University of Zurich[UZH]

"Choose your own route" - Supporting pedestrian navigation without restricting the user to a predefined route

GEO 511 Master's Thesis

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27.09.2019
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Abstract

Map applications on mobile devices are used more and more in everyday life. Such applications make navigation easier thanks to the continually updated information about the current location of the device and the possibility of providing detailed navigation instructions and displaying routes directly on the map interface. This type of navigation assistance is called turn-by-turn (tbt) navigation. However, studies have shown that the acquisition of spatial knowledge decreases due to the "blind" following of these route instructions. Therefore, in the context of this work, two research objectives have been defined: The first objective deals with how a pedestrian navigation system can be designed without restricting the user to a pre-defined route. Within the second objective, it wants to be found out, how the designed system performs compared to a conventual turn-by-turn navigation system relating to the acquisition of spatial knowledge and the user experience. To deal with the stated problems, a user-centered design (UCD) approach was applied. In the first step, an initial design of the interface was created, which was then discussed with a focus group and adapted again. The main components of the system are global and local landmarks on the one hand and a component called Potential Path Area (PPA), which was developed within the framework of this work on the other hand. The idea of these areas is derived from the concept of time geography. The system shows at any time an area to the user in which he can move around and reach the desired destination within defined time limits. In a further step, the system was implemented as an application using the Adobe PhoneGap framework. However, the most essential step in the workflow of this work is the user study. The system was tested against the commonly used turn-by-turn navigation system *Google Maps*. Eighteen participants had to complete two navigation tasks in a real environment study in Winterthur, Switzerland. With the help of a direction estimation task and the drawing of a sketch map after each completed navigation task, the acquisition of spatial knowledge was analyzed. Additionally, the user experience was examined in further questionnaires. The study revealed that the acquisition of spatial knowledge can be increased when using the PPA-System. Referring to the overall user experience, the test users rated the degree of guidance with a significantly better score for the PPA-System. On the other hand, the perceived demand was higher for the developed system. However, the participants indicated that this demand would probably decrease with a more frequent use. Finally, it can be noted that a user-centered design approach was very suitable for the research project.

Keywords:

Navigation, spatial knowledge acquisition, user-centered design, landmarks, Potential Path Area, user study

Acknowledgements

Various people have contributed to the success of this work. First of all, I would like to thank my thesis supervisor Dr. Haosheng Huang who supported me from the first idea until the completion of the work with good advice and constructive discussions. Further thanks go to all members of the Institute of Geography who gave me advice on conducting a field study. Additionally, by leaning out a mobile device, this work was in part supported by the University Research Priority Program „Dynamics of Healthy Aging“ of the University of Zurich.

Secondly, I would like to thank my colleagues from work who invested time to help me with the implementation of the application. Thanks to the in-depth knowledge I was able to draw on, I was spared desperate hours.

Thirdly, a big thank goes to all the participants of the user study, the pre-tests and the focus group. Without your invested time and interest, it would not have been possible to carry out a study on this scale. Besides that, I was happy to see many old familiar faces again through this opportunity.

I would also like to thank my friends, fellow students and family for the support and all the encouraging words during the project.

Last, I would especially like to thank my parents, who made my studies possible and who have always supported me over the years.

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Abbreviations

GL	Global landmark
GPS	Global Positioning System
LBS	Location-based services
LL	Local landmark
NASA tlx	NASA task load index
POI	Point of interest
PPA	Potential Path Area
RAM	Route Aware Map
RO	Research objective
Sat Nav	Satellite navigation
SBSOD	Santa Barbara Sense of Direction (scale)
TA	Test area
tbt	turn-by-turn
UCD	User-centered design
UX	User experience
YAH	You-are-here (map)

1. Introduction

In recent years, the smartphone has become a constant companion in our everyday life and, thanks to its numerous functions and applications, has become indispensable. In addition to the communication capability of the devices, the use of mobile maps is one of the most popular functions provided by such devices. This has not only changed the way how maps are used; it has also given navigation itself a whole new meaning.

However, navigation is not always dependent on aids. Each of us knows the way from his home to his place of work or can give directions to a stranger in his hometown. If someone goes to an unknown city, he first has to rely on a map to find his way, but after a few days, he can easily move around in a particular environment without being dependent on external orientation aids. This phenomenon is possible due to the **acquisition of spatial knowledge** and the construction of a mental map (Siegel & White 1975). With the development of mobile devices such as smartphones or tablets, map applications and navigation systems became more accessible and easier to use. Map applications such as *Google Maps* have a worldwide reach and run based on an extensive database. This enables someone to reach a destination anywhere in the world without much effort.

As it will be described in more detail later, navigation consists of two components: wayfinding and locomotion (Montello 2005). Whereas wayfinding is about the orientation and the finding/planning of a route to a specific destination, locomotion describes the movement towards the destination. One of the features of modern map applications that make navigation so intuitive is the provision of one's location. Such (mobile) maps are called You-Are-Here maps. Thus, state of the art navigation systems completely take over the process of finding a way: The system provides the user with his current location, where the destination is and which way has to be taken. This specific kind of route communication is called turn-by-turn navigation (Button & Hensher 2001). Such systems communicate the route information not only in graphical means by the help of the visualized route on a map but also in form of written or spoken information about turns that have to be made. During locomotion, much attention must be paid to the navigation system and the display of the mobile device so that a user can accurately follow the instructions of the system. Research has shown, that even though automated instructions for the wayfinding task result in a reduced cognitive workload, other problems may arise: Over-reliance on automated systems may cause users to be mindless of the environment they are navigating in and not develop wayfinding and orientation skills by their own. Thus, users of such navigation systems cannot acquire the spatial knowledge that may be required when automated systems fail (Parush *et al.* 2007).

While the process of spatial knowledge acquisition when using a mobile navigation system is perceived by the user most of the time unconsciously, there is another essential aspect to evaluating the usage of mobile navigation aids: The **user experience**. Fang *et al.* (2015) stated that mobile navigation systems have to serve people in comfortable, respectful and confident ways. Notably, the aspect of mental satisfaction of a user is attributed a high degree of importance. Factors such as *security*, *appeal*, *traffic*, *pavements*, *noise* or the *layout of the walkway* can have a strong influence on how a user perceives the process of wayfinding and locomotion while navigating through an unfamiliar environment. Whereas all these factors mainly derive from the environment, pedestrians also need a sense of confidence from controlling a navigation system rather than being controlled by it. However, conventional navigation systems based on the concept of turn-by-turn route instructions restrict the user in many of the above-mentioned points. A qualitative user study from Peake (2015) has shown, that many users still prefer paper maps over mobile navigation systems since they feel too much in control by the navigation system and prefer to explore an area by themselves. Additionally, the feeling of proudness when achieving a task by oneself, here to find a way to a particular destination, was often mentioned in the evaluation of the user study.

In summary, it can be said that conventional *TBT* navigation systems, on the one hand, have a diminishing influence on the acquisition of spatial knowledge because the users are not dependent on interactions with the physical environment. On the other hand, the provided route communication may restrict the user regarding his abilities to alternate a route on the fly according to his preferences. In turn, these limitations weaken the user experience, especially regarding the user's mental satisfaction. Since there exists no conceptual alternative of route communication other than turn-by-turn, this is the main subject this Master's Thesis will focus on.

Within the framework of this work, the open question is explored how a navigation system can be designed to move the users' attention more to the physical environment and therefore increase the acquisition of spatial knowledge during a navigation task. This should be accompanied by an improvement in the user experience of the system regarding the independence of the user to the application. To do so, a user-centered research approach is applied: An own developed concept for a navigation system will be implemented and tested against a conventional navigation system in an empirical user study.

The thesis is structured as follows: Chapter 2 gives an overview of the state of the art of current research and introduces topics as spatial knowledge acquisition, basic concepts of navigation, map application design and user experience. In Chapter 3, the research objectives and a methodical overview are presented. The methodology of the thesis will then be presented in the next three chapters: Chapter 4 focuses on the system design, chapter 5 explains the implementation of the system as an application and chapter 6 presents the procedure of the empirical user study. The results of the user study are then presented in chapter 7. In Chapter 8, the discussion places the results into context with the defined research objectives. The main findings are put together in conclusion and an overview of continuing research of the topic is presented in the last chapter.

2. Research Context

Within this chapter, it is given a broad overview of the state of the art about the research in navigation. First, the basic principles of navigation and spatial knowledge acquisition are introduced. Subsequently, A closer look will be taken at the role of navigation supporting systems and whose effect on the acquisition of spatial knowledge and the user experience. Within that, a discourse about local and global landmarks will be presented and the field of mobile map design will be explored in more depth.

2.1. Basic Principles of Navigation

The term *navigation* is described as a coordinated and goal-directed movement through the environment and consists of two components: Wayfinding and locomotion (Montello 2005). *Wayfinding* is the part of navigation which composes of the efficiently planning of the actual movement. Wayfinding therefore requires a destination we wish to reach. Frequently, this destination is not localized in the local surrounds of a navigator. Therefore, wayfinding is coordinated distally and beyond the local surrounds. Memory stored internally in a navigator's head or externally in artefacts such as maps play an important role in wayfinding. On grounds of the available information and the existing knowledge about the environment, a sequence of actions (such as *going straight forward and then turn right*) is planned, which will lead to the place goal. *Locomotion*, on the other hand, is the movement of one's body around an environment and describes the actual motion itself. This movement is coordinated to the environment that is directly accessible to our sensory and motor systems at a given moment. When the part of locomotion is executed, behavioral problems such as avoiding obstacles and barriers or directing the movement toward perceptible landmarks are solved.

Hence, successful navigation means to reach a destination in an efficient way without getting harmed or lost. This requires a navigating person while moving to be clear about its position related to the destination or other objects in space. As a result, a further important component of navigation is the *orientation* in space. Human beings use a combination of two different processes to maintain orientation – to update knowledge of their location – as they move around: landmark-based and dead-reckoning processes. *Landmark-based* orientation processes involve the recognition of (salient) features in an environment – known as landmarks. This requires a navigator to have an internal or external (e.g. a map) memory of his environment. In contrast, *dead-reckoning* involves keeping track of components of locomotion such as the velocity and/or acceleration of the movement to update the orientation in space. With this kind of information, one can find out his position in relation to the initial position of the route. However, dead-reckoning does not provide a complete method of updating the knowledge of position while navigating. This method requires a start location and is therefore not useful for getting orientation relative to places other than from which the recent movement was initiated. Additionally, dead-reckoning is sensitive to error accumulation since any error in sensing or processing movement information accumulates over time. For this reason, a combination of both processes, landmark-based updating and dead-reckoning, is always necessaire (Montello 2005).

2.2. Acquisition of Spatial Knowledge

The way how the acquisition of spatial knowledge works was first described and conceptualized by Siegel & White in 1975. According to this concept, spatial knowledge about an unfamiliar environment is built up in three stages – or in other words, spatial knowledge can be categorized into three different components: Landmark knowledge, route knowledge and survey knowledge.

The first stage describes the ability to identify entities in an environment as salient, known as landmarks. This stage is called *landmark knowledge*. However, a landmark does not necessarily have to be an individual object, but it can also be understood as a clearly recognizable pattern of several objects together (e.g., a city center).

In a second step, *route knowledge* is built. At this stage, a person learns to connect landmarks and how to move from one landmark to another. Siegel & White (1795) describe that a person has a route in mind as soon as this person knows which landmarks, and in which order they will appear. Werner *et al.* (1997) also describe route knowledge as the ability to navigate along a particular route without getting lost.

At the third and highest stage of spatial knowledge – the *survey knowledge* – a person has a notion of the whole spatial structure of a particular environment. This allows a person to locate different landmarks and routes in a common reference frame. It is thus the result of the accumulation of route knowledge. Hence, a person with this level of knowledge about space knows different routes and shortcuts between landmarks. Werner *et al.* 1997 describe this kind of knowledge as *spatial awareness*. According to the theory of Siegel & White (1975) that the form of knowledge about space depends on how often a person has already moved around in an environment.

2.2.1. Mental Maps

The cognitive process of absorbing knowledge is a process that is carried out almost continuously and begins as soon as a person is confronted with something new (Richter 2013). This can also be applied for the learning of a spatial environment: When a person navigates through an environment, this person automatically absorbs knowledge about the spatial structure of the environment. This "random" learning process can be described as a kind of side effect of navigation (Münzer *et al.* 2006). This knowledge is stored in the brain in the form of a mental representation of the space and is in the literature often referred to as a *cognitive* or *mental map* (Tversky 1993).

2.3. Navigator's Information Need

In order to provide efficient wayfinding services, it is essential to know how people understand and communicate route directions in their daily life. Efficient wayfinding services should provide information which is tailored to the actual information needs of users. In the following, we mainly investigate what navigational information is needed to be conveyed to users during a navigation task. Agrawala (2001) classified the information which can be conveyed to navigators into three classes: (1) *turning point information*, (2) *local context*, and (3) *overview context*. A turning point can be defined by a pair of roads and the turn direction between those two roads. Turning point information is essential for a useful route map. Local context consists of information about the route itself as well as the environment immediately surrounding the route, such as distance to be traveled along that road, cross-streets, and local landmarks. Overview context consists of global properties of the route, such as global landmarks, the overall shape and heading of the route (e.g., north-south vs. east-west). Local context and overview context are not essential for following the route and are usually included in the route guidance only when they do not interfere with the primary turning point information. Nevertheless, once global and local context is conveyed to the navigator, the acquisition of survey knowledge increases.

2.4. Route Communication

In order to produce route instructions, several processes have to be completed (Kray *et al.* 2003). In a first step, the **origin** and **target location** (and fixed intermediate locations if necessaire) have to be determined. These points have to be defined by the user itself. If the origin of the route corresponds to the user's current position, the system should be able to determine this position on its own.

In a second step, the system has to compute a **suitable route** between the origin and target location (and possibly intermediate locations). Here, the system ideally takes into account situational factors such as the user's preferences for a route such as the complexity, the scenery, the velocity or other factors such as the means of transportation. In an early work of Golledge (1995), different route types were matched to routes chosen by participants in a user study (Tab. 1).

The study has shown that criteria relating to velocity and complexity were chosen first by the participants of Golledge's (1995) study. However, different user groups may have different route preferences (Reichl 2003). Meeting these demands made by different user groups, loads of different algorithms have been developed. The most common one is undoubtedly the *Dijkstra's shortest path algorithm*. This algorithm is used for finding the shortest paths between nodes in a graph, which may represent, for example, road networks. The *Simplest Path Algorithm* (Duckham & Kulik 2003) on the other hand evaluates a route according to the complexity of its turns. A simple route minimizes the number of decision points and maximizes decision points of low complexity. The *Easy-to-Follow Routes algorithm* (Richter & Duckham 2008) accounts for decision point complexity, references to *landmarks*, and *spatial chunking*.

Table 1: Ranking of criteria most often used in route selection (Golledge 1995)

Criteria	Rank
Shortest Distance	1
Least Time	2
Fewest Turn	3
Most scenic/Aesthetic	4
First Noticed	5
Longest Leg First	6
Many Curves	7
Many Turns	8
Different from Previous	9
Shortest Leg First	10

In the last step, the route has to be **presented** and **communicated** to the user. Hence, this stage of route instruction can be seen as the direct connection between user and a navigational assistance device. Such assistance is typically provided by verbal or graphical means, i.e., either as (spoken or written) text or as a map. The crucial information that needs to be communicated is what to do at certain places where the user has more than one possibility how to continue the route, known as decision points (Daniel & Denis 1998). Therefore, the presentations generated by the system have to be timed according to the movement of the user and presented at the right location (Kray *et al.* 2003).

2.4.1. Text-based Route Communication

Depending on the availability of rendering resources, the system can either chose to output route instructions textually, using speech synthesis or a combination of both (Kray *et al.* 2003). Efficient navigation systems should provide information that is tailored to the actual information needs of users; although it is possible to follow route guidance that only indicates the road names and turn direction at each turning point, additional information as local and global context can greatly facilitate navigation. However, additional information should only be included when it does not reduce the clarity of the turning point information (Agrawala 2001). The overall goal of the route, for example, does not have to be mentioned at every moment but should be communicated at the beginning of the route or when the route is resumed after an interruption to confirm the target location.

Depending on the user's knowledge of the environment, the system may leave out additional local or global context (if the user us familiar with the environment) or include more of it if the user does not know the environment. Schwering *et al.* (2017) tested three types of route instructions: machine-based *turn-by-turn (tbt) instructions* provided through currently available routing services, route instructions with orientation information, and skeletal instructions based on the methodology introduced by Denis (1997).

Table 2: Example instructions for the machine-generated, orientation-based, and skeletal wayfinding task (Schwering *et al.* 2017)

Type	*Instructions*
1. Machine-generated	• Turn left onto Empire Street and drive 350 m • Continue onto Hudson street for 650 m • Continue onto Main street for 140 m
2. Orientation-based	• Follow the street, which is heading *away from* the *city center* • You cross the intersection *on the inner ring road* that *runs around the city* • Right after you pass the *big church on your right-hand side*, you reach an intersection.
3. Skeletal	• Walk along the Empire Street • Right after you passed the big church, which is on the right side, you reach an intersection

Table 2 provides examples of all types of instructions. The machine-based instructions are generated from *Google Maps*. The orientation-based instructions provide additional information based on landmarks at decision points and alongside the route, as well as distant global landmarks. The third type is the skeletal instruction, which contains information about landmarks as well, but only if they are necessary for the identification of the route with its turns. The results have shown that sketch maps drawn based on different types of instructions show some distinctive characteristics: Sketch maps drawn based on machine-generated instructions only contain the route itself, indicated by a sequence of route segments. Thus, the only drawn spatial entities are streets, but only less to no intersections and recognizable decision points. Sketch maps drawn based on orientation instructions indicate a spatial layout of the area not only containing the actual route, but also intersections and additional street segments. The general observations of sketch maps suggested that orientation-based instructions contribute to more comprehensive spatial knowledge possessing both global and local orientation. Sketch maps drawn based on skeletal instructions contain only route segments with similar length, due to minimal information content in this type of instruction.

