAL

**Convenience**

Text excerpts indicating that a test person would like to have his/ her location determined.

Text excerpts indicating that a test person would rather click less on 'next'.

**Observations/ descriptions**

Descriptions from test objects about experiences during testing.

Use of navigation aids: Lists apps that are used for navigation and their features.

Interpretation of Routi element

Position determination (landmarks): Features on map that help orientate oneself like rooms, doors or stairs.

**Improvement**

Features that would help improve Routi.

Voice instructions: Opinions from test subjects on whether voice instructions would be helpful.

QR-Codes: Opinions from test subjects on whether the QR-Codes are useful, whether there are enough QR-Codes, and where they should be located.

GPS: Opinions on whether GPS would be helpful.

Improvement search: Ideas from test subjects on how to improve the search of/ entering the destination.

Improvement map: Ideas from test subjects on how to improve the display of the map/ map features.

Features that exist, but couldn't be found: Test subjects note that they missed a certain feature, but this feature already exists, but the test subject didn't notice it.

**Navigation**

QR-Codes were not scanned: Test subjects list reasons why they didn't scan QR-codes.

Step-by-step was not used: Test subjects list reasons why they didn't use the step-by-step function, either it was not necessary or it was not found.

Walking without Routi: Test subjects list reasons why they didn't use Routi for some tasks.

**Good implementation**

Test subjects list features of Routi that they liked.

**Problems**

Bug in the prototype: Test subjects list bugs appearing while testing.

Refusal: Features a test person would refuse to use.

Accessibility: Test subjects list features that were not accessible for them.

Doesn't work on all devices: Test subjects list problems they had on their own devices.

Understanding: Test subjects list problems they had understanding certain features.

Operation: Opinions from test subjects on operation.

Clicking too often/ not often enough on 'next': Problems test subjects had, because they clicked too often/ not enough on the 'next' button.

Performance and responsiveness: Problems test subjects had, because of responsiveness issues.

Rooms were not found in search: Problems test subjects had finding the correct destination.

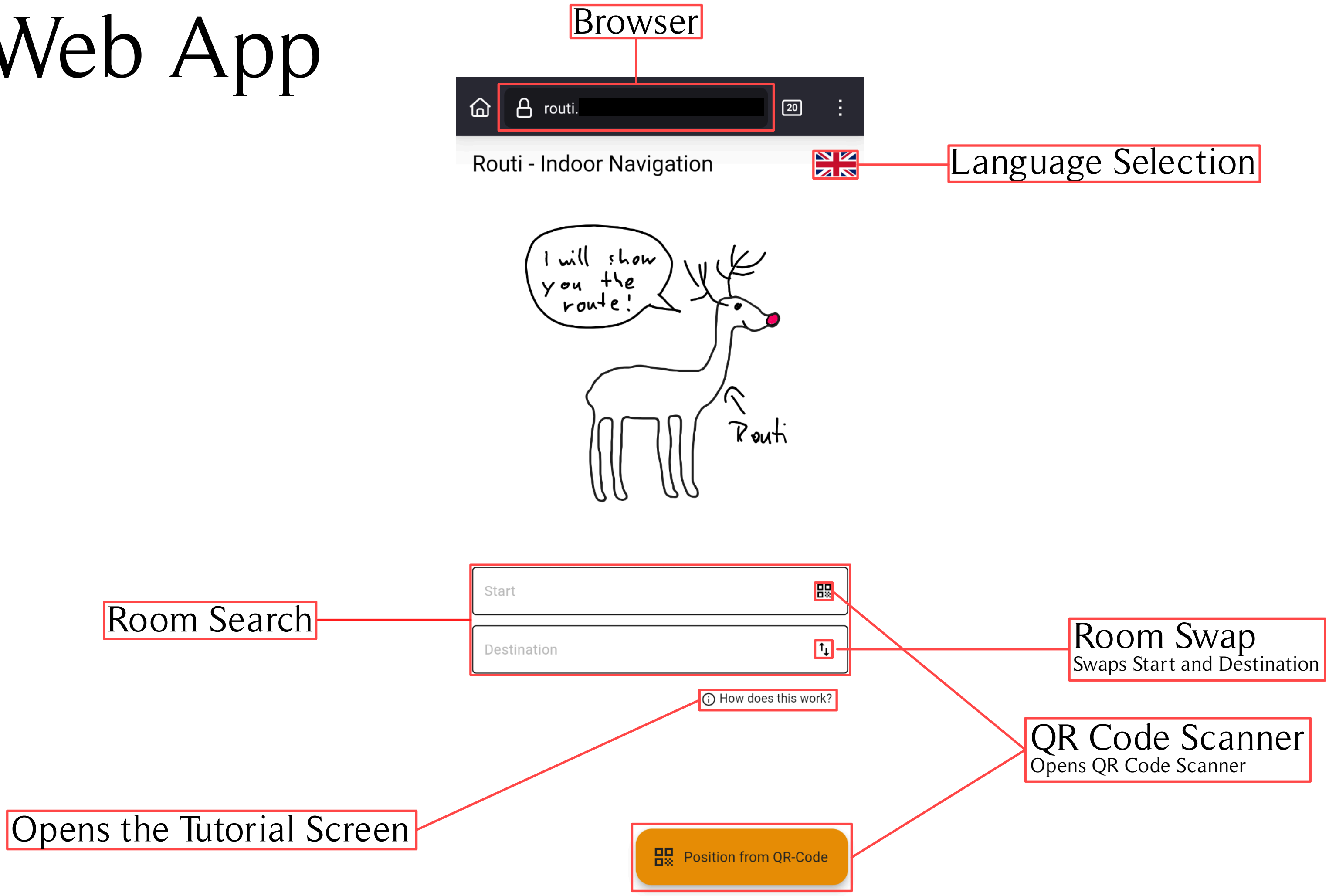
# Appendix E

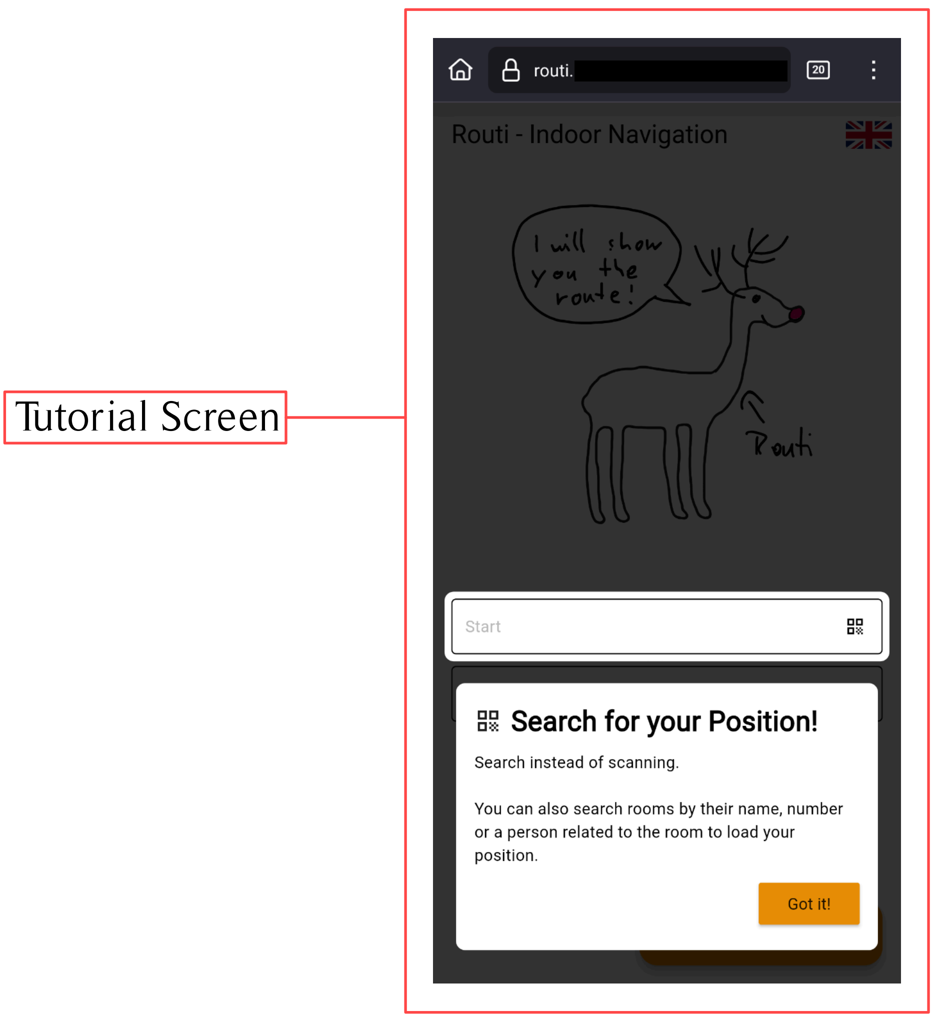
# User Interface

Map data from OpenStreetMap[1] available under the Open Data Commons Open Database License[2].

