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Human-Centered Design and Development of a Web-Based Frontend for Safe School Route Planning

Alischa Leona Förster

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der Fakultät für Ingenieurwissenschaften

Human-Centered Design and Development of a Web-Based Frontend for Safe School Route Planning

vorgelegt von
Alischa Leona Förster

betreut und begutachtet von
Prof. Dr.-Ing. Maximilian Altmeyer
Prof. Dr. Markus Esch

Saarbrücken, 11. Oktober 2025

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Saarbrücken, 11. Oktober 2025

Alischa Leona Förster

Abstract

This master's thesis presents the human-centered design and prototype development of a web-based frontend to support safe school route planning. By replacing analog, paper-based processes with digital data collection, structured analysis, and interactive visualization, the system streamlines workflows for municipal planners, parents, and students. The application comprises two components: a mobile survey and route-tracking tool enabling parent–child dyads and mobility experts to document actual school journeys and hazards in real time, and a desktop planning interface allowing municipal staff to review incoming data, visualize route usage and danger reports on an interactive map, and design optimized school route plans. Built with Angular and Leaflet on the frontend and a RESTful Spring Boot/PostGIS backend, the prototype demonstrates significant improvements in efficiency, data accuracy, and stakeholder engagement. Iterative user research—encompassing stakeholder interviews, expert consultations, and focus groups—guided requirement derivation and interface design, ensuring alignment with user needs for simplicity, flexibility, and trust. The work confirms the feasibility of a fully digital, human-centered workflow for school route planning and lays the groundwork for future enhancements, including automated route suggestion, AI-driven risk analysis, and seamless digital plan distribution.

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1 Introduction

1.1 Motivation

Ensuring the safety of children is a challenge, that parents have to face on a daily basis. Numerous potential hazards (such as small objects that can be swallowed, uncovered sockets, or hot stove tops) require constant attention. In the domestic environment, parents can largely control and minimize these risks through preventive measures and appropriate supervision [17].

In public spaces, particularly in road traffic, parents are far less able to actively ensure safety. While awareness and education can strengthen children's perception of risks, external risk factors such as heavily trafficked roads or poorly visible intersections remain. Younger children in particular are often not yet able to correctly assess vehicle speeds or interpret complex traffic situations [37]. Their impulsiveness and desire for movement frequently lead to reckless behavior, such as suddenly crossing a street without a traffic light or crosswalk [37].

The daily journey to school is especially critical in this regard. Many children complete this route without adult supervision. Often during morning and afternoon rush hours, when commuter and drop-off traffic further increases the volume of vehicles. Given these circumstances, it is not surprising that a significant proportion of child-related traffic accidents occur on the way to school [33]. In 2023 alone, the German Social Accident Insurance (DGUV) recorded 92,308 reportable school route accidents, 16 of which were fatal [7].

Ensuring a safe school route is not merely a private matter for individual families but a societal responsibility. It touches upon fundamental issues of equal opportunity and sustainable urban development. Children should have the opportunity to travel to school independently and safely, regardless of place of residence, social background, or parental accompaniment. Child-friendly traffic planning also contributes to the promotion of independence, everyday physical activity, and environmental awareness [39].

An essential aspect of school route safety already begins with the choice of the route itself [35]. Poor visibility, missing safe crossing opportunities, and heavy traffic significantly increase the risk of accidents [23]. Children, however, often prefer the shortest or fastest route rather than the safest one. To support parents and students in selecting the least hazardous school route possible, school route plans represent a valuable tool. These mark recommended routes with safe infrastructure and thus foster risk-aware behavior on the way to school [35].

Web-based applications offer the opportunity to make traditional school route plans more interactive, individualized, and practical for everyday use [13].

1.2 Problem Statement

Currently, there is no nationwide standard in Germany for the creation of school route plans. Each federal state regulates school route planning under its own responsibility, which leads to considerable differences in procedure. In Saarland, the responsibility lies with the individual municipalities, more precisely with the respective town halls. These are in charge of planning the school routes of the schools within their respected areas [11].

A survey of the responsible stakeholders in Saarland has shown that the creation of a school route plan is a time-consuming and highly fragmented process. First, contact with a school must be established. Only if the school is willing to cooperate can the next step take place: the collection of school route data. For this purpose, students are asked to document their daily school route and subjectively perceived danger spots in a questionnaire.

The next step is the evaluation of this data, which represents a particularly high workload. Several hundred questionnaires have to be analyzed manually, a task often carried out by dedicated teachers or parents. The processed results are then forwarded to the responsible town hall, where they are further processed by the administration and finally transferred into an official school route plan.

Since this process consists of many individual steps and depends heavily on cooperation between the school and the administration, usually only few school route plans can be manually created. In particular, manual data collection and analysis represent a central obstacle. The lack of digitization and standardization leads to inefficient workflows and lengthy processes.

The consequences of these problems are far-reaching: planners face high administrative burdens and long processing times. For many schools, this means that they do not receive a school route plan for long periods. This in turn poses a significant safety risk for students. Without a structured and up-to-date analysis of dangerous sections of the route, many potential hazards remain undetected.

The relevance of this problem is therefore high: safe school routes are a central societal concern. Every child should be able to reach school safely, regardless of place of residence or parental accompaniment. School route planning is an essential component of preventive traffic safety work, as it helps to identify potential danger spots at an early stage and prevent accidents. In addition, it contributes to restoring parents' confidence in allowing their children to walk to school independently, promoting both autonomy and physical activity among children.

This thesis deliberately does not claim to replace direct contact with students or qualitative surveys. Rather, the aim is to digitally support and make the existing process more efficient by using digital tools to collect, analyze, and visually present data, by following the Human-Centered Design (HCD) approach.

1.3 Objective of the thesis

The goal of this master's thesis is the HCD and prototype development of a web-based frontend to digitally support school route planning in Saarland. The application is intended to make the previously analog, fragmented, and time-consuming process more efficient and user-friendly through digital means.

The focus is on relieving planners and the schools involved, particularly through digital data collection, structured analysis, and transparent visualization of school route specific data. The development of the accompanying backend will be undertaken in a separate thesis; however, both components are designed for close functional collaboration.

To meet the needs of different user groups, the application is divided into two sections:

1. **Digital survey questionnaire for students and parents** A digital form replaces the previous paper-based survey, allowing students, together with their legal guardians, to document their school routes and record hazards in real time during an actual walk. This increases data accuracy and timeliness and promotes active engagement with one's own route to school.

2. **Analysis and planning tool for planners** This part of the application is used to evaluate the collected data. Planners receive an overview of all active school-route plans and can access an interactive map that visualizes, among other things, the usage frequency of individual route segments, existing traffic features (e.g., speed limits, crossing opportunities), and reported hazards. Additionally, a structured presentation of the submitted questionnaires is provided.

The development is explicitly prototypical in nature. The aim is to demonstrate conceptual and functional viability and to establish a solid foundation for possible further development and productive deployment.

The frontend design and development follow a HCD approach. The primary focus is on the needs, requirements, and contexts of the main user groups (students, parents, mobility experts and municipal planners). The design process is guided by iterative cycles that gather user requirements, develop prototype solutions, and validate them with the target groups. The goal is to achieve high usability and acceptance of the application.

2 Background

In this chapter we establish a common basis for the rest of the thesis. We give an overview of the current state of school route safety in Germany as well as its challenges, examine the fundamentals of HCD principles, and discuss current digital implementations of school route planners. This foundation reveals the need for a more participatory, context-sensitive approach to digital school route planning tools, which will be further discussed in Section 4.

2.1 School Route Safety in Germany: Current State and Challenges

In this Section we give an overview of school route plans and how they are implemented, as well as discuss current challenges in school route safety and relevant statistics. While the focus is on Germany, where this application is deployed, we also include broader national and international perspectives.

2.1.1 Definition and Purpose of School Route Plans

A school route plan is a map outlining recommended paths between home and school, in order to enhance children's safety on their way to school. According to the *BASt* guide-line, a comprehensive school route plan includes a detailed base map showing all relevant infrastructure, such as buildings, roads, sidewalks, crossings. It should also highlight designated safe routes for walking and cycling based on traffic conditions [5].

It is best to develop each school route plan in collaboration with the students and parents of that particular school, since they have the most insight into local conditions and needs. In addition, conducting on-site inspections of the streets, crossings, and pathways around the school is highly recommended, because purely map-based reviews can overlook hidden hazards [5].

There is no one-size-fits-all format for a school route plan; each must be tailored to the specific school and its surroundings. Because traffic conditions, street layouts, and local hazards vary from one neighborhood to another, planners must adapt their maps and recommendations to address the unique challenges and needs of each school community. Continuous collaboration with students, parents, and on-site observations ensures that every plan reflects the realities of the area and maximizes the safety of the routes [5].

The primary purpose of a school route plan, according to the *BASt* guide-line, is to:

- Identify the safest available routes by analyzing accident data, traffic volumes, and environmental factors.

- Mark suitable crossing locations equipped with pedestrian infrastructure (e.g., crosswalks, signals) to minimize exposure to hazards.
- Provide clear, age-appropriate guidance on which side of the street to use and which intersections to avoid or approach with caution.
- Educate children and parents about common risks and safe behaviors through supplementary legends and annotations.

These plans serve not only as navigational aids but also as educational tools, through hazard awareness and encouraging safe travel habits among school-age children.

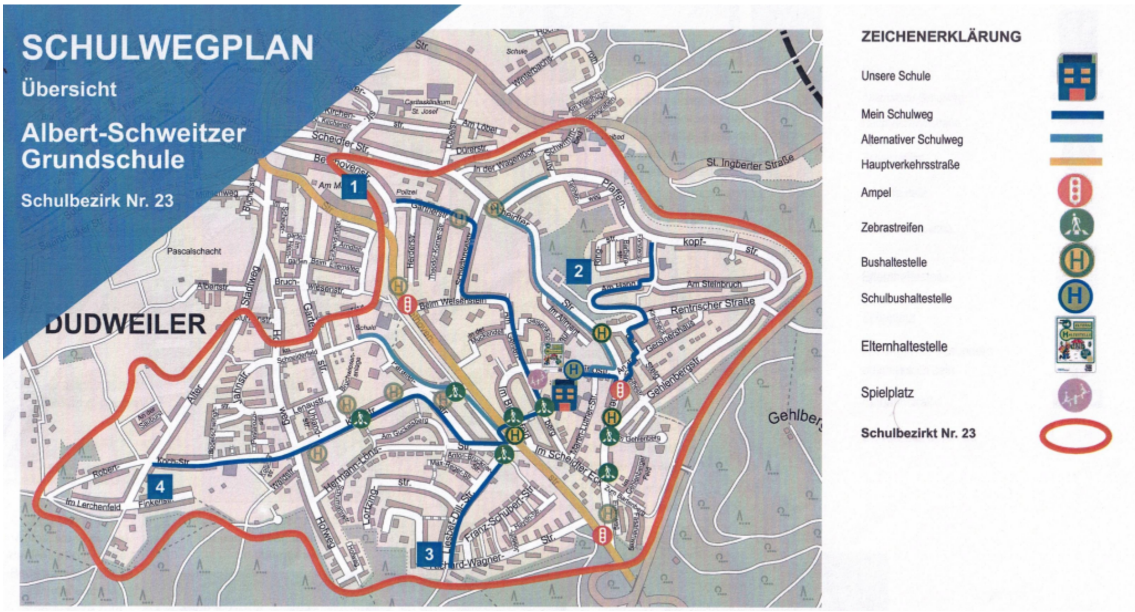

Figure 2.1: Example of a traditional school route plan from Albert-Schweitzer Primary School, Saarbrücken [20].

Figure 2.1 shows a school route plan from *Albert-Schweitzer Grundschule* in Saarbrücken, provided by the Landeshauptstadt Saarbrücken [20]. The map outlines School District No. 23 and highlights four primary safe walking routes in dark blue, alongside several alternative routes in light blue, all converging on the school. Key traffic infrastructure is marked using standardized symbols: traffic lights, zebra crossings, and bus stops. This traditional, static representation clearly communicates navigational guidance and critical safety features to students, parents, and planners.

Different variants of school route plans address distinct user groups and transportation modes. **Pedestrian plans** focus on young children's walking routes, while **cycling plans** incorporate wider lane assessments and suitable bike infrastructure. Some plans integrate public transport stops and schedules to accommodate multi-modal commutes, creating a comprehensive mobility concept for older students [5].

To develop an effective plan, practitioners first compile a base map and perform an analysis, drawing on local traffic accident reports and field assessments. The guideline emphasizes participatory on-site inspections with children and guardians to validate route safety and identify site-specific concerns not evident in quantitative data.

2.1.2 Process for Developing a School Route Plan

According to the *BASt* guideline, the development of a school route plan follows a structured, four-phase process, concluding with an optional evaluation phase [5]:

1. **Initiation Phase** Establish a working group composed of key stakeholders (school staff, parents, traffic authorities, and local experts). Define project goals, roles, and responsibilities, and agree on a timeline and resources.

2. **Survey and Analysis Phase** Conduct comprehensive data collection and analysis. Methods include:

   - Surveys of students and parents on mobility behavior and route concerns

   - Analysis of local accident records and traffic volumes

   - On-site inspections of school routes using standardized checklists to identify deficiencies in infrastructure or signage

3. **Implementation Phase** Create the school route plan by mapping recommended paths on the base map and annotating with safety tips, crossing recommendations, and hazard warnings. The guideline provides instructions for using freely available software to produce high-quality plans without additional costs.

4. **Evaluation Phase (Optional)** Assess the effectiveness of the school route plan against the initial objectives. This may involve follow-up surveys, observation of route usage, and analysis of any changes in incident rates.

It is most effective to develop a school route plan through close co-creation with local stakeholders. Their first-hand knowledge of the neighborhood holds important insights, such as precise geographic landmarks, known trouble spots, heavily trafficked streets, and hazardous crossings, that must inform every stage of the planning process. By integrating these perspectives, the resulting route plan is grounded in real conditions and tailored to the specific safety needs of the school community [4].

2.1.2.1 Challenges

There are several challenges inherent in producing paper-based school route plans. First, coordinating the many stakeholders (teachers, parents, local authorities, and safety experts) requires significant time and effort. Our research revealed that data collection and analysis are carried out by different teams, complicating coordination and extending project timelines. As a result, the number of school route plans is limited and might fall short of community needs.

2.1.3 Legislative Framework and Responsibilities

In Germany, responsibility for school route safety lies with the individual federal states rather than with the country [11]. Consequently, each state has adopted its own regulations and recommendations. Table 2.1 summarizes the status of school route planning across all sixteen states.

In total, four states mandate the creation of formal school route plans (*Hessen, Nordrhein-Westfalen, Schleswig-Holstein, Thüringen*), four states issue non-binding recommendations (*Mecklenburg-Vorpommern, Rheinland-Pfalz, Saarland, Sachsen*), and eight states have no specific provisions in place (*Baden-Württemberg, Bayern, Berlin, Hamburg, Sachsen-Anhalt, Brandenburg, Bremen, Niedersachsen*). Despite evidence that well-designed school route plans reduce pedestrian accidents [7, 33], only four states enforce mandatory implementation [11]. Potential barriers include the absence of uniform federal guidelines, ambiguous procedural responsibilities, and administrative inertia.

This creates challenges for developing consistent, nationwide solutions and highlights the need for adaptable approaches that can work within diverse legal and administrative contexts.

Table 2.1: Legal provisions for school route safety and planning across German states

State	Status	Regulation	Authority	Ref.
Baden-Württemberg	Mandatory	Decree 2024/25	Municipalities + Schools	[22]
Bayern	Recommended	Verwaltungsvorschrift (VwV) 2005	Municipalities + Police	[2]
Berlin	Recommended	Joint guidelines with Brandenburg	Senate for Education + Districts	[25]
Brandenburg	Recommended	Guidance manual 2016	Brandenburg Road Safety Network	[25]
Bremen	None	—	—	[11]
Hamburg	None	—	—	[11]
Hessen	Mandatory	VwV 2003	School management + Traffic auth.	[14]
Mecklenburg-Vorp.	None	—	—	[11]
Niedersachsen	Recommended	State Traffic Watch guidance	Schools + State Traffic Watch	[11]
Nordrhein-Westfalen	Partial	School street decree 2023	Municipalities	[19]
Rheinland-Pfalz	None	—	—	[11]
Saarland	Recommended	—	—	[11]
Sachsen	Recommended	VwV 2025	Traffic auth. + School boards	[34]
Sachsen-Anhalt	None	—	—	[11]
Schleswig-Holstein	Mandatory until 2013, now recommended	VwV 2013	School management + Police	[21]
Thüringen	Recommended	Safety programme 2030	Schools + Traffic offices + Police	[36]

2.1.4 Statistical Evidence of Safety Issues

In Germany, a considerable number of children experienced injuries or fatalities related to road traffic in recent years. In 2024 alone, approximately 86,687 children were either injured or killed in traffic accidents, averaging roughly one child every 10 minutes [32]. This statistic underscores the persistent safety risks faced by young pedestrians and cyclists during their journeys to and from school.

Figure 2.2 illustrates the annual reported number of school route accidents across Germany from 2014 to 2024. The data reveal fluctuations over the decade, with a slight decline starting in 2020. This reduction may be attributable to the COVID-19 pandemic, during which schools were periodically closed and international travel restrictions significantly reduced overall mobility patterns [1]. The numbers remained lower in 2024 than before the pandemic. Possible contributing factors include increased parental decisions to transport their children by car or changes in commuting behavior following pandemic-related mobility shifts [29]. Unfortunately, no comprehensive study was found to definitively support these hypotheses.