Spatial Chunking

By analyzing great varieties of verbal navigation assistance, Denis *et al.* (1999) found out that all of these instructions considered very detailed route directions, where every potential decision point and landmark was mentioned. This can be somewhat confusing for a wayfinder since some of the communicated instructions with a lot of details are less appropriate than sparser ones. Therefore, Klippel *et al.* (2003) suggested that it seems preferable to chunk some information units – elementary route segments – together, in order to optimize the amount of information. Spatial chunking and the resulting verbalization of chunked route segments help to avoid overload of information as it is exemplified hereafter:

> *You arrive at a crossing, go straight, you pass another branching-off street to your left, do not take this turn, walk straight on until there is a street branching off to your left; Here you turn.*

In contrast to a chunked verbalization from the same instruction:

> *Turn left at the third intersection*

However, Klippel *et al.* (2003) suggest that a zooming-in process on a mobile map makes spatial elements at the lower levels accessible and may result in selecting all decision points for verbalization, whereas zooming out results in spatial chunking and yields higher-order segments.

2.4.2. Map-based Route Communication

The fundamental visualization element when communicating routes is always a map. Radoczky (2004) summarized the work of Agrawala & Stolte (2000), and listed the following four essential design goals for effective route maps:

(1) **Readability** (all essential components, especially the roads, should be visible and easily identifiable)
(2) **Clarity** (the route should be clearly marked and readily apparent from a quick glance)
(3) **Completeness** (the map must provide all necessary information for navigation)
(4) **Convenience** (the map should be easy to carry and manipulate)

Especially when developing route maps for mobile devices, these design goals, the first three goals become very challenging. Different factors have to be considered while designing mobile route maps, such as small display size, low resolution, reduced processing power and memory, short battery lifetime, bandwidth and many more.

Schmid *et al.* (2010) developed a new concept for navigation-maps, which focus most importantly on the design goals *readability* and *completeness*. These visualizations called *route aware maps* (RAMs) concentrate on the route as the essential information to reach a destination, but also provides the necessaire information to anchor the route within its relevant spatial and functional context. Route aware maps shall ease information extraction by focusing on the route as the crucial piece of information and at the same time impart the feeling of efficient and safe navigation by keeping the wayfinder in global context. Providing a global context in route following invokes spatial awareness concerning the overall environment and, thus, decreases the (felt) risks of making wayfinding errors. The construction of RAMs starts with the route itself that can be computed by using any favored algorithm, such as the classical shortest path. Afterward, additional information is added stepwise to the map. To enhance the initial and final orientation, the environment around origin and destination of the route is displayed in more detail. In a second step, alternative routes are added at intersections with a complex configuration. Third, global context is provided by displaying regions within different hierarchical levels of granularity, such as e.g. districts within a city. In the last step, landmarks along the route are added to map. These features help the wayfinder to disambiguate locations along the route and to identify locations in the environment.

This discussed approach can be summarized as enhancing relevant information and reducing or removing irrelevant information. Based on literature and some experiments, Gartner & Uhlirz (2005) provided some guidance on route map design to achieve the discussed design goals *readability*, *clarity*, *completeness* and *convenience*:

(1) Offering different (but not too many) routes with different characteristics (shortest, most scenic, …), so that the user can adapt the route to his current situation himself.
(2) Providing an overview of the whole route at the beginning of wayfinding, and during route following,
(3) automatic scrolling (automatic adaptation of the presented map section to the position of the user),
(4) egocentric map view (providing "track up" oriented map: the map is always adapted to the user's direction of move),
(5) supported change of scale (changing from one scale-dependent cartographic presentation to anther),
(6) the route (trail) should be visible to the user at any time, and the distinction between the past and the future path should be unambiguous (e.g., the past trail could be dyed in a very light color),
(7) offering and combing different presentation forms.

2.5. Landmarks

The term landmark stands for a salient object in the environment that aids the user in navigating and understanding the space (Sorrows & Hirtle 1999). When generating directions, people not only specify what to do, they also refer to landmarks located along the route (Michon & Denis 2001), which is why landmarks appear to be essential for pedestrian navigation systems. Research showed that landmarks sever for multiple purposes in wayfinding: they act as referencing points in the environment to help people organize space, and they support the navigation by identifying choice points, where a navigational decision (e.g., changing a direction) has to be made (Golledge 1999, Klippel 2003).

Landmarks can act as simple orientation cues somewhere along the route to keep users' confidence during route following.

2.5.1. Landmark Classification

Lovelace *et al.* (1999) classified landmarks into four groups: choice point landmarks (at decision points), potential choice landmarks (where a re-orientation would be possible, but should not be done to follow the current route), on-route landmarks (along a path with no choice), and off-route landmarks (distant but visible from the route). They concluded that choice point and on-route landmarks are the most frequently used ones in route directions of unfamiliar environments. Raubal & Winter (2002) classified landmarks into **global landmarks** (i.e., off-route landmarks), and **local landmarks** (i.e., choice point landmarks and on-route landmarks). They proposed that local landmarks should be added to wayfinding instructions for effective route communication. Sorrows & Hirtle (1999) categorized landmarks into visual (visual contrast), structural (prominent location), and cognitive (functional, user, meaning) ones, depending on their dominant individual quality.

In order to extract landmarks for wayfinding, Raubal & Winter (2002) defined a formal model to measure the attractiveness of landmarks (landmark saliency), and then derive local landmarks. The attractiveness was measured in terms of visual, semantic, and structural features. Elias *et al.* (2005) proposed two steps for automatically deriving route-dependent generation of landmarks: the detection of potential landmarks in the database, and the exploration of those that are relevant for a particular route. The detection of potential landmarks depends on the general geometric and semantic characteristics of the investigated objects and the defined neighborhood used for the analysis process. Brunner-Friedrich (2003) compared six different methods of landmark derivation and gave an overview on which landmarks can be derived with each method regarding different aspects: the characteristic (visual, cognitive, or structural landmarks), the position (local landmarks or global landmarks; choice point landmarks or on-route landmark).

2.5.2. Landmark Visualization

Local Landmarks

Elias (2002) proposed different methods for the visualization of (local) landmarks: The landmark is marked with an arrow; the landmark is colored, emphasized and highlighted; all other objects are simplified in their geometry apart from the landmark; less important objects are merged; the landmark is presented with a self-explanatory symbol. Radoczky (2004) argued that photos could also be beneficial to visualize landmarks.

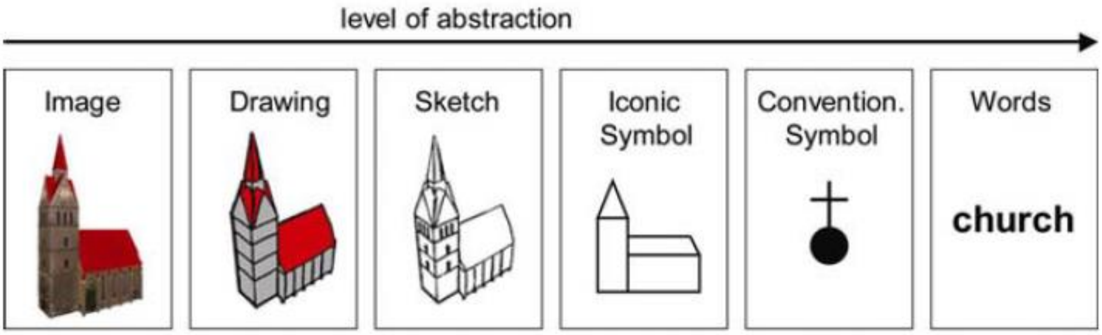


Figure 1: Levels of abstraction proposed by Elias & Paelke (2007)

Additionally, Elias & Paelke (2007) analyzed the descriptions of two different routes in the city of Hanover from a user study and found that 50% of all landmarks used in these descriptions are buildings. Elias & Paelke (2007) identified four different categories of building landmarks: (1) Well-known shops (trade chains), (2) shops referenced by their type, (3) buildings with a specific name or function and (4) buildings described by specific visual aspects. They then examined how landmarks from each of these four categories can effectively be visualized by comparing possible visualizations at different abstraction levels, ranging from photo-realistic image presentations, over drawings, sketches and icons to abstract symbols and words (*Figure 1*). As a guideline, they provided a matrix, from which possible and recommended presentation styles for each landmark category can be derived (*Table 3*). The results of the user tests supported the designed matrix as well. However, the guideline is only for building landmarks, a guideline for the visualization of other types of landmarks is not yet defined.

Table 3: Design proposals for landmarks stated by Elias and Paelke (2007)

	Image	**Drawing**	**Sketch**	**Icon**	**Symbol**	**Words**
Shop (Name)			(+)	+		
Shop (Type)				+	+	+
Function/Name	+	+	+			+
Visual Aspect	+	+				

Global Landmarks

According to Denis (1997), landmarks are most often used to re-orientate at decision points where a change of direction is necessary to reach the destination. If there is no landmark at a particular decision point, it becomes much more difficult for a wayfinder to re-orient in order to change his heading direction. Hence, Lovelace *et al.* (1999) suggested that landmarks are not only crucial at locations where reorientation is necessaire but also crucial at points where change of direction can be possible. At these potential decision points, wayfinders need to maintain their orientation by continuing the same heading direction. In general, there have been limited studies addressing the role of distant – *global* – landmarks from a route providing a global orientation or confirming the heading direction.

In an experimental study, Steck & Mallot (2000) showed that distant landmarks provide initial global orientation before the execution of wayfinding. Later, these global landmarks can serve as local landmarks as soon as they are actually on the designed route. These findings were then supported by the study of Winter *et al.* (2008), which showed that wayfinders first refer to prominent distant landmarks to establish global orientation. Another study on the role of global landmarks has suggested that humans frequently refer to distant landmarks when giving wayfinding instructions to help other persons to orient themselves in an unfamiliar environment (Schwering *et al.* 2013).

Gustafson *et al.* (2008) differentiate between three different techniques that can be used to visualize distant global landmarks: overview+detail, focus+context and contextual views. **Overview+detail** techniques present a miniature view of the entire (global) environment, comparable to an inset map in cartographical means including all the global landmarks which lie outside the displayed map extent on the mobile device. This inset map can be displayed in a separate window or as an overlapping inset window over the main map which shows a zoomed-in view. Such overview+detail views have been shown to be effective (Nekrasovski *et al.* 2006), but they cause additional cognitive processing on the user when switching between the different views / windows (Baudisch *et al.* 2002). Another disadvantage is that inset overview maps overlaid onto the detail view occlude part of the context in the main window (Gustafson *et al.* 2008).

A prominent example of **focus+context** techniques is the fisheye view. Such visualizations eliminate the need for multiple windows by presenting a distorted view of the entire (global) environment providing a smooth transition between an enlarged focus region and the surrounding environment (Carpendale & Montagnese 2001). The disadvantage of most focus+context views is that the distortion can degrade the spatial knowledge acquisition and irritate the user when trying to orient himself (Hornbæk & Frøkjær 2001).

In comparison to focus+context techniques, **contextual views** only represent objects of interest – here distant global landmarks – which lie outside the visualized map extent without the whole environment around them. Distant landmarks are represented using abstract shapes that are overlayed onto the present map. Here, the most common methods of contextual views from current research will be presented: Arrows, Halos and Wedges.

Arrows are used to indicate the direction in which the landmark can be seen or is located on the map. These arrows are then placed at the hypothetical point between the border of de visualized map and a line between the current user position and the landmark. In some recent studies (Li *et al.* 2014, Schwering *et al.* 2017) small icons instead of arrows were

Figure 2: Most commonly used contextual view techniques: a) Arrows, b) Halos, c) Wedges

displayed at the border of the display to indicate the direction of the landmarks, since the actual direction pointing of the arrow is not absolutely necessaire because the direction is already indicated by the position of the icon itself. Since the arrow approach only indicates directions but no distances, Burigat *et al.* 2006 further developed the arrow-based approach and introduced the *Scaled Arrows* approach. This approach visualizes direction and distance information of off-screen locations using arrow orientation for direction and arrow size for distance.

Another approach called *Halo* (Baudisch & Rosenholtz 2003) uses an arc to indicate the direction and distance of an off-screen landmark. Each arc is part of a circle that lies around one of the off-screen landmarks. The relative size of the arc implies approximately the center of the corresponding circle where the landmark is located. Another similar approach called *Wedge* was introduced by Gustafson *et al.* 2008. Instead of using arcs at the edges of the screen, *Wedges* use triangulated arrows to indicate the direction and distance of the off-screen landmark. The triangulated arrows then imply the position of the landmark where the tip of the triangle is present. In comparison the *Halo* approach, *Wedges* are still practical when off-screen landmarks are clustered in the direction of a corner from the display. However, similar to the *Halo* approach, *Wedges* do not give information about the identity of a landmark (in contrast to the icon-based arrow approach) (Li *et al.* 2014).

Another quite different approach was proposed and implemented for smartwatches by Wenig *et al.* 2017: The implemented system extended turn-by-turn navigation instructions using a single global landmark rather than multiple, hard-to-select landmarks. Instead of visualizing the landmark as an off-screen object, the global landmark was included in the navigation instructions itself by providing information about the landmark's direction at every point the object can be seen in real life by the user. Their user study showed that users navigate more confidently and build more accurate mental maps of the navigated area than when using *tbt* instructions with further information about global landmarks.

Figure 3: Turn-by-turn navigation on the left and the turn-by-turn navigation instructions including global landmarks on the right (Wenig *et al.* 2017)

2.6 Location-Based Services & Digital Maps

Within the last two decades, there has been an explosion of new GPS-based mobile devices. This technological development opened up an entirely new field of research and technology itself called *location-based services* (LBS). According to Raper *et al.* (2007) the term of LBS can be defined as follows:

"Location-based services are computer [typically, mobile device] applications that deliver information depending on the location of the device and user."

With the emerge of the first smartphone, location-based services were no longer only a promising new research field but also entered into the public as applications used in daily life. LBS technology not only deals with maps in a pervasive sense but also finds application in areas like gaming, health applications, tracking, information provision or advertisement. Hence, some of the most promising application areas have been 'satnav'-navigation systems for drivers and so-called *You-Are-Here* (YAH) Maps for pedestrians. Most of these new services have rapidly been developed commercially by major concerns to meet this new growing market. Despite being successful in the market, the further development of such devices took place without substantial scientific input from researchers (Raper *et al.* 2007).

2.6.1. You-Are-Here Maps

YAH maps are the most common, original form of all location-based services, aiming to create spatial awareness and to plan routes (Klippel *et al.* 2010). YAH maps existed even before the emerge of LBS in its technological form: Boards or wall posters showing the broad environment and the current position of this map. This statically form of YAH maps provides location information at defined points in a particular environment such as malls, oldtowns, parks, etc. Mobile navigation assistance based on global positioning systems (GPS) allows for continuous information about a user's current location and therefore, can offer potentially easy to follow turn-by-turn instructions. A complete map is therefore not even required as long as people do not go off the predefined route.

2.6.2. Degradation in Spatial Knowledge Acquisition

Although automated instructions for the way-finding task results in a reduced cognitive workload, other problems may arise. Over-reliance on the automated system may cause users to be mindless of the environment they are navigating in and not develop way-finding and orientation skills on their own nor acquire the spatial knowledge that may be required when automated systems fail (Parush *et al.* 2007).

Degradation in Spatial Knowledge Acquisition through Passivity

In a real environment study from Münzer *et al.* (2006) the effects of two different modes of information provision on spatial knowledge acquisition were investigated: learning from a paper map and learning from a mobile map. In a first test, pictures of crossroads were shown to the test users, and the users had to comment in which direction they went at this decision point. In a second test, the participants had to place photos of decision points at the right location on a map. The results showed that there are apparent differences in the spatial knowledge acquisition between the two test groups: Mobile map users performed worse than the paper map user in both tests. Münzer *et al.* (2006) assumed that this degradation in spatial knowledge acquisition is caused by a certain passivity of a mobile map user to the environment. By just following the given route instructions of a mobile navigation system, the user is not dependent on perceiving the environment in a way as a user of a paper map has to. The results from Münzer *et al.* (2006) were later confirmed in two studies of Parush *et al.* (2007) and Richter *et al.* (2010). In both studies the usage of different types of maps was compared. The maps differed in the way information is provided and how users have to interact with the map. Both studies showed that a more active dispute with the map causes a better acquisition of spatial knowledge.

Degradation in Spatial Knowledge Acquisition through Screen Size

Ishikawa *et al.* (2008) and Willis *et al.* (2009) presumed that the restricted size of the map caused through the limited display size of the device could have a negative influence on the acquisition of spatial knowledge. Dillemuth (2009) and Gartner & Hiller (2009) examined the influence of the limited screen size in two user studies.