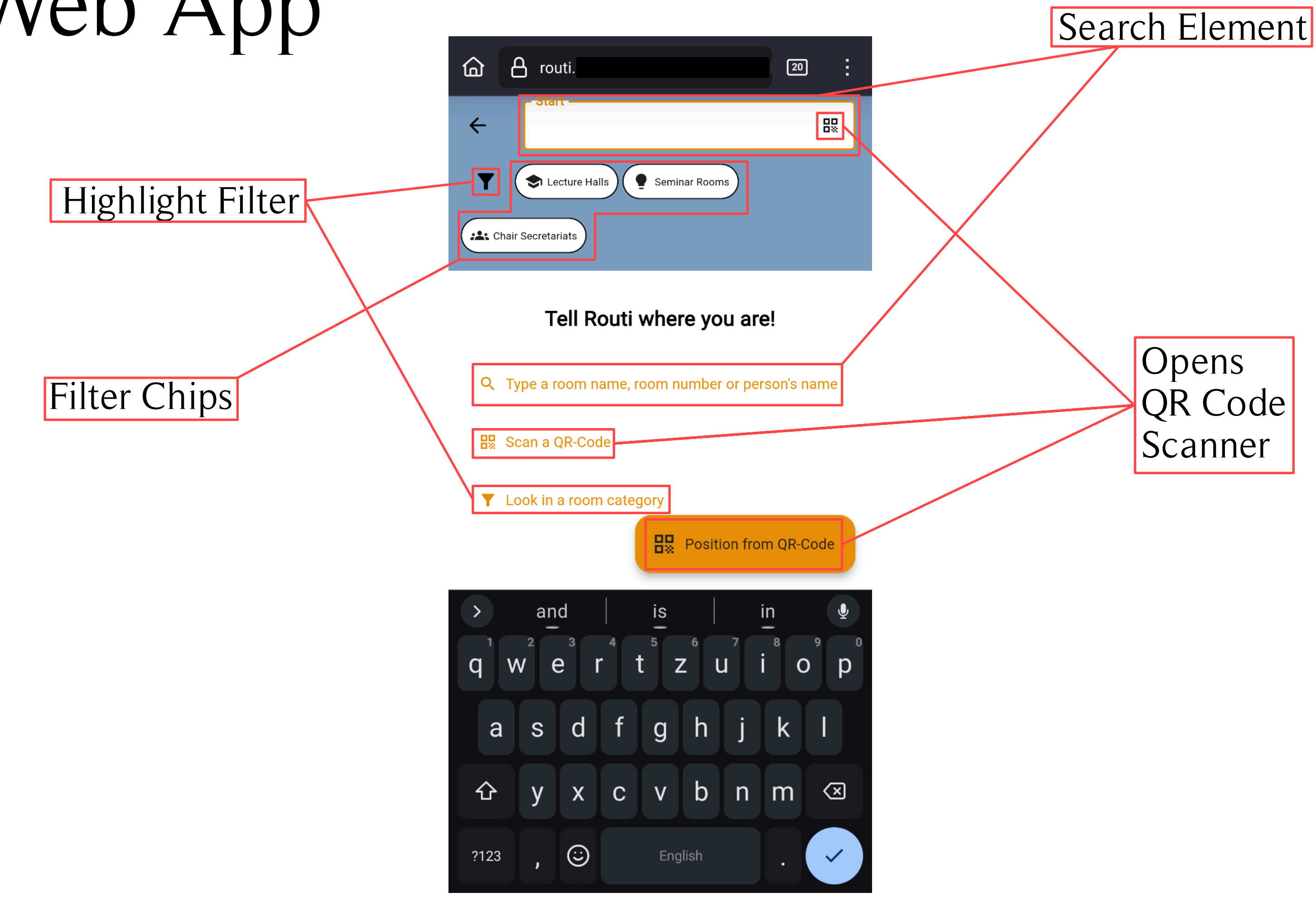
[1] https://www.openstreetmap.org/copyright/en
[2] https://opendatacommons.org/licenses/odbl/

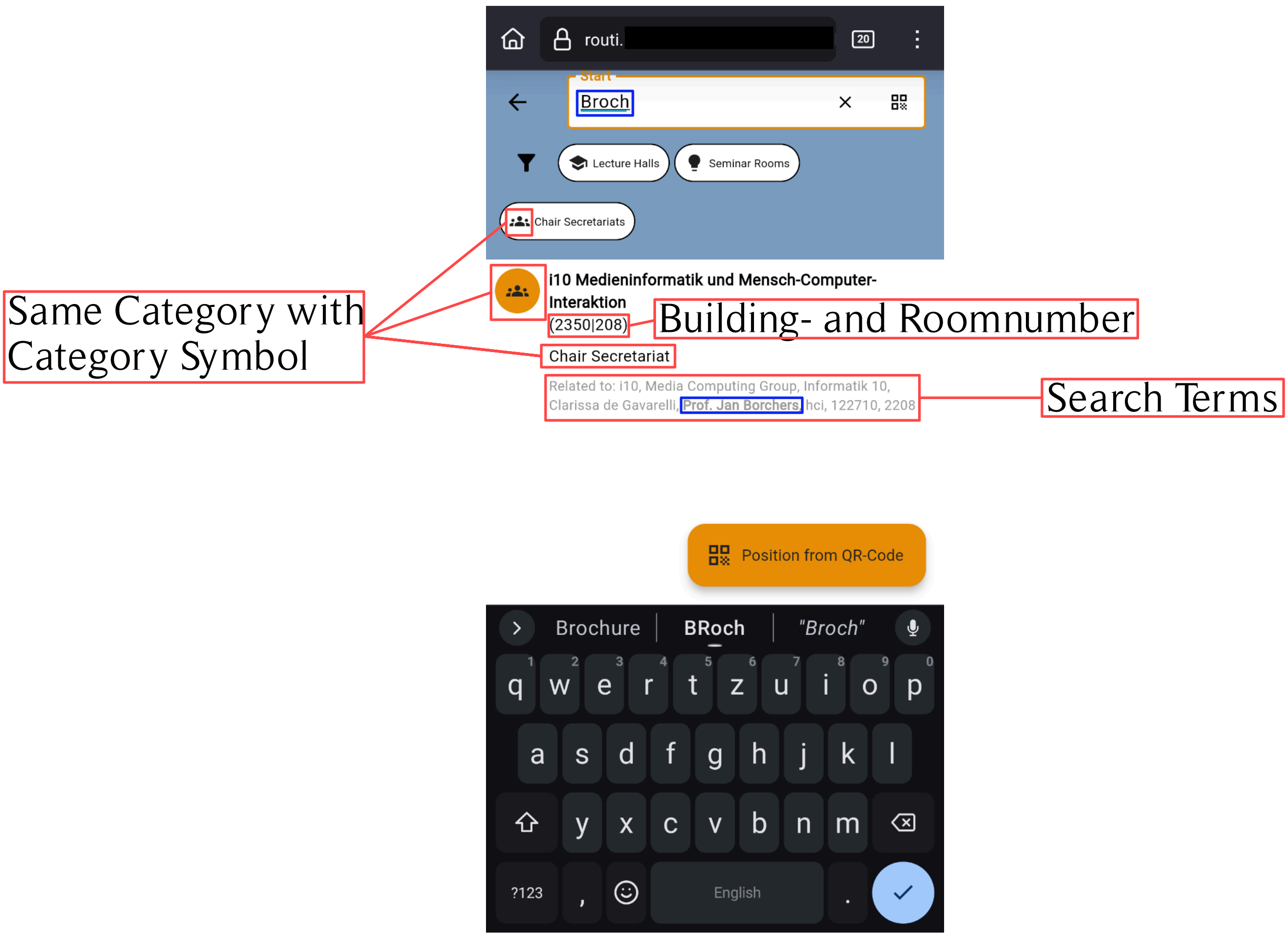
# Web App


Browser
routi.[redacted]
20
Routi - Indoor Navigation
Language Selection
I will show you the route!
Routi
Room Search
Start
Destination
Room Swap
Swaps Start and Destination
How does this work?
QR Code Scanner
Opens QR Code Scanner
Opens the Tutorial Screen
Position from QR-Code