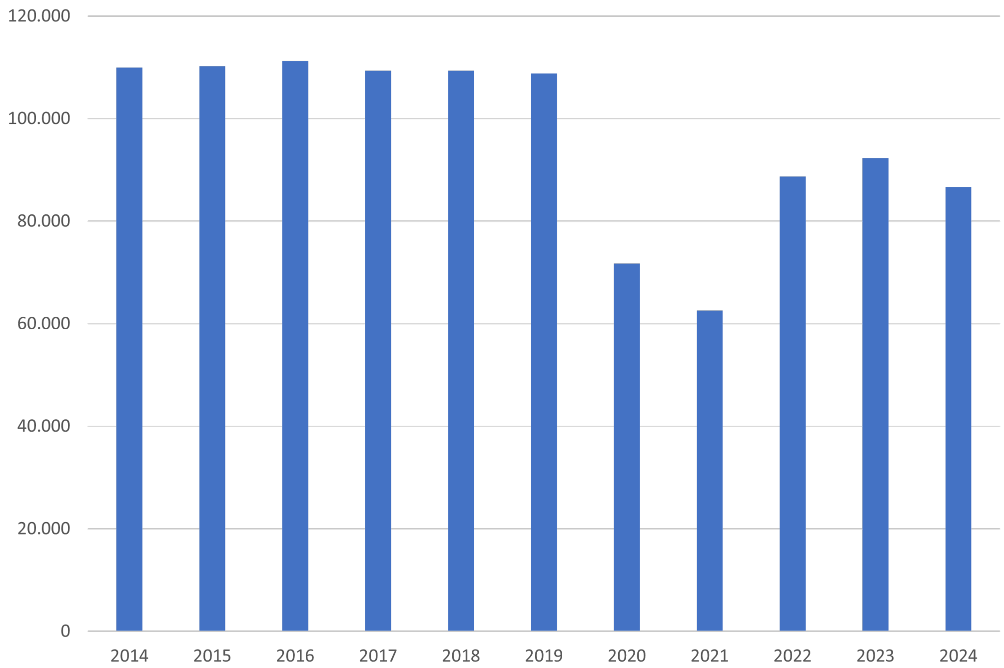

Figure 2.2: Number of reported school route accidents in Germany between 2014 and 2024

Age-related vulnerability patterns emerge distinctly from the statistical evidence. Children aged 6-10 represent the highest-risk demographic for pedestrian incidents, with developmental factors significantly impacting their ability to navigate traffic safely [37]. Research indicates that only approximately 10% of five-year-olds can independently plan a safe route to school, improving to over 70% following targeted safety interventions. This places traffic-trained five-year olds at the same level of competence as untrained nine-year olds [35].

Temporal analysis reveals that school-related accidents cluster around specific time periods corresponding to commuting patterns. The *Statistisches Bundesamt* reports distinct peaks between 07:00-08:00 hours (accounting for 13% of daily incidents) and 15:00-17:00 hours (18% combined) on weekdays [33]. This temporal concentration aligns directly with typical school start and dismissal times across German educational institutions.

Modal analysis of accident causation identifies pedestrian crossings as the primary risk scenario. Traffic incident reports indicate that 48% of school route accidents involve children crossing streets without adequate observation of traffic conditions, while 26% result from sudden emergence into roadways [5]. These behavioral patterns reflect developmental limitations in hazard perception and traffic judgment among school-age children.

The *parent taxi* (private vehicle trips to school) phenomenon has introduced additional complexity to school route safety dynamics. Contemporary data suggests that over 40% of primary school children are transported to school by private vehicle [29], contributing to increased congestion around educational facilities and creating additional hazardous interactions between pedestrian and vehicular traffic during peak arrival and departure periods.

International comparative analysis positions Germany favorably within European context despite persistent challenges. The European Transport Safety Council's PIN Flash Report indicates Germany maintains one of the lowest child road fatality rates in the European Union, with 7 deaths per million child population compared to the EU average of 14 [10]. However, this relative success should not obscure the continuing need for systematic safety improvements.

The persistence of these safety challenges, combined with changing mobility patterns, demonstrates the ongoing need for innovative approaches to school route planning that can adapt to evolving circumstances and engage multiple stakeholders in safety improvement efforts.

2.1.5 Analysis of School Route Plans in Germany

The most comprehensive analysis of school route plans in Germany was conducted by Gerlach et al. in 2007. Their study provides valuable insights that are particularly relevant for the development of a school route planning system targeted at the German context. The authors performed an extensive nationwide investigation involving multiple stakeholders, including State Ministries responsible for culture, interior, and traffic. A stratified random sample of 1,178 councils was generated, yielding analyzable responses from 377 councils and 1,646 schools. Within this context, 622 school route maps (referred to as *Schulwegpläne* or school route maps) were collected, systematically classified, and evaluated. Further qualitative analyses entailed interviews with urban administrations, schools, and the police, as well as on-site inspections of 26 selected plans. Parents from 16 schools were surveyed to capture use, importance, and valuation of the route plans [12].

Key Findings Gerlach et al. stress the critical importance of **flexibility** in school route plans, arguing that safety challenges are highly localized and cannot be universally standardized. The authors highlight various location-dependent factors influencing school route requirements, including urban versus rural context, population density, traffic volume, topographical features such as hills or flat terrain, and infrastructure characteristics. These contextual differences necessitate on-site route inspections to ensure plan accuracy and effectiveness.

Moreover, the study places strong emphasis on the **involvement of parents and children** in the planning process, as their perspectives and knowledge of habitual routes significantly improve plan relevance and acceptance.

The analysis identified several persistent deficiencies in route recommendations commonly observed across plans:

- Excessively high permitted and actual vehicle speed limits along recommended routes,

- Insufficient lines of sight that impair pedestrian and driver visibility,
- Routes featuring inefficient and overly long detours that reduce parental and student acceptance.

These shortcomings jeopardize the intended safety improvements. Accordingly, the authors argue that route plans should be accompanied by practical guidelines for **practicing the route** with children to reinforce safe behaviors.

A notable outcome of the project was a **step-by-step guide** for producing school route plans, offering a standardized yet adaptable methodology for practitioners. The guide incorporates practical checklists and suggests incorporating photographic documentation of hazardous locations, further enhancing plan utility [12].

Contemporary Relevance While conducted in 2007, the findings from Gerlach et al. remain highly pertinent, given that structural issues associated with local variability, stakeholder engagement, and common planning errors are enduring challenges in school route safety. Modern applications for school route planning in Germany would benefit considerably from embracing these principles by:

1. Allowing customizable, locally adaptable routes based on up-to-date inspections and community input,
2. Enabling active participation of parents, students, schools, and municipal authorities in plan development and feedback,
3. Embedding mechanisms to identify and warn of typical problem areas such as high-speed corridors or poor visibility zones,
4. Including educational and practice-oriented features to facilitate safe route familiarization.

Therefore, Gerlach et al.'s empirical foundations offer a scientifically grounded and practical framework for enhancing school route safety planning in Germany, which modern systems should incorporate to address known limitations effectively [12].

2.1.6 Contemporary Challenges Concerning School Route Safety in General

Contemporary efforts to improve school route safety in Germany face several interrelated challenges despite clear evidence of risk and existing guidelines.

First, the increasing prevalence of *parent taxis* has increased congestion and conflict at school entrances. Parent taxis receive minimal approval among parents: the vast majority evaluate them negatively, even a substantial proportion of those who routinely chauffeur their own children to school. In total, 59% of parents report that parent taxis provoke hazardous traffic situations ADAC2025. This shift toward passive transport undermines active mobility strategies and reduces opportunities for children to develop road-crossing competencies.

Second, digitization of school route planning remains uneven across municipalities. Although web-based tools exist many local authorities lack the technical capacity or resources to implement them effectively [12].

Third, coordination between stakeholders continues to be fragmented. Traffic authorities, school administrations, parent councils, and local police often operate in silos, leading to duplication of effort and inconsistent safety standards.

Finally, demographic and spatial changes (e.g. urban sprawl and shifting school catchment areas) have introduced new complexities. These trends highlight the need for dynamic, data-driven planning processes that can adapt to evolving urban forms and travel behaviors.

Addressing these challenges requires a HCD approach that leverages digital tools, fosters stakeholder collaboration, and actively promotes safe, sustainable mobility options for school-age children.

These contemporary challenges provide important context for understanding how current approaches may fall short and why alternative methodologies warrant exploration.

2.1.7 International Research Perspectives

Comparative research highlights both common and divergent approaches to school route safety across different countries. A bibliometric analysis of 1,546 publications from 2000 to 2023 reveals that North America and Europe account for over 75% of peer-reviewed studies, with an increasing emphasis on digital and participatory planning tools in the last decade [23].

These international findings underscore the importance of combining infrastructural improvements, targeted education, and community participation in school route planning. They also highlight that context-specific factors (such as urban form, resource availability, and cultural attitudes toward child mobility) must inform HCD processes for maximum effectiveness.

The global emphasis on participatory approaches provides valuable precedent for developing more engaging, community-driven solutions in the German context.

2.2 Fundamentals of Human-Centered Design

Given the complex nature of school route safety challenges identified above, traditional top-down planning approaches may prove insufficient. HCD offers a methodological framework specifically designed to address complex problems involving diverse users, contexts, and organizational structures.

2.2.1 Theoretical Foundation and Definition

> "**Human-centered design** is an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques."
> — ISO 9241-210:2010, *Ergonomics of human–system interaction — Part 210: Human-centred design for interactive systems*

> "**Interactive system** [is a] combination of hardware and/or software and/or services and/or people that users interact with in order to achieve specific goals."
> — ISO 9241-210:2010, *Ergonomics of human–system interaction — Part 210: Human-centred design for interactive systems*

HCD is an iterative approach that positions users and their contexts at the heart of design. The first quote defines the philosophy of HCD: prioritizing usability by integrating ergonomic principles and usability methods into each stage of development. The second quote clarifies the scope of HCD's target—any interactive system, whether software, hardware, services, or people-driven interfaces.

Originating in the 1980s from cognitive psychology and ergonomics, HCD counters technology centered models by ensuring that design decisions are driven by actual user needs, behaviours, and environmental contexts [9, 27].

Throughout the process, designers and stakeholders co-create prototypes, conduct usability evaluations, and refine solutions in repeated cycles. This is done in order to ensure that the final system effectively supports users' goals and satisfies their requirements [15].

Although engaging in iterative collaboration with stakeholders introduces additional effort and cost, this approach aligns the final deliverable more closely with user needs, resulting in a higher-quality outcome and greater user satisfaction [3].

2.2.2 Principles of Human-Centered Design

The ISO 9241-210 standard defines six core principles that must guide any HCD process, regardless of the specific methodology:

a) **Design based on explicit understanding of users, tasks and environments.** A thorough analysis of user characteristics, goals, tasks and contexts is essential to derive valid requirements and avoid failures caused by incorrect assumptions.

b) **Users involved throughout design and development.** Engaging representative users in co-creation workshops, interviews, prototyping sessions and usability tests ensures that real needs drive every stage.

c) **Design driven and refined by user-centred evaluation.** Iterative usability and field evaluations with real users validate designs against real-world scenarios, uncover hidden requirements and reduce the risk of post-deployment rework.

d) **Process is iterative.** Repeated cycles of prototyping, evaluation and refinement progressively reduce uncertainty and align the system with evolving user insights.

e) **Design addresses the whole user experience.** Beyond functional usability, the design must consider emotional, social and contextual factors—such as satisfaction, comfort, branding, help/support services and long-term adoption.

f) **Multidisciplinary design team.** Combining expertise in human factors, domain knowledge, technical development, visual design, business analysis and user support fosters creative trade-offs and shared understanding of constraints.

All six principles apply to every stage of system development and can be integrated into existing processes to ensure that the final product truly meets user needs.

2.2.3 Planning Human-Centered Design

Effective integration of HCD requires deliberate planning and resourcing at every stage of the product. This includes initial concept and requirements analysis through design, implementation, testing and maintenance. Project leads must assess the relevance of human factors by examining how usability relates to the product's purpose, user population and operational context (for example, safety or accessibility concerns), as well as the potential risks of poor usability (financial loss, safety hazards or market rejection) and the constraints of the development environment (timeline, budget, technologies and contractual arrangements) [9].

A comprehensive HCD plan should identify the methods and resources for each activity (contextual inquiry, persona workshops, prototyping, usability testing and evaluation), define procedures for integrating HCD outputs with other development tasks, and assign clear roles and responsibilities to team members with the necessary multidisciplinary skills. It must also establish feedback loops and communication channels between HCD practitioners and other stakeholders, document trade-off decisions, and set milestones and timescales that allow for iterative design and user feedback.

Embedding the HCD plan into the overall project schedule and governance—subjecting it to the same change control, risk management and review processes as other key activities—ensures that usability considerations are neither overlooked nor deprioritized. Allocating sufficient time and budget for iterative prototyping, stakeholder workshops and usability evaluations up front reduces the likelihood of costly redesigns later and guarantees that the final system aligns with real user needs and delivers a satisfying experience [15].

2.2.4 Reasons for adopting Human-Centered Design

Systems designed using HCD methods improve quality, for example, by:

- Increasing the **productivity** of users and the operational efficiency of organizations;
- Being **easier to understand and use**, thus reducing learning and training costs;

- Increasing **accessibility** and usability for people with a wider range of capabilities;
- Enhancing overall user experience through intuitive interfaces and interactions;
- Reducing user **discomfort and stress** during operation;
- Providing a **competitive advantage** through differentiation in the marketplace;
- Contributing towards **sustainability objectives** by minimizing resource waste and supporting long-term user satisfaction.

Although the initial investment in iterative stakeholder engagement may appear to increase project costs, the long-term advantages (meeting user needs, fostering confidence and satisfaction, and ensuring product longevity) far outweigh those upfront expenses [3].

By applying an HCD approach, long-term costs can be reduced, since a well-designed system can command a premium price, incur lower support expenses, and minimize health-related risks [9].

2.2.5 Human-Centered Design Activities

In a HCD process, four core activities are executed in a continuous, overlapping cycle. Each activity informs and refines the others, ensuring that insights from usability tests, stakeholder feedback, and environmental observations feed back into design and requirements. Common challenges include managing a wide range of stakeholder perspectives, reconciling evolving or conflicting requirements, and addressing a diverse set of usage contexts that may vary in user characteristics, physical environments, and organizational constraints [9].

2.2.5.1 Activity 1: Context Exploration.

Establish a deep understanding of the people, environment, and tasks:

- User and stakeholder analysis: Document user roles, skills, motivations, and pain points.
- Task mapping: Break down primary workflows into goals, steps, frequency, and performance challenges.
- Environmental scan: Assess physical, technical, social, and organizational conditions that influence interaction.

2.2.5.2 Activity 2: Requirements Definition.

Translate insights into clear, testable specifications:

- Functional needs: Describe what the system must enable users to do, using measurable criteria.

- Quality attributes: Specify performance, accessibility, and ergonomic benchmarks.
- Constraints: Capture business rules, regulatory mandates, and technical limitations.

2.2.5.3 Activity 3: Conceptual Design.

Generate and iterate on solution ideas:

- Interaction frameworks: Define user–system roles, navigation logic, and interface patterns.
- Wireframes and mock-ups: Create low-fidelity sketches and progressively refined prototypes.
- Design rationale: Record key decisions, trade-offs, and alignment with user requirements.

2.2.5.4 Activity 4: Evaluation and Refinement.

Validate and evolve the design through user feedback:

- Usability sessions: Conduct task-based tests to measure efficiency, effectiveness, and satisfaction.
- Expert reviews: Apply heuristic checks and accessibility audits to identify potential issues.
- Iteration cycles: Incorporate findings into updated prototypes and repeat evaluations until requirements are met.

Figure 2.3 shows the interdependence of HCD activities [9]. Throughout the development of our prototype these activities were executed iteratively.

2.3 Current Digital Approaches to School Route Planning

Having established the challenges facing school route safety in Germany and the theoretical foundation of HCD, we now examine how existing digital solutions address these challenges and where opportunities for human-centered innovation may exist. As mentioned, most current solutions to create school route plans are paper based. These will not be taken into consideration here.

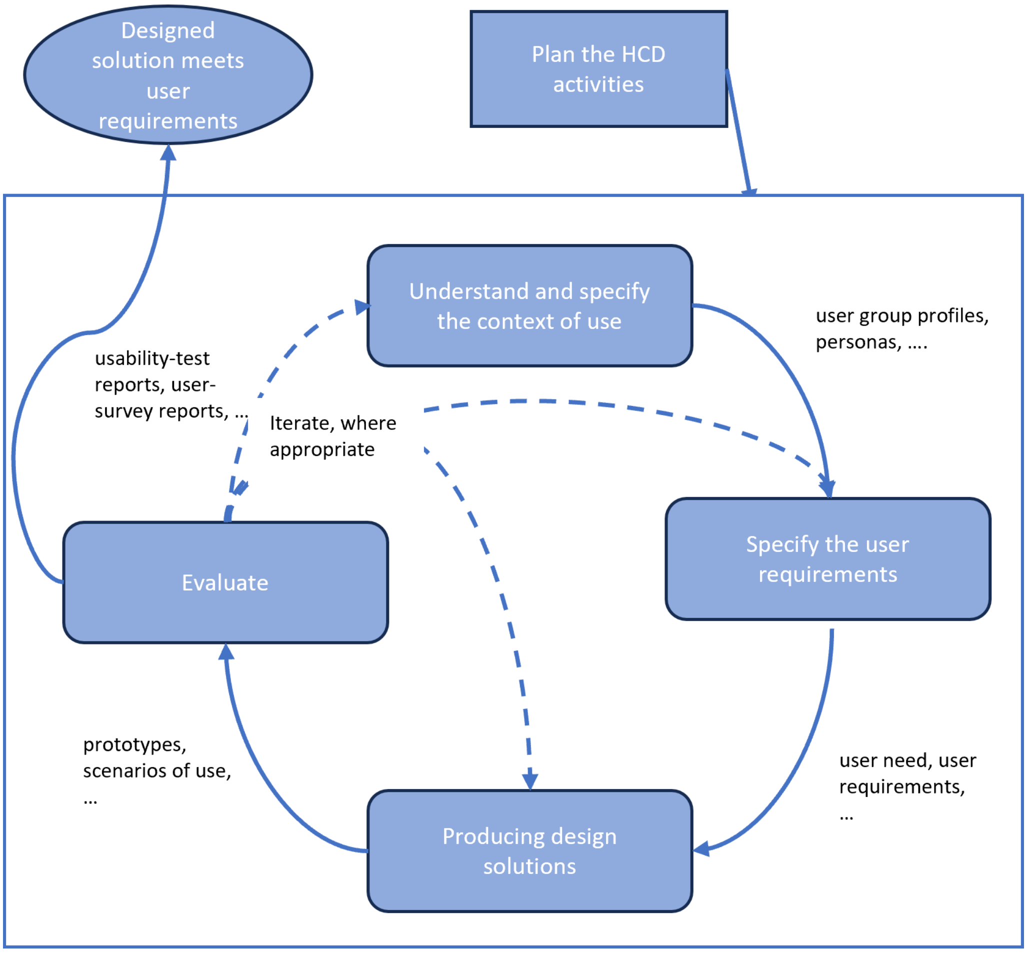

Figure 2.3: HCD activities in the development process of the project

2.3.1 Existing Technical Solutions

Two major digital solutions currently support school route planning in Germany. The first is **schulwege.de**, an interactive platform based on nationwide accident and hazard data, developed in partnership with research institutions [30]. Users input start and destination, and the tool calculates the safest route by factoring in detailed accident records, vehicle data, and crowd-sourced hazard reports. The algorithm assigns a safety score to each segment, and users can adjust their risk tolerance. Notably, children and parents can report hazardous locations, making the hazard map both current and adaptive. Additionally, schools and municipalities can embed the hazard map on their own websites, and access complementary planning tools for proactive safety work.

The second tool is **schulwege-bw**, an online platform designed for Baden-Württemberg. This system allows families to record their routes digitally, relying on municipal recommendations and locally contributed data. Live route assessments ("walk audits") are optional, and children mostly document their daily journeys online.