In the study of Gartner & Hiller (2009) the generation of spatial knowledge between two test groups was compared, whereas the first group had to do a navigation task with a paper map (13.5 x 16.5 cm) and the second group had to do a navigation task with a mobile map (with a screen size of 4.7 x 5.5 cm). The assessment was of the spatial knowledge acquisition was made by direction pointing tasks and drawings of sketch maps. The results of the study showed that the group with the digital map was worse in generating spatial knowledge. Therefore, the assumptions of Ishikawa *et al.* (2008) and Willis *et al.* (2009) could have been confirmed.

In contrast to Gartner & Hiller (2009), the study of Dillemuth (2009) was conducted in a laboratory and four different map sizes were compared by doing some direction- and distance guessing task. While the negative effect of small map sizes was apparent in Gartner & Hiller's (2009) study, this causality could not be confirmed in all results of Dillemuth (2009). However, concerning the acquisition of spatial knowledge, a trend to an adverse effect of small screen sizes is recognizable.

2.6.3. Different digital Map Types and their Influence on the Acquisition of Spatial Knowledge

As has been seen, mobile maps can have a negative influence on the acquisition of spatial knowledge. The passivity on the usage of digital maps for wayfinding purposes caused by automated processes such as the provision of location information or the limited screen size leads to a worse generation of a mental map. Therefore, many researchers dealt with the question about how a mobile map should be designed to increase the acquisition of spatial knowledge. Dillemuth (2005) and Jordi (2010) investigated this question and found out that a generalized topographical map is preferred to an orthophoto as a base map. However, their studies concerned more about navigation in general and less with the construction of spatial knowledge. The question about map design and provision of information when examining the acquisition of spatial knowledge was then taken up by Huang *et al.* (2012). In a field experiment three different types of navigation assistance systems were tested on mobile devices: An augmented-reality navigation system, a digital topographical map and a text-based navigation system. All test users were randomly assigned to one type of navigation assistance system and had to absolve three navigation tasks in an urban environment. Subsequently, all users had to solve some tasks to measure the acquired spatial knowledge. The results from Huang *et al.* (2012) showed no significant differences between the three different types of information provision. In the statement of reasons from Huang *et al.* (2012) they referred to the similar results of Münzer *et al.* (2006), where no significant differences between different types of navigation system referring to the acquisition of spatial knowledge could have been found. According to Huang *et al.* (2012) the result can be justified by the fact that no dispute with the environment was needed in all three types of navigation systems.

Other results were found by Münzer *et al.* (2012). In a similar study, three different presentation-modes of navigation systems were tested against each other: The route

Figure 4: Presentation modes from Münzer *et al.* (2012)

presentation mode providing graphics of eye-level, the map north-up aligned map presentation and the compass presentation which rotated with the orientation of the user.

The test users had to absolve some similar navigation tasks as in the user study from Huang *et al.* (2012) with some following tasks to examine the acquisition of spatial knowledge. The results have shown, that a navigation system can either support the user in the efficiency of wayfinding (measured by the number of wrong turns at decision points) or help to generate some spatial knowledge of the environment. The map- and compass presentation modes helped to generate solid spatial knowledge while participants using the route presentation mode were more efficient in wayfinding. (Münzer *et al.* 2012).

2.7. User Experience

Despite the fact, that user experience (UX) became an important concept of measurement in the field of human-computer interaction in the last two decades, there is a lack of a shared definition of UX what leads to a different view and usage of this term from different authors and researchers. However, Hassenzahl & Tractinsky (2006) provided a very broad definition of the term UX and described it as:

> *"A consequence of a user's internal state (predispositions, expectations, needs, motivation, mood, etc.), the characteristics of the designed system (e.g. complexity, purpose, usability, functionality, etc.) and the context (or the environment) within which the interaction occurs (e.g. organisational/social setting, meaningfulness of the activity, voluntariness of use, etc.)"*

The second component of the presented definition (characteristics of the designed system) is probably the most explored component of UX and has a high significance in the research field of Geovisualization (Roth 2017). Two important concepts of this component are *interfaces* and *interactions* of a system (*see chapter 2.7.1*).

The first component of the definition deals more with questions about 'what a user expects and wants from a system' and takes place more likely in the research field of location-based services (*see chapter 2.7.2*).

2.7.1. Characteristics of the designed System

An interface is a tool enabling users to view and manipulate maps and their underlying geographic information for digital mapping. Interaction on the other hand describes the two-way question-answer or request-result dialogue between a user and a computing device (Roth 2012). As a result, humans use interfaces and at the same time experience interactions and - in conclusion – the UX determines the success of an interactive product (Norman 1988).

User interface design requires cartographers to rethink conventions for both representation and interaction since the visualization technique differs from a conventional static map. *Table 4* provides design recommendations for mobile maps from Muehlenhaus (2013) and Roth *et al.* (2018).

Table 4: Emerging conventions in mobile map design (Muehlenhaus 2013 and Roth *et al.* 2018)

Map Composition & Layout	**Constraint**	**Reference**
maximize the screen real-estate used for the map view	screen size	Muehlenhaus (2013)
use full-screen dialog windows for text & interface menus	screen size	Muehlenhaus (2013)
respond to vertical and horizontal aspect ratios	handheld	Chittaro (2006)
Scale & Generalization	**Constraint**	**Reference**
present only task-relevant information	bandwidth; screen size	Meng (2005)
generalize basemap	bandwidth; screensize	Meilinger *et al.* (2007)
include salient landmarks for orientation	mobility	Raubal & Winter (2002)
increase default map scale (i.e., zoom in)	screensize	van Tonder & Wesson (2009)
constrain smallest map scale (i.e., max zoom out)	mobility	Davidson (2014)
provide visual affordance for off-screen content	screensize	Chittaro (2006)
load map progressively, using tiles	bandwidth	Muehlenhaus (2013)
cache essential information on load	bandwidth	Roth *et al.* (2018)
use vector tilesets	bandwidth	Buttenfield (2002)
Projection	**Constraint**	**Reference**
center map on the user's location	mobility	Meng (2005)
update the user's position on the map	mobility	Peterson (2014)
reorient view so that forward is up	mobility	van Elzakker *et al.* (2009)
Symbolization	**Constraint**	**Reference**
emphasize wayfinding	mobility	Muehlenhaus (2013)
use self-explanatory icons for POIs	mobility; screen size	Robinson *et al.* (2013)
increase contrast within the visual hierarchy	viewing conditions	van Tonder & Wesson (2009)
increase brightness and saturation of map features	viewing conditions	Roth *et al.* (2018)
increase the size of interactive point symbols	touchscreen	Stevens *et al.* (2013)
include vector and imagery base map options	mobility	Davidson (2014)
symbolize unsafe crossings or other hazards	divided attention; mobility	Roth *et al.* (2018)
Typography	**Constraint**	**Reference**
use sans serif fonts	screen size	Muehlenhaus (2013)
increase text size and tracking	Screen size	Muehlenhaus (2013)
divide long sections of text into multi-window blocks	Screen size	Muehlenhaus (2013)
keep text upright as a user rotates the map	handheld	Muehlenhaus (2013)
Map Elements	**Constraint**	**Reference**
use loading screen for the map title	screen size	Muehlenhaus (2013)
hide the legend, help, and supplementary info by default	screen size	Muehlenhaus (2013)
include persistent north arrow for egocentric view	mobility	Muehlenhaus (2013)
allow text and audio options for descriptions/directions	screen size	Davidson (2014)
Interaction	**Constraint**	**Reference**
include post-WIMP widgets only	multi-touchscreen	Muehlenhaus (2013)
provide visual affordances for interactive widgets	multi-touchscreen	Stevens *et al.* (2013)
support double-tap and pinch for zoom	multi-touchscreen	Muehlenhaus (2013)
support grab-and-drag for pan	multi-touchscreen	Muehlenhaus (2013)
support two-finger twist for rotate	multi-touchscreen	Muehlenhaus (2013)
eliminate pan arrows and large zoom bar	multi-touchscreen	Muehlenhaus (2013)

include +/- zoom buttons to zoom with one hand	multi-touchscreen	Muehlenhaus (2013)
enable voice recognition for keying interactions	void	Muehlenhaus (2013)
use sound and vibration for interaction feedback	handheld	Muehlenhaus (2013)
allow the user to tap anywhere to close popups	multi-touchscreen	Muehlenhaus (2013)
support tap and hold for advanced options	multi-touchscreen	Muehlenhaus (2013)
include a search for user's current location	battery; mobility	Roth *et al.* (2018)
include calculating wayfinding routes	mobility	Davidson (2014)
support an offline or (for responsive) printable version	bandwidth; battery	Roth *et al.* (2018)

Scale and Extent

In the next two sections, the following points in mobile map design are further developed: map scale and extent, map view and rotation.

The selection of a map scale needs to be considered legibility so that the scale is related to the size and resolution of the device's display. Studies of route planning suggest that spatial knowledge is hierarchically structured and stored based on different scales (Chown *et al.* 1995, Wiener & Mallot 2003). Additionally, Tversky (2000) notes that people may have different mental representations of three spatial knowledge scales: *overview*, *view* and *action*, and therefore expect different information at each scale.

In a user study of Dillemuth *et al.* (2007), six popular navigation assistance systems were investigated with respect to display scale and zoom levels. The study showed that these map scales were chosen arbitrarily and they argued that zoom level while driving is determined by one or more of the following points: Speed, type of road, interaction between the user and the map and length of the current road. Dillemuth *et al.* (2007) proposed a velocity-based time-to-edge measurement to consider the appropriate display scale and map extent.

In another study of Dillemuth (2008) several experiments to investigate the effects of map extent on map use were conducted. In the first two experiments map use was considered for navigation tasks involving distance and direction estimation. It was shown that the smaller the map extent at any given time, the less effective was the map in terms of accuracy and task completion time. Map extent differences were also reflected in terms of spatial knowledge acquisition. In another outdoor experiment it was shown that differences in route following were not significant across different map extent levels. The interaction with the map in the form of panning did not interfere with the route following tasks in the navigation experiment as well.

Map View and Rotation

Darken & Peterson (1999) suggested that the map orientation should be matched to the task of a user. Egocentric tasks like wayfinding should use a forward-up map while geocentric tasks such as overall exploration should use north-up maps. When using conventional paper maps as navigation aids, humans tend to twist and turn the map in order to facilitate wayfinding and avoid mental rotation. Research in wayfinding and cognitive mapping has also shown that the efficiency of wayfinding tasks is generally higher with an egocentric map and therefore the use of forward-up maps in navigation systems suggested (Radoczky 2004, Zipf & Joest 2004, Hohenschuh 2004).

Compared to the convention of aligning a mobile map in a way so that the current position of the user is in the center of the map, Winter & Tomko (2004) argued that "it is more intuitive for a map user to find her actual position at the bottom of the map". When the user is looking down at the device in his hand, he perceives the bottom line of the map as the closest part to his body, and the top line is heading off. Hence, the top line points towards features in the vista space (visible space in the real environment) ahead of the user, where the horizon of the map matches cognitively with the horizon of the vista space.

When using a mobile map for navigation, this forward-up egocentric map view can be achieved by several ways: The device can be physically rotated within the user's hands, the user can manually operate buttons to digitally rotate the map, and the map can be rotated automatically using data from an electronic compass. In a real environment experiment of Seager & Fraser (2007), the three methods for maintaining forward-up alignment were compared against a north-up aligned map. They measured task performance (timings, errors and disorientation events), user satisfaction workload and spatial orientation. The study showed that physical rotation is the most practical way to maintain forward-up alignment. Most users complained about automatic rotation that the map was also rotating when they have not even looked at the device. Participants of the study seemed to have trouble recognizing the map in its new orientation when using automatic rotation. Another opinion about the methods of maintaining forward-up alignment is given by Radoczky (2007): She argued that by turning the map manually, labels and other information would lack readability and therefore suggested to provide automatic map rotation for forward-up alignment.

2.7.2. The User's internal State

Fang *et al.* (2015) made use of Maslows's (1943) psychology theory in sociology research and adapted it to their research to analyze pedestrian's needs while navigating. Therefore, they stated that innovative pedestrian navigation theory and technologies have to serve people in comfortable, respectful and confident ways to meet the user's needs in all aspects of physical sense, physiological safety and mental satisfaction. These layers are shortly introduced with a focus on the third component *mental satisfaction*.

The *physical sense layer* concerns about the visual, auditory, tactile and olfactory senses of a pedestrian. These senses are used to perceive navigation instruction information from a navigation system. While visual and auditory senses are most often used in conventional paper or digital map-based visualizations and *tbt* guidance, auditory and tactile senses are used for the guidance of visually impaired pedestrians. There has been a lot research about the guidance of blind pedestrians making use of haptic feedbacks (Azenot *et al.* 2011, Kammoun *et al.* 2012). There exist several approaches in delivering the effect of vibration indicating the direction a pedestrian has to take: Kammoun *et al.* 2012 suggest a wrist belt which can give a haptic feedback and therefore covers up all directions from the user's location. Azenot *et al.* 2011 explored different methods using vibration strips around the smartphone to give information about the direction a pedestrian has to take.

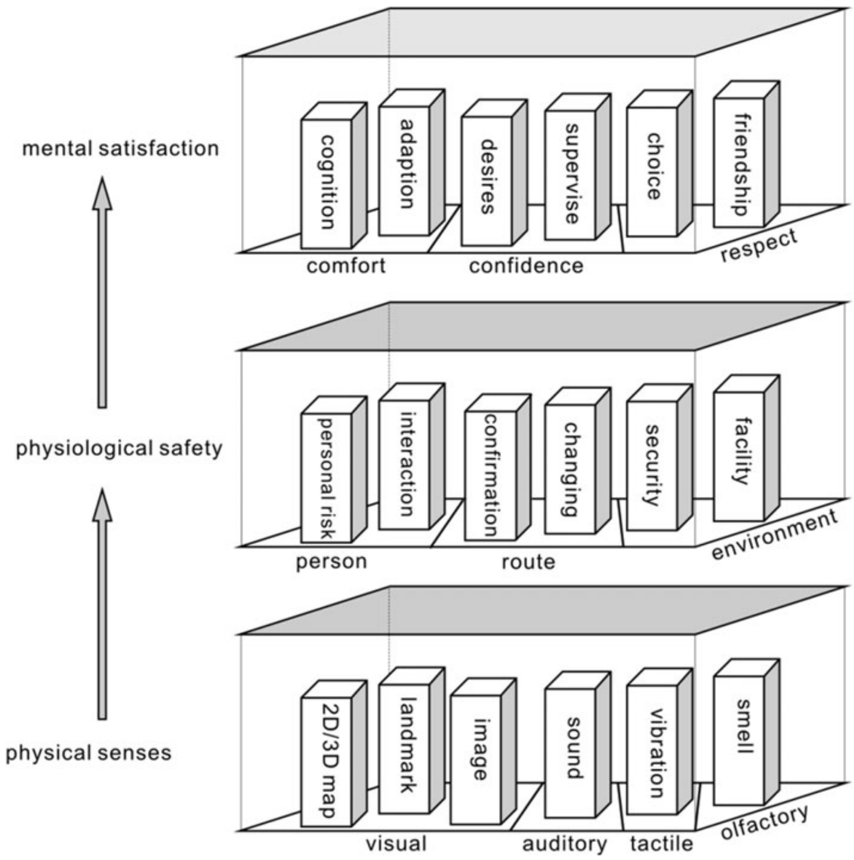


Figure 5: Three layers of pedestrian's need (according to Maslows's theory, adapted by Fang *et al.* 2015)

The *physiological safety layer* can be split up in different aspects of safety. The first aspect is the person's safety. Pedestrians could fall accidents when they pay too much attention to the navigation system and therefore, could be hurt or misled by the device. Furthermore, misunderstanding navigation guidance may lead to wrong navigation behaviors and may even cause potential personal risks. The second aspect concerns the routes itself. If a pedestrian is unsure about the correctness of a route, he must frequently confirm his current walking route with the planned route, because he lacks a sense of safety on the route and is worried about getting lost in an unfamiliar environment.

Mental satisfaction is a pedestrian need that is easily ignored by researchers and even pedestrians themselves. Fang *et al.* (2015) state that satisfaction of pedestrians in the navigation process requires comfort, confidence and respect. There are many existing factors that can influence the comfort of pedestrians, such as *weather*, *security*, *appeal*, *traffic*, *pavement conditions*, *noise*, *air pollution* and the *layout of the walkway*. All these factors mainly derive from the environment. Furthermore, pedestrians need a sense of confidence from controlling a navigation system rather than being controlled by it. This confidence can be achieved when a user has the possibility to, e.g., alter the planned route by choosing a cleaner or more beautiful environment to pass through. Concerning the aspect of respect, pedestrians need navigation systems that respect their (route) choices and adapts to them. For example, a pedestrian will not experience respect when the navigation system gives endless instruction alerts about going back on the predefined route.