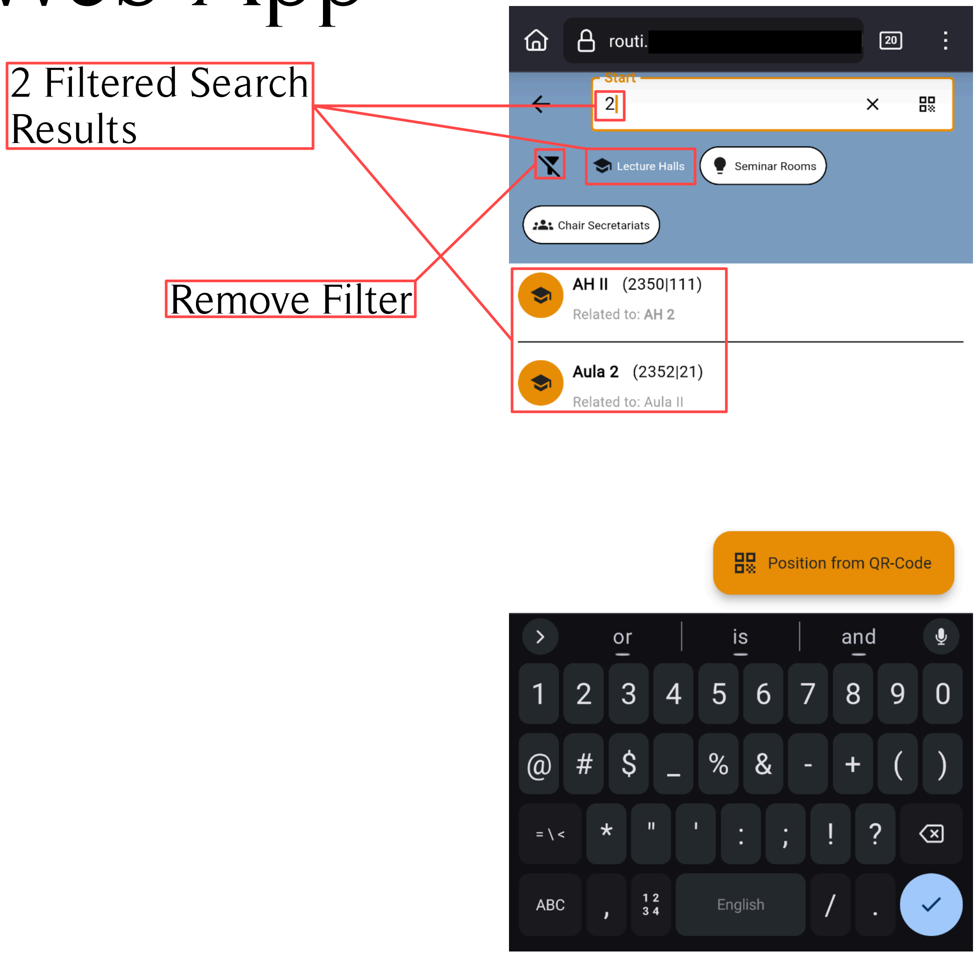

Tutorial Screen
routi.[redacted]
20
Routi - Indoor Navigation
I will show you the route!
Routi
Start
Search for your Position!
Search instead of scanning.
You can also search rooms by their name, number or a person related to the room to load your position.
Got it!

# Web App

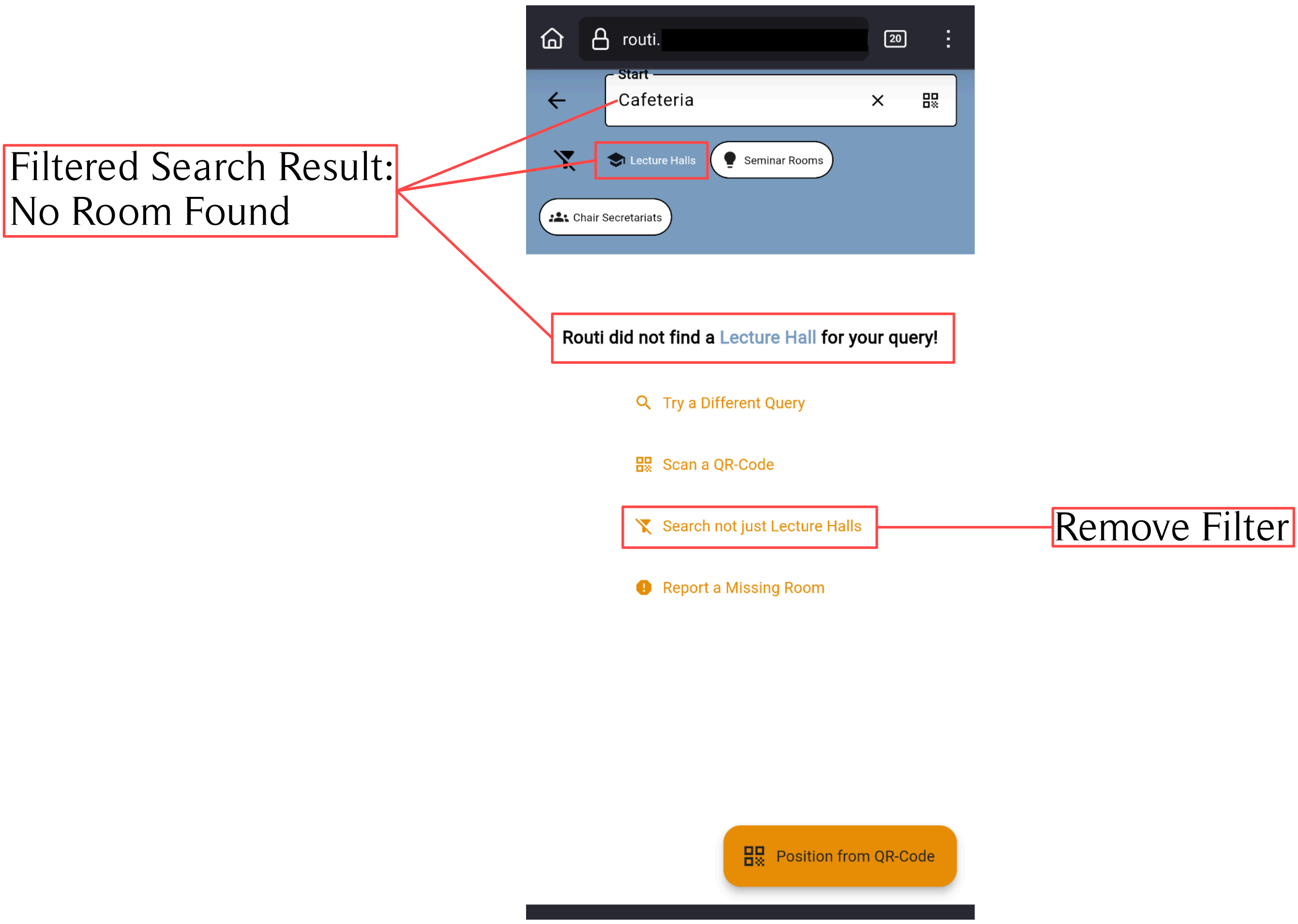

Search Element
Highlight Filter
Filter Chips
Opens QR Code Scanner
routi.[redacted]
Start
Lecture Halls
Seminar Rooms
Chair Secretariats
Tell Routi where you are!
Type a room name, room number or person's name
Scan a QR-Code
Look in a room category
Position from QR-Code
and
is
in
?123
English


routi.[redacted]
Start
Broch
Lecture Halls
Seminar Rooms
Chair Secretariats
Same Category with Category Symbol
i10 Medieninformatik und Mensch-Computer-Interaktion
(2350|208)
Building- and Roomnumber
Chair Secretariat
Related to: i10, Media Computing Group, Informatik 10, Clarissa de Gavarelli, Prof. Jan Borchers, hci, 122710, 2208
Search Terms
Position from QR-Code
Brochure
BRoch
"Broch"
?123
English