2.3.2 Limitations of Current Approaches

Schulwege.de stands out for its comprehensive data integration and participatory hazard reporting, but its safety recommendations are data-driven aids and final route selection remains the parents' responsibility [30]. There is no formal expert review or liability for route safety outcomes; instead, the platform serves as a decision-support system, not a legally binding recommendation. In addition, the accuracy of hazard scoring relies heavily on user participation and reporting, which may vary by region or school engagement.

Schulwege-bw, meanwhile, is restricted to Baden-Württemberg and does not offer national coverage. The process of real-world route audits is not mandatory, potentially omitting critical on-the-ground safety insights. The emphasis on digital submissions may exclude children with limited digital access or families less engaged with online platforms [12].

2.3.3 Opportunities for Human-Centered Innovation

There is substantial potential to enhance digital school route planning by deepening the participatory and contextual aspects. Integrating systematic expert reviews and clear protocols for formal liability would improve trust in digital recommendations. National expansion, multi-lingual access, and adaptive interfaces for different age groups and abilities would increase inclusivity and uptake.

Further, embedding human-centered methods such as facilitated "walk audits," co-design workshops with parents, children, and stakeholders, and feedback channels for continuous hazard reporting could improve route relevance and safety. Platforms should support hybrid approaches, combining real-world experience and digital mapping. This would ensure technology serves as an effective complement to lived experience and community engagement.

This would ensure technology serves as an effective complement to lived experience and community engagement, addressing the participatory gaps identified in current approaches while building on their technological foundations.

2.4 Synthesis: Toward Human-Centered School Route Planning

The analysis in this chapter highlights the necessity for a HCD digital school route planner. Traditional paper-based approaches demand labor-intensive data review and stakeholder coordination, resulting in slow turnaround and inconsistent quality. A digital tool would streamline data processing, reduce manual effort, and enforce a standardized workflow for route creation.

Existing digital platforms either cover only limited regions or fail to clearly flag hazardous segments. Since on-site inspections are essential for accurately identifying danger spots, purely map-based tools risk misclassifying unsafe routes as safe. Current solutions lack systematic mechanisms for integrating in-person observations and stakeholder input.

The principles of HCD (emphasizing collaboration among diverse stakeholders and iterative prototyping) provide a robust methodology to overcome these challenges. Although platforms such as **schulwege.de** and **schulwege-bw** offer foundational technology, they do not fully capitalize on participatory design techniques or real-world insights.

International studies underscore the benefits of combining digital mapping tools with community-driven, participatory processes. These precedents demonstrate how blending technical features with local engagement yields more inclusive, accurate, and widely adopted planning solutions. This synthesis establishes a clear rationale for applying HCD methods to develop a contextually attuned, user-centered digital school route planner tailored to the German setting.

3 Related Work

This chapter surveys three core categories of related approaches (safety systems in road traffic, planning support tools, and crowdsourcing citizen science) highlighting their objectives, methods, and applicability to school route planning.

3.1 Overview of Research Trends in Safe Route Planning

The topic of safe route planning has gained considerable importance over the last two decades, reflecting the global increase in vehicle numbers and overall traffic volume. The bibliometric analysis conducted by Muhammad et al. [23] offers a comprehensive overview of research activities and trends in this domain. Their study analyzed 1,546 publications (including 938 articles, 592 proceeding papers, 51 review articles, and 16 early access papers) from 84 countries, published between 2000 and January 2023. The United States emerged as the most prolific contributor, accounting for 406 papers, while Germany ranked tenth with 53 publications. The authors did not delve into detailed explanations for this distribution, and during the research of this project, no work was found.

Muhammad et al. also performed a keyword analysis, identifying *path planning* (100 occurrences), *children* (40 occurrences), *safety* (38 occurrences), *walking* (35 occurrences), and *safe routes to school* (35 occurrences) as the most frequent terms. These results underline the increasing emphasis on safe mobility for vulnerable groups, especially children, highlighting the prominence of school route safety as a distinct subfield. The trend towards integrating safety concerns with pedestrian behavior reflects the need for interdisciplinary approaches [23].

Overall, this work positions safe route planning as a rapidly evolving research field with growing scientific attention worldwide. The relatively low research output from Germany, despite its advanced transport sector, may indicate underexplored potentials in national scholarly engagement. This supports the motivation for targeted research and innovative digital solutions for school route planning to enhance child safety and sustainable mobility.

3.2 Categories of Related Systems and Approaches

This Section explores different categories in the school route planning and safe routing field.

3.3 Safety Systems in Road Traffic

Safety systems interventions aim to modify the built environment or vehicle behavior to prevent crashes and mitigate severity. Traffic calming measures, regulatory speed limits, and advanced driver-assistance technologies exemplify infrastructure-centric strategies that have demonstrated statistically significant crash reductions and speed management benefits. While their vehicle-focused orientation delivers quantifiable safety gains, integrating pedestrian needs and contextual variability remains a challenge for school route applications.

3.3.0.1 Traffic Calming Measures and Crash Reduction

Muse et al. [24] conducted a systematic review and meta-analysis of traffic calming interventions, examining controlled before–after studies and empirical Bayes methods from 1990 to 2024 across ten countries. A total of 24 studies met inclusion criteria from an initial 1,588 identified studies, providing evidence on the effectiveness of various traffic calming measures in reducing road traffic crashes.

Key Findings The pooled results indicate a 28% reduction in total crashes, a 33% reduction in injury crashes, and an 18% decrease in pedestrian crashes.

- **Horizontal deflections and narrowing** (e.g., roundabouts, road diets) achieved the highest safety benefit, with a 44% reduction in total crashes and a 73% reduction in injury crashes.
- **Vertical deflections** (e.g., speed humps, raised crosswalks) yielded moderate improvements, with a 19% reduction in total crashes and a 23% reduction in injury crashes.
- **Area-wide measures** produced a 12% decrease in total crashes and a 15% reduction in injury crashes.
- **Posted speed limit reductions and signal-related interventions** showed minimal or statistically insignificant impacts, with only 3% and 8% reductions, respectively.

Contemporary Relevance Traffic calming measures remain central to Vision Zero [6] and sustainable mobility strategies worldwide. The evidence base is dominated by studies from high-income countries (primarily the United States (n=10), Australia (n=4), and the United Kingdom (n=3)), highlighting a gap in research for low- and middle-income regions. Future implementations should account for local road geometry, traffic volumes, and community contexts, integrating traffic calming within comprehensive transport policies to avoid unintended traffic displacement and public resistance.

Relation to the Present Work While Muse et al. analyze the effectiveness of already implemented traffic calming infrastructure measures, the present work addresses a complementary but different challenge: the preventive identification of hazardous school route areas through participatory digital planning. The findings of Muse et al. regarding particularly effective horizontal deflections and narrowing measures serve as background information integrated into the developed planning application. Planners can directly incorporate this data when making route recommendations.

3.3.0.2 Advanced Driver-Assistance Systems (ADAS)

Neumann [26] analyzed key ADAS technologies (including adaptive cruise control (ACC), blind spot detection (BSD), lane departure warning/keeping (LDW/LKS), intelligent headlamp control (IHC), and emergency brake assist (EBA)) drawing on system descriptions, sensor overviews, regulatory mandates, and a driver survey of 80 participants conducted in 2023.

Key Findings

- **Adaptive Cruise Control (ACC)**: Radar- and camera-based ACC was present in 75% of vehicles surveyed. Drivers report reduced rear-end collision risk and lower cognitive load in motorway and congested traffic scenarios.
- **Blind Spot Detection (BSD)**: Installed in 60% of vehicles, BSD uses radar/ultrasonic sensors to monitor flank zones. Visual, auditory, and haptic alerts improve lane-change safety, though false alarms under adverse weather remain a challenge.
- **Lane Departure Warning/Keeping (LDW/LKS)**: Available in 43% of vehicles, these camera-based systems warn (LDW) or gently steer (LKS) upon unintentional lane drift. Drivers value fatigue mitigation, but performance degrades over worn or obscured lane markings.
- **Intelligent Headlamp Control (IHC)**: Automatically switches and adapts beam intensity/direction based on ambient light, oncoming traffic, and steering angle. Half of respondents cited improved night-time visibility and reduced glare.
- **Emergency Brake Assist (EBA)**: Present in 40% of cars, EBA augments driver braking in imminent collision scenarios and can autonomously initiate full deceleration. Users credited EBA with accident avoidance, but noted variability in sensor detection under heavy rain or snow.

Contemporary Relevance ADAS adoption is accelerating under EU mandates requiring systems such as speed-limit assistants, lane keeping, tire-pressure monitoring, emergency braking, and driver fatigue detection by 2029. Survey responses indicate high user acceptance (65% "always" or "often" use ADAS) and significant perceived gains in safety (82% report increased safety) and comfort (60% report enhanced comfort). Challenges remain in reducing false alarms, improving sensor fusion in adverse conditions, and educating drivers on system capabilities and limitations to prevent over-reliance and ensure proper situational awareness [26].

Relation to the Present Work While Neumann's research examines vehicle-centric safety enhancement through automated driver assistance, the present work addresses a different but complementary challenge: pedestrian-centric safety improvement through participatory route planning. Neumann's findings reveal that ADAS technologies effectively reduce collision risks for vehicle occupants by automating critical driving tasks and alerting drivers to immediate hazards. However, these systems operate within the constraints of existing road infrastructure and traffic patterns. They cannot address the planning decisions that determine which routes children encounter and how hazardous those encounters become.

While Neumann demonstrates that EBA systems can prevent collisions when detection sensors function properly, the developed school route planning application enables systematic identification of locations where such emergency interventions are most likely to be needed. The proactive hazard mapping and route optimization capabilities of the present system can reduce pedestrian exposure to high-risk scenarios, potentially decreasing the frequency with which ADAS systems must engage their emergency protocols.

3.3.0.3 City-Wide 30 km/h Speed Limits and Multidimensional Benefits

Yannis and Michelaraki [40] conducted a systematic review of 40 European cities that implemented city-wide 30 km/h speed limits, synthesizing quantitative and qualitative evidence on safety, environmental, traffic, livability, and health outcomes using PRISMA guidelines.

Key Findings

- **Safety**: Average reductions of 23% in road crashes, 37% in fatalities, and 38% in injuries following implementation.
- **Environment**: Mean decreases of 18% in CO_2/NO_x/PM emissions, 2.5 dB reduction in noise levels, and 7% lower fuel consumption.
- **Traffic**: Generally minimal impacts on travel times (3–5% increases) and traffic volumes (2–3% decreases), with some cities reporting smoother flow and negligible delays.
- **Livability & Modal Shift**: Freed roadway space (20–50cm per lane) repurposed for cycling lanes, greenery, and pedestrian areas; notable increases in walking and cycling mode share (up to six-fold in some cases).
- **Health & Well-being**: Reduced noise- and pollution-related health risks, enhanced opportunities for active travel, and positive community perceptions of safety and quality of life.

Contemporary Relevance City-wide 30 km/h limits align with EU Vision Zero and the 2021–2030 road safety framework targeting a 50% reduction in deaths and serious injuries. These measures underscore the importance of low-speed urban environments for sustainable mobility, public health, and smart city initiatives, and highlight the need for integrated enforcement, public engagement, and ITS-enabled monitoring to maximize long-term benefits.

Relation to the Present Work While Yannis and Michelaraki examine the outcomes of implemented speed reduction measures across entire urban networks, the present work addresses a different but complementary challenge: participatory identification and planning of specific hazardous locations before policy interventions are required. Their research demonstrates the effectiveness of city-wide speed limits as a regulatory approach that operates uniformly across urban areas. However, this approach cannot address the granular spatial intelligence needed to identify which specific streets, intersections, and route segments pose the greatest risks to school-age pedestrians.

The present work fills a critical pre-implementation planning gap that systematic policy reviews like Yannis and Michelaraki's cannot address: how to systematically identify priority locations for targeted interventions before implementing broad regulatory changes. While their findings show that 30 km/h limits reduce crashes by 23% on average, the developed participatory school route planning system enables proactive identification of high-risk locations where such speed reductions would have maximum protective impact for children.

The methodological synergy between the works is significant: Yannis and Michelaraki provide quantitative evidence for the effectiveness of speed reduction policies, while the present work provides community intelligence about where such policies are most urgently needed. The developed platform can incorporate their findings as background data for planning recommendations, enabling planners to prioritize locations where 30 km/h implementations would have maximum safety benefits for school routes.

3.4 Planning Support Tools

Planning support tools leverage geographic information systems (GIS), optimization algorithms, and real-time data streams to generate, evaluate, and visualize safe walking routes. From network prioritization indices to hazard-aware path planners, these systems offer decision-support capabilities that tailor routes to local conditions and user requirements. However, many remain prototype implementations with limited stakeholder co-design and validation in actual school contexts.

3.4.0.1 Towards a Route Planner Supporting Pedestrian Navigation in Hazard Exposed Urban Areas

Opach et al. [28] present a framework and proof-of-concept implementation of WayFinder, a pedestrian route planner that integrates real-time environmental sensor data and citizen observations to support navigation during extreme heat and pluvial flooding. Developed under the CitizenSensing project for four European cities (Norrköping, Porto, Rotterdam, Trondheim), WayFinder demonstrates both passive and active routing concepts within a web-based decision support tool.

Key Findings

- **Passive routing**: Displays real-time temperature overlays, blue-spot flood maps, and user-reported hazard markers alongside shortest-path suggestions, enabling manual waypoint adjustments based on environmental context.
- **Active routing (conceptual)**: Embeds sensor measurements and citizen reports directly into cost functions, optimizing routes to minimize exposure to heat and inundation while balancing distance and safety.
- **Use cases**:
  - Kindergarten staff in Trondheim avoid flooded sidewalks by selecting routes that circumvent reported blue spots.
  - Tourists in Norrköping plan cooler walking paths using urban heat island overlays and shaded POI waypoints.

Contemporary Relevance This work highlights the potential of combining IoT sensor networks, volunteered geographic information, and web GIS to enhance pedestrian safety in hazard-exposed urban areas. The passive framework offers immediate decision support, while the active approach points toward future developments in context-aware navigation for climate resilience and smart city applications.

Relation to the Present Work While WayFinder demonstrates context-aware pedestrian routing for climate hazards, the present work targets school-route safety by systematically capturing diverse hazard types (such as high-volume traffic, poor lighting, and sidewalk discontinuities) before extreme events occur. Opach et al. focus on environmental exposures (heat, flooding) and require manual user adjustments in the passive mode. In contrast, the developed school route planner uses a participatory approach that, identifies everyday hazards along children's routes.

3.4.0.2 A Personalised Pedestrian Navigation System

Shah and Wang [31] introduce a prototype pedestrian navigation application that generates personalized walking routes based on individual preferences, such as safety, accessibility, and comfort, by extending Dijkstra's algorithm with weighted cost functions. The system was implemented as a web-based tool for a case study area in Harrow, London, using OpenStreetMap and crime data.

Key Findings

- Seven routing preferences (safety, tactile paving, leisure proximity, residential areas, low traffic, straightforwardness, step-free access) were encoded as additional edge weights, yielding alternate routes that better match user needs than shortest-path solutions.

- Passive routing displays hazard and comfort overlays alongside conventional directions, enabling users to manually adjust routes based on real-time temperature, flood maps, and citizen reports.
- Active routing incorporates user-selected preferences directly into the cost function, producing optimized paths that minimize exposure to hazards (e.g., crime hotspots, heat islands) while balancing distance and safety.
- In comparative trials, preference-based routes increased perceived safety and accessibility, with prototype suggestions achieving up to a 37% lower hazard exposure cost than Google Maps routes.

Contemporary Relevance This work demonstrates the feasibility of integrating IoT sensor feeds and volunteered geographic information into pedestrian routing engines to support climate-resilient and inclusive navigation. The preference-driven framework offers a foundation for future developments in smart city wayfinding, emphasizing real-time context awareness and user empowerment in urban mobility.

Relation to the Present Work While Shah and Wang focus on individualized route selection by modifying graph-based algorithms to respect personal comfort and safety preferences, the present work targets community-centered hazard identification for school routes. Their system excels at tailoring routes for specific pedestrian profiles but relies on existing network data (e.g., OSM tags, crime incidents) and individual user input at the time of routing. In contrast, the developed school route planning application aggregates multi-stakeholder observations (students, parents, mobility experts) via a digital survey, capturing both objective hazards (e.g., missing crosswalks) and subjective safety perceptions (fear zones).

Thus, the present work extends the personalized navigation paradigm by shifting from reactive preference handling to proactive, community-driven hazard mapping and standardized planning workflows.

3.4.0.3 A GIS-Based Method for Evaluating Walkability and Prioritising Investments

D'Orso and Migliore [8] propose a comprehensive GIS-based decision support methodology to assess the walkability of urban pedestrian networks and to prioritise infrastructure investments. Developed around three walkability factors (practicability, safety, and pleasantness) the method evaluates each network segment (arc) using twenty objectively measured indicators and expert-based weights, producing a Quality Index (0–5) and an Importance Index (1–5) that combine into a Priority Index for intervention.

Key Findings

- Quality Index: Segments scored across indicators such as sidewalk slope, pedestrian level of service, surface degradation, street lighting, traffic volume/speed, and urban amenities. Weights (safety 0.4, pleasantness 0.3, practicability 0.3) reflect their relative impact on walkability.

- Importance Index: Estimated via all-or-nothing assignment of pedestrian flows to shortest-path trees between key attractor–generator pairs (e.g., stations, schools, shopping), identifying high-demand arcs.
- Priority Mapping: Combining Quality × Importance highlights critical arcs where low walkability and high pedestrian demand coexist, guiding cost-effective allocation of resources.
- Case Study (Palermo): Application around three railway stations revealed that 10% of arcs had Quality 4, indicating urgent need for interventions such as sidewalk repairs, lighting upgrades, and crosswalk installations.

Contemporary Relevance By integrating multi-criteria scoring, network analysis, and GIS visualization, this tool enables planners to transparently identify and prioritise pedestrian infrastructure improvements. Its modular framework can be adapted to diverse urban contexts, supporting Sustainable Development Goals for safe, accessible, and inclusive active mobility.

Relation to the Present Work While D'Orso and Migliore focus on expert-driven walkability assessment using standardized indicators and algorithmic importance weighting, the present work advances this paradigm through community-centered participatory hazard identification specifically tailored for school route planning. Their methodology excels at providing systematic infrastructure prioritization but relies primarily on technical auditing and shortest-path flow modeling. In contrast, the developed school route planning application integrates multi-stakeholder perspectives (students, parents, mobility experts, municipal planners) via a digital survey, capturing both objective hazards and subjective safety perceptions.

D'Orso and Migliore's focus on flow assignment assumes pedestrians always choose shortest paths, which may not hold for school routes where safety concerns override distance optimization. The present work creates more realistic models of how children actually navigate urban environments.