In a qualitative user study from Speake (2015), the engagement between users and Sat Nav (satellite navigation) devices as well as conventional paper maps or other navigational aids in a national and international setting was investigated. Thirty-six geography students were asked, which kind of navigational aid they use for places they visit the first time and how they describe the experience of whose usage. Students who use Sat Nav technologies often use positive adjectives to describe the feeling while using it, like for example: *confident, happy, in control, safe, relaxed, trusting, independent*. These words express notions of control and confidence and were narrated by participants like for example as follows:

> *'It was very relaxing and convenient to use because of how accurate it was.'*

> *'I feel confident and assured that I will not get lost'*

Nevertheless, feelings suggesting concerns or worry relating to Sat Nav technologies were expressed as well:

> *'[Sat Nav] is not always reliable, feel happy when I find the place.'*

> *'very worried don't trust it [Sat Nav]'*

On the other hand, the emotional outcome when using other navigation aids relying on the own spatial cognition abilities were expressed by using words like 'enjoyment', 'accomplishment', 'achievement' or 'pride' when navigation had been successfully completed:

> *'exciting… I prefer to explore the area by myself by chance'*

Table 5: Types of navigation technology and feelings expressed when using it on the first visit to a place (Speake 2015)

Type of navigation technology	Feeling (UK)	Feeling (international)
Sat Nav	Confident (7), happy (7), in control (5), safe (3), relaxed (2), indifferent, trusting, independent, reassured, 'easy-peasy', pleased, chuffed, insecure, don't like them	Less isolated, trusting, confident, empowered, worried, not reliable, unsure
Other map (including paper-based maps)	In control, comfortable, don't trust it	NA
Non-cartographic methods of navigation (e.g. asking for directions)	NA	Calm, safe, happy, confident, unsure, confused

2.8. User-centered Design

User-centered design (UCD) is an iterative multistage process during which an interactive system (for example a map-based application) is evaluated by its potential users to receive feedback concerning the usage of the system. The application can then be defined in a further stage in the process of UCD (Nielsen 1994). The fundamental principle of a UCD is to involve the potential users already in the design phase of the system. This approach has been increasingly recommended for interactive maps and cartographic products (Roth *et al.* 2017) and has been applied for the design and evaluation of various applications such as smartphone-based pedestrian navigation systems (Rehrl *et al.* 2014). In the study of Rehrl *et al.* (2014), it has been shown that UCD is an effective method to ensure that the system is being developed meeting users' expectations.

2.9. Integration of this Work into the Research Context

Navigation consists of two components, wayfinding and locomotion (*chapter 2.1*). Navigation aids, such as mobile navigation assistance systems, can help pedestrians in both tasks by giving them decision point information, local context and global context (*chapter 2.3*). However, the way how this information is communicated by a navigation aid has a significant influence on how the pedestrian perceives his immediate environment and what he learns about it. This process is called spatial knowledge acquisition (*chapter 2.2*). Conventional navigation systems are based on the concept of turn-by-turn navigation. The pedestrian gets text (or voice) -based instructions about the action at a decision point and map-based instruction by providing a predefined route on a base map. Research has shown, that a certain over-reliance on automated systems may cause users to be mindless of the environment they are navigating in and not to develop way-finding and orientation skills on their own nor acquire the spatial knowledge that may be required when automated systems fail. There has been a lot research about enhancing the acquisition of spatial knowledge (in particular survey knowledge) of pedestrians using digital mobile map applications. Researchers agree that the use of local and global (distant) landmarks (*chapter 2.5*) can help the users in getting a better orientation in an unfamiliar environment and therefore acquiring more spatial knowledge. Nevertheless, mainly global landmarks are not yet broadly disseminated in navigation systems. Even though, there exist approaches that increase the acquisition of spatial knowledge, all of them are still based on the concept of tbt navigation what restricts the user in terms of freedom while navigating. This, on the other hand, has an impact on the user experience. Expectations and needs of users relating to navigational aids and route choices can vary a lot and can be conceptualized by the term *mental satisfaction*. Without a doubt, for some people and situations they are in, tbt navigation systems providing the shortest or fastest path to the destination may be the best solution. However, there are other people as well, that do not want to be restricted by turn-by-turn navigation systems due to worries about their trustworthiness or the simple fact that they want the explore an area on their own (*chapter 2.7.2*).

Collectively, conventional tbt navigation system can have diminishing influence on the acquisition of spatial knowledge. Although there exists approach to enhance it (such as global landmarks), there are not broadly used or not researched yet. Additionally, being restricted to a predefined path may have a bad influence on the user experience in terms of mental satisfaction.

There exists no alternative solution yet for a pedestrian navigation system in the form of a mobile map application, which faces the state problems from above. This is where my Master's Thesis will tie up. The research aim and research question are formulated in *chapter 3*.

3. Research Objectives and methodical Overview

As shown in the state of the art literature review, spatial knowledge acquisition and the user experience are strongly dependent on the design of a mobile map and the way how route instructions are communicated. It is proven that conventional turn-by-turn navigation systems can cause users to be mindless of the environment and for some cases a predefined route may restrict the user in his preferences and expectations about a route and the whole navigation experience.

Based on the stated problem, two main research objectives are defined, which will be addressed within this Master's Thesis:

(1) How can a navigation system be designed without restricting the user to a predefined route?

(2) How does this system perform compared to a turn-by-turn system in terms of spatial knowledge acquisition and the user experience?

Hypothesis to RO 1:

Based on the presented findings from previous research, the hypothesis is stated that a system should present to the user a potential path area (PPA) instead of just one predefined route. This PPA proposes an area to the user in which he can move around freely but still reaches the destination within certain time boundaries. Going hand in hand with the PPA, the direction of the destination is presented as an off-screen landmark. As an additional component, the system will make use of local and global landmarks to help the user orientate himself in the environment and to increase the acquisition of spatial knowledge.

Hypothesis to RO 2:

It is stated that a System with integrated local and global landmarks and a potential path area instead of a predefined route enhances the acquisition of *route* and *survey* knowledge compared to a turn-by-turn navigation system. Additionally, it is stated that the system increases the user experience in terms of (1) the usability and functionality of the system design, and (2) the confidence, sense of safety and freedom perceived by the user.

Methodology

In the context of this Masters's Thesis a user-centered design (UCD) approach is applied. Within the framework of this work, all stages of this circular workflow are processed once (*Figure 6*).

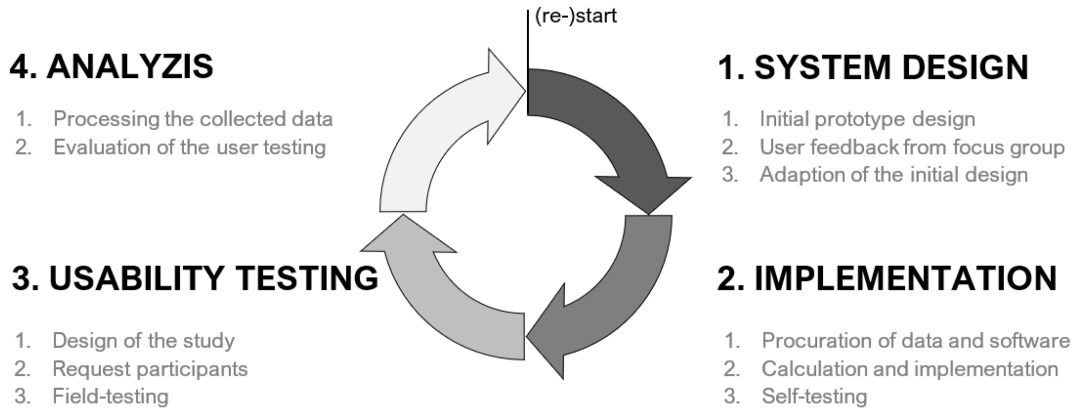


Figure 6: (Iterative) workflow of the methodology

Thus, chapter 4 describes how the system was conceptually designed. After a first initial mockup was generated, the design was discussed in a focus group to get some user-centered feedback. The design was then revised and completed. In the next chapter, it is described how the system was implemented with the aim to test it in a real environment. The procedure and structure of the conducted user study are then described in chapter 6, the last section of the methodology part. In a real environment study, the usage of the implemented navigation system was compared to the conventional tbt system *Google Maps* relating to the acquisition of spatial knowledge and the user experience.

4. System Design

Having the aim to provide a completely new solution for a pedestrian navigation system, many design decisions have to be made. Nevertheless, for many components, it will be referred to design goals developed in previous research. These design suggestions will be packed together in a way they built a novel composition and function as a pedestrian navigation assistance. Since it is the idea to propose a novel system, the process of the system design is *from the bottom up* without paying much attention to the design and components of common pedestrian navigation aids. The design phase alone is, therefore, an iterative process by its own: In a first step, possible components and within that different design

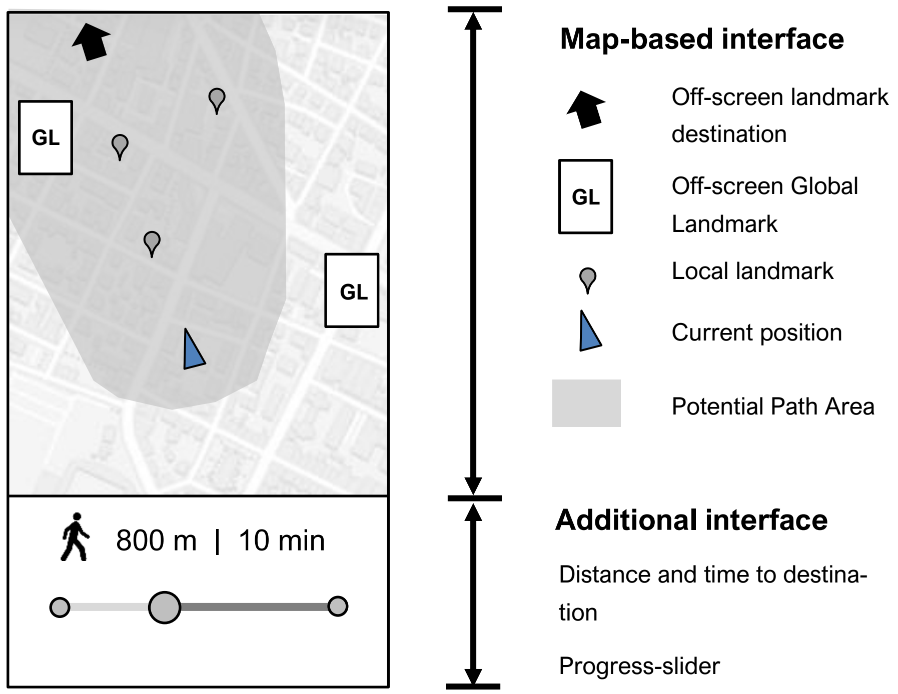


Figure 7: Initial sketch of the user interface

variants are discussed and adapted until a set of possible solutions have been mapped out. These different design solutions were then discussed in a focus group pre-test. With the help of the qualitative feedback collected from this discussion, the designed system is then adapted once again so that it can be used for the implementation. In the following, the different components and their design are presented. It has to be mentioned that the presented design variants are already the final ones, which were defined with the focus group. In the last section of this chapter, the initial design presented to the focus group is shown. The results of this discussion are also presented in this section.

4.1. Components of the System

As a most basic design step, it was decided to have two main elements in the interface of the system: (1) A map-based visualization and (2) a second part for further information assisting the map-part of the interface.

4.1.1. Map-based Interface

Since YAH maps are the most common, original form of all location-based services, aiming to create spatial awareness and to plan routes (Klippel *et al.* 2010), it will be made use of the concept as a basis of the map-part. As additional *static* elements on the map the start and endpoint of a potential navigation task are accentuated as it was proposed by Schmid *et al.* (2010). Furthermore, local landmarks are highlighted as a further orientation help for the users and therefore it will be followed the design principles of Elias & Paelke (2007). As defined in the research objectives, the system should on the one hand not restrict the user in his possibilities by providing a predefined path, and on the other hand, should increase the spatial knowledge acquisition. To achieve these goals, two main elements will be included in the system: (1) Global landmarks and (2) a potential path area (PPA).

Base Map

As a base map for the PPA-System a map tile from CARTO (formerly CartoDB) was used. The base map shows a clean layout and visualizes streets / paths, building and natural objects. The map includes no labelling of the streets since the attention of the user should be consciously directed to the real environment. Since the reference system *Google Maps*, which will be used for the user study, shows labelled streets on the map, the need for labelling will be assessed and evaluated within the user study (*chapter 7.3 & 8.1*). The scale of the map is set to 1:4000. This scale was chosen so that the user can get as much overview as possible but can still see enough details to orientate himself in his direct environment. In contrast to navigation systems for vehicles, the scale always remains the same, since

Figure 8: Base map of the PPA-System

the speed of pedestrians' movement does not vary much. However, the user has the possibility to zoom in and out, whereby after a moment the map moves back to the standard scale. Since the destinations of both test areas are located south of the start points, the map is aligned south up. Due to that, the direction of walking will be most of the time on top of the map interface what feels the most natural for most users (Seager & Fraser 2007). Additionally, in the real environment study of Seager & Fraser (2007), the participants stated that the automatic rotation of the map could be too irritating. Since *Google Maps* provides an automatic rotation, it will be possible to make a direct comparison and collect the feedback from the test users in the user study.

Current Position

The users can see their location at every time on the map. A blue circle was chosen as a location marker. Additionally, there is another semi-transparent circle around the smaller point, which shows the GPS inaccuracy. A dark blue bar indicates the direction in which the device is pointing to. Based on the findings of Winter & Tomko (2004), the location marker is placed on the lower third of the map height. By that, the user can see more of the environment, which still lies ahead of him.

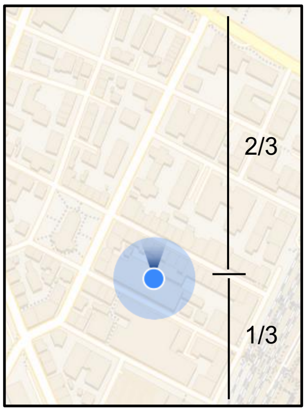


Figure 9: Location marker of the PPA-System

Local Landmarks

Local Landmarks help the user to orientate themselves along the route. Therefore, the design suggestions of Elias & Paelke (2007) were followed in visualizing the landmarks according to different building categories: Shops, restaurants and bars / cafés. Additionally,

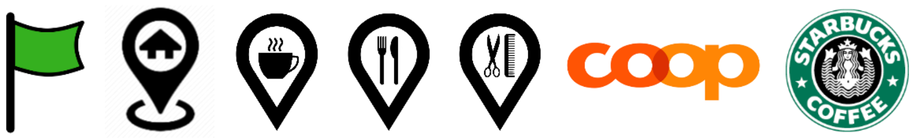


Figure 10: Different icons used for local landmarks (from left to right): End point, start point, bar / café, restaurant, hairdresser, well-known shop, well-known cafe

two local landmarks for the start- and endpoint of the routes were added to the map. The different landmarks are either visualized with a conventional symbol or well-known shops and restaurants / bars are visualized with the company's logo.

Global Landmarks

Global Landmarks help the user to get a sense of direction and within that an overall orientation of the environment. Therefore, the design suggestions of Li *et al.* (2014) and Schwering *et al.* (2017) were followed in visualizing the global landmarks as off-screen icons indicating the direction to the corresponding landmark on the edge of the map-based interface part of the system. Since not every test user will be familiar with the global landmarks in the real environment, they will be displayed with photos. So, the users can connect the represented off-screen photo with the landmark in the real environment. Additionally, the destination and the start point of the routes are visualized as off-screen objects as well, indicated with an arrow or the house icon.

Figure 11: Different off-screen icons for global landmarks (from left to right): Destination, start point, Sulzer tower (Test area 1), city church (test area 2)

Potential Path Areas

However, the most popular element of the map-interface is the PPA, since it is serving as the main map-based object communicating route instructions. The main idea behind not providing the shortest path for the user has two reasons. First, the difference in length

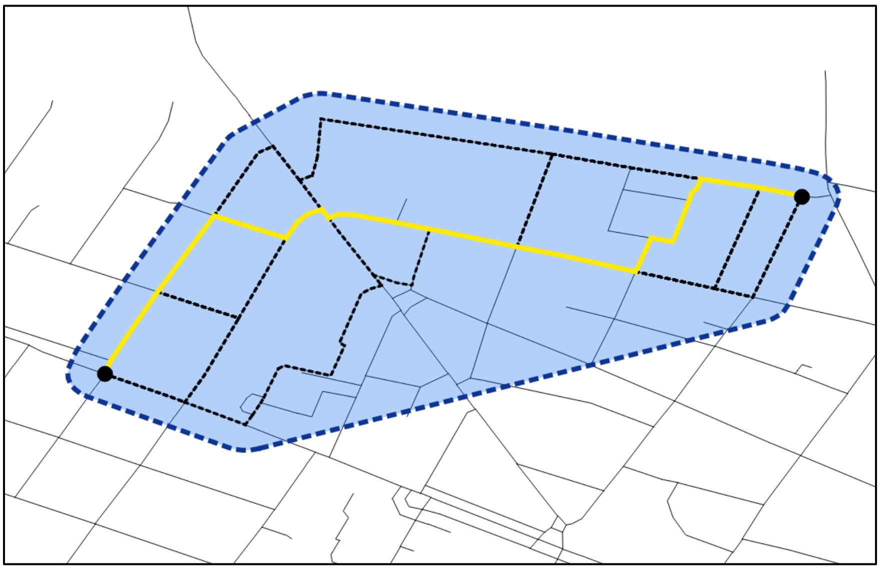


Figure 12: Schematic vizualization of a PPA: Shortest-path in yellow, k-shortes paths dashed black, buffered convex hull around k-shortest path in blue

(depending on the used algorithm, here referring to Dijkstra's shortest path) between the shortest path and the k-further shortest paths between two points can potentially be very small. This means, that a shortest-path-based system then chooses the very shortest path while some other paths would also have been suitable. The second reason is that users may not even take the shortest path of their own free will due to subjective preferences. Therefore, the PPAs base on the concept of a **detour**. The operating principle of the PPAs is described in the following paragraph.