# Web App

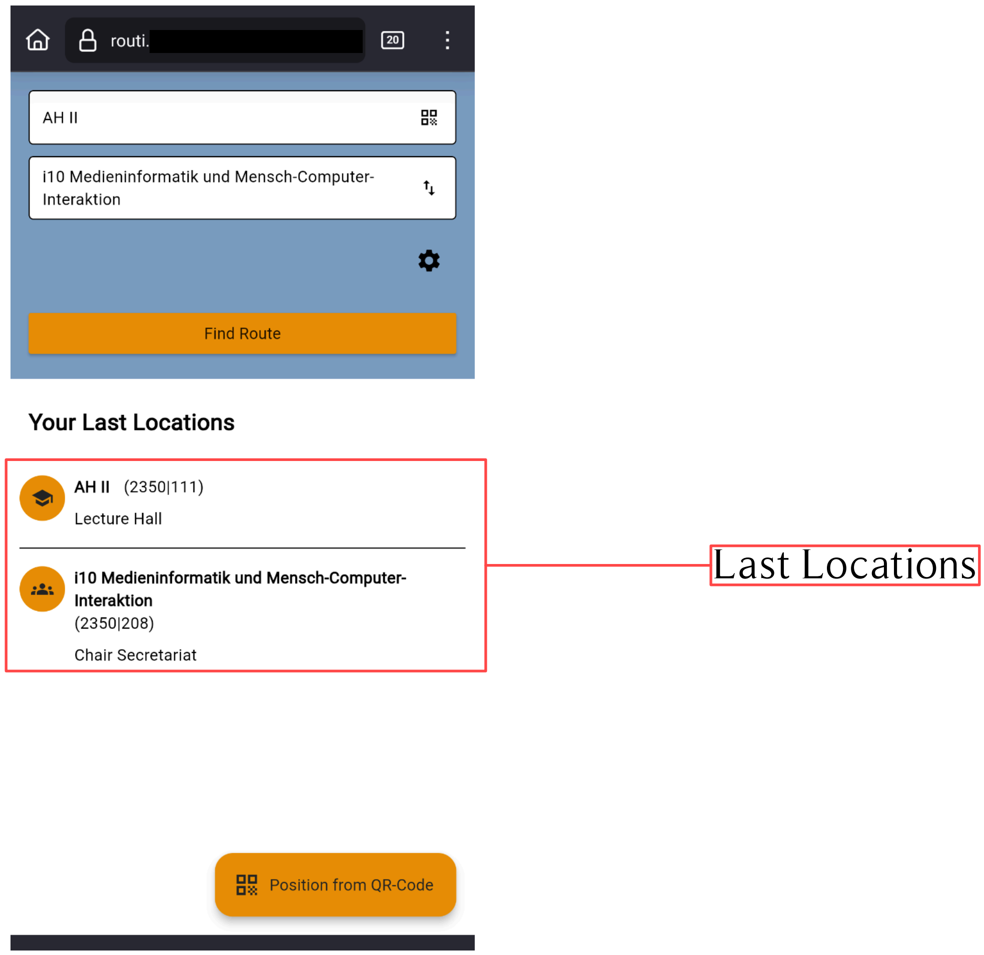


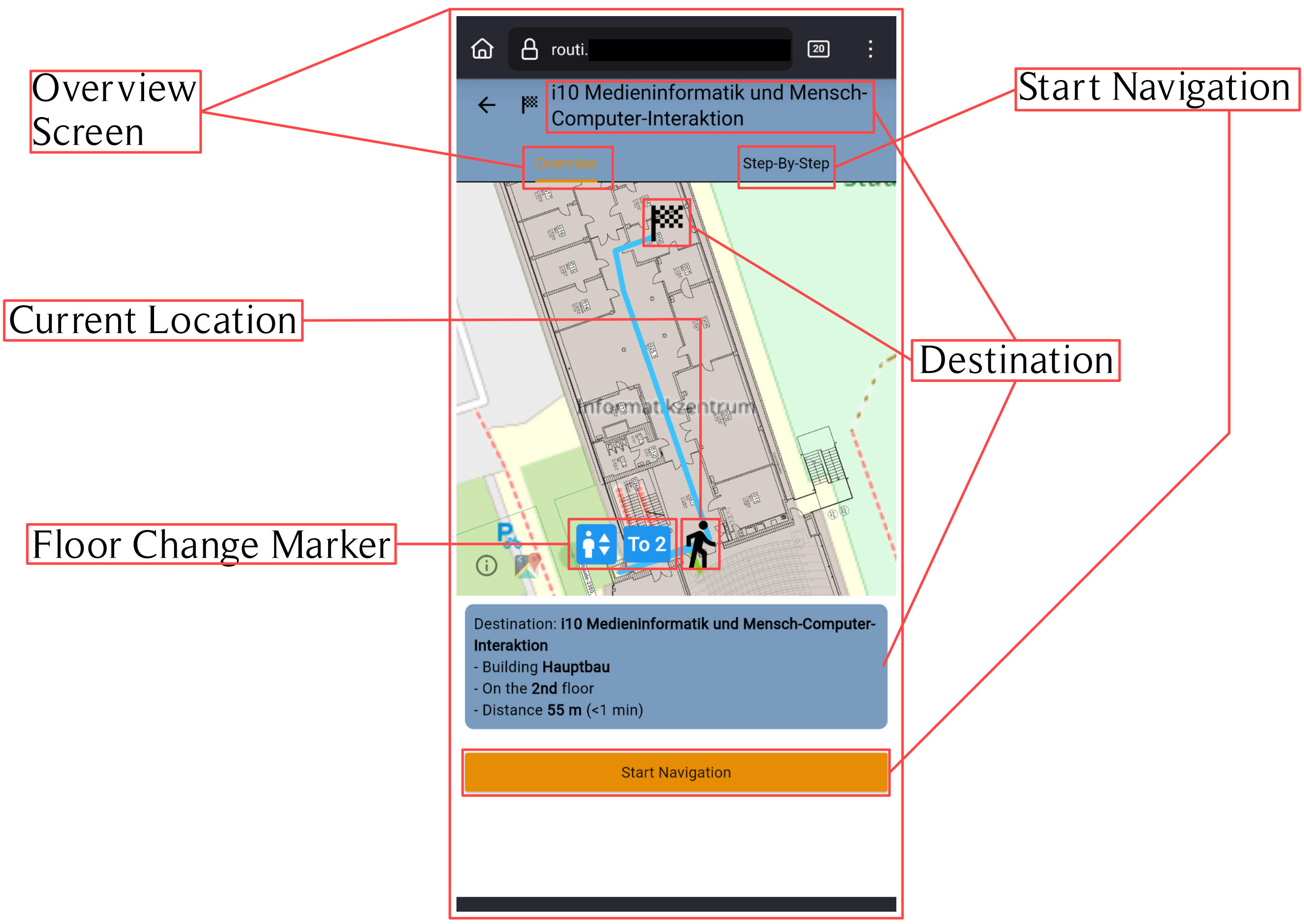
2 Filtered Search Results
Remove Filter
routi.[redacted]
Start
2
Lecture Halls
Seminar Rooms
Chair Secretariats
AH II (2350|111)
Related to: AH 2
Aula 2 (2352|21)
Related to: Aula II
Position from QR-Code
or
is
and
English
ABC