3.5 Crowdsourcing Citizen Science

Crowdsourcing citizen science platforms engage community members as active contributors of safety data, reporting near misses, infrastructure barriers, and behavioral hazards via mobile apps or web maps. By capturing granular, user-generated insights, these initiatives fill gaps in official statistics and enrich understanding of micro-level safety concerns. Ensuring data quality, representativeness, and sustained participation are critical challenges when applying these models to school route assessment and continuous monitoring.

3.5.0.1 SimRa: Crowdsourcing Near-Miss Hotspots in Bicycle Traffic

Karakaya et al. [16] introduce SimRa, a smartphone-based crowdsourcing platform for cyclist safety that collects GPS traces, accelerometer data, and user-annotated near-miss incidents to identify hazardous hotspots in urban bicycle networks. Deployed in six European cities (Berlin, Bern, Augsburg, Bochum, Pforzheim, Stuttgart) since 2019, SimRa leverages both automated incident detection—via acceleration peaks—and manual labeling to gather large-scale data on dangerous street segments.

Key Findings

- **Data Collection**: Over 10,000 rides recorded, with sensor data sampled at 0.33 Hz for GPS and 50 Hz (aggregated) for accelerometers; anonymized uploads include route traces, incident locations, descriptions, and cyclist demographics.
- **Incident Detection**: Heuristic spike-based algorithm identifies potential incidents (e.g., swerving, braking) with manual verification to filter false positives and add omissions; current limitations include underreporting of non-spike events such as close passes.
- **Hotspot Analysis**: A graph model maps incidents and rides to street segments and intersections, calculating a dangerousness score $S = \frac{s+\alpha n}{r}$, where s and n are scary and non-scary incident counts, r is ride count, and $\alpha = 4.4$ is a severity factor; length-adjusted scores further normalize by segment length.
- **Insights**: Case studies in Berlin revealed critical segments where illegal parking forced cyclists into tram tracks, and close-pass–prone narrow lanes; results guided targeted infrastructure improvements and sensor-enhanced routing.

Contemporary Relevance SimRa exemplifies the power of citizen science in transport planning, filling gaps in official crash statistics by capturing near misses at scale. Its modular, open-source design supports integration with live tagging and additional sensors, offering a blueprint for data-driven active mobility interventions and community-driven road safety research.

Relations to the Present Work SimRa uses cyclists' GPS and accelerometer data to map near-miss hotspots after they occur, focusing on adult riders and sensor-based incident detection. In contrast, the school route planner gathers hazard reports from students, parents, and experts before travel, covering traffic speed, crosswalk quality, lighting and more. By integrating these reports into cost functions, it recommends low-risk routes in advance without requiring real-time user input. The HCD process ensures ongoing stakeholder engagement and delivers a desktop interface for planners to review, edit, and prioritize interventions based on a complete hazard database. This shift from reactive incident mapping to proactive hazard identification and route optimization helps ensure that children's daily journeys avoid the most dangerous locations.

3.5.0.2 WalkRollMap.org: Crowdsourcing Barriers to Mobility

Laberee et al. [18] introduce WalkRollMap.org, a web-based mapping platform that enables community members to crowdsource fine-scale barriers to walking and rolling through an interactive map interface integrated with demographic and contextual survey data. This includes hazards, missing amenities, and incidents (falls, near misses, collisions).

Key Findings

- Over the first nine months, 897 reports were submitted globally, with 53% mapping hazards (e.g., uneven sidewalks, high vehicle speeds), 34% reporting missing amenities (e.g., sidewalks, crosswalks, curb cuts), and 14% documenting incidents involving vehicle conflicts or falls.
- Participant demographics indicated modest representation of people with disabilities (10%) and mobility-aid users (7%), with targeted outreach efforts needed to improve inclusivity.
- Spatial analysis tools—including bar charts, treemaps, word clouds, and time-series filters—enabled stakeholders to identify temporal and spatial hotspots of barriers, such as seasonal hazards (snow/ice) and localized infrastructure gaps.
- Community engagement strategies (in-person events, social media campaigns, targeted walks with older adults) influenced report distribution, with 640 reports from the initial pilot region (Capital Regional District, Canada) and the remainder from other North American and European locales.

Contemporary Relevance WalkRollMap.org demonstrates the effectiveness of citizen science in filling data gaps on microscale pedestrian environments, offering real-time, open-access datasets to inform equitable infrastructure planning and policy. Its open-source architecture and modular design support adaptation for diverse urban contexts and integration with other active-transport decision support tools.

Relation to the Present Work WalkRollMap.org excels at capturing fine-scale, user-reported barriers to pedestrian mobility, yet it emphasizes individual reporting of environmental and infrastructural issues without integrating these data into network-wide routing models. The school route planner complements this approach by aggregating reports from students, parents, and experts into a hazard database and embedding these hazards directly into route cost functions. This allows the system to recommend safe school routes, rather than merely visualizing barrier locations. Moreover, the planner's desktop interface supports municipal stakeholders in validating, editing, and prioritizing based on both the distribution of reported barriers and expert assessments. By shifting from crowd-mapping to a participatory, planner-driven workflow, the present work ensures that community-sourced barrier data inform route optimization and infrastructure improvements for child pedestrians.

3.5.0.3 Improving Road Safety Knowledge in Africa Through Crowdsourcing

Usami et al. [38] describe the African Road Safety Observatory (African RSO), a participative web portal developed under the SaferAfrica project funded by the European Union's Horizon 2020 program. The platform combines traditional data analysis and knowledge sharing with innovative crowdsourcing and dialogue functions to address the substantial data gaps in African road safety, where the fatality rate (26.6 per 100,000 inhabitants) is nearly three times that of Europe.

Key Findings

- Multi-faceted platform: The African RSO integrates a Dialogue Platform for experts and stakeholders, a crowdsourcing reporting tool for citizens, web surveys targeting road safety professionals, and **webinars** for knowledge dissemination across English, French, and Portuguese languages.
- Crowdsourced data collection: By February 2019, 35 reports from 17 African countries were received, with the majority addressing risky behavior of road users** (40%) and unsafe roads (35%). Citizens reported issues such as lack of pedestrian crossings, inadequate traffic signs, driver distraction, vehicle overloading, and poor post-crash care.
- Stakeholder engagement: Over 190 African stakeholders from 54 countries participated in the Dialogue Platform, supported by a Management Board comprising ten international institutions including the European Commission, World Bank, and WHO.
- Evidence-based insights: Reports revealed systemic challenges across all five pillars of the African Road Safety Action Plan, highlighting needs for unified traffic management systems, infrastructure improvements, enforcement measures, and institutional coordination.

Contemporary Relevance The African RSO exemplifies how crowdsourcing can complement official data sources in regions with limited road safety information systems. By engaging citizens as sensors and facilitating expert dialogue, the platform supports evidence-based policy making and capacity building across the continent, offering a scalable model for participatory road safety governance in data-scarce environments.

Relation to the Present Work While the African RSO leverages expert dialogue and citizen reports to fill data voids at the national level, its focus remains on broad policy discussion and high-level needs assessment. The school route planner instead aggregates detailed, geolocated hazard data from students, parents, and experts to model and optimize individual walking routes. By embedding these fine-grained reports into route cost functions, the planner delivers targeted recommendations for safe school paths, rather than general recommendations for national systems. Moreover, its desktop interface allows planners to validate and prioritize interventions at the street-segment level, ensuring that community-sourced insights directly inform local infrastructure improvements and educational measures for child pedestrians.

3.6 Critical Comparison and Positioning of Related Work

The surveyed literature reveals three primary strands *infrastructure-based safety systems*, *planning support tools*, and *citizen science platforms*) each contributing distinct strengths and facing specific limitations when applied to school route planning.

Infrastructure measures such as traffic calming, speed limit reductions, and ADAS offer **quantifiable crash reductions** and speed management but tend to focus on vehicle-centric interventions, lacking integration with pedestrian behavioral data [24][26]. City-wide 30 km/h limits demonstrate broad safety and environmental benefits yet require comprehensive enforcement and public buy-in to sustain effects [40].

Planning support tools present **tailored GIS analyses** and **context-aware routing** functionalities. Methods for network prioritization [8] and hazard-aware navigation [28][31] leverage spatial metrics and real-time data, enhancing decision support. However, many tools remain *proof-of-concept* with limited user studies in school contexts and often lack seamless incorporation of stakeholder feedback loops.

Crowdsourcing platforms (SimRa, WalkRollMap, African RSO) excel at **filling data gaps** through user-generated reports and sensor feeds, capturing near misses and infrastructure barriers at granular scales [16][18][38]. These initiatives underscore the value of *co-creation* and community engagement but face challenges in *data representativeness*, *standardization*, and *sustained participation*—critical factors for reliable school route assessments.

In positioning the current work, a **hybrid approach** emerges as most promising: combining robust infrastructure guidelines, dynamic GIS-based decision support, and participatory data collection tailored to school route specifics. Key differentiators include:

- Embedding **parent and child participation** directly into route generation and verification, addressing the engagement gap noted by Gerlach et al. [12].
- Integrating **real-time environmental and traffic data** with **crowdsourced local insights** to deliver adaptive, safety-prioritized routes.
- Coupling **multi-criteria GIS ranking** of network segments with **interactive feedback mechanisms**, ensuring both expert-driven prioritization and community validation.

This synthesis informs the design of a human-centered school route planning system that leverages evidence-based interventions, technological innovation, and participatory processes to maximize safety, usability, and sustainability.

4 User Research

This chapter defines the context of use and derives user requirements to guide prototype development.

4.1 Context of Use

We examine user characteristics, tasks, and the technical, organizational, and physical environment to understand how the system will be employed. Insights from existing tools (see Section 2.3.1). This analysis establishes the baseline for the future system and informs requirement prioritization.

4.1.1 User Groups and Stakeholders

Stakeholder interviews are a fundamental user research technique for uncovering the needs, expectations, and constraints of all parties affected by a system, not just end users. This inclusive approach aligns with best practices in user-centered design (see Chapter 2).

4.1.1.1 Primary Users

The primary users of the planning support system can be divided into three main groups.

The first group comprises *school route planners*, typically municipal employees, who are responsible for designing safe school route plans for specific schools within their assigned districts. These users primarily access the system from their workplace, most often using a desktop computer. Their core tasks include managing existing plans, creating new plans based on collected data, and maintaining communication with school representatives. Planners require access to the full functionality of the planning interface, including the ability to review reported danger points, add further mobility data, and make route recommendations.

The second group consists of *parent–child dyads*, who access the "school view" of the application. They are not granted access to the planning view, as their role focuses on contributing relevant input rather than modifying plans. Parents and children typically use the application on mobile devices, allowing them to interact with the system during their daily school journeys. Their main tasks include reporting the actual routes taken, highlighting perceived hazards, and completing questionnaires that provide planners with valuable contextual information about the school commute.

The third group includes *mobility experts*, such as traffic safety officers or volunteers. These users contribute high-value, domain-specific data that supports planners in improving route safety. Similar to parent–child dyads, mobility experts generally do not require access to the full planning interface. Their primary function is to report danger spots, provide professional assessments of road safety conditions, and submit relevant traffic or accident statistics. Unlike parents, they are not expected to fill out questionnaires, but they may submit periodic reports or structured data to supplement planners' decision-making processes.

By addressing the distinct needs, access levels, and typical device contexts of these three user groups, the system ensures that each group can effectively fulfill its role within the safe school route planning process.

4.1.1.2 Other Stakeholder Groups

These are groups of people that are not users of the final system, but are in any way involved in it.

Primary school principals coordinate the planning process between their institution and the route planners. Although they do not use the system directly, they play a critical role in gathering and relaying information from teachers and parents. Principals typically interact via email or briefings and require concise summaries of progress, timelines, and decisions. Their priority is efficient coordination to minimize disruption to school operations.

Teachers receive planning updates and assignments through the principal. They act as intermediaries, assigning observational or mapping tasks to students and integrating route safety topics into lessons. While teachers do not directly access the digital planner, they benefit from clear, easy-to-understand materials—such as printable maps, summary reports, and classroom activities—that they can distribute without extensive training.

4.1.2 Characteristics of Primary Users

Understanding the characteristics of the identified user groups is essential for informing the design of a human-centered system. While the description of primary users outlines the roles and general responsibilities of each group, this Section focuses on digital literacy, motivations, and patterns of technology use. These factors directly influence the usability requirements, interface design, and interaction models of the proposed planning support system [9].

In contrast to the previous subsection 4.1.1, the parent–child dyads are considered separately here, as parents and primary school students differ in their capabilities, needs, and interaction patterns with the system.

4.1.2.1 Planners

Planners are typically between 30 and 65 years old and have professional experience in municipal planning, traffic safety, or related administrative domains. They regularly create and maintain safe school route plans as part of their responsibilities. Their work is carried out in office environments with access to desktop computers, allowing for focused and detail-oriented tasks. Given their professional background, they are accustomed to structured workflows and desktop-based software tools.

4.1.2.2 Parents

Parents are generally between 30 and 45 years old and have at least one child of primary school age. Their digital literacy varies, although many are familiar with basic smartphone applications. Their primary motivation is the safety of their children, particularly on the way to school. Time constraints, such as work schedules and commuting responsibilities, mean that their engagement with the system is likely to be occasional and focused on efficiency. The system must therefore enable quick and intuitive data entry, ideally in a single session, to accommodate their voluntary contribution.

4.1.2.3 Primary School Students

Primary school students are between 6 and 11 years old, with varying levels of digital competence depending on parental regulation of screen time. Their preferred modes of travel to school differ, with a considerable proportion being driven by parents, while others walk, cycle or take the bus. Motivation to use the system directly may be limited; participation will typically occur under parental guidance. Interfaces targeting this group should therefore be simple, visually engaging, and require minimal text input.

4.1.2.4 Mobility Experts

Mobility experts are typically between 40 and 70 years old and possess varying levels of digital competence, with some users less familiar with modern web or mobile applications. They are actively engaged in their local communities and have a strong personal and professional interest in traffic safety. Their primary interaction with the system involves reporting identified danger zones or traffic hazards. Given that these observations often occur in the field, mobile access is essential. The interface for this group should therefore priorities simplicity, minimal navigation steps, and rapid data entry to facilitate efficient reporting during on-the-go use.

4.1.3 Personas

Personas are a powerful tool that is often employed as part of the define-phase in human-centered design. A persona represents a fictional user or stakeholder in order to, understand user needs and pain points in hopes to improve user experience and accessibility.

4.1.3.1 Dascha (45)

Role: Municipal employee in traffic safety

Background: Dascha has been working at her local town hall for eight years, serving as a traffic safety administrator. For the past three years, she has also been responsible for creating school route plans, in addition to her many other duties. Due to a high workload and slow bureaucratic processes, she can complete only two to three plans per year. Although she is highly motivated to improve the safety of school routes, the current process is tedious: evaluating all data submitted by students on paper, researching traffic conditions, and creating the plans manually is both time-consuming and messy.

Key Statement: "Working on school route plans is important, but managing it all on paper is exhausting and slow. I wish there was an easier and faster way to do things."

Motivation/Goals:

1. Provide high-quality school route plans to make school routes safer and more attractive for children.
2. Easily manage and gain insights from student-submitted data.
3. Receive support in identifying good routes more quickly.

Frustration/Pain Points:

1. Bureaucratic processes are slow and complicated
2. Managing all the data on paper is exhausting
3. Identifying dangerous areas requires time-consuming manual research.

4.1.3.2 Johannes (37)

Role: Father of primary school student

Background: Johannes is the father of Lea (7), who just started second grade. He works full-time as a policeman and commutes daily to the city, which leaves him limited time in the mornings. Concerned about traffic safety, he prefers to drive Lea to school on his way to work. Although he would like her to walk independently, he feels the current route is too dangerous. Johannes is moderately tech-savvy and uses his smartphone for most everyday tasks. He is willing to contribute to improving school route safety, but only if the process is quick and easy.

Key Statement: "I want my daughter to walk to school one day, but I need to know the route is safe before I let her try."

Motivation/Goals:

1. Ensure Lea's daily route to school is as safe as possible.
2. Provide accurate feedback on the current route to planners.
3. Access clear and practical recommendations for safer walking routes.

Frustration/Pain Points:

1. Concern over heavy traffic and unsafe crossings on the current route.
2. Limited time to participate in lengthy surveys or complex tools.
3. Lack of clear, trustworthy information about alternative safe routes.

4.1.3.3 Lea (7)

Role: Primary School Student

Background: Lea is in the second grade and lives about 1,2 km from her school. She enjoys playing with her friends after class and is curious about her surroundings. She currently gets driven to school by her father, Johannes, but sometimes walks short stretches when accompanied by an adult. Lea can use a smartphone for basic games and photos but has little interest in using apps for anything other than fun. Her understanding of road safety is developing, but she is easily distracted.

Key Statement: "I like walking with my friends, but I don't like crossing the big street, it's scary."

Motivation/Goals:

1. To be able to walk to school with her friends without feeling scared.
2. To explore her neighborhood safely.
3. To have fun and feel independent while getting to school.

Frustration/Pain Points:

1. Feeling nervous about crossing busy streets without help.
2. Being told she cannot walk alone even though she wants to be independent.
3. Lack of safe meeting points where she can join friends for the walk.

4.1.3.4 Mira (67)

Role: Mobility Expert

Background: Mira spent her entire professional life working at her local town hall, where she developed a deep understanding of municipal processes and a strong sense of responsibility for her community. Since retiring last year, she has been looking for ways to stay engaged in local matters. She takes daily walks through her neighborhood with her dog, during which she frequently notices unsafe crossings, poorly marked pedestrian areas, and heavy traffic near schools. Mira often reports these issues to the municipality, but the process is slow, bureaucratic, and offers her no clear feedback on whether her reports lead to improvements. She wishes there were a simple way to document and submit dangerous spots directly from the field while on her walks.

Key Statement: "I know this town by heart, I just want an easy way to flag dangers when I see them."

Motivation/Goals:

1. To help make her neighborhood safer for pedestrians, especially children.
2. To quickly report unsafe areas without having to navigate complicated processes.
3. To stay connected and contribute meaningfully to her community after retirement.

Frustration/Pain Points:

1. Bureaucratic reporting processes that feel slow and ineffective.
2. Lack of feedback on whether reported issues are addressed.
3. Inability to submit reports immediately while out in the field.

4.1.3.5 Kaylee (55)

Role: Primary School Principal

Background: Kaylee has led Woodland Primary for ten years. She coordinates between teaching staff, parents, and municipal authorities to ensure a safe and supportive school environment. With a background in educational administration, she balances strategic planning with day-to-day operational challenges.

Key Statement: "My priority is keeping our students safe without overburdening teachers or interrupting lessons."

Motivation/Goals:

1. Ensure minimal disruption to school routines.
2. Provide clear, actionable guidance to teachers and parents.
3. Foster trust and collaboration among parents, staff, and others to support long-term uptake.