Presumed a user is willing to take into account a detour of 25 %. This would mean, if the shortest path would take him 10 minutes, he would also accept all paths which would not cost him more than 12.5 minutes. By the help of Yen's K-shortest loopless paths (1971) all paths for which the user does not need longer than 12.5 minutes can be calculated. Then, a convex hull is calculated around these k-shortest paths and additionally provided with a specific buffer to avoid any biases due to some inaccuracies of the geolocation function of the device and to go sure that streets at the edge of the convex hull lie inside the PPA. After a user started the navigation task, the PPA will continuously adjust by taking the current location of the user as the new starting point for the calculation of the new PPA.

The PPAs can be visualized in various ways. Since the concept of a potential path area is a product of this Master's Thesis itself, the visualization of the PPAs will be discussed in the focus group. As design suggestions, different design solutions were worked out (*Figure 13*). The two variants on the left side of *Figure 13* show the PPA as a colored, semi-transparent area whereas the borders are either straight or smooth. On the right side of *Figure 13* the counter pieces of the PPAs are dimmed, either with straight or smooth edges. The final variant will be evaluated by the help of the feedback of potential test users.

Figure 13: Different visualization styles for the potential path areas

4.1.2. Additional Interface Part

Besides the map, an additional element is added to the interface. The idea about this element is to give the user further information about the route which cannot be visualized on the map itself. The main element in this second part of the interface is a horizontal bar graph indicating the progress a user has made on the route. Additionally, time and distance of the shortest path are given at this place. Thus, the user can see the proportional progress he made on the route so far and how much time it takes him to finish the route, consequently. The idea of enabling the user to see the progress made so far is to give him the

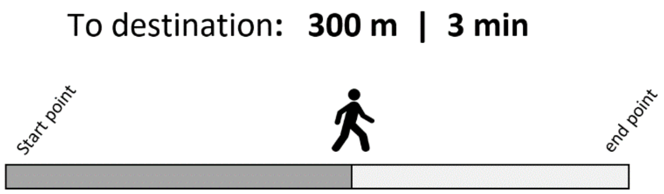


Figure 14: Sketch of additional interface part

feeling of certainty of being on the right way. Knowing how much time it takes the user to finish the navigation task can help him decide on which route he should take.

4.2. Focus Group Feedback

The first initial mockup of the interface was discussed with a focus group consisting of potential users of the system. This method aims to collect some feedback regarding the design and revise the interface before implementing it. First, the method *focus group* is shortly introduced, and in a second paragraph the procedure of the held discussion is presented. After that, the feedbacks are summarized and discussed whether they were taken into account or not.

Focus groups are an informal technique to assess user needs and feelings both before the interface has been designed and after it has been in use (Nielson 1993). In the context of this Master's Thesis, four potential, male users at the ages of 23 - 25 were brought together to discuss the system design and identify possible issues for 40 minutes. According to Nielson (1993), focus groups often bring out users' spontaneous reactions and ideas through the interaction between the participants. The focus group was moderated by myself to lead through the discussion.

The participants were shown a mockup of four different design solutions for the self-implemented navigation system (*Figure 15*). First, the elements of each design variant were explained to the participants. After that, the discussion was opened up and the participants were asked which design variant they think visualizes the navigation instructions in the most comprehensive way. More detailed questions were then asked about various components of the interface.

Results

As a preliminary remark, it should be noted that most of the spontaneous feedback has been fed into the design revision to improve it as much as possible. For other discussion points, it was communicated, that there already exists a clear idea about the design in

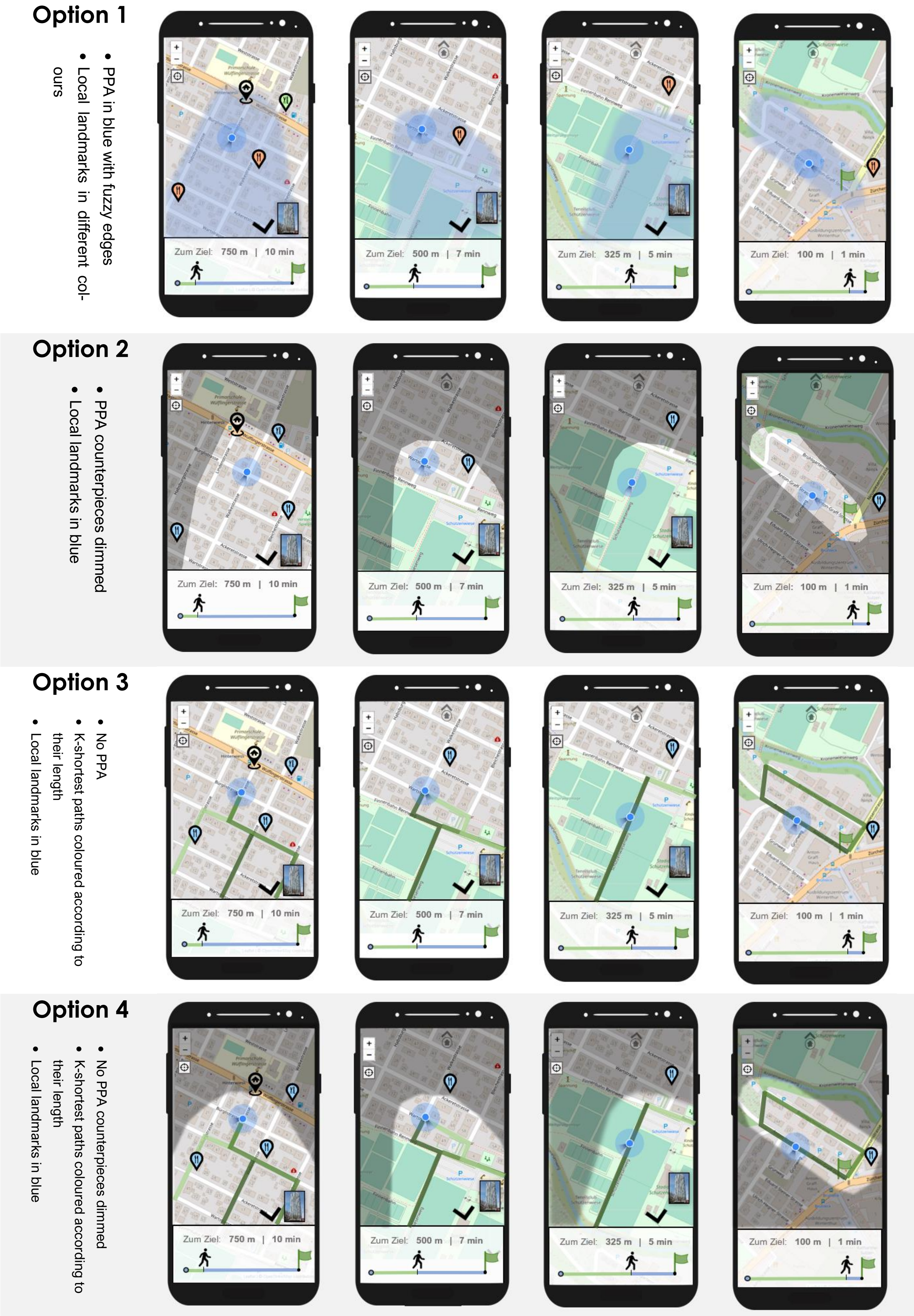


Figure 15: Interface mockup discussed at the focus-group evaluation

advance. If the participants had a good suggestion for improvement, it was also included in the revision.

In the following, the most crucial findings from the survey are recorded. Additionally, some of the given feedbacks are underlined with quotes from the participants.

- Most of the participants preferred the design variants, where the potential path area was visualized without the k-shortest paths. Showing the k-shortest paths colored according to their length would probably be too irritating. However, one participant suggested that besides the PPA the shortest paths to the destination should be displayed.

  «*The user can see the shortest way but does not have to take it. It would only be a reference for the user, so that he can estimate how big a certain detour is within the area.* »

  However, this proposal was not included in the system because it wanted to be realized without any turn-by-turn route communication. By doing that, the users can be specifically asked whether they missed information concerning the shortest path.

- The participants preferred the design variant, where the PPA is not visualized with a specific color, but all the area around the PPA is dimmed. They preferred this variant not only due to aesthetic reasons but also because it makes more sense to them: The PPA should not be covered; this could reduce the information content. According to the participants, the edged of the PPAs should be straight since it could lead to confusion.

  «*The darkening around the surface makes it intuitively and clearly visible in which part of the map one is allowed to move.*»

  «*The area should have clear edges, otherwise you could take paths that are no longer within the area or lead out of it.*»

- The color of the local landmarks did not play a role for the participants. However, if they have the same color, the icons have to unambiguously and clearly refer to the corresponding feature.

  «*Well-known shops or restaurants could be displayed with the corresponding logos. I think that a landmark will stay in your memory better if you use already known symbols.*»

- North alignment of the map would probably be irritating since the users would have to rotate the map mentally, which could be quite hard for some users. Automatic rotation according to the direction of the device, on the other hand, could possibly be too nervous. The participants suggested that if the relative direction towards the destination of the route is very close to the south, the map should be aligned south up.

> «*For me it would make sense if the map is oriented to the direction of the sky, north, south, east or west, which is closest to the relative direction of the destination from the start point.*»

- If the map is rotated and the labelling is upside down, it should then be blanked out.

  > «*Labelled streets might be helpful, but if they were upside down I would leave them out. Since you have your own location and the direction of the device as information, the street labels are not necessary to orientate yourself.* »

5. Implementation

In this chapter, the implementation of the PPA-System is described in more detail. The chapter is split up into two parts: (1) the architecture of the application and (2) the informational content of the system. The first part describes how the software of the application is structured and build, whereas the second section describes how the components of the PPA-System (e.g., PPA, landmarks, …) were calculated and implemented for the application.

5.1. Architecture of the Application

The PPA-System was implemented within the framework *Adobe PhoneGap*. This framework allows a user to create hybrid applications for mobile devices. PhoneGap makes it possible to write application software for mobile devices with JavaScript, HTML5 and CSS3 instead of device-specific programming languages such as Java. The resulting applications are hybrid applications. They are neither native, because the layout is written using web technologies and not native user interface frameworks, nor are they web-based

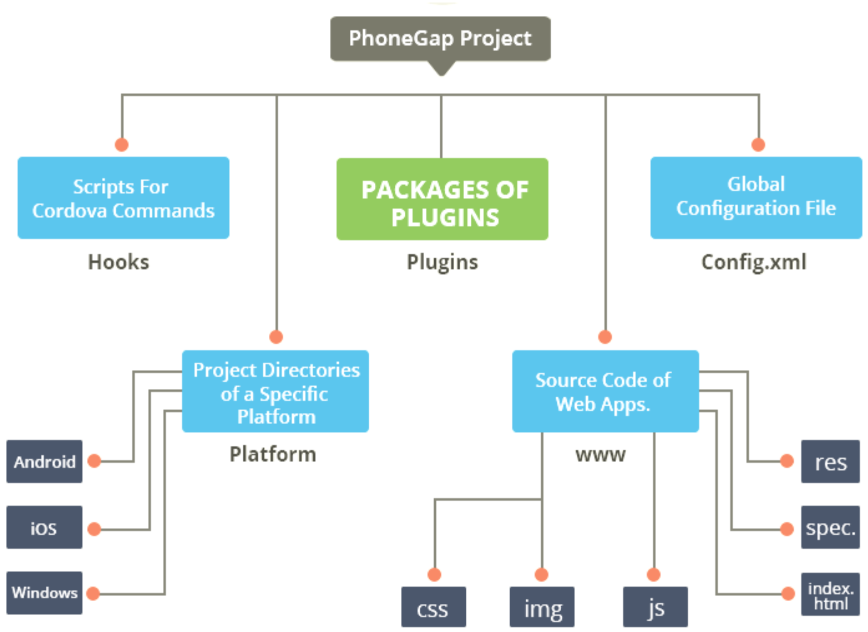


Figure 16: Structure of the Phonegap Application (FormGet 2019)

applications because they can be distributed as apps via the sales portals of the operating system manufacturers. The basis of a Phonegap project is a *config.xml* file, which is a platform-specific configuration file. With the help of this configuration file, it is possible to modify the default values of PhoneGap application elements like its name, the icons, APIs and more. One of its primary purposes is to let developers specify the metadata about the application. The most important APIs which were used in order to implement a location-based application are (1) Geolocation, (2) Device orientation and (3) Leaflet map library. The Geolocation API provides information about the device's location, such as latitude and longitude. It allows the application to receive the coordinates of the device via GPS signal at a defined time interval. These coordinates can then be used for further spatial analysis. The Device Orientation API allows the application to receive information about the orientation of the smartphone within its environment. The information about orientation can then be used to e.g. visualize at the current position marker. The Leaflet API is a free JavaScript library that can be used to create map-based applications. The library uses HTML5, CSS3 and supports most desktop and mobile browsers. With Leaflet, Web Map Tile Services can easily be presented together with own geodata on a website or a mobile browser. The geodata can be loaded from GeoJSON files and provided with interactive functions such as pop-ups.

In the *config.xml* file, the project contains some specially named sub-directories that contain assets that are part of the build process. The most important directory is the *www* directory containing the Html, javascript and CSS files that build the source code of the whole application. Within the Html file, the layout of the application is structured. The interface is split into the map-based and the further information part. With Html, text can be added to the interface as well. The CSS file describes how HTML elements are to be displayed on the screen; colors, text styles and sizes and more can be defined. With the javascript file, the Html elements can be extended by functions. The whole map-based interface is defined by javascript: The map is loaded, the location can be displayed as a marker and geometries can be visualized on the map.

In a directory called *plugins*, additional javascript files containing a set of functions can be added to the project. Within the *www* directory, one can access the plugins to extend its functionality. One prominent plugin that was used to build the PPA-Application is the *Leaflet EdgeMarker Plugin* (Pape 2013). With the help of that plugin, point locations can be visualized as off-screen landmarks when they are not on the extent of the map which is visualized on the interface of the application.

The whole application, including all the files mentioned above (*Figure 16*), was then uploaded to the Adobe PhoneGap Build cloud. This online service compiles the application by just giving it the source files. The compiled application can then be downloaded on every iOS, Android and Windows Smartphone (for the download to iOS systems one has to pay).

5.2. Informational Content

In this section, the calculation and implementation of different components of the systems are described. Some of them are implemented inside the application framework whereas other components were preprocessed within other technical frameworks and loaded into the scripts of the application afterward.

5.2.1. Local landmarks

All local landmarks were depicted in advance and loaded into the application as geojson-objects. The landmarks were selected from the OpenStreetMap points of interest (POI) database. Via an API called *Overpass*, POIs can be selected according to defined criteria and exported as geojson point objects. The Overpass API can be accessed via the web-based data collection tool *Overpass Turbo*. Overpass turbo provides an interface with which one can quickly make overpass queries and have the results displayed in a user-friendly way. For the PPA-System, the following three types of POIs (local landmarks) were used: Restaurants, bars / cafés and shops.

```
  (
   node[amenity=bar]({{bbox}});
   node[amenity=cafe]({{bbox}});
   node[amenity=pub]({{bbox}});
   node[amenity=fast_food]({{bbox}});
   node[amenity=restaurant]({{bbox}});
   node[amenity=nightclub]({{bbox}});
   node[amenity=shop]({{bbox}});
   node[shop]({{bbox}});
   );
out;
```

Figure 17: Overpass API query used in overpass turbo to select and export the local landmarks.

Due to a massive number of resulting POIs, the selection of landmarks was filtered manually. Landmarks at decision points got the highest priority while landmarks along a street between two decision points were deleted if there was an overload of POIs. Additionally, well-known POIs such as big retailers got a higher priority than small shops. The landmarks were then loaded into the PhoneGap application and visualized according to *chapter 4.1.1*.

5.2.2. Global landmarks

For each test area (*see chapter 6.3*), one global landmark was chosen. Since the global landmarks in the PPA-system are primarily about being frequently in the field of vision, they were selected according to their size. This can be done in various ways: With the help of a digital surface model / 3D model of the city, by an (internet) investigation or by exploring the environment itself. Since the testing environment was well known, the two global landmarks were selected with the help of existing spatial knowledge.

For both types of landmarks, a geojson point file was generated. This file was then uploaded into the PhoneGap application and visualized by an icon. If the landmarks are not on the extent of the map itself, they are visualized as off-screen landmarks. This was done through the help of a plugin called *Leaflet EdgeMarker*, which allows indicating Markers, Circles and CircleMarkers that are outside of the current view by displaying the markers at the edges of the map with a customized symbol (icon).

5.2.3. Potential Path Areas

As the PPAs only have to be calculated for two different environments, they are not computed in real-time in the PhoneGap application. Therefore, the PPAs are calculated on every significant decision point which lies inside the first PPA between the start- and endpoint and are displayed on the map, if a user approaches a certain decision point. The maximum value for the detour was set at 25 percent. The computation complexity and practical implementation of the potential path areas in real-time are further discussed in *chapter 8.1*. For the calculation of the individual areas on every decision point Yen's k-shortest paths algorithm has to be applied on a suitable street network dataset of the test area. Therefore, it was made use of pgRouting, which is an extension of the PostGIS / PostgreSQL geospatial database and provides geospatial routing functionality. An additional advantage of pgRouting is that attributes can directly be modified by Desktop GIS clients like QGIS.