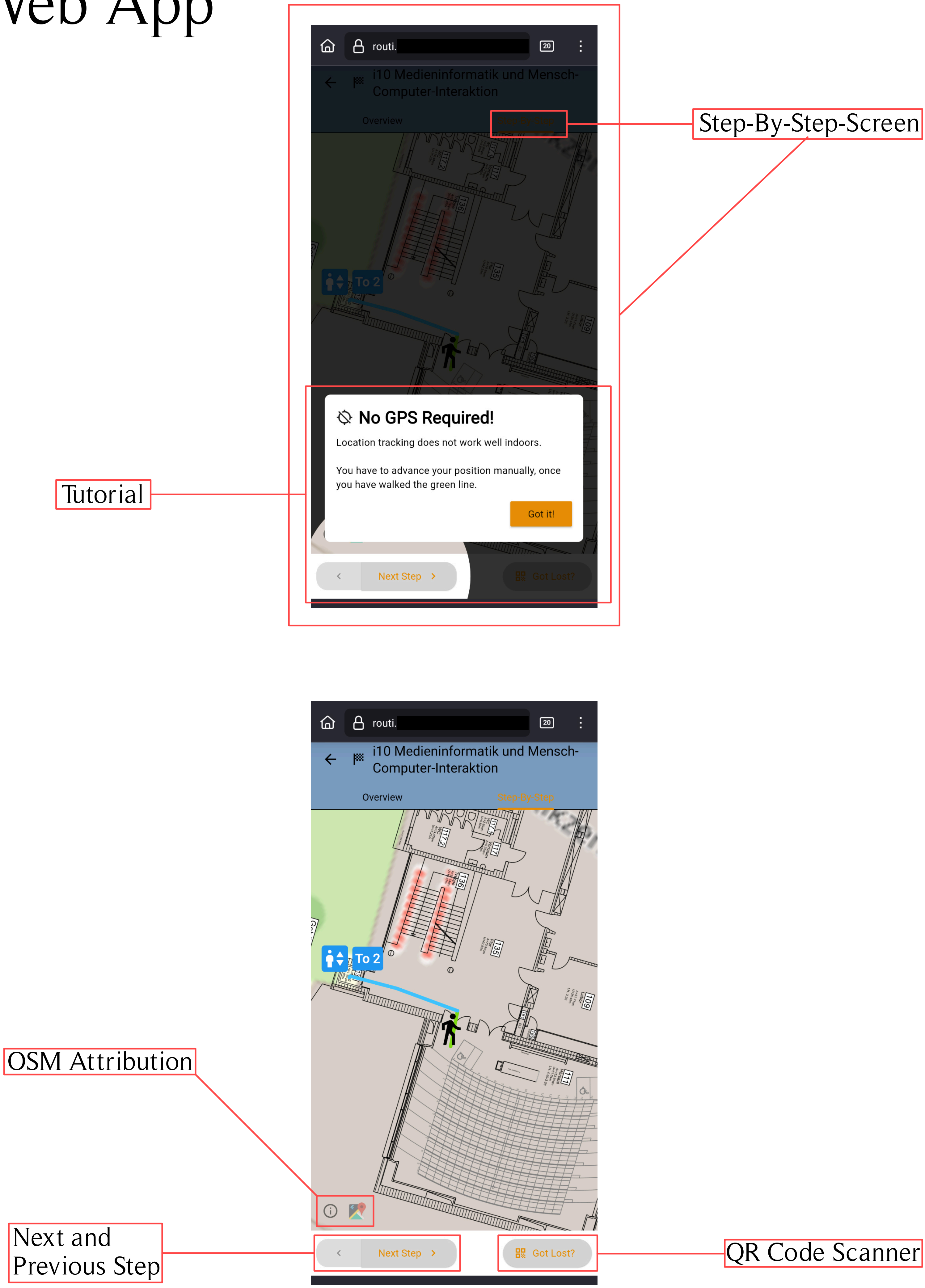
Filtered Search Result: No Room Found
Remove Filter
routi.[redacted]
Start
Cafeteria
Lecture Halls
Seminar Rooms
Chair Secretariats
Routi did not find a Lecture Hall for your query!
Try a Different Query
Scan a QR-Code
Search not just Lecture Halls
Report a Missing Room
Position from QR-Code

# Web App

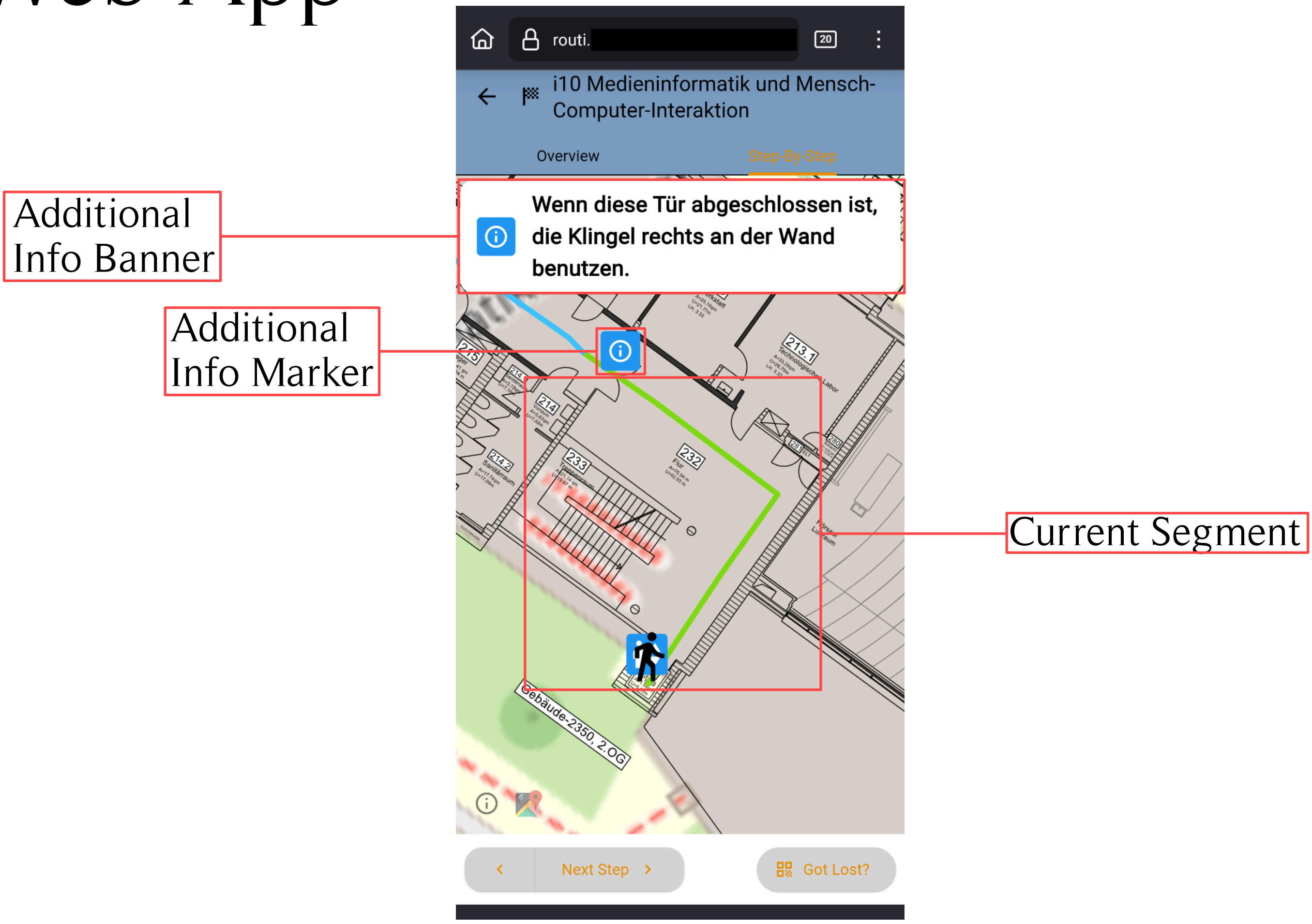

routi.[redacted]
AH II
i10 Medieninformatik und Mensch-Computer-Interaktion
Find Route
Your Last Locations
AH II (2350|111)
Lecture Hall
i10 Medieninformatik und Mensch-Computer-Interaktion
(2350|208)
Chair Secretariat
Last Locations
Position from QR-Code