Frustration/Pain Points:

1. Lack of concise, easy-to-understand updates makes it hard to keep teachers informed.
2. Coordination tasks add to her already heavy administrative load.
3. Delays in plan finalization lead to concerns and questions from parents that she must manage.

4.1.3.6 Steffen (29)

Role: Primary School Teacher

Background: Steffen teaches fourth grade at Woodland Primary. He integrates route safety topics into his curriculum and assigns observational tasks to students as part of their regular homework. With a degree in primary education, he balances lesson planning with extracurricular responsibilities.

Key Statement: "I need resources that I can quickly share with students and parents without extensive preparation."

Motivation/Goals:

1. Provide clear, age-appropriate safety information to students.
2. Assign and review mapping exercises that reinforce classroom learning.
3. Ensure minimal disruption to teaching time when coordinating with planners and parents.

Frustration/Pain Points:

1. Insufficiently formatted materials require extra work to adapt for his classroom.
2. Lack of direct access to planning tools forces reliance on the principal for updates.
3. Complex instructions from municipal authorities can confuse students and parents.

4.2 User Research Methods

This Section describes the user research methodology that grounded the HCD process.

4.2.1 Stakeholder Analysis

We began our HCD research by mapping out all parties involved in school route planning. Three complementary methods were employed: (i) informal interviews with two traffic association experts to understand professional inspection protocols; (ii) direct observation of a school-route survey conducted by a traffic specialist alongside parents and teachers at a local primary school; and (iii) a focus group discussion with municipal employees who regularly develop and maintain route plans. Through these we were able to make five initial observations.

4.2.1.1 Initial Observations (O1–O5)

O1: **Experts** highlighted the need for a guided inspection workflow that allows them to log hazard types (e.g., uneven pavements, poor lighting) with standardized labels and photos during on-site surveys.

O2: **Experts** and **parent–child dyads** both noted that an easy, mobile-friendly interface for marking danger spots in real time would increase the accuracy and completeness of collected data.

O3: **Parents** and **children** expressed a desire to submit GPS-tracked route segments automatically, reducing reliance on memory and manual drawing of paths on paper.

O4: **Planners** reported frustration with fragmented data sources (paper forms, spreadsheets, and emails) and requested a unified dashboard to view all community and expert inputs together.

O5: **Planners** emphasized that transitioning from raw observations to finalized route diagrams should be seamless, ideally by enabling in-app annotation tools that generate ready-to-export maps without third-party software.

4.2.2 Semi-Structured Interview

The next phase of our user research consists of a semi-structured interview with a municipal employee in charge of planning safe school routes. Although we were already familiar with some of the problems, this one on one discussion revealed even more user needs for us to take into account. All in all the semi-structured interview was 60 minutes long. After that we were able to make six additional observations.

4.2.2.1 Additional Observations (O6–O11)

O6: **Planners** emphasized the importance of visualizing danger spots collected by community members or mobility experts, alongside official traffic data, to identify potential hazards.

O7: **Planners** indicated that knowing which routes are most frequently taken by **parent–child dyads** would help them prioritize safety improvements. They described heat maps or similar visual summaries as particularly useful for identifying high-traffic areas.

O8: **Planners** stated that additional contextual data from **parent–child dyads**, such as transportation methods and basic demographic information, would provide valuable insights when creating safe school routes.

O9: **Planners** expressed the need for a tool that allows them to draw school routes directly on a map and annotate them with relevant symbols, such as bus stops or crossing points.

O10: **Planners** reported that being able to export completed school route plans as a map-based PDF would streamline communication with schools and parents.

O11: **Planners** reported the need for a central overview (dashboard) showing all existing and ongoing school route plans with clear status indicators (e.g., ongoing, paused, finished) and filtering options (e.g., by school, district, last update) to manage workload and prioritize tasks.

4.2.3 Focus Group

To validate and refine our initial observations, we developed low-fidelity wireframes illustrating core workflows and features derived from **O1–O11**. A two-hour focus group session was held with two municipal route planners and one primary school principal. During the session, participants were guided through each screen (covering hazard reporting, route drawing, data dashboards) and asked to comment on ease of use, clarity of visual elements, and potential gaps.

Overall, stakeholders reacted enthusiastically to the wireframes, confirming that the proposed interactions aligned with their mental models and daily practices. Feedback also highlighted two additional considerations for the design:

4.2.3.1 Additional Observations (O12–O13)

O12: **Planners** requested a pre-annotated, georeferenced base map that automatically includes crossings, bus stops, and speed limit data, eliminating the need for manual layer management.

O13: **Parent–child dyads** expressed a desire to mark "fear zones" with distinct pictogram pins (separate from general danger spots) to capture subjective safety perceptions (e.g., poor lighting or intimidating underpasses).

4.3 User Needs and Consolidated Requirements

This Section describes the user needs uncovered through stakeholder interviews, expert consultations, and focus groups, and translates them into a coherent set of actionable requirements for the system.

4.3.1 User Needs

Following the principles of the HCD process described in Section 2.2, the user needs were derived iteratively from stakeholder interviews, expert consultations, and focus group sessions (see Section 2.2). The statements below are expressed in a way to capture not only the functional requirement but also the underlying motivation. These needs remain neutral and form the basis for the consolidated requirements in Section 4.3.2.

4.3.1.1 Planner: Dascha

- Dascha in her role as planner, needs to view all existing and ongoing school route plans with their status because managing multiple projects across different schools requires efficient prioritization and progress tracking given her heavy workload and bureaucratic constraints.
- Dascha in her role as planner, needs access to relevant background data such as crossings, bus stops, and traffic statistics in one centralized location because manually collecting information from multiple municipal departments is both time-consuming and error-prone, preventing her from completing more than 2-3 plans per year.
- Dascha in her role as planner, needs to filter and process input from parents, children, and mobility experts efficiently because the volume of paper-based submissions can become overwhelming and difficult to analyze within her limited administrative capacity.
- Dascha in her role as planner, needs to create and edit school route plans quickly and accurately because her municipal role encompasses many responsibilities beyond route planning, and slow bureaucratic processes already constrain her ability to deliver timely safety improvements to schools.

4.3.1.2 Parent-Child Dyads: Johannes and Lea

- Johannes and Lea in their role as father and primary school student, need to share observations about their child's school route easily via a mobile-friendly interface because they volunteer their time and can only contribute briefly.
- Lea in her role as primary school student, needs to mark not only danger spots but also "fear zones" because perceived safety strongly influences her willingness to walk to school.
- Johannes in his role as father of an primary school student, needs to guide his daughter in reporting information together because she may have limited digital literacy and require supervision.

4.3.1.3 Mobility Expert: Mira

- Mira in her role as mobility experts, needs to report dangerous areas on the go because she often notice safety issues while moving through the community.
- Mira in her role as mobility experts, needs to submit observations without navigating complex menus because she has limited digital skills and values simplicity.

4.3.1.4 Primary School Principals: Kaylee

- Kaylee needs a guided, step-by-step planning workflow tailored to Woodland Primary, because a clear process reduces back-and-forth with municipal planners and staff.
- Kaylee needs custom route maps that emphasize her school's specific catchment area and known hazards, because generic regional plans overlook local conditions.
- Kaylee needs one-click access to the current route plan from her dashboard or email, because she must relay updates to teachers and parents without delay.

4.3.1.5 Primary School Teachers: Steffen

- Steffen needs student-friendly visual templates and concise talking points, because he integrates route safety lessons into his curriculum with minimal preparation time.

4.3.1.6 All Users

- All users need to access the system from their preferred device because flexibility increases adoption and participation.
- All users need to see data visualized in a clear, task-relevant way because interpretation errors could compromise the quality of the plans.
- All users need to trust that their data is secure and handled responsibly because the system processes sensitive information, particularly from children.

4.3.2 Consolidated Requirements

The consolidated requirements were derived directly from the user needs identified in Section 4.3.1 and the observations collected during the user research activities in Sections 4.2.1, 4.2.2 and 4.2.3. While the user needs express the *what* and *why* from the users' perspective, the consolidated requirements translate these into clear, actionable, and testable specifications for the system.

Each requirement is assigned a reference code (**R1**, **R2**, . . .) to ensure traceability throughout the design, implementation, and evaluation phases. These requirements focus primarily on functional aspects, outlining what the system must do to address the identified user needs. They serve as the foundation for the implementation in Chapter 5 and will be revisited during evaluation in Section 5.4.1 to verify that the final product meets the expectations of its intended users.

R1: The system should i) support **experts** during school route inspections and support recording a list of dangers, ii) empower **parent-child dyads** to inform planning,

iii) support **municipal/school employees ("planners")** when planning safe school routes

R2: For **experts** and **parent-child dyads** it should be possible to record danger spots on school routes

R3: For **parent-child dyads** it should be possible to record their route to school as a basis for planning

R4: **Planners** should see all relevant planning information at a glance

R5: **Planners** should be able to create digital school route plans

R6: The system should allow **planners** visualize all existing and ongoing plans, indicate their status (e.g. ongoing, paused, finished) and allow to filter them

R7: The system should visualize the frequency of routes taken by parent-child dyads as a heat map, so that **planners** can use them as a basis for school route plans

R8: The system should allow **planners** to obtain further information from parent-child dyads such as transportation methods and basic demographics

R9: Danger spots collected by parent-child dyads or experts together with official traffic information should be visualized on a map, so that **planners** can consider them to enhance school route safety

R10: **Planners** should be able to draw school routes on a map and add customizable icons (e.g. for bus stops).

R11: The system should deliver final map-based school route plans as PDF.

R12: The system should provide a georeferenced base map already annotated with crossings, bus stops, and speed limits, so **planners** no longer add these manually

R13: The system should allow **children/parents** to log fear zones with pictogram pins in addition to danger spots

4.4 Design Artifacts

After the Semi-Structured Interview, we were able to create wireframes of the system based on **O1–O11**. The system is divided into two parts. Planners use the system on their desktop computer, while parent-child dyads and mobility experts can participate in the planning process via their smartphone. This sub-subsection focuses on a walkthrough of how the users would interact with the app. Later we will focus on how these individual processes fulfill our list of requirements in more detail.

4.4.1 Wireframes for Mobile App

The smartphone app targets two primary user groups: the parent–child dyads (see Sections 4.1.2.2 and 4.1.2.3) and the mobility experts (see Section 4.1.2.4). It comprises two main components: a questionnaire and a live-tracking with danger-spot reporting module. Mobility experts will focus primarily on the danger-spot reporting page, while parent–child dyads will use all features.

Upon launching the app, parent–child dyads first encounter a welcome screen with instructions for the upcoming questionnaire. After tapping the "Start" button, they proceed to the questionnaire screen, where they enter details about their daily school route (e.g., departure time, mode of transport, known hazards). Once the questionnaire is completed, the app displays a screen with instructions for the live inspection, prompting users to mark and report danger spots on their route.

Figure 4.1: Wireframes of the app for parent-child dyads representing general information and the survey to be answered by parent-child dyads cf. **R1, R8**.

While parent-child dyads have to finish the questionnaire, the mobility experts can access the route-tracking page shown in Figure 4.2 (left) right away. From here parent-child dyads can record their route from their home to school. If they notice a dangerous spot, they can report it which leads them to a page like in Figure 4.2 (right). Here they can provide further information about this danger spot. Mobility experts report dangerous areas whenever they encounter one on their daily schedule.

4.4.2 Wireframes for Planner Desktop App

The desktop app's target group are planners, i.e. municipal employees and, where applicable, employees of the schools themselves. For authentication, we provide a login-page shown in Figure A.1. After the login, the user lands on a home-page providing information e.g. about new data from questionnaires (Figure A.2).

Figure 4.2: Wireframes of the app for parent-child dyads / experts representing a map screen as well as a screen to record the route taken to school and danger spots.

From here the user can access the planning overview screen (Figure 4.3 (left)). Here the user has an overview of all created plans and can see their progress. The user can also create a new plan as shown in Figure A.3. The core of the app is the planning view (Figure 4.3 (right)). Here planners can see all incoming data (from surveys, inspections, and danger reports) for a specific (school) district. Furthermore, the planning view offers map information such as speed limits, bus stop locations and crossings. Based on visualizing all these data at a glance, planners can draw a school route plan supported by the system.

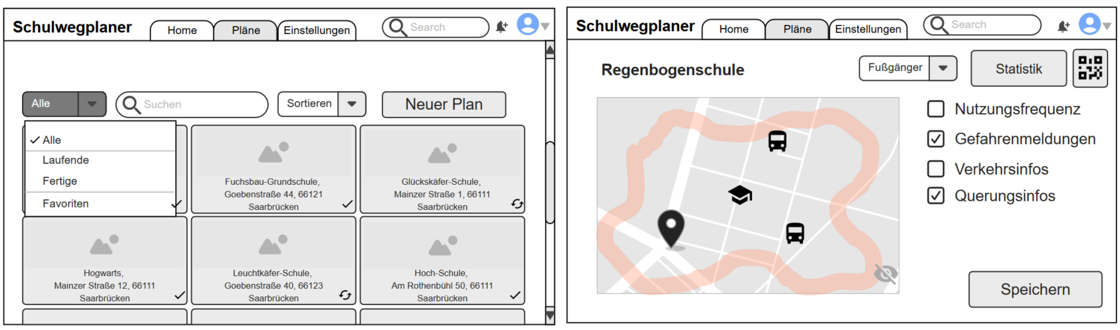

Figure 4.3: Wireframes of the system for planners representing i) an overview of existing school route plans and several filters (left) the planning view with a map, and possibilities to show relevant planning information such as frequencies of routes taken as a heatmap, danger spots, and several traffic information (right).

4.4.2.1 Adjustments Based on Evaluation

Since the wireframes and the overall concept was received well, we did not have to make any adjustments to our prototype and could start our implementation based on our findings.

5 Implementation and System Development

This chapter presents the HCD development and implementation of the school route planning system, emphasizing frontend design decisions that directly address user needs identified in the research phase in chapter 4. The implementation follows HCD principles by iteratively translating user requirements into functional interfaces and technical solutions. The result is a software prototype. The focus of this work is the frontend implementation. The backend was implemented as part of a different thesis.

5.1 Technical Concept and Architecture

In this Section, we present the overall technical concept and system architecture underlying the school route planning prototype.

5.1.1 System Architecture Overview

Figure 5.1 presents the system architecture of the school route planning prototype and indicates which general requirements are addressed by each frontend application. The desktop application implements requirements **R4** and **R5**, while the smartphone application fulfills requirements **R1**, **R2**, and **R3**. Only the general requirements are depicted in this overview; the complete requirement mapping is provided in Section 4.3.2.

Both frontend applications communicate with a centralized backend through a REST API. The backend (not part of this work) manages data storage and retrieval for all system entities, including danger spot reports, route geometries, questionnaire responses, and finalized school route plans. The system integrates with OpenStreetMap services to provide geographical data and map rendering capabilities for both planning and data collection functions. This architecture ensures separation of concerns between user interfaces while maintaining consistent data handling across all system components.

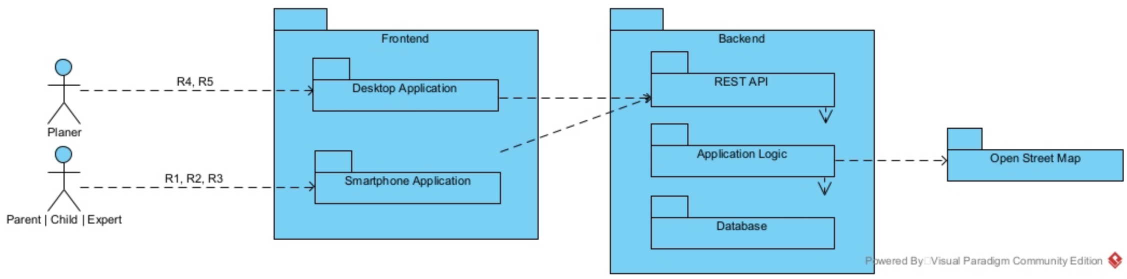

Figure 5.1: System overview showing the main components of the system and their interconnection.

5.1.2 Technology Stack and Framework Selection

This Section outlines the core technology stack and framework selections that form the basis of the system implementation. The choices for frontend, backend, and API layers were made to ensure robust performance, maintainability, and straightforward integration between components.

1. **Frontend**
   - **Framework:** Angular 19 (TypeScript)
   - **Styling:** SCSS for styling; Bootstrap 5 and FontAwesome for layout and icons
   - **Mapping:** Leaflet (including Leaflet-Draw, Leaflet-Heat, Leaflet-TextPath) for interactive maps
   - **Charts:** Chart.js (via ng2-charts) for heatmaps and statistics.
   - **QR:** angularx-qrcode for questionnaire distribution.
   - **Build/Serve:** Angular CLI with production/development configurations; SSL enabled for local dev (zielsicher.pem).
2. **Backend**
   - **Framework:** Spring Boot 3.5.0 on Java 17 as Maven project
   - **Web:** spring-boot-starter-web with Jackson Afterburner and JSR-310 for JSON and date/time support.
   - **Security:** spring-boot-starter-security plus JWT (jjwt-api/impl/jackson) for stateless authentication.
   - **Data:** spring-boot-starter-data-jpa with Hibernate Spatial (jts-core 1.20.0) and PostgreSQL driver (42.7.3).
   - **PostGIS:** PostgreSQL PostGIS extension for advanced spatial queries and indexing.
   - **Lombok:** Project Lombok for reducing boilerplate in domain models.
   - **Caching:** spring-boot-starter-cache with Ehcache 3 for in-memory caching of frequent queries (e.g. hotspot data).
   - **Logging:** spring-boot-starter-log4j2.
3. **API Layer**
   - **Protocol:** REST over HTTPS, JSON payloads, using Spring MVC controllers.
   - **Schema:** Request/response DTOs
   - **Security:** JWT bearer tokens

5.1.3 Directory and File Structure

The project root contains three TypeScript configuration files:

- `tsconfig.json`: Base configuration targeting ES2022 with Angular compiler options and strict settings.
- `tsconfig.app.json`: Application build settings for the Angular CLI.
- `tsconfig.spec.json`: Testing configuration with Jasmine and Angular-specific typings.

The `src/` directory includes:

- `main.ts`: Bootstraps the Angular application via `bootstrapApplication`, and imports global providers (e.g., Bootstrap JS bundle).
- `index.html`: Application shell incorporates `<app-root>`.
- `styles.scss`: Global SCSS defining CSS custom properties (colors, spacing, utilities).
- `app/`: Main application code, organized as follows:
  - `core/`
    - `constants/` – Application constants for different Leaflet map layers (pedestrian and bicycle).
    - `services/` – Singleton services (e.g., `planAPI.service.ts`, `auth.service.ts`, `questAPI.service.ts`).
  - `environments/` – Environment-specific configuration files (`environment.ts`).
  - `interceptors/` – HTTP interceptors for auth tokens, error handling, and request logging.
  - `models/` – TypeScript interfaces and enums (e.g., `tracking.ts`, `QuestType.ts`, `SurveySteps.ts`).
  - `pages/` – Page-level components mapped to routes:
    - `plan-page/` (`plan-page.component.ts, .html, .scss, .spec.ts`)
    - `quest-page/` (`quest-page.component.ts, .html, .scss, .spec.ts`)
    - `settings-page/`, `report-page/`, `students-page/`, etc.
  - `shared/`
    - `components/` – Reusable UI components (navbar, sidebar).
    - `directives/` – Custom directives (e.g., `disable-right-click.directive.ts`).