As a basis for the calculation of the PPAs, a street network from OpenStreetMap was used. With the help of the command line tool *osm2pgrouting* OpenStreetMap data is imported into a pgRouting database. osm2pgroutig builds the routing network topology automatically and creates tables for the edges (roads) and vertices (decision points) respectively. In the database manager of QGIS, the areas could then be calculated using the k-shortest path algorithm query from pgRouting (*Figure 18*).

After inserting the calculated shortest paths into QGIS, the convex hulls were calculated and a buffer of 25 meters was laid around them. These geometries were then saved as .geojson objects. To achieve having the counterpieces of the PPAs dimmed and the area itself as usual, bright map, the polygons had to be intersected with a large polygon of the size larger than the test area. The result of this intersection is a polygon with a hole in the shape of the PPA. The polygon could then be colored in a semitransparent grey tone. These geometries were then loaded into the PhoneGap project. In a separate table, every PPA geometry is assigned to the (potential) decision point which functions as the start point for the PPA. Whenever a test user approaches a decision point on the route, the assigned geometry is loaded on the map.

```sql
SELECT
     k.seq, k.path_id, k.node, k.edge, k.cost, ST_AsText(ways.the_geom)
FROM
     pgr_ksp(
          -- edges
          'SELECT gid AS id, source, target, length_m::numeric::integer AS cost
          FROM ways',
          -- source node
          881,
          -- target node
          992,
          -- # of routes
          20,
          -- directed graphs
          FALSE,
          -- process heap
          FALSE
     ) as k
LEFT JOIN ways
ON (edge = gid) ORDER BY seq;
```

Figure 18: SQL code of a k-shortest path query with k = 20

Table 6: Attribute table from the results layer of the SQL query from above

seq	path_id	node	edge	cost	wkt_geom
1	*1*	*881*	*492*	*62*	*LineString (8.71831 47.50431, ...)*
2	*1*	*701*	*916*	*19*	*LineString (8.71820 47.50416, ...)*
3	*1*	*132*	*177*	*47*	*LineString (8.71791 47.50379, ...)*
4	*1*	*170*	*121*	*98*	*LineString (8.71791 47.50379, ...)*
5	*1*	*94*	*122*	*51*	*LineString (8.71882 47.50296, ...)*
				...	
23	*2*	*375*	*492*	*62*	*LineString (8.71831 47.50431, ...)*
24	*2*	*701*	*916*	*19*	*LineString (8.71820 47.50416, ...)*
25	*2*	*132*	*177*	*47*	*LineString (8.71791 47.50379, ...)*
				...	
238	*20*	*290*	*1285*	*4*	*LineString (8.71712 47.49824, ...)*
239	*20*	*992*	*-1*	*0*	*NULL*

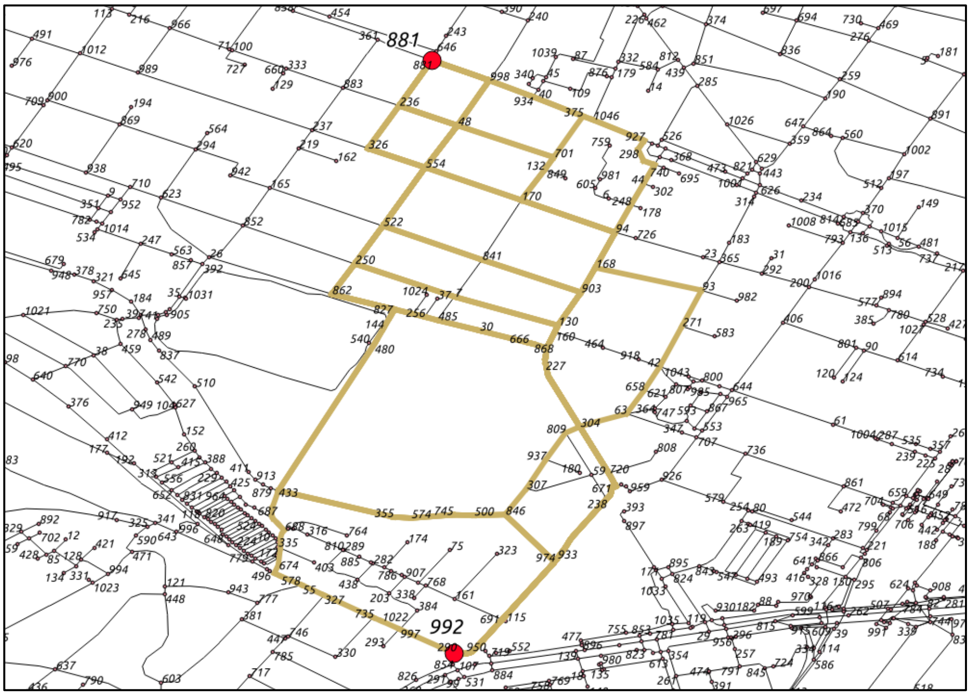


Figure 19: 20 shortest paths between the nodes 881 and 992

6. Usability Testing

6.1. Structure and Procedure of the Study

Since the methodology of this work follows a user-centered design approach, the PPA-System will be tested in a real environment. With the second research objective, it wanted to be found out how the *PPA-System* performs compared to a conventional turn-by-turn system. Therefore, every user will not only test the PPA-System but also a conventional tbt-System on a comparative basis. Since *Google Maps* by the us-American company Google LLC is the most used navigation app in the world, it was made use of *Google Maps* as the comparative variable.

The user-study be conducted based on the concept of *within-subject design.* This means that both systems will be tested by one single subject (participant). In contrast to within-subject design, *between-subject design* is a method where the two systems would be tested by two different participants (Martin 2008). Within-subject design has been chosen due to several advantages. First, if *N* participants are required to give a significant number of data points (tests of both systems), then *N* x 2 participants would be required for a between-subject experiment because every participant would only test one system. Additionally, having tested both systems allows a participant to do a qualitative, comparable evaluation of both systems.

The participants were individually contacted, and a date for the experiment was arranged. The tests took place during daytime from June to July 2019. Care was taken to ensure that the user-tests were only carried out on days without rain. Since rain and other weather conditions such as fog influence visibility and the behaviour during locomotion, the user-tests were cancelled and rescheduled when bad weather was forecasted. Under good weather conditions, the participants were met at the bus station "Hinterwiesli" in Winterthur, close to the starting point of the first navigation route. The participants were then asked to sign a consent form approved by the Department of Geography at the University of Zurich and were told that they could stop the experiment at any time. First, they were asked to fill in a form with questions about their usage of digital maps on mobile devices and the widely used Santa Barbara Sense of Direction Scale (SBSOD) (*see chapter 6.4*). Then, the participants were introduced to the procedure of the experiment. Following this introduction, participants were familiarized with one of the two systems, which were randomly assigned to the participants. If they used the PPA-System for the first navigation task, they used *Google Maps* for the second one and vice versa. The first task (as well as the second one) includes the exercise of moving from a given starting point to a given destination. The participants should not take any breaks. However, it was not the aim to reach the destination as quickly as possible, but at a reasonable pace for the participants. The

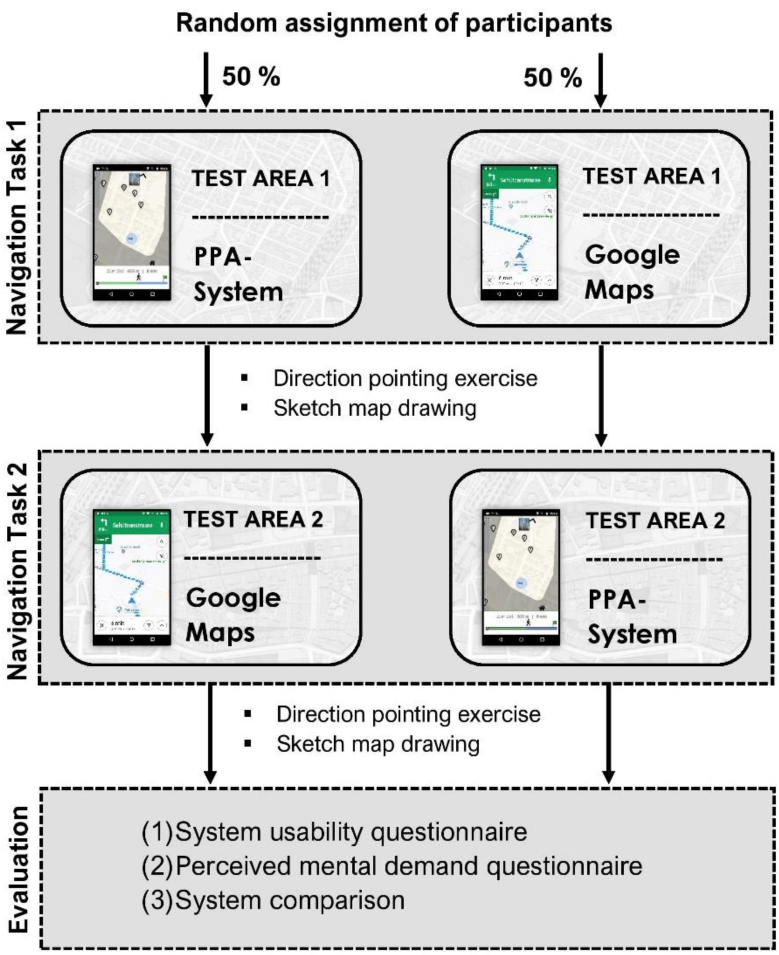


Figure 20: Structuring of the user study based on within-subject design

participants then received the mobile device and were asked to perform the navigation task nr. 1. The distance covered by the participants was recorded using an application integrated into the smartphone. Additionally, the screen of the smartphone was recorded and stored as video file. Furthermore, the test-users were shadowed by myself at about 15 meters. By the help of this screen recorder, the behavior of participants could be better understood when, e.g., a stop was made. By re-inspecting at the interface afterwards, it was possible to determine whether a user stopped because the GPS was inaccurate or because he had lost orientation. After arriving the destination, participants were asked to do a direction pointing exercise and a sketch map of the route. After completing these exercises, the participants were guided to the starting point of the second route at the main station Winterthur. There, the second system was explained, and the participants were asked to complete the second navigation task. Again, they were shadowed by myself at about 15 meters. After completing the second navigation task, the participant was asked to do another pointing exercise and a sketch map of the route taken. After finishing the second navigation task, the participants were asked to fill in another three questionnaires: (1) A Likert scale to assess the system usability of the PPA-System compared to *Google Maps*, (2) A Likert scale to assess the perceived mental demand of the PPA-System compared to *Google Maps* and (3) An additional questionnaire with open questions about the usage of the two systems. In the end, the participants were thanked for taking part in the user-study. They were also reminded to keep the experimental procedure confidential. The experiments lasted about 80 min, on average per person.

Material

The participants were given a smartphone of the brand *Motorola*, model Moto GP3, for solving the navigation tasks. All necessary applications were already installed on the device. The smartphone runs with an Android operation system. In order to guarantee a continuous internet connection for the device, a mobile mobile-radio hotspot of the brand *Huawei* was used. Due to the availability of the participants, the schedule of the study had to be tightly planned. On certain days the smartphone was used up to 6 hours at a time. To prevent the smartphone running out of battery due to intensive use (brightness setting, number of interactions, data transfers, etc.), a mobile battery charger was always carried along. This could ensure the power supply for a whole day. For doing the direction pointing exercise an iPhone 6 was used since its compass alignment with a real compass was much better than the Motorola Moto GP3.

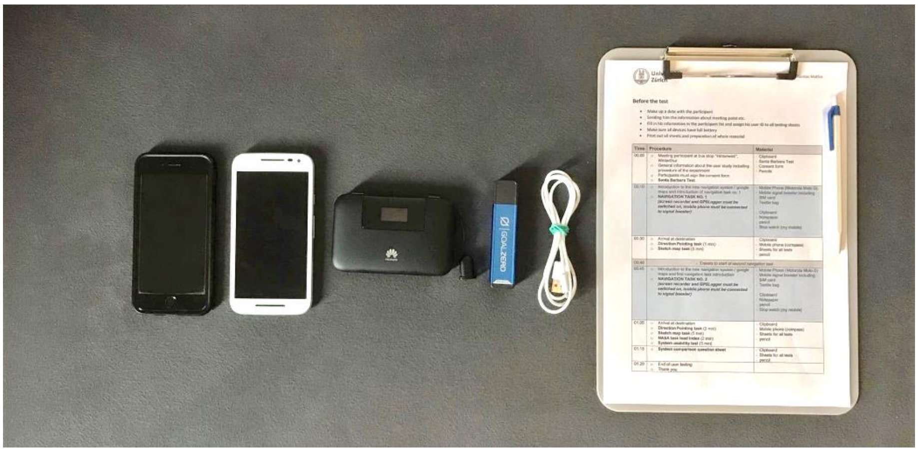


Figure 21: Material used for the user study

Applications

The Following applications were used for the user study:

- **PPA-System:** Own-developed navigation system for navigation task 1 / 2

- ***Google Maps*:** Reference navigation system for navigation task 1 / 2
- **GPSLogger:** Records the travelled path of the participants
- **VRecorder:** Records the screen / the interface of the navigation system that is used by the participants
- **Compass:** Measurement tool for the direction pointing exercise

6.2. Participants

When the participants were recruited, care was taken to ensure that the group of persons was as homogeneous as possible. It was decided to test the navigation system on young people, who all have experience with the use of maps on digital devices. Thus, a specific basic knowledge could be assumed, by which the results can be better compared. A total of 18 participants, seven females and 11 males, were recruited (whereas four women and five men used the PPA-System for test area 1 and three women and six men used the PPA-System for test area). The youngest person was 22 years, the oldest was 31 years old. The mean age of all participants was M = 25.28 (SD = 2.02). All participants were little to not familiar with the testing environment. Before doing the experiment, all test users were asked to answer some questions about their experience in the use of digital maps on mobile devices.

6.3 Test Areas

As an environment for the two test areas, the town of Winterthur in the canton of Zurich, Switzerland, was chosen. Test area 1 (TA1, *Figure 22*) is settled in the living district and city center Neuwiesen / Schützenwiese, whereas test area 2 (TA2, *Figure 22*) is located in the city center and old town of Winterthur. Both test areas show no significant topographic elevations and are located approximately 430 meters above sea level. Additionally, the areas were chosen in such ways that the test users do not have to cross major main roads. Therefore, the locations ensure that the participants are not disturbed by traffic while

Figure 22: Left: Test area 1 – Neuwiesen living district and Schützenwiese sports facilities. Right: Test area 2 – City center / Oldtown. Path provided by *Google Maps* as a red line, Potential path area in semi-transparent red.

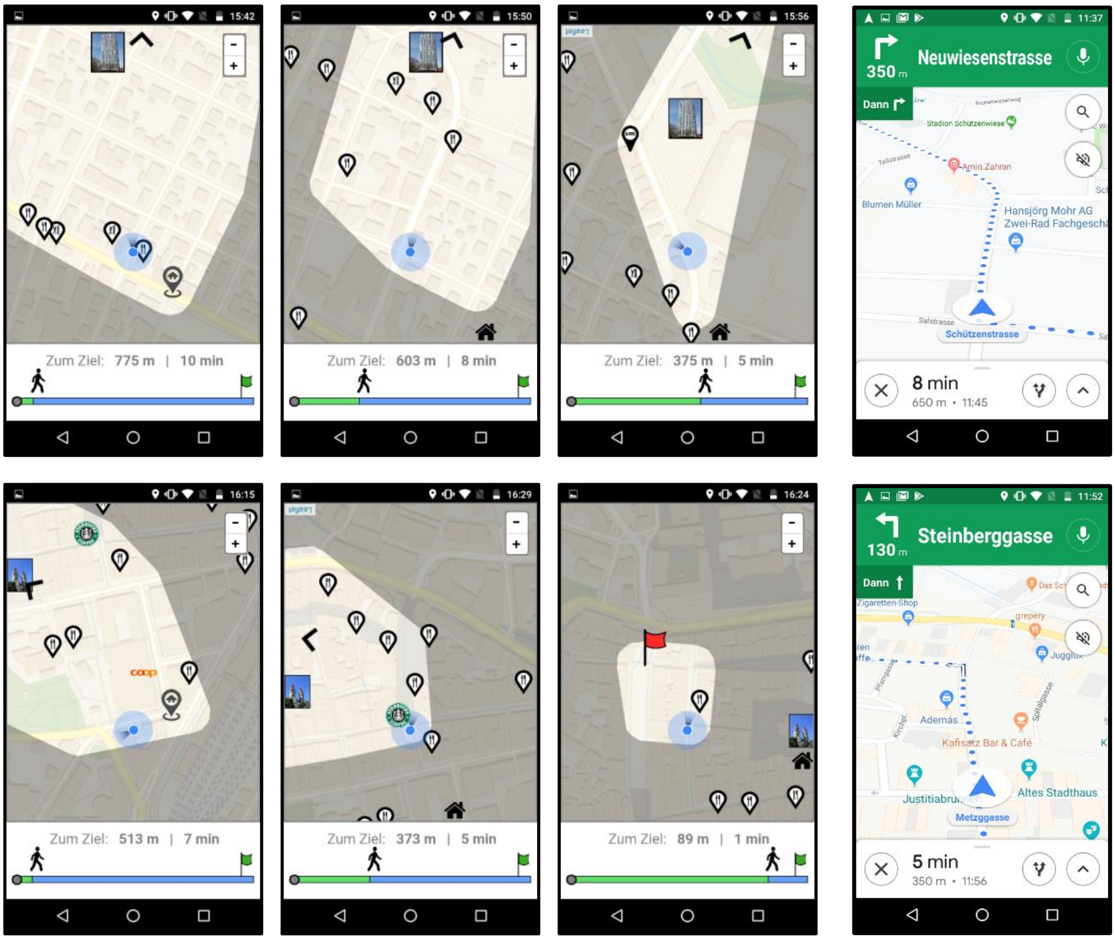


Figure 23: Screenshots of the PPA-System and *Google Maps* at TA1 (on top) and TA2 (bottom)