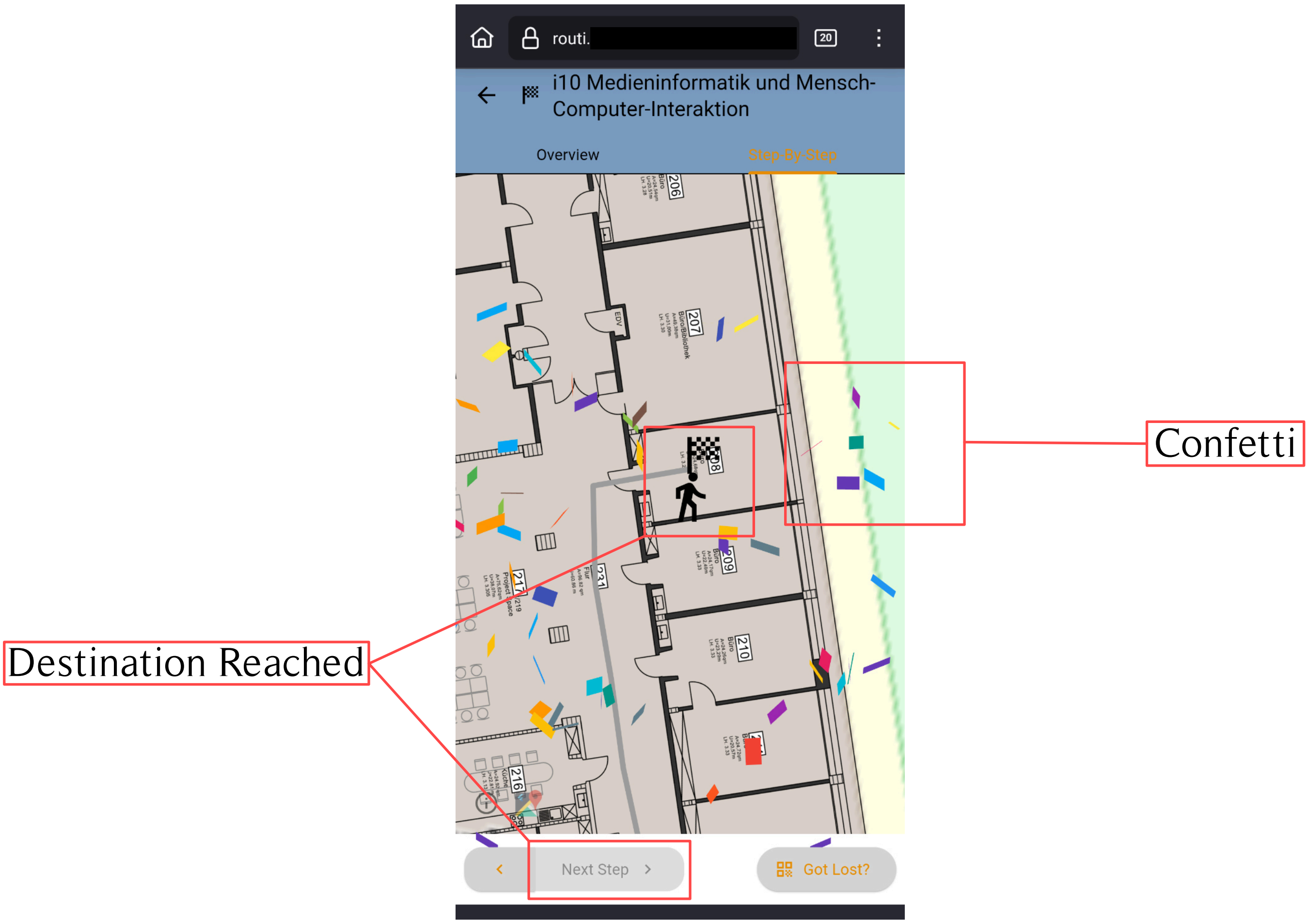

routi.[redacted]
i10 Medieninformatik und Mensch-Computer-Interaktion
Overview
Step-By-Step
Overview Screen
Start Navigation
Current Location
Destination
Informatikzentrum
Floor Change Marker
To 2
Destination: i10 Medieninformatik und Mensch-Computer-Interaktion
- Building Hauptbau
- On the 2nd floor
- Distance 55 m (<1 min)
Start Navigation

# Web App

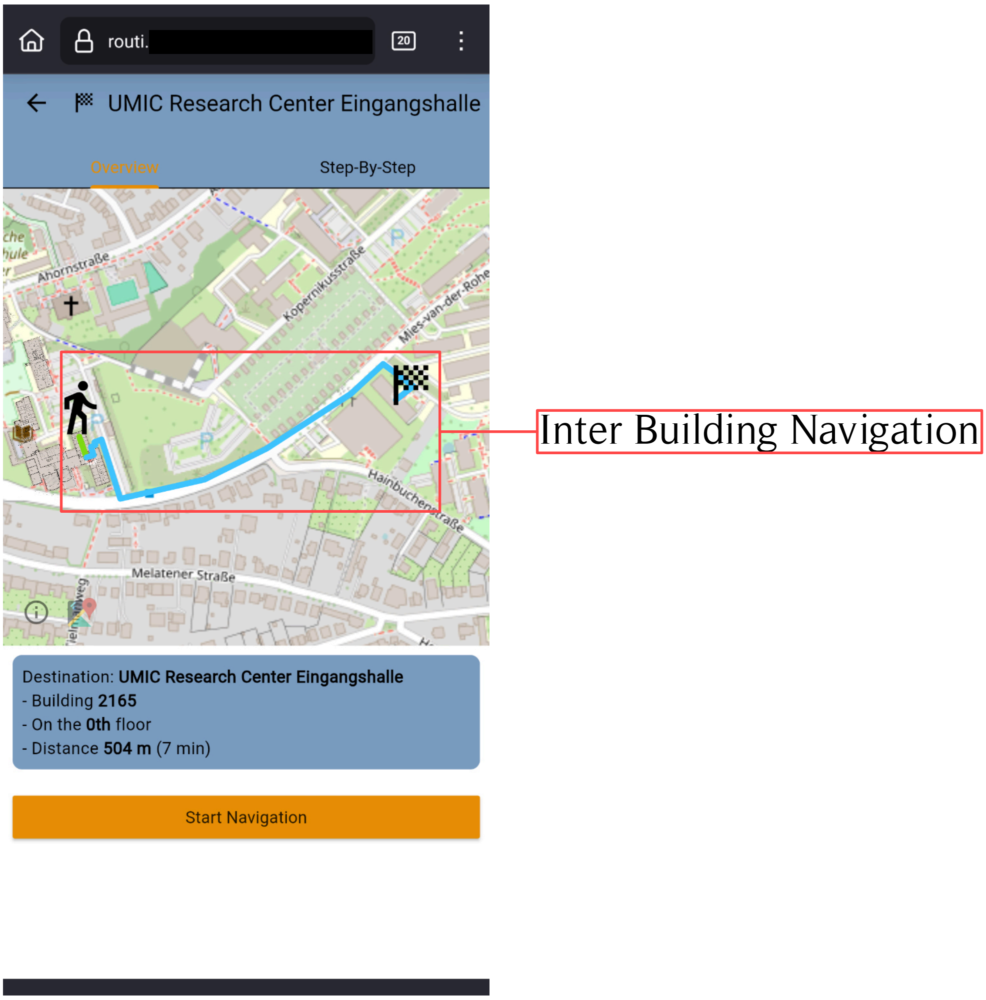

Step-By-Step-Screen
Tutorial
routi.[redacted]
i10 Medieninformatik und Mensch-Computer-Interaktion
Overview
Step-By-Step
To 2
No GPS Required!
Location tracking does not work well indoors.
You have to advance your position manually, once you have walked the green line.
Got it!
Next Step
Got Lost?
OSM Attribution
Next and Previous Step
QR Code Scanner

# Web App


Additional Info Banner
Additional Info Marker
Current Segment
routi.[redacted]
i10 Medieninformatik und Mensch-Computer-Interaktion
Overview
Step-By-Step
Wenn diese Tür abgeschlossen ist, die Klingel rechts an der Wand benutzen.
Gebäude-2350, 2.OG
Next Step
Got Lost?