    * `modals/` – Modal dialogs (e.g., `submit-track-modal/`, `statistic-modal/`, `add-quest-modal/`).

  - `app.config.ts` – Application-wide providers and configuration.
  - `app.routes.ts` – Route definitions.

5.1.4 Angular Modules and Components

The application leverages Angular's standalone-component pattern. In `src/main.ts`, the call

```
bootstrapApplication(AppComponent, appConfig)
```

initializes the root and all standalone components with global providers.

- **AppComponent** (`standalone: true`):
  - Selector: `app-root`
  - Template: contains the primary `<router-outlet>`
  - Providers: defined in `appConfig` (HTTP interceptors, core services)
- **Page Components**: Each route is backed by a standalone page component under `src/app/pages/`, for example:
  - `PlanPageComponent` (`plan-page.component.ts`)
  - `QuestPageComponent` (`quest-page.component.ts`)
  - `SettingsPageComponent`, `ReportPageComponent`, `StudentsPageComponent`, etc.
- **Modal Components**: Multiple modals provide dialogs across the app. All are standalone:
  - `SubmitTrackModalComponent` (`app-submit-track-modal`):
    * Imports: none (uses global Bootstrap CSS/JS)
    * Template/`.scss`/`.spec.ts` in `shared/modals/submit-track-modal/`
    * Injects `SurveyAPIService`, `ActivatedRoute`, `Router`
  - `StatisticModalComponent` (`app-statistic-modal`):
    * Imports: `CommonModule`, `BaseChartDirective` (ng2-charts)
    * Template/`.scss` in `shared/modals/statistic-modal/`
    * Injects `QuestAPIService`, configures bar, pie, line charts

- Additional modals in `shared/modals/`:
  * `AddQuestModalComponent`
  * `DeleteConfirmationModalComponent`
  * `ReportExportModalComponent`
  * ...

- **Shared Components**: Reusable UI parts under `src/app/shared/components/`, such as:
  - `NavbarComponent`, `SidebarComponent`
- **Core Services** (`src/app/core/services/`): `PlanAPIService`, `QuestAPIService`, `AuthService`, `LayersService`, etc.
- **Shared Directives** (`src/app/shared/directives/`): `DisableRightClickDirective`

5.1.5 Services and Dependency Injection

All services are implemented as singletons in `src/app/core/services/` and utilize constructor-based injection to share state and reuse the HTTP client.

- **SurveyAPIService**:
  - Methods: `createRecording()`, `getSurvey()`, `updateSurvey()`
  - Responsibilities: Handles CRUD operations for survey data.
- **QuestAPIService**:
  - Methods: `getEvaluation()`, `submitResponses()`
  - Responsibilities: Retrieves questionnaire statistics and submits user responses.
- **PlanAPIService**:
  - Methods: `getPlans()`, `createPlan()`, `deletePlan()`
  - Responsibilities: Manages school route plans.
- **AuthService**:
  - Methods: `login()`, `logout()`, `getUser()`
  - Responsibilities: Handles authentication tokens and user session management.
- **LayersService**:
  - Methods: `getMapLayers()`, `toggleLayer()`

  - Responsibilities: Provides map layer configurations and visibility controls.

Each service is provided in the root injector (via `@Injectable(providedIn: 'root')`) to ensure a single shared instance across the application. This design supports efficient HTTP client reuse, centralized error handling, and consistent application state.

5.1.6 Component Communication and State Management

- **Property Binding**: Parent components pass data to children using `@Input()` decorators, for example:
  - `@Input() tracking?: Tracking`
  - `@Input() surveyString?: string`
- **Event Emission**: Child components notify parents via `@Output()` and `EventEmitter`, e.g.,
  - `@Output() onSubmit = new EventEmitter<Tracking>()`
  - Emitted events trigger parent workflows such as navigating to the next page.
- **Router Navigation**: Uses Angular's `ActivatedRoute` to read route parameters and `Router.navigate()` to perform programmatic navigation between pages and modals.
- **Reactive Streams**:
  - Components subscribe using `.subscribe()` for real-time updates.
- **Modal Control**: Bootstrap modals are instantiated and controlled by referencing the DOM element:
  - `const modal = bootstrap.Modal.getInstance(element);`
  - `modal.show()` and `modal.hide()` manage visibility.

5.1.7 Styling Architecture

- **Global Styles (`styles.scss`)**: Defines CSS custom properties (e.g., `-color-primary`, `-color-background`), global resets, and utility classes.
- **Component SCSS**: Scoped styles adjacent to each component for modularity and encapsulation.
- **Design System**: Semantic color variables, hover states for interactive elements.
- **External Dependencies**: Bootstrap 5 for layout and modals.

5.2 Frontend Implementation

The frontend is the main focus of this work. As already mentioned in Section 5.1.2 it was implemented with Angular. The application is divided into the desktop view and the mobile view. The following description shows how the requirements defined in Section 4.3.2, alongside the user needs elaborated in Section 4.3.1, were translated into frontend features.

5.2.1 System Sequence Overview

Figure 5.2 illustrates the end-to-end interaction among planners, parent–child dyads, and the system components.

The process begins with a planning phase, during which the planner uses the desktop application to define a new school-route plan and generate an associated questionnaire. Upon successful creation, the system enters into a distribution phase, issuing a QR code that grants parent–child dyads access to the questionnaire and enables GPS-based route tracking via the smartphone application.

Next, a data collection phase captures both questionnaire responses and live tracking data. Once sufficient data are collected, the planner proceeds to a analysis phase, reviewing submitted responses and GPS traces to refine and finalize the school-route plan. Finally, in a final distribution phase, the completed route plan is exported (as a PDF document) and disseminated to the school community for implementation.

By aligning these phases in a single sequence diagram, Figure 5.2 provides a depiction of stakeholder interactions, system operations, and data flows throughout the application life cycle.

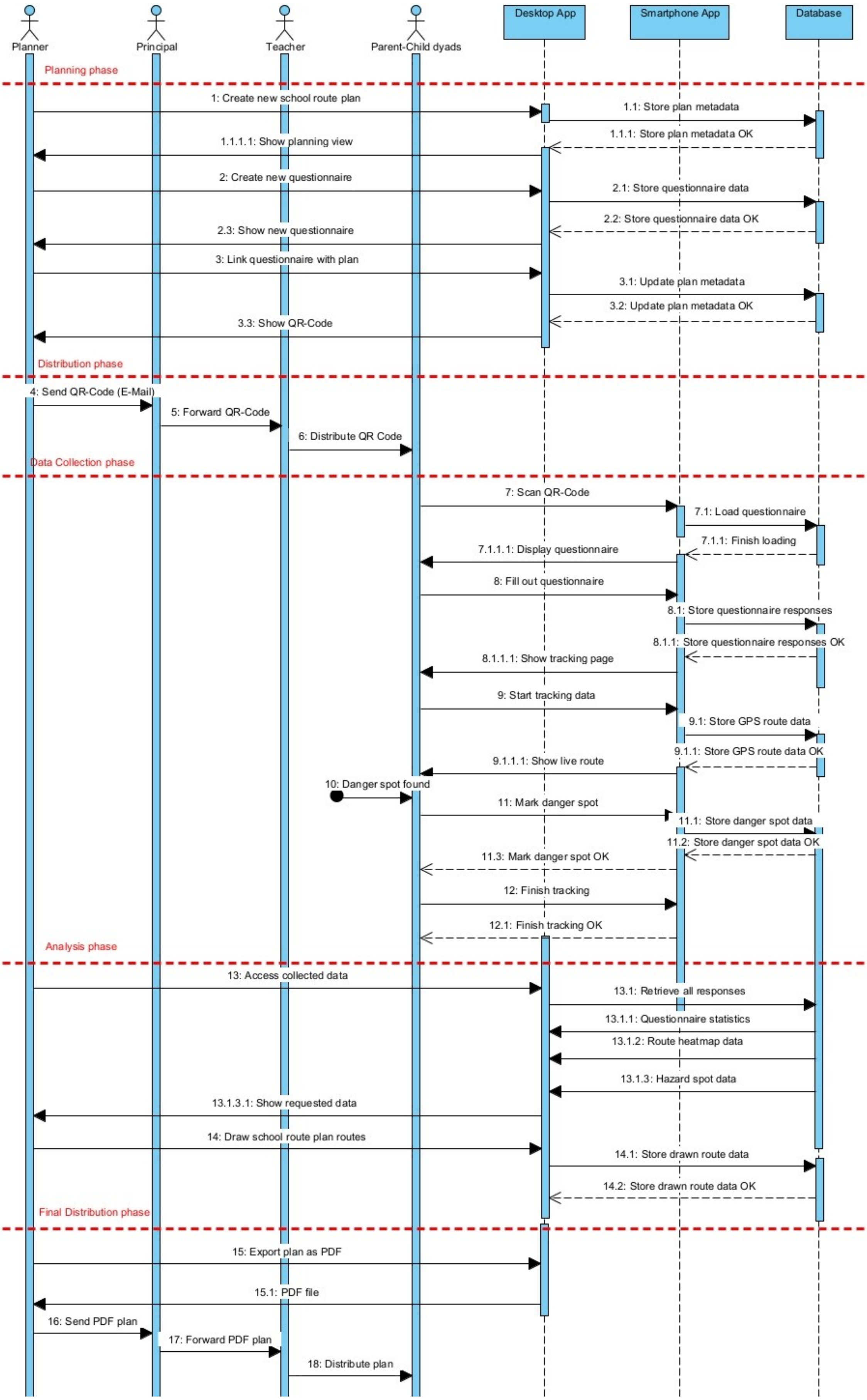

Figure 5.2: Sequence diagram overview of application

5.2.2 Desktop Implementation

The desktop application targets planners, such as municipal staff exemplified by the persona Dascha (4.1.3.1). Its feature set reflects the information management and planning needs associated with project oversight at a municipal level.

5.2.2.1 Home Page

The home page functions as the default landing page following authentication (see Section 5.2.2.5) and remains accessible via the application's toolbar.

Feature - Plan Management Dashboard The home page provides planners with a consolidated overview of all created school route plans, addressing **R4**. It supports the visualization of both completed and ongoing planning projects in accordance with **R6**.

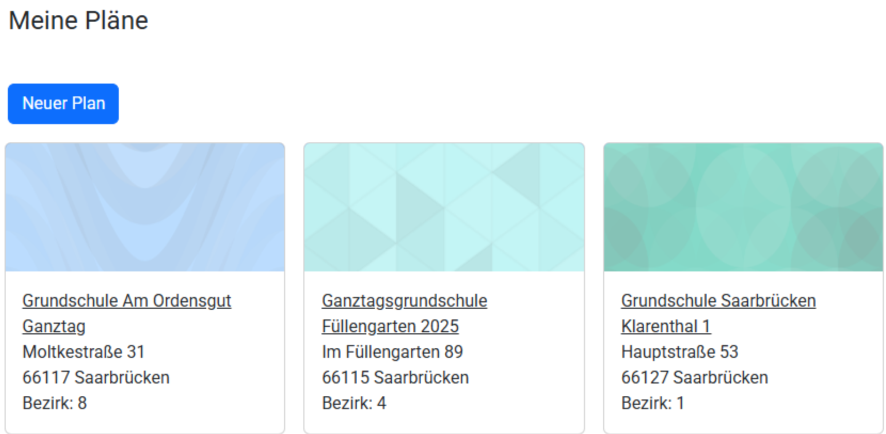

Figure 5.3: Home page snippet of three created plans and their general information.

Figure 5.3 presents the interface, listing existing plans alongside core information such as school name, address, district, and plan description. This layout enables users to navigate to a plan's detailed planning page (cf. Section 5.2.2.2) for further action.

Feature - New Plan Creation The interface includes a button for plan creation, which, when selected, triggers the modal dialogue depicted in Figure 5.4. This process streamlines the creation of new school route plans by guiding users through the input data. Figure B.1 displays a comprehensive overview of this interface component.

Human-Centered Usage Scenario Dascha (see Persona 4.1.3.1) uses this page to obtain a quick overview of all her plans, addressing her need to manage multiple projects across different schools with efficient prioritization and progress tracking. Given her heavy workload and bureaucratic constraints, she requires immediate access to plan status information and the ability to create new plans without navigating through complex menu structures. The design responds to her frustration with inefficient systems by presenting all

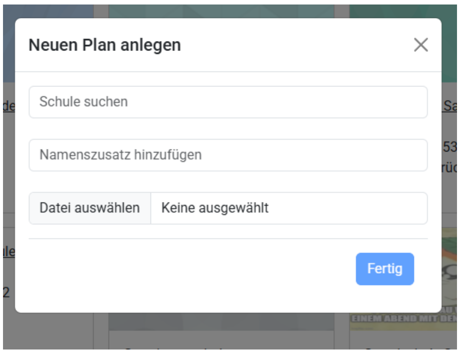

Figure 5.4: Modal to create a new plan for a specific school.

essential information at a glance, while the single-click access to plan details and creation functions aligns with her time-pressured work environment. This implementation directly addresses her user need to "view all existing and ongoing school route plans with their status because managing multiple projects across different schools requires efficient prioritization and progress tracking."

5.2.2.2 Planning Page

Upon selecting a plan on the home page (Section 5.2.2.1), the planner is presented with the Planning Page, which facilitates the creation and refinement of digital school route plans (**R5**). A georeferenced base map displays the school district boundary, school location, pedestrian crossings, bus stops, and speed-limit zones, eliminating the need for manual annotation (**R12**). Figure B.2 provides a full-page overview of the planning interface.

Feature - Route Drawing Toolbar A drawing toolbar (Figure 5.5) enables planners to sketch and edit school routes directly on the map. Customizable icons (for example, stop signs or crosswalk symbols) may be added to highlight specific route features (**R10**).

Figure 5.5: Toolbar of Planning Page with pen and customizable icons.

Feature - Traffic Data Visualization Official traffic infrastructure and hazard reports submitted by parent–child dyads or experts are overlaid on the map (Figure 5.6). This combined display of real-world danger spots and municipal data supports informed decision-making to enhance student safety (**R9**).

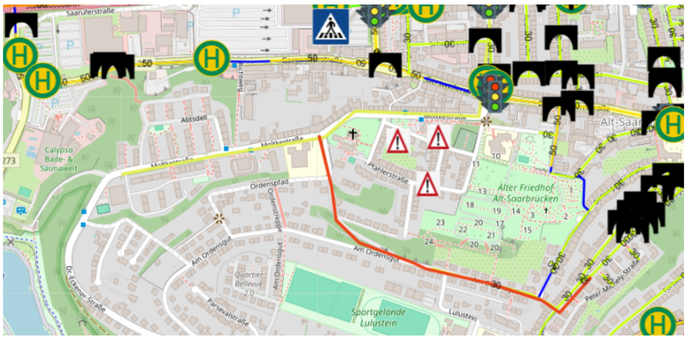

Figure 5.6: Overview of different map data (districts, bus stops, drawn routes and more.

Feature - Route Frequency Heatmap A heatmap layer (Figure 5.7) visualizes the frequency of actual routes taken by parent–child dyads (**R7**). Planners use this empirical data to identify high-traffic corridors and optimize proposed school routes.

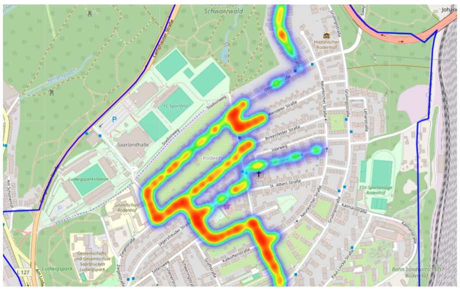

Figure 5.7: Heatmap showing frequency of routes taken by parent-child dyads.

Feature - QR Code Generation To initiate data collection, planners attach a preconfigured questionnaire to the current plan and generate a QR code (Figure 5.8). Distributing this code to parent–child dyads grants them access to the questionnaire and live GPS tracking session for the specified school.

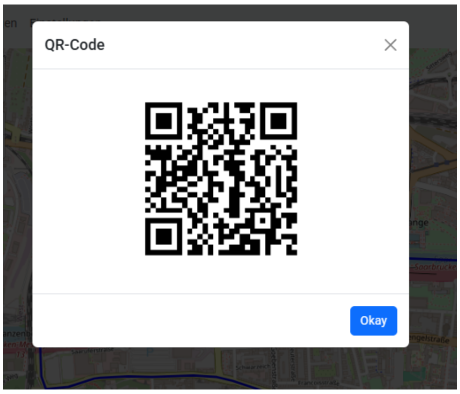

Figure 5.8: QR code generated for a specific school route plan.

Feature - Questionnaire Statistics Dashboard A statistics dashboard (Figure 5.9) presents aggregated survey results, including transportation modes and demographic information collected via the questionnaire (**R8**). This summary view aids planners in identifying patterns and tailoring route recommendations.

Figure 5.9: Modal to create a new plan for a specific school.

Feature - Export Once route planning is complete, the finalized map (with all overlays and annotations) can be exported(**R11**). We decided to use PNG instead of PDF, for more practicality.

Human-Centered Usage Scenario Dascha (see Persona 4.1.3.1) uses the Planning Page daily to streamline her workflow. Upon opening the page, she immediately sees relevant background layers (crossings, bus stops, speed limits, and community-reported hazard data) in one view. This directly addresses her need to "access relevant background data such as crossings, bus stops, and traffic statistics in one centralized location because manually collecting information from multiple municipal departments is both time-consuming and error-prone, preventing her from completing more than 2–3 plans per year."

She relies on the route frequency heatmap to prioritize safe pathways and uses the drawing toolbar to refine routes, satisfying her requirement to "create and edit school route plans quickly and accurately because her municipal role encompasses many responsibilities beyond route planning, and slow bureaucratic processes already constrain her ability to deliver timely safety improvements to schools."

Generating a QR code and distributing it to families ensures efficient data collection without paperwork, while the statistics dashboard and PDF export enable her to analyze results and share final plans rapidly.

5.2.2.3 Questionnaire Page

Accessible from the main navigation bar, the Questionnaire Page enables planners to manage and distribute custom surveys to parent–child dyads, gathering essential data on daily school routes.

Feature - Questionnaire Dashboard On this page the planner has an overview of all created questionnaires. There is a possibility to quick view all questionnaires with a carousel. The system should allow planners to obtain further information from parent-child dyads such as transportation methods and basic demographics (**R8**).