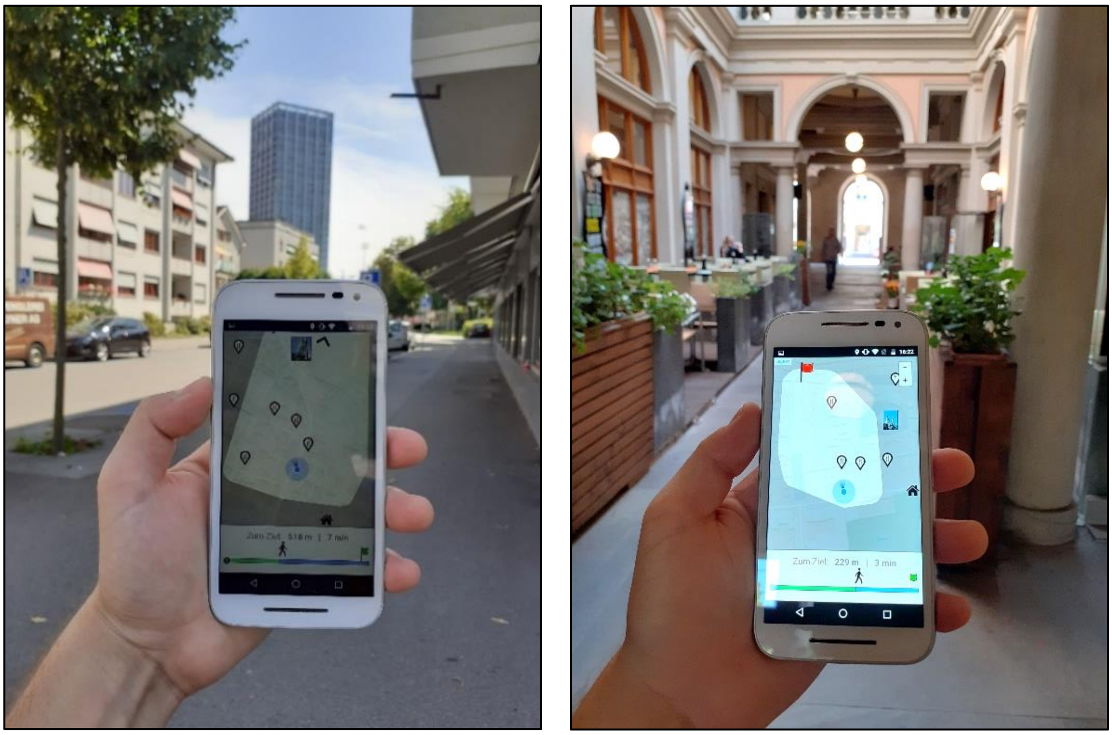


Figure 24: Using the PPA-System in the field (TA1 left, TA2 right)

navigating. Additionally, care was taken to ensure that there was a global landmark in both areas.

TA1 is located to the west of the main railway station and starts at the bus stop Hinterwiesli at Wülflingerstrasse. The target of the navigation task is located and the crossroad between Zürcherstrasse and Neuwiesenstrasse, close to the Sulzer tower. The shortest path of TA1 is 1050 meters long and has three decision points included where a user has to actively make a turn. The test users first have to navigate through the living district. In the second section, they will cross or pass the sports facilities Schützenwiese and navigate towards the city center.

The route of TA2 starts east of the main railway station. The first part of the route leads south through the city center until the navigator enters the oldtown at Stadthausstrasse. The oldtown is a completely traffic-free pedestrian area. The users will navigate around the city church and have a free field of view to it. In the last section of the path, the participants will follow the Steinberggasse until they reach the destination and the very south of the Oberen Graben. The shortest path of TA2 is 800 meters long and includes three decision points as well.

6.4. Sense of Direction

To find out whether the test group is balanced regarding the sense of direction and orientation of its participants, all test-users were asked to fill in *the Santa Barbara Sense of Direction* (SBSOD) form (*see Appendix C*) before doing the first navigation task. The SBSOD-scale was developed in the year 2002 (Hegarty *et al.* 2002) and has established to a broadly used tool in research to evaluate a person's sense of direction. The SBSOD scale is structured as a 15 question Likert scale, whereas every question is worded as a statement about orientation skills. For each statement, the participants had to determine how strongly they agreed with it (7 = strongly agree, ..., 1 = strongly disagree). Similar to Perebner *et al.* (2019) and Rehrl *et al.* (2014), negatively stated questions had been reversed to positively stated ones so that higher scores mean a better sense of direction and orientation. The SBSOD score is calculated for each participant as the average of all 15 questions with a score of 7 representing the highest possible sense of direction.

6.5. Sketch Maps

Sketch maps are a tool often used to assess people's knowledge of spatial environments. However, the evaluation of sketch maps has always been challenging as they differ in many aspects and can, therefore, be rated on many possible criteria. Sketch maps are most often analyzed in qualitative means, where researchers try to find some general differences between sketch maps drawn by two (or more) different participant groups, which used two different navigation systems (e.g. Schwering *et al.* 2017). On the other hand, there exist approaches, where sketch maps are analyzed in much more detail. In a study by Wang &

Li (2012), they analyzed sketch maps according to the direction of drawn streets and angles of crossroads and turns at decision points.

In this study, another approach, developed by Krukar *et al.* (2018), was used. They developed a set of criteria to score sketch maps on two dimensions simultaneously: its "route-likeness" and its "survey-likeness". The scoring is based on the presence or the absence of six features each which assess the acquisition of route knowledge and survey knowledge, respectively. If a criterion is present, it will be graded +1, if a criterion is absent it will get no point. Therefore, a sketch map can get up to 12 points or six points for the route-likeness and survey-likeness each. It has to be mentioned that some of the criteria have been adapted to fit this specific user study.

Table 7: Evaluation schema for the sketch maps

dimenstion	criteria	description
route-likeness	**r1 - Side streets at decision points**	Does the sketch include some indication (at least a single line or arrow) of possible choice alternatives at junctions?
	r2 - Side streets outside decision points	Does the sketch depict route alternatives along the straight stretches of the route, for instance indicating the number of junctions that need to be passed before turning?
	r3 - Local landmarks at decision points	Does the sketch depict at least one local landmark at junctions?
	r4 - Local landmarks not at decision points	Does the sketch depict at least one local landmark along the route?
	r5 - Correct number of turns	Does the sketch include the correct number of turns?
	r6 - Street names	Does the sketch include some nomination of street names?
survey-likeness	**s1 - Global landmark - point**	Does the sketch include a point-like landmark located off-route or visible from many parts of the route? Example: a city cathedral.
	s2 - Global landmark - line	Does the sketch depict a line which does not constitute an integral path of the street network but provides structure to the sketch or a global spatial reference for other objects? This feature can include barriers to movement. Examples: a highway disjoint from the city streets, a river, a railroad.
	s3 - Global landmark - region	Does the sketch include a region, either with clearly depicted, or vague boundaries, or with a label making it a uniquely identifiable area? Examples: a zoo, an oldtown.
	s4 - Street network	Are at least two streets connected outside the main path, so that taking an alternative route or a shortcut would be possible, at least at a short stretch of the route?
	s5 - Overall shape	Does the overall shape of the sketch mirror the route?
	s6 - Spatial relationship between distant objects	Does the sketch depict a relationship between two distant landmarks?

In addition to quantitative evaluation, the sketch maps are checked for qualitative differences between the two systems used.

6.6. Direction Pointing Task

Another approach to assess the acquisition of survey knowledge is to ask participants after a navigation task to point in the direction of particular locations. While the evaluation of

Sketch Maps focuses more on the environment around the route itself, direction pointing tasks can be used to assess the understanding of a pedestrian about the relationship between different objects in the broader environment. One broadly used method is called *Judgments of relative direction*, which involves mentally accessing the spatial relationships among three locations and attempting to accurately determine their relative direction (Shelton & McNamara, 2004).

For this user study, the method *Judgments of relative direction* was adapted with some minor changes. When using the PPA System, a test-user can see three points all the time on the interface while navigating: the start- and endpoint of the route as well as one Global Landmark somewhere in between. When the start- and endpoint of the navigation task are not located on the map extent of the interface, they are visualized as off-screen landmarks as well. At the endpoints of both TAs, the Global Landmark which is situated somewhere between the start- and endpoint of the route is still visible in the real environment. Regardless of which system (*PPA System / Google Maps*) the participants have used for the navigation task, they were then asked to point towards the starting point of the route. To do so, the participants got an iPhone 6, which had to be aligned using the compass app.

6.7. Perceived Demand

The NASA task load index (NASA tlx) from Hart & Staveland (1988) is a broadly used questionnaire for the subjective assessment of the perceived workload on six different subscales: (1) mental demand, (2) physical demand, (3) temporal demand, (4) performance, (5) effort and (6) frustration. All participants were asked to fill in the questionnaire after completing both navigations tasks in order to assess the two different navigation systems on their cognitive load. Similar to Perebner *et al.* (2019) and Rehrl *et al.* (2014), the raw tlx version of the test was used. This means that the six different subscales were not weighted. Therefore, for every participant the two task load scores (for both systems) were computed by summing up the scores of each of the six scales calculating the average score.

6.8. System Usability

The System Usability Scale (SUS) (Brooke 1996) is a questionnaire composed of 10 statements about the usage of a system, scored on a 5-point scale of the strength of agreement. Every participant had to fill in the questionnaire and answer the statements for both systems at a time. A score is then generated for both systems. Final scores for the SUS can range from 0 to 100, where a higher score indicates better usability. Since the statements alternate between positive and negative statements, care must be taken when scoring the statements. To calculate the final SUS score (for one participant and one system), the score contributions from each item (statement) have to be summed up. Each item's score contribution will range from 0 to 4 (Strong disagreement to strong agreement). For items 1, 3, 5, 7 and 9 the score contribution is the scale position minus 1. For items 2, 4, 6, 8, and

10, the contribution is 5 minus the scale position. To obtain the overall value of the system usability, the sum of the scores have to be multiplied by 2.5. Based on research, a SUS score above a 68 would be considered above average and anything below 68 is below average. A SUS score of 100 would be considered as the perfect usage (Sauro 2011).

6.9. Overall User Experience

In a final evaluation form, the participants were asked to reveal their thoughts about the usage of both systems and the feeling they had while using it. They were asked to score three statements according to their degree of agreement (1: totally disagree, …, 5: totally agree). Additionally, they were asked to justify their decisions. The three statements are:

1. During the navigation task, I felt safe and on the right path.
2. I felt guided to the destination by the system to a pleasant and sufficient degree (vs. too little or too firmly guided by the system).
3. I had fun using the system.

The second part of the evaluation form concerns the different components of the PPA-System. The test users were asked to give each component a score depending on how much the component contributed to the system and to the successful fulfillment of the navigation task. In a last open question, the participants were asked which components of the PPA-System, in particular, led to a better / worse performance compared to *Google Maps*.

7. Results

This section presents and describes the results of the user experiment (*see chapter 6*). All examined variables were tested for significant differences between the PPA-system and *Google Maps*. In order to select the correct statistical test, all measurement series were checked to see whether they were normally distributed. For this, the Shapiro-Wilk test was used. If it could be assumed that the measurement series were normally distributed, a t-test for independent random samples was applied. If the data were not distributed normally, the Mann-Whitney-U test was used to test the measurement series for statistically significant differences. All statistical tests were performed in R. The test results are listed in detail in chapter *Appendix I*. Within this chapter, all test results are summarized and described using the p-values.

7.1. Pre-Experience of the Participants

All participants stated that they owe an own smartphone. Half of all participants (nine from 18) stated that they use mobile map applications occasionally (=two to three times a month), eight participants frequently (= two to three times a week) or very frequently (=at

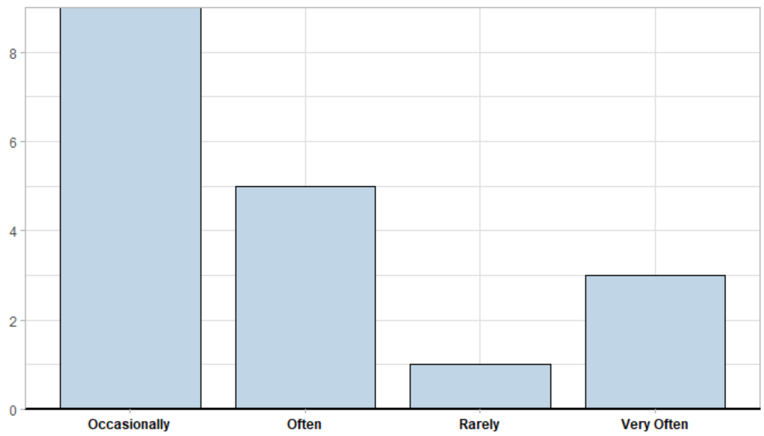


Figure 25: Frequency of mobile map applications usage in everyday life

least once a day) and only one participant stated to use digital maps only rarely (= two to three times every half year). Most of the participants (14 in total) use the application *Google Maps*. Five participants use the application *maps.me* and four use the pre-installed application *Maps* from Apple.

Sense of Direction

The results of the SBSOD (mean value = 4.85, SD = 1.32) revealed no significant difference in sense-of-direction between the 18 participants. Female participants estimated their sense-of-direction slightly worse than males (Female: 4.54 (1.45), Male: 5.04 (1.24)). Since the calculated mean value in the user study of Rehrl *et al.* (2014) with 48 participants is very similar (mean = 4.89; SD = 0.72), the test group in this user study is considered as balanced regarding the sense-of-direction.

7.2. Chosen Routes and Task Completion Time

In this section, the selected routes of the navigation tasks are investigated. The participants who used *Google Maps* in one of the two test areas just followed the provided shortest path (*Figure 26, dashed line*) while participants using the PPA-System had a say in

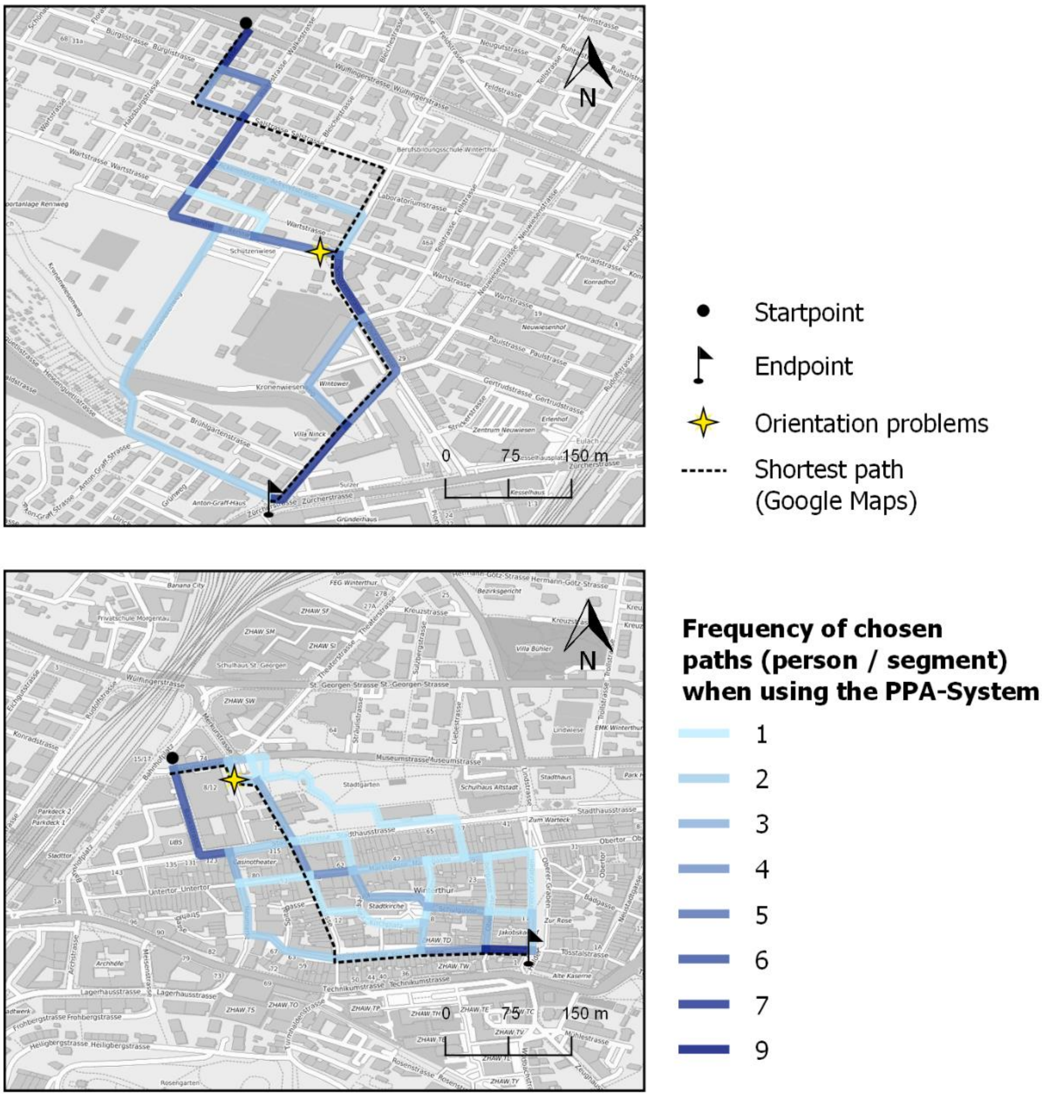


Figure 26: Chosen routes in the two test areas. TA 1 on top, TA2 below

choosing their route. For both test areas, no PPA-System user has chosen exactly the same route which was provided by *Google Maps*. Since there exists no direct way in both test areas, which leads from the start point to the endpoint without any turns, the shortest paths from *Google Maps* show some large legs (in both test areas three turns each). Users of the PPA-System generally avoided to choose large legs and did more turns instead. PPA-System users did 5.6 turns on average in TA1 and 5.9 turns in TA2. The users of the PPA-System avoided following a certain street for too long if its direction differs too much from the direction to the destination of the navigation task.