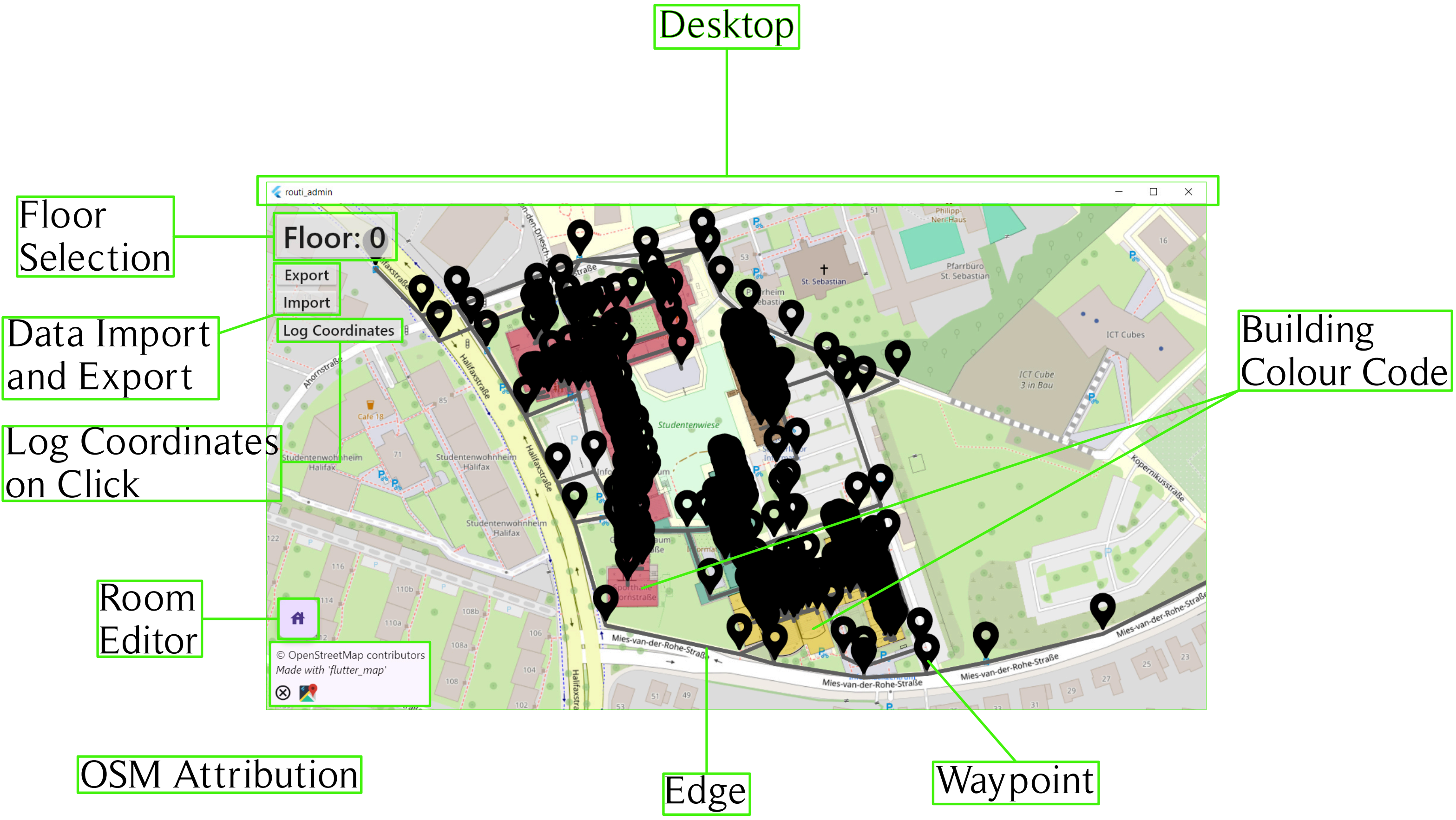

Confetti
Destination Reached
routi.[redacted]
i10 Medieninformatik und Mensch-Computer-Interaktion
Overview
Step-By-Step
Next Step
Got Lost?

# Web App

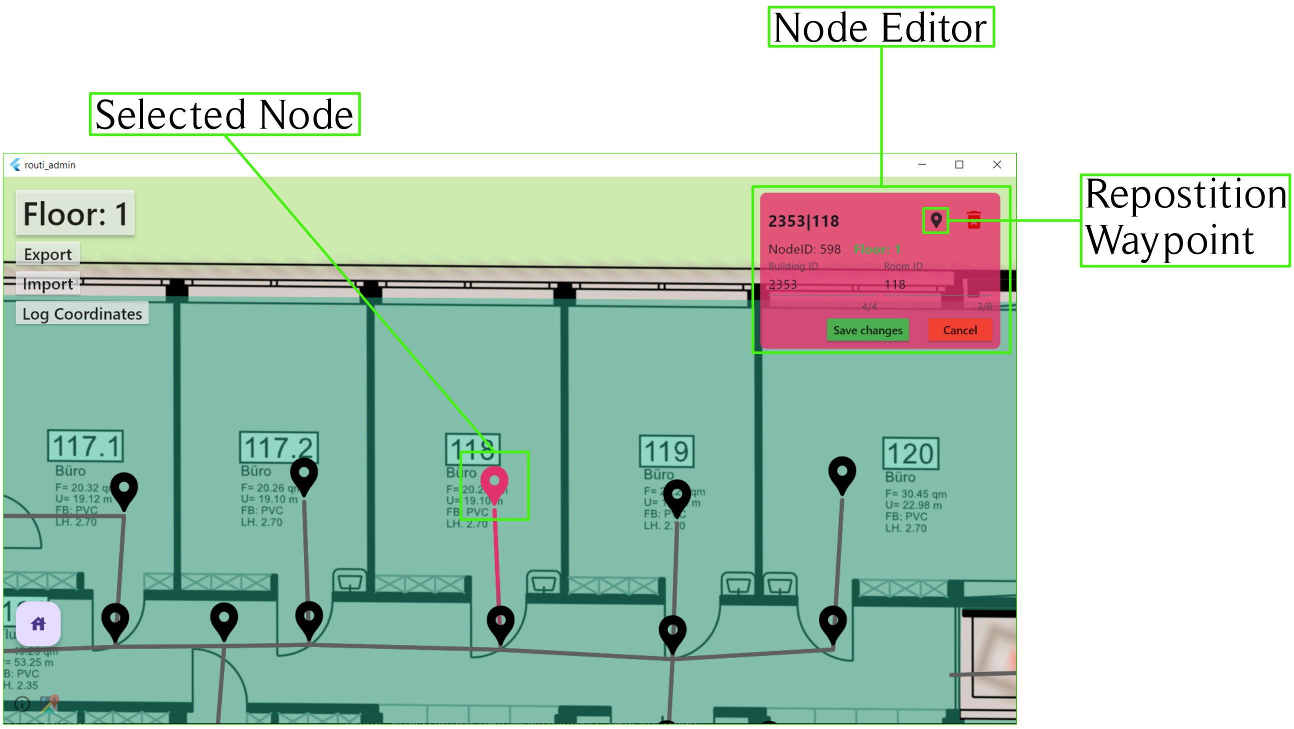


routi.[redacted]
20
UMIC Research Center Eingangshalle
Overview
Step-By-Step
Ahornstraße
Kopernikusstraße
Mies-van-der-Rohe
Hainbuchenstraße
Melatener Straße
Inter Building Navigation
Destination: UMIC Research Center Eingangshalle
- Building 2165
- On the 0th floor
- Distance 504 m (7 min)
Start Navigation