Figure 5.10: Overview of created questionnaires

Feature - Flexible Questionnaire Builder Recognizing that each school's context differs (urban versus rural settings, varying topography, and distinct safety concerns (Section 2.1.5)),the system offers a dynamic builder. Planners assign a unique name to each questionnaire and add any number of questions using input types such as *checkbox*, *dropdown*, *radiobutton*, *numeric*, *textarea*, and *textfield*. Figure 5.11 illustrates the creation of a *radio − button* question. Saved questions appear immediately in the questionnaire overview (Figure 5.12), supporting iterative refinement based on school feedback.

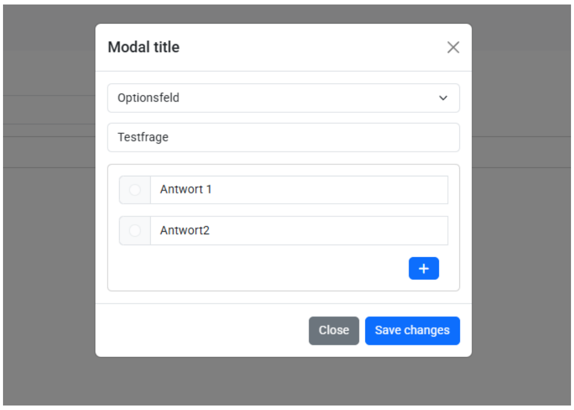

Figure 5.11: Modal to create new question.

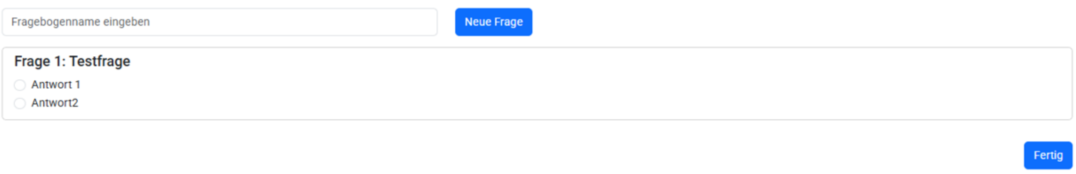

Figure 5.12: Create questionnaire overview.

Human-Centered Usage Scenario Dascha (see Persona 4.1.3.1) relies on the Questionnaire Page to tailor surveys to each school's needs and incorporate stakeholder feedback.

By selecting from general templates or building new questionnaires on demand, she responds to evolving school requirements efficiently.

5.2.2.4 Settings Page

Accessible via the main navigation tab, the Settings Page allows planners to manage custom point of interest (POI)s used throughout the application.

Feature - POI Management Dashboard The dashboard lists all existing POI in an editable table (Figure 5.13), enabling planners to review and modify each entry.

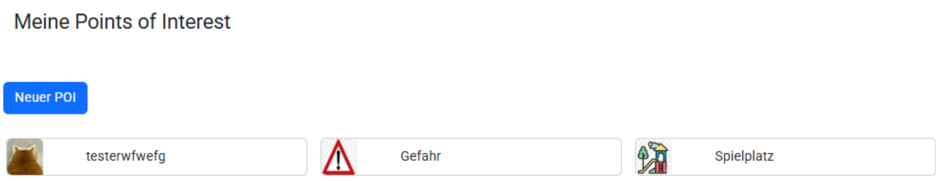

Figure 5.13: Overview of POI page

Feature – Custom POI Creation Planners can define new POI using customizable icons (**R10**), choosing symbols that match local landmarks or hazards. Figure 5.14 shows the creation modal. Once saved, these icons become available in the planning toolbar (see Figure 5.5), supporting context-specific map annotations.

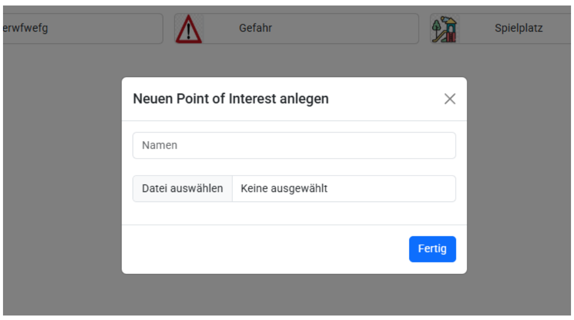

Figure 5.14: Modal to create a new POI

Feature – Drag-and-Drop POI Placement After creation, POI appear in the Planning Page toolbar for direct placement on the map via drag-and-drop. This interaction meets Dascha's need to annotate routes with meaningful landmarks quickly, reducing the time spent manually aligning map markers.

Human-Centered Usage Scenario Dascha (see Persona 4.1.3.1) frequently adds and removes POI to reflect each school's unique environment. By managing POI in one interface, she ensures that parents and children can interpret maps accurately, while maintaining her capacity to update icons (such as hazard markers) across multiple plans without repetitive data entry.

5.2.2.5 Login Page

The Login Page serves as the entry point to the application (Figure B.4). Upon successful authentication, users are redirected to the Home Page (Section 5.2.2.1).

Human-Centered Usage Scenario Each morning, Dascha (see Persona 4.1.3.1) launches the application and enters her credentials. She occasionally shares account access with trusted colleagues to distribute workload, but the authentication mechanism ensures that only users with valid credentials can view or modify planning data. This design meets her requirement to protect sensitive geographic and survey information from unauthorized access.

5.2.3 Mobile Implementation

The mobile application targets parent–child dyads (e.g., Johannes and Lea; Section 4.1.3.2, 4.1.3.3) and mobility experts (e.g., Mira; Section 4.1.3.4). It supports data collection via questionnaires and hazard reporting.

5.2.3.1 Questionnaire Pages

Accessed by scanning the QR code generated on the Planning Page (Figure 5.8), the Questionnaire Pages guide participants through survey completion and live route tracking.

These pages are mainly for parent-child dyads, but mobility experts can access them as well, if wanted.

Feature – Step-by-Step Instructions An initial instruction screen (Figure 5.15) explains the purpose and steps of the questionnaire, ensuring that users with varying digital literacy can complete the survey correctly (**R8**).

Feature – Embedded Questionnaire Interface The main questionnaire screen (Figure 5.16) presents dynamically generated questions (such as transportation mode or perceived "fear zones") and captures responses in a mobile-optimized format. Upon submission, data are sent directly to the backend for planner review.

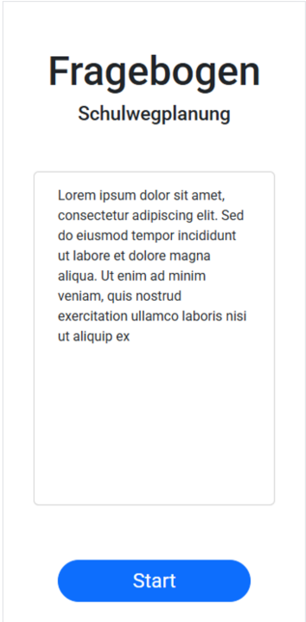

Figure 5.15: Instruction Page

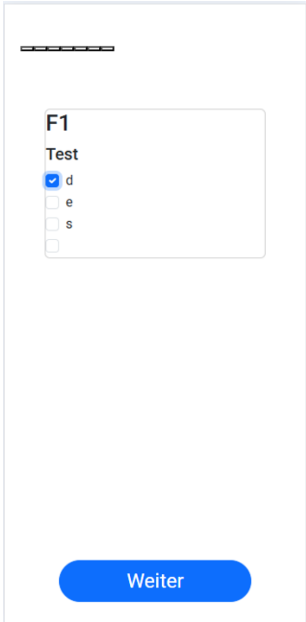

Figure 5.16: Questionnaire Page

Figure 5.17: Instruction and Questionnaire Pages of the Mobile App

Human-Centered Usage Scenario Johannes (see Persona 4.1.3.2) and Lea (see Persona 4.1.3.3) completed the questionnaire as a home exercise and reported that the clear instructions and simple interface motivated their participation. Lea, in particular, appreciated the ability to mark both "danger spots" and "fear zones" on the map, meeting her need to highlight areas that influence her willingness to walk to school.

Mira (see Persona 4.1.3.4) often bypasses the survey and proceeds to the hazard-reporting screen (Section 5.2.3.2), in line with her need "to report dangerous areas on the go because she often notices safety issues while moving through the community" and "to submit observations without navigating complex menus because she has limited digital skills and values simplicity" .

5.2.3.2 Tracking Pages

The Tracking Pages are available immediately to mobility experts, while parent–child dyads gain access only after submitting the questionnaire (see Section 5.2.3.1).

Feature – Privacy-Preserving Route Tracking Parent–child dyads initiate daily school-route tracking via a mobile map interface (Figure 5.19). To protect home-location privacy, users are instructed to begin recording a short distance from their residence. The initial segment is automatically discarded nevertheless. As the dyad proceeds toward school, live GPS data are captured. Planners leverage these trackings to generate heatmaps (see Figure 5.7).

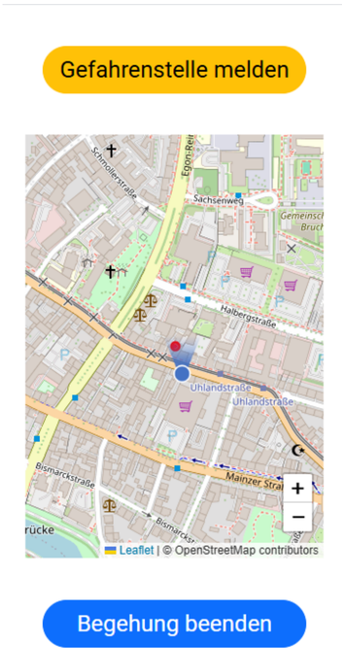

Figure 5.18: Tracking Page

Figure 5.19: Report Page

Feature – Immediate Danger Reporting When a dangerous spot is encountered en route, dyads can tap the "Gefahrenstelle melden" button to open a dedicated reporting form (Figure 5.18). Submitted danger-spot reports, optionally supplemented with text descriptions or photos, are sent to planners for review.

Human-Centered Usage Scenario Johannes (see Persona 4.1.3.2) and Lea (see Persona 4.1.3.3) found the map interface and one-tap reporting highly intuitive. Johannes valued the ability to log hazards in real time without disrupting their walk, while the exercise of identifying danger spots turned their routine route into an engaging activity. This practice not only reinforced Lea's familiarity with her daily path to school but also revealed previously unnoticed safety risks.

Mira (see Persona 4.1.3.4) often skips the questionnaire and goes straight to route tracking. She values the clear privacy guidance and the quick "Report Danger" workflow, allowing her to document safety issues immediately during her field observations.

5.3 Frontend-Backend Communication

The frontend applications access backend services via a versioned REST API. Below the endpoints are categorized and summed up into tables.

5.3.0.1 /api/data

This endpoint group provides general reference data required by both frontend applications. It exposes the current Overpass API version, a list of all schools, and points of interest (POI). Individual POI records can be retrieved by ID, and new POI entries can be created or removed. These routes support the initial data lookup and management workflows in the desktop and mobile clients.

Operation	Method	Endpoint	Description
Get API version	GET	/version	Returns current OverpassAPI version as string.
List all schools	GET	/schools	Returns list of schools in a metadata-wrapped response.
List all POIs	GET	/poi	Returns list of all points of interest (POIs).
Get single POI by ID	GET	/poi/{id}	Returns a single POI by its ID.
Delete POI by ID	DELETE	/poi/{id}/delete	Deletes the specified POI and returns empty response metadata.
Create new POI	POST	/poi/create	Creates a new POI from supplied JSON request body and returns the created POI.

Table 5.1: DataController REST Endpoints

5.3.0.2 /api/auth

The authentication endpoints handle user login and logout. The login route accepts credentials, delegates to the authentication service, and returns a JWT-bearing response entity. The logout route invalidates the current session token. These secured routes ensure that only authenticated users with the appropriate roles can access protected resources.

Operation	Method	Endpoint	Description
User login	POST	/api/auth/login	Authenticates user and returns JWT in response entity.
User logout	POST	/api/auth/logout	Invalidates current user session and returns empty response metadata.

Table 5.2: AuthController REST Endpoints

5.3.0.3 /api/survey

Survey endpoints drive the parent–child questionnaire and recording workflows. Clients retrieve the questionnaire by survey string, submit questionnaire answers and GPS/hazard recordings under a session cookie, and query survey progress. Additional routes evaluate completed questionnaires and retrieve associated heatmap or danger-spot data. A session-creation endpoint issues a new surveySession cookie to track individual participation.

Operation	Method	Endpoint	Description
Get questionnaire by survey string	GET	/getQuestionnaire/{surveyString}	Returns the questionnaire for the specified survey.
Submit questionnaire responses	POST	/submitQuestionnaire/{surveyString}	Saves questionnaire answers; requires surveySession cookie.
Submit recording data	POST	/submitRecording/{surveyString}	Saves recorded movement and hazard data; requires surveySession cookie.
Get survey progress	GET	/progress	Returns current survey progress; optional surveySession cookie.
Evaluate questionnaire	GET	/evaluate/{surveyString}	Returns evaluation results for the specified survey.
Get heatmap data	GET	/heatmap/{surveyString}	Returns heatmap data for the specified survey.
Get danger spots	GET	/dangerspots/ {surveyString}	Returns reported danger spots for the specified survey.
Create survey session	POST	/session	Creates a new survey session and sets surveySession cookie.

Table 5.3: SurveyController REST Endpoints

5.3.0.4 /api/layers

Layer endpoints deliver various map overlays scoped to a geographic area. For a given district ID, bus stops, speed limits, and intersection data are fetched from Overpass via the layers service. A separate route returns district boundary coordinates for a specified school. These routes populate the map components used in planning and field data collection.

Operation	Method	Endpoint	Description
Get bus stops by district ID	GET	/busstops/{districtId}	Returns list of bus stops for the specified district.
Get speed limits by district ID	GET	/speeds/{districtId}	Returns speed limit data for the specified district.
Get crossings by district ID	GET	/crossings/{districtId}	Returns intersection data for the specified district.
Get district boundaries by school ID	GET	/districts/{schoolId}	Returns district boundary geometry for the specified school.

Table 5.4: LayersController REST Endpoints

5.3.0.5 /api/planning

Planning endpoints enable creation and management of questionnaires and school-route plans. Clients can create, retrieve, list, and delete questionnaires and plans. Preview images for plans are served as byte arrays. Additional PATCH and DELETE endpoints support adding questionnaires to plans and managing user-drawn route sketches. A placeholder PDF-generation route is included for future implementation.

Operation	Method	Endpoint	Description
Create questionnaire	POST	/questionnaire	Creates a new questionnaire.
Get questionnaire by ID	GET	/questionnaire/{id}	Returns the questionnaire with the given ID.
List all questionnaires	GET	/questionnaires	Returns all questionnaires.
Get plan preview image	GET	/{planId}/previewImage	Returns preview image for specified plan as byte array.
Delete plan by ID	DELETE	/{planId}/delete	Deletes the specified plan.
List all plans	GET	/all	Returns all plans.
Get plan by ID	GET	/{planId}	Returns the specified plan.
Create new plan	POST	/create	Creates a new plan.
Add questionnaire to plan	PATCH	/{planId}/addQuestionnaire	Adds a questionnaire to the specified plan.
Get plan drawing	GET	/{planId}/drawing	Returns drawing for the specified plan.
Save plan drawing	POST	/{planId}/drawing	Saves drawing for the specified plan.
Delete plan drawing	DELETE	/{planId}/drawing/delete	Deletes drawing for the specified plan.

Table 5.5: Planning Controller REST Endpoints

5.4 Reflection on Human-Centered Implementation

In this Section, we examine how the HCD goals shaped each stage of implementation.

5.4.1 Requirements Traceability

Each user requirement defined in Chapter 4 maps directly to implemented frontend features. Experts conducting school route inspections can pin georeferenced danger spots using the hazard-marker tool, satisfying **R1.i** and **R2**. Parent–child dyads record both danger spots (**R2**) and their actual walking routes via integrated GPS tracing to capture real-world travel patterns (**R3**), enabling collaborative planning (**R1.ii**). Planners access a unified dashboard listing all school route plans, fulfilling **R4** and **R6**. The interactive map interface supports creation and editing of digital plans (**R5**), overlays heatmap visualizations of route frequency (**R7**) and aggregated hazard reports combined with official traffic data (**R9**), and displays derived data (**R8**). Custom POI icons (e.g., bus stops) can be added directly on the map (**R10**), and the final annotated route plan is exported (**R11**).

A pre-annotated base map with crossings, speed limits, and bus stop layers removes manual drawing tasks (**R12**), while dedicated pictogram pins allow logging of subjective fear zones by children and parents (**R13**).

5.4.2 Design Decision Rationale

The implementation choices described above were continually evaluated against the HCD goals and user requirements established in Sections 4.3.2 and 4.3.1. Key reflections include:

5.4.2.1 Empathy-Driven Feature Prioritization

Features such as the consolidated data layers on the Planning Page and the dynamic questionnaire builder directly responded to Dascha's expressed need to "access relevant background data such as crossings, bus stops, and traffic statistics in one centralized location because manually collecting information from multiple municipal departments is both time-consuming and error-prone, preventing her from completing more than 2–3 plans per year". This focus on reducing administrative overhead proved essential to user satisfaction.

5.4.2.2 Iterative Validation with Personas

The regular validation with the help of personas, helped ensure that the QR code–driven mobile workflow and heatmap visualizations met real-world needs.

5.4.2.3 Balancing Flexibility and Structure

The Flexible Questionnaire Builder offered the adaptability required for diverse school contexts, while maintaining a consistent data schema for planner analysis. This balance ensured both user autonomy in survey design and reliable backend processing.

5.4.2.4 Technical Decisions as Enablers of HCD

Choosing component-based frameworks (Angular, Spring Boot) and interactive mapping tools facilitated rapid prototyping and feature iteration.

6 Discussion and Limitations

The preceding evaluation demonstrates that the HCD, web-based approach to school route planning delivers significant improvements in efficiency, data quality, and user satisfaction. However, several points merit critical discussion and highlight limitations that should be addressed in future work.

6.1 Discussion

The preceding evaluation confirms that a HCD, web-based frontend can enhance efficiency, data quality, and user satisfaction in school route planning. Beyond these improvements, the application's design aligns closely with several findings from Chapter 3:

First, participatory mapping approaches (highlighted by Gerlach et al. as critical for contextual accuracy) are supported by the tool's stakeholder interview and annotation features. Users can pin hazards and comment on route segments, operationalizing the co-creation methods recommended in recent participatory GIS studies. This digital co-design capability extends on the paper-based checklists of Bundesanstalt für Straßenwesen, enabling asynchronous, location-based feedback loops that Gerlach et al. identified as missing in 2007.

Second, international research underscores the value of integrating real-time data streams (such as live traffic and weather alerts) to adapt routes dynamically [10]. While the current prototype uses static layers, its modular architecture permits future integration of APIs (e.g., city traffic feeds or crowd-sourced incident reports). This potential addresses the temporal clustering of accidents at school commute peaks noted by Destatis [33].

Finally, route planning can be accommodated by the application's layer toggle system. By adding public-transport schedules or bike-lane quality indices, the frontend can embody the mobility concepts recommended by BASt and ETSC, supporting seamless transitions between walking, cycling, and transit modes.

6.2 Limitations

1. **Incomplete Backend Coverage:** The backend design is omitted from this thesis, as it is detailed in a companion work. Consequently, API specifications, security measures, and performance benchmarks were not evaluated here.

2. **Qualitative-Only Evaluation:** Usability testing was confined to qualitative sessions without standardized benchmarks. Objective performance indicators and usability scores remain undetermined.

3. **Sample Bias:** User research involved only two expert interviews, three planner interviews, and one small focus group. This limited sample undermines generalizability and risks demographic and professional bias.

4. **Privacy and Security Considerations:** Detailed analysis of GPS data handling for minors, consent workflows, and encryption methods was not conducted.

5. **Accessibility Compliance:** No systematic evaluation against WCAG or similar accessibility standards was performed, potentially excluding mobility-impaired and visually impaired users.

6. **Scalability and Performance:** The frontend's behavior under large data volumes (e.g., tens of thousands of hazard reports) remains untested. Data paging, client-side caching, and clustering techniques have not been implemented.

7. **Real-Time Data Integration:** Static map layers were used exclusively. Real-time traffic, weather, and hazard updates were not incorporated, limiting dynamic risk assessment.

8. **Mobile Optimization:** Testing was restricted to a single device and browser version. Diverse screen sizes, OS versions, and touch interactions were not validated.

7 Conclusion, Improvements and Future Work

This Chapter synthesizes the thesis's outcomes by summarizing how the system met nearly all formal requirements, enabled fully paperless school-route planning, and demonstrated the suitability of the chosen technology stack. It then outlines targeted improvements (such as PDF export, performance optimizations, up-to-date map data imports, and expanded field testing) to refine the prototype. Finally, it presents directions for future work, including end-to-end digital plan distribution, integration of external data sources, automated route suggestion algorithms, AI-driven risk analysis, enhanced offline and accessibility support, and scaling the solution for broader deployment.

7.1 Conclusion

The formal requirements set out at the outset of this master's thesis have been met almost in their entirety, with only minor deviations.

The developed web-based system enables fully paperless planning of school routes by replacing analog questionnaires with GPS-assisted digital data capture and interactive mapping. The chosen technology stack (Angular for the frontend, Leaflet and OpenStreetMap for cartographic rendering, Chart.js for data visualization, in combination with a Spring Boot backend and PostGIS) proved robust, maintainable, and scalable for the project's scope. Human-centered design methods fostered high user acceptance, as school planners report significant time savings and parents appreciate the intuitive data entry process. Overall, the system demonstrates that digital transformation of school route planning is feasible, efficient, and oriented toward safety and usability.

7.2 Proposed Improvements

- **Export of Finalized Plan as PDF:** Implement a server-side module to generate and style PDF documents of completed route plans, including embedded map snapshots and risk annotations, to facilitate sharing with stakeholders.
- **Minor Performance Upgrades:** Optimize database queries and implement client-side caching for frequently accessed map tiles and questionnaire data to reduce latency in both mobile and desktop environments.
- **Currency of Map Data:** Integrate automated update routines to fetch the latest OpenStreetMap extracts or alternative authoritative sources at regular intervals, ensuring that new infrastructure changes are reflected without manual intervention.

- **Field Testing:** Conduct extensive pilot studies with local school authorities to collect real-world feedback on usability, data accuracy, and reliability under varying network conditions, feeding results back into iterative refinements.

7.3 Future Work

In this Section, we outline the planned extensions and enhancements that will guide the project beyond its current prototype stage.

7.3.1 Digital Plan Output

Develop a fully digital end-to-end workflow in which finalized route plans are published via a secure web portal or mobile app, enabling participants to access interactive route guides without physical handouts.

7.3.2 Integration of External Data Sources

Extend the system to consume and fuse data from external providers—such as police accident records, public transportation schedules, and local traffic sensor feeds—to enrich risk assessment and route validation processes.

7.3.3 Automated Route Suggestion Generation

Incorporate algorithmic pathfinding based on weighted criteria (safety, distance, traffic) to propose optimized route alternatives, allowing planners to compare manual designs against system-generated suggestions.

7.3.4 Artificial Intelligence for Analysis and Evaluation

Leverage machine learning techniques to analyze aggregated route and incident datasets, enabling predictive modeling of high-risk zones and automated prioritization of infrastructure improvements. Techniques under consideration include clustering algorithms for hotspot detection and supervised models for risk scoring.

7.3.5 Live Evaluation and Market Readiness

Conduct comprehensive live evaluations with municipal planners and student participants to validate usability, data accuracy, and user acceptance under real-world conditions. Based on feedback, refine the prototype's feature set, performance, and user interface, and undertake the engineering and quality-assurance efforts required to advance the system into a market-ready product.

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List of Abbreviations

VwV Verwaltungsvorschrift
HCD Human-Centered Design
POI point of interest

Appendix

A Wireframes

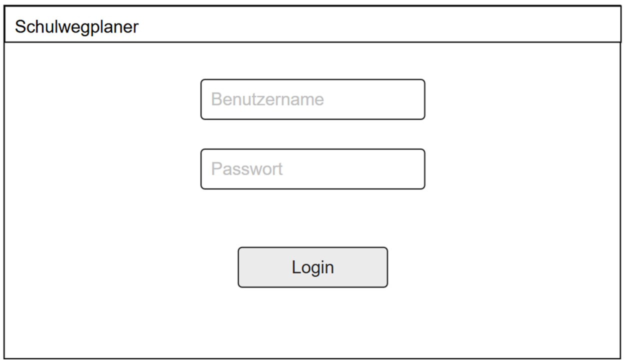

Figure A.1: Wireframe of the system for planners representing the login-page for authentication.

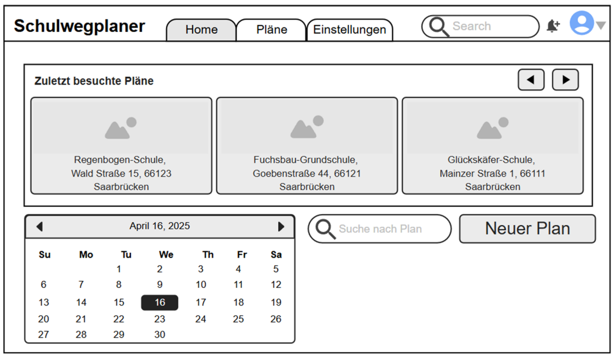

Figure A.2: Wireframe of the system for planners representing the landing-page.

Figure A.3: Wireframe of the system for planners showing the modal to create a new plan.

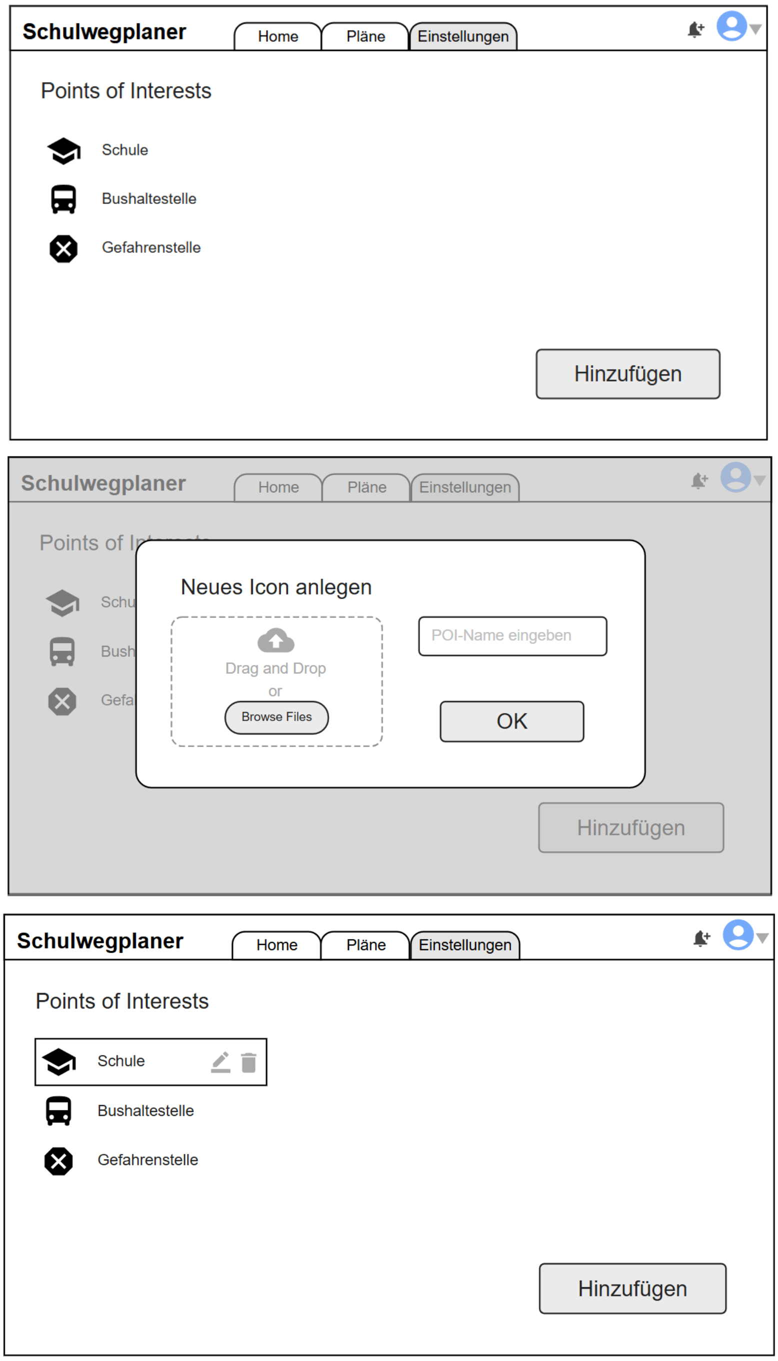

Figure A.4: Wireframes of the system for planners showing the point-of-interest-page to create, edit and delete custom icons (e.g. bus stops) **R10**.

B Frontend

B.1 Desktop Application

B.1.1 Home page

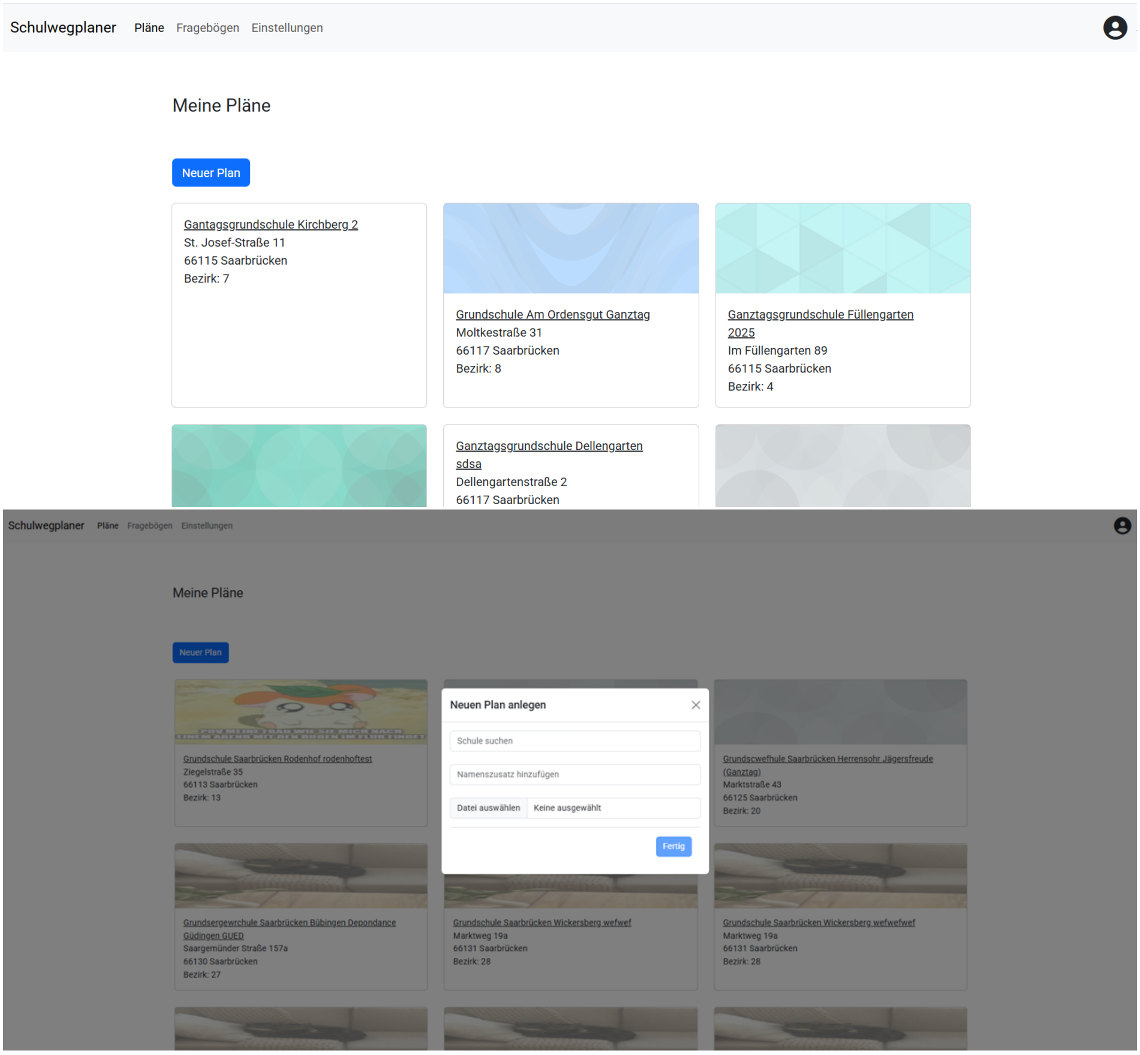

Figure B.1: Home page overview

B.1.2 Planning page

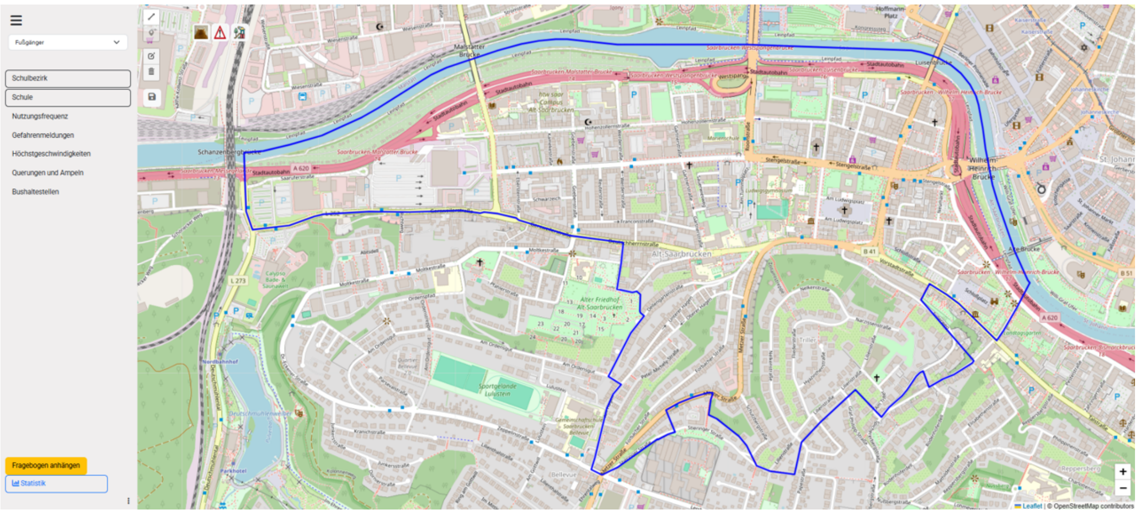

Figure B.2: Planning page overview

B.1.3 Questionnaire page

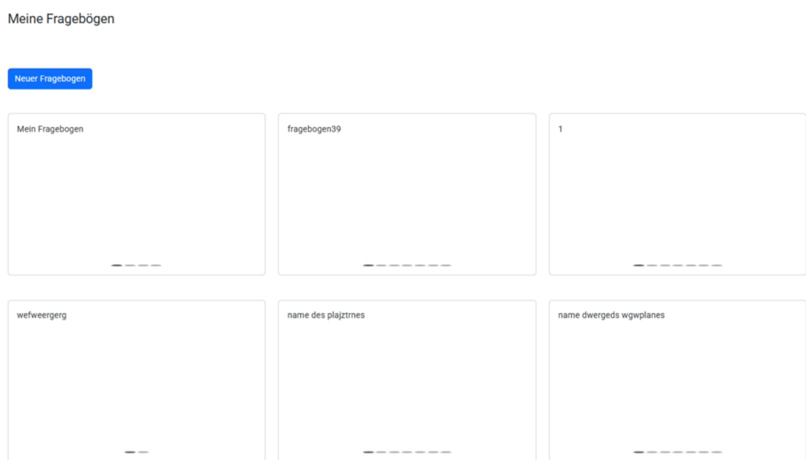

Figure B.3: Questionnaire page overview

B.1.4 Login page

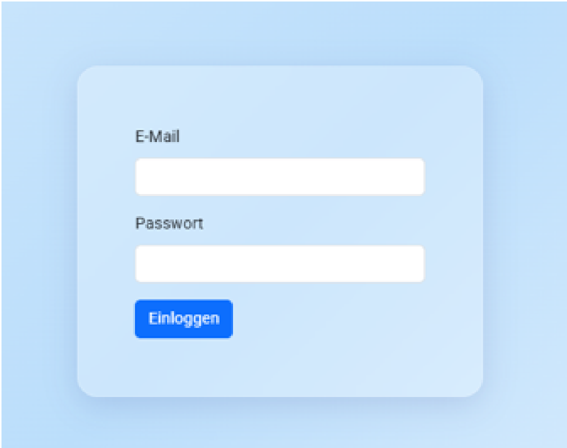

Figure B.4: Login page overview

Kolophon

Dieses Dokument wurde mit der LaTeX-Vorlage für Abschlussarbeiten an der htw saar im Bereich Informatik/Mechatronik-Sensortechnik erstellt (Version 2.23, März 2022). Die Vorlage wurde von Yves Hary und André Miede entwickelt (mit freundlicher Unterstützung von Thomas Kretschmer, Helmut G. Folz und Martina Lehser). Daten: (F)10.95 – (B)426.79135pt – (H)688.5567pt