Additionally, participants were observed regarding their task completion time (even though it was not the aim to complete the navigation task as quickly as possible). As the two routes from TA1 and TA2 were not equally long, task completion times varied between the two test areas. Since in both routes, no road had to be crossed, which was controlled by a light signal, the time from start to finish was measured, including potential

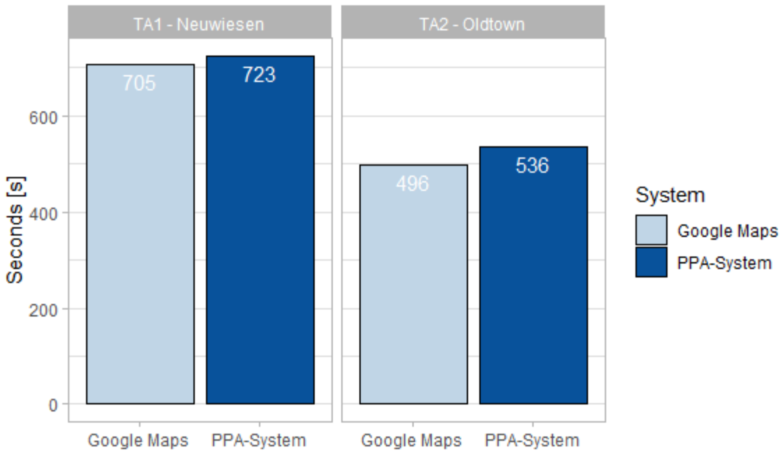


Figure 27: Average task completion time by system and area

stops due to orientation problems or other reasons. Figure 27 shows that, in general, the actual walking time for TA1 was longer than for TA2. Additionally, the average walking times were in both test areas longer when using the PPA-System than *Google Maps*. In TA1, the test users needed on average 18 seconds longer when using the PPA-System, which can be considered as a detour of 2.5 %. In TA2, the test users needed on average 40 seconds longer when using the PPA-System, which is a detour of 8.1 %. For both test areas, the differences in the task completion times were not significant.

Stops due to Orientation Problems

Generally, only a few participants had orientation problems while solving the navigation tasks and therefore, only a few stops were made either. There was only one stop recorded in TA1 from one participant using the PPA-System (*Figure 26*). The participant stated afterward that he had difficulties with the orientation of the map at this decision point. However, in TA2 five from nine participants using *Google Maps* experienced some orientation problems at decision points one and two (*Figure 26*), while no participants using the PPA-System experienced some problems in TA2. These experienced uncertainties when using

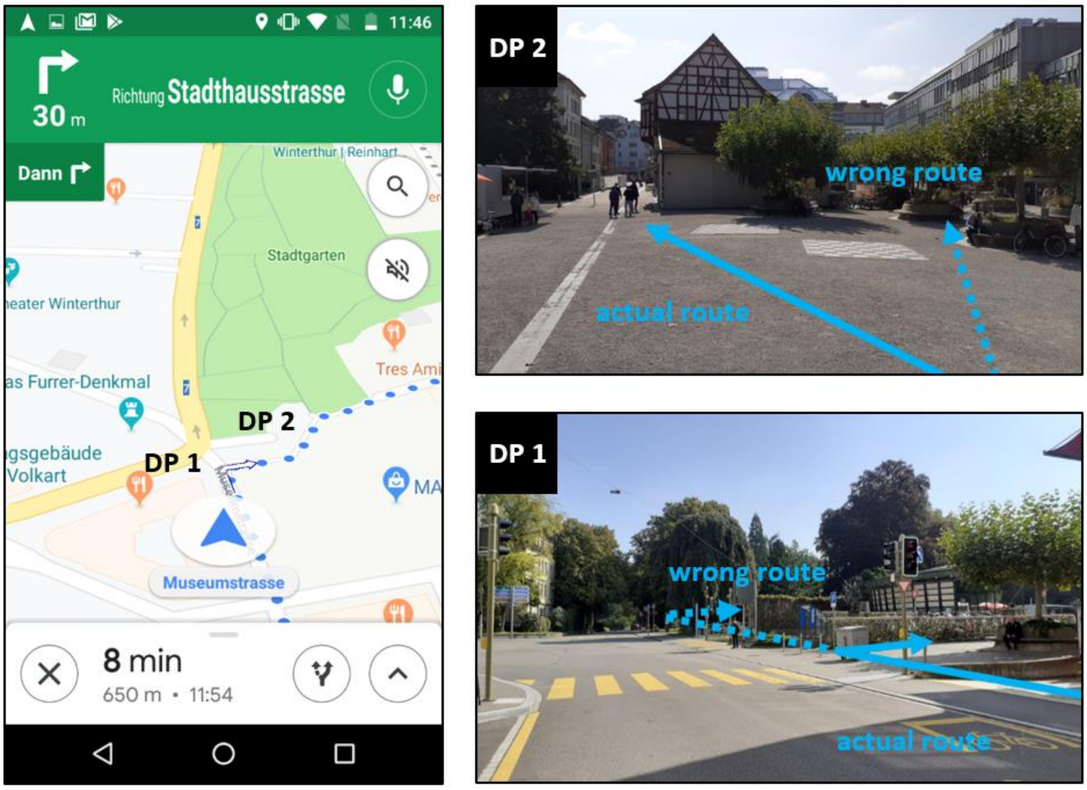


Figure 28: Problematic area of TA2 for *Google Maps* users

Google Maps have arisen because the underlying road network at decision points 1 and 2 is very narrow, although it was a relatively open place. It was difficult for the users to connect the corresponding paths in the real environment with those on the map. As soon as the users deviated from the given route, the navigation system reported this, even if it would have been a possible route as well. Users of the PPA system did not experience this problem, because there was no default route and only the rough direction to the destination is decisive.

7.3. Spatial Knowledge Acquisition

7.3.1. Direction Pointing

The estimated direction values are visualized in *Figure 29.* For both test areas, the average deviation from the correct direction was slightly lower from participants using the PPA-System. Additionally, the variances were greater in estimates after using *Google Maps*. It is also noticeable that the estimates in TA1 are much more accurate than in TA2, regardless of which system was used. The two measurement series (PPA-System and *Google Maps*) from each test area were then tested for significant differences. For this purpose, a t-test for independent variables with different variances was carried out. However, the tests revealed no significant differences between the two systems (TA1: *p-value*: 0.474 / TA2: *p-value*: 0.564, both > 0.05). Regardless of whether the values are significantly different or not, a higher number of participants would have been desirable to exclude a possible coincidence. Additionally, it is noteworthy that it could be observed that most of the participants who used the PPA-System orientated themselves by the help of the global landmarks when estimating the direction.

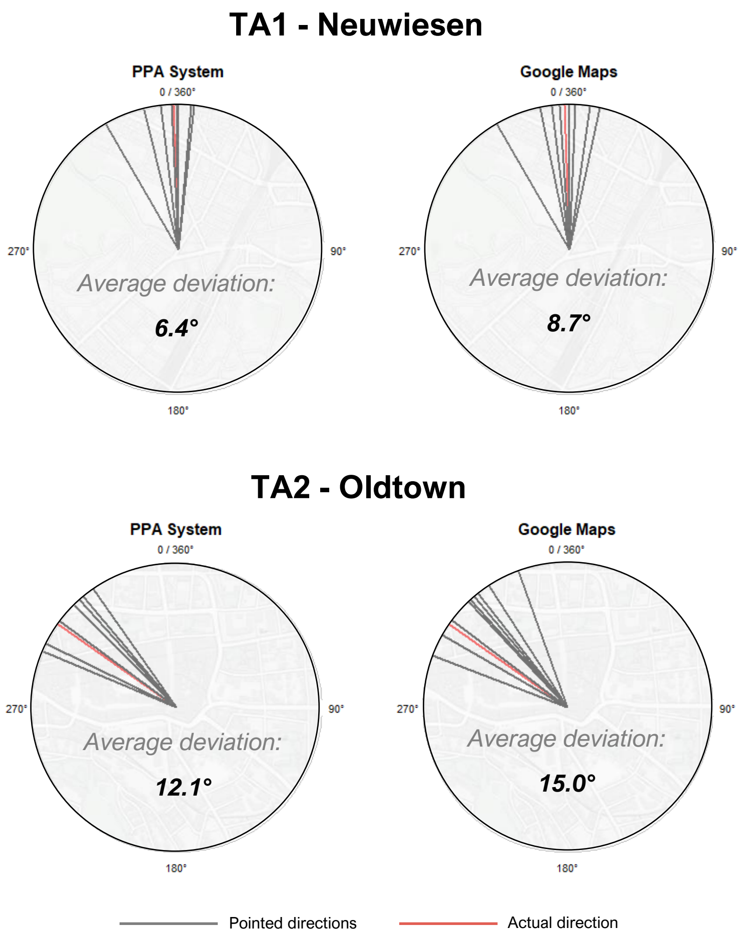


Figure 29: Direction estimations by area and system

7.3.2. Sketch Maps

Quantitative Evaluation

All sketch maps have been evaluated according to the criteria presented in chapter 6.5. Each drawn map was rated according to its route likeness and survey likeness, which results in an overall rating, the overall likeness. The highest possible score for the route- and survey likeness is a total of 6 points each. The highest possible overall score is consequently a score of 12 points in total. Besides, the local and global landmarks marked on each map were counted. Drawn sketch maps after using the PPA-System reached an average route likeness of 5.0, whereas drawn sketch maps after using *Google Maps* reached an average score of 4.3 points. However, the difference between the two systems was scarcely not significant (*p-value* = 0.073). The survey likeness for the PPA-System was 3.5, whereas

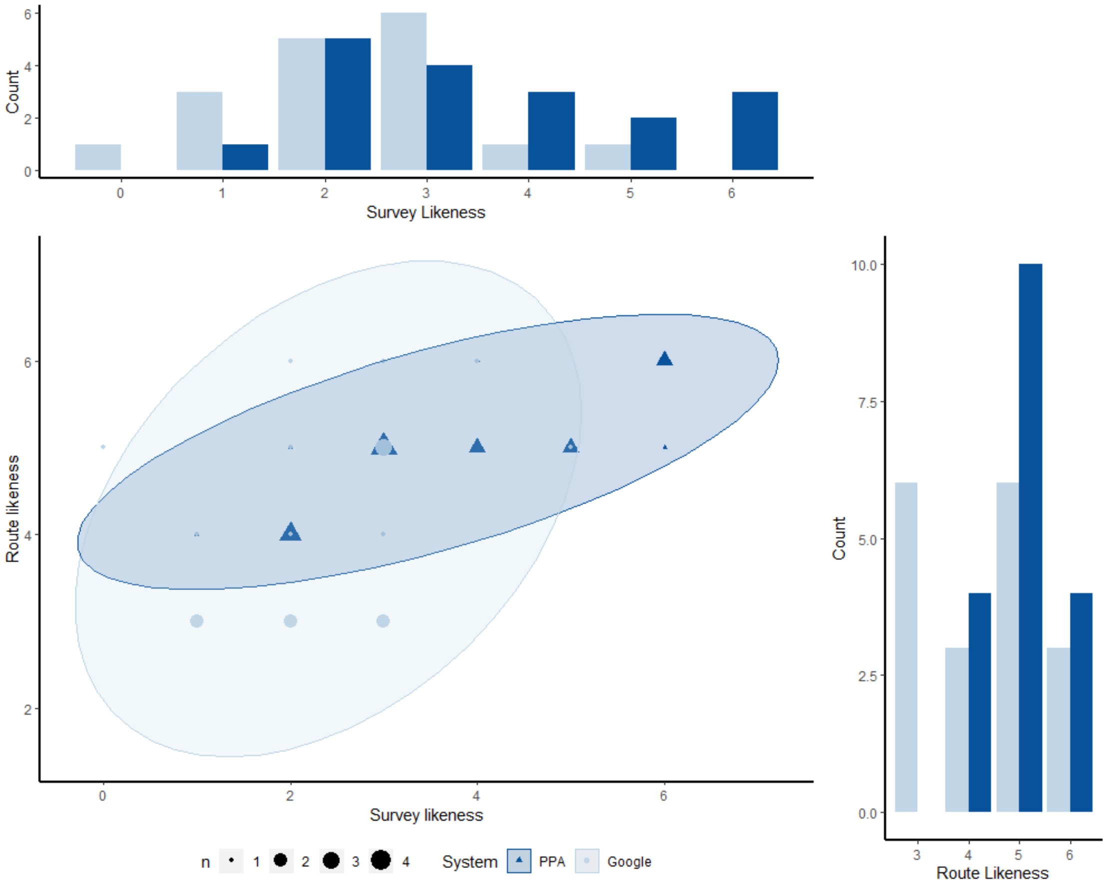


Figure 30: Route- and survey likeness of the sketch maps after using the PPA-System and *Google Maps* respectively

Google Maps only got 2.4 points. Here, a significant difference between the two systems could be found (*p-value* = 0.047). This results in an overall likeness of 8.5 after using the PPA-System. The overall likeness after using Googles is with a score of 6.7 significantly lower (*p-value* = 0.016). The relation between route- and survey likeness of the two systems is visualized in *Figure 30*. The two histograms show the survey- and route likeness of the sketch maps after using the PPA-System (dark blue) and *Google Maps* (light blue). In the scatterplot (bottom, left) every sketch is visualized as a point or triangle respectively, demanding on which system that was used before drawing the sketch. The two axes represent the route- and survey likeness. The circular areas in the scatterplots are the 95% confidence ellipsoids. This means, that, e.g., the sketches after using the PPA-System lie within a certainty of 95% inside the dark blue area. The plot aims to point out the correlation between route- and survey knowledge, depending on which system was used - and the general differences between the two systems itself. The 95% confidence ellipsoids show mainly two things: Route likeness of PPA-sketches will not be below 4 with a high degree of certainty, whereas *Google Maps* sketches tend to have scores below 4 as well.

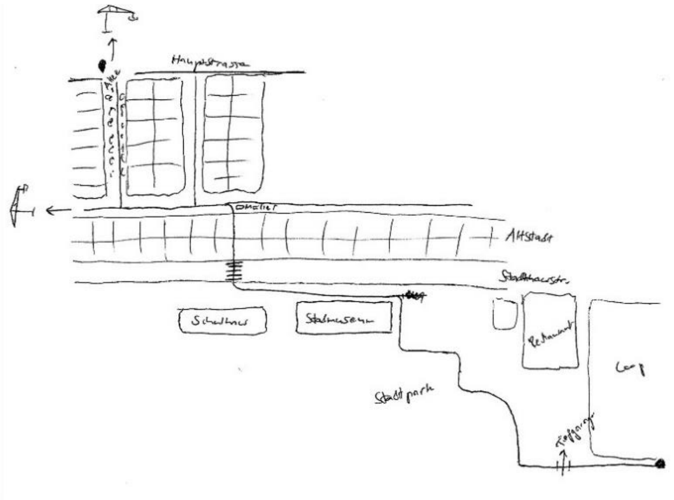
Additionally, the survey likeness of *Google Maps* sketches will not go beyond 5 with very high certainty, whereas PPA-sketches tend to have a score up to 6.

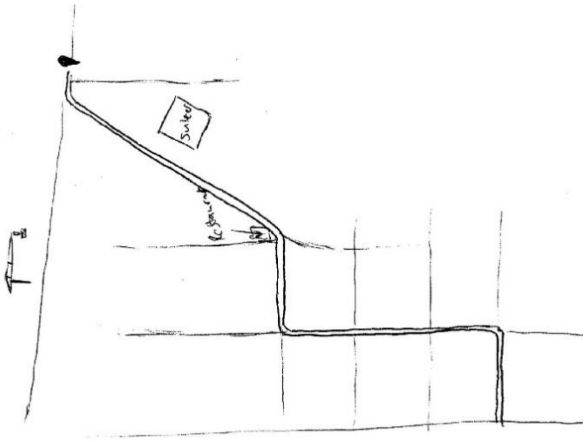
Participants included on average 5.7 local landmarks in their sketch maps after using the PPA-System, whereas only 4.1 were included after using *Google Maps*. The same phenomena could be observed for the global landmarks: 2.3 on average were included after using the PPA-System, 1.4 after using *Google Maps*. Both were tested for significant differences, whereas only the number of included global landmarks was significantly higher.

Qualitative Evaluation