# Admin Tool

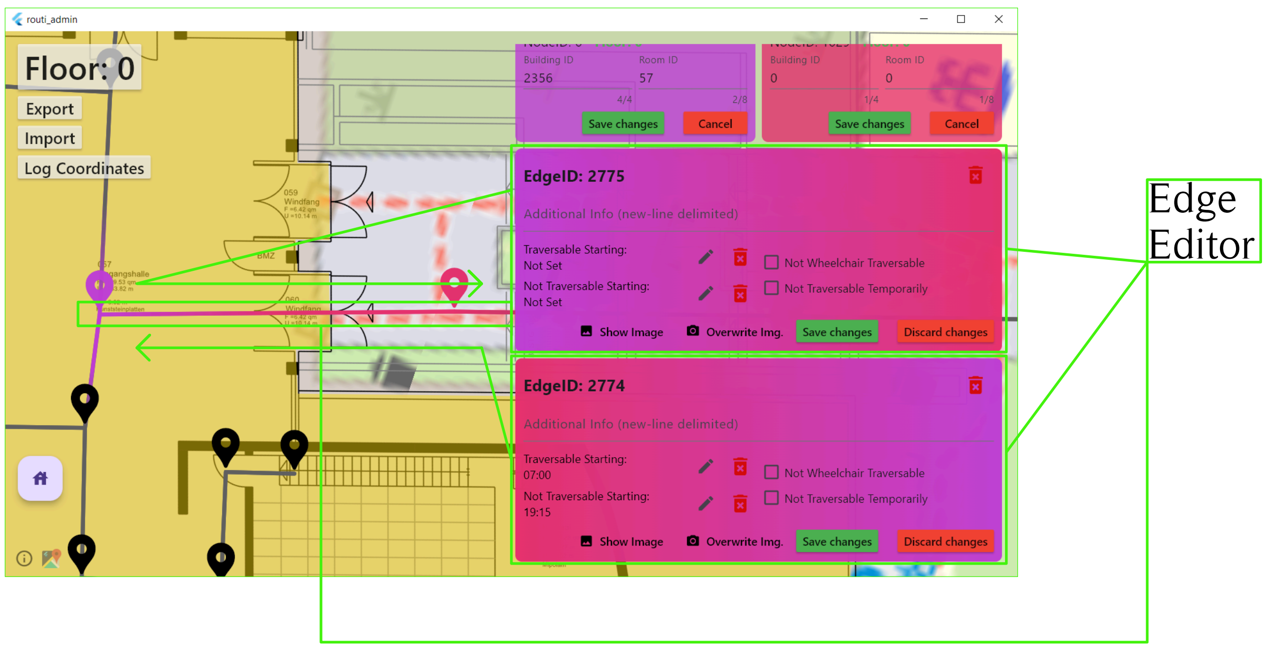

Desktop
routi_admin
Floor Selection
Floor: 0
Export
Import
Log Coordinates
Data Import and Export
Log Coordinates on Click
Building Colour Code
Room Editor
© OpenStreetMap contributors
Made with 'flutter_map'
OSM Attribution
Edge
Waypoint
Mies-van-der-Rohe-Straße
Halifaxstraße
Studentenwiese
Studentenwohnheim Halifax
ICT Cubes
St. Sebastian
Pfarrbüro St. Sebastian
Kopernikusstraße
Ahornstraße

# Admin Tool



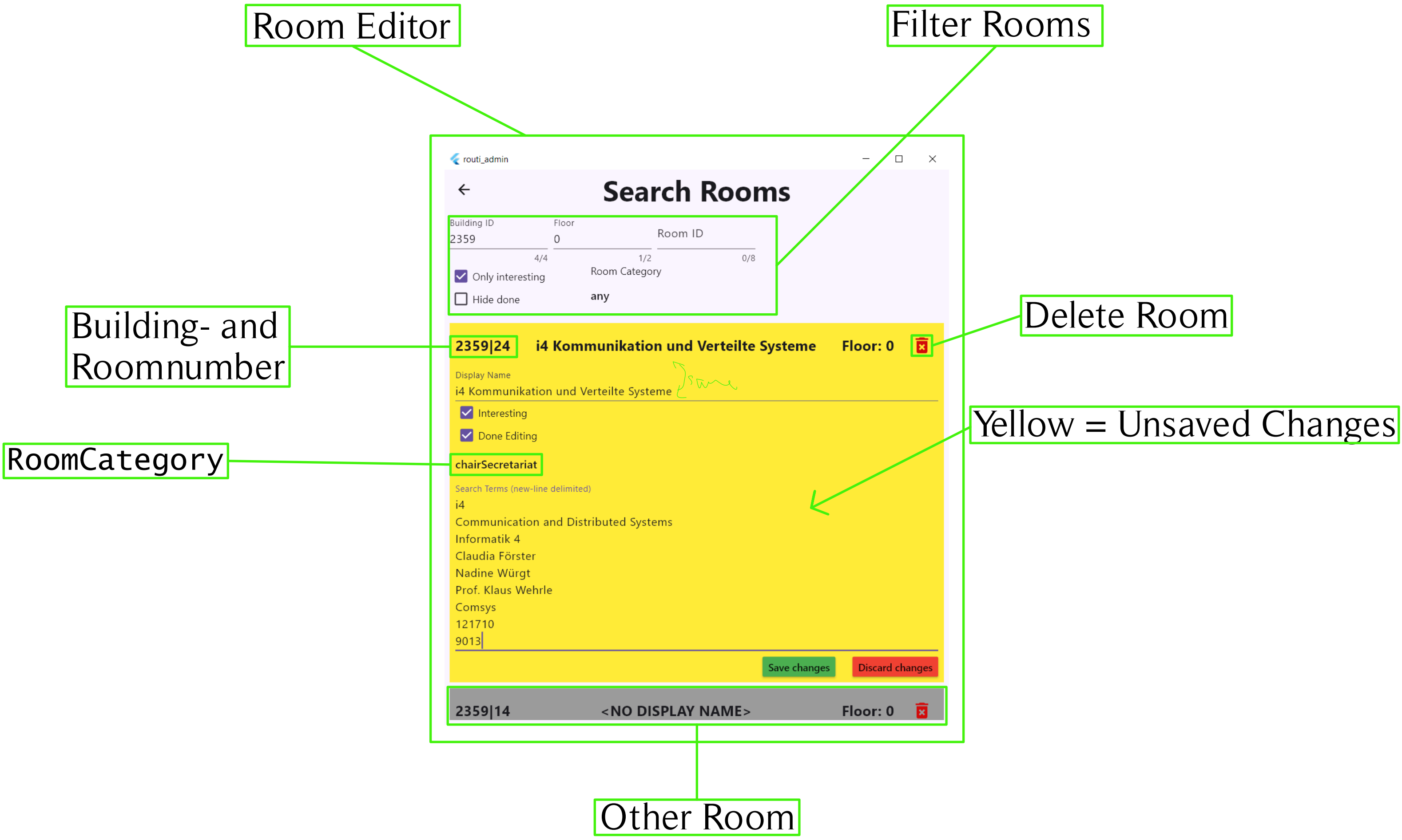
Node Editor
Selected Node
Repostition Waypoint
routi_admin
Floor: 1
Export
Import
Log Coordinates
2353|118
NodeID: 598
Floor: 1
Building ID
Room ID
2353
118
Save changes
Cancel
117.1
117.2
118
119
120

# Admin Tool



routi_admin
Floor: 0
Export
Import
Log Coordinates
Building ID
Room ID
2356
57
Save changes
Cancel
Building ID
Room ID
0
0
Save changes
Cancel
EdgeID: 2775
Additional Info (new-line delimited)
Traversable Starting:
Not Set
Not Traversable Starting:
Not Set
Not Wheelchair Traversable
Not Traversable Temporarily
Show Image
Overwrite Img.
Save changes
Discard changes
EdgeID: 2774
Additional Info (new-line delimited)
Traversable Starting:
07:00
Not Traversable Starting:
19:15
Not Wheelchair Traversable
Not Traversable Temporarily
Show Image
Overwrite Img.
Save changes
Discard changes
Edge Editor

# Admin Tool



Room Editor
Filter Rooms
Building- and Roomnumber
Delete Room
Yellow = Unsaved Changes
RoomCategory
Other Room
routi_admin
Search Rooms
Building ID
2359
Floor
0
Room ID
4/4
1/2
0/8
Only interesting
Hide done
Room Category
any
2359|24
i4 Kommunikation und Verteilte Systeme
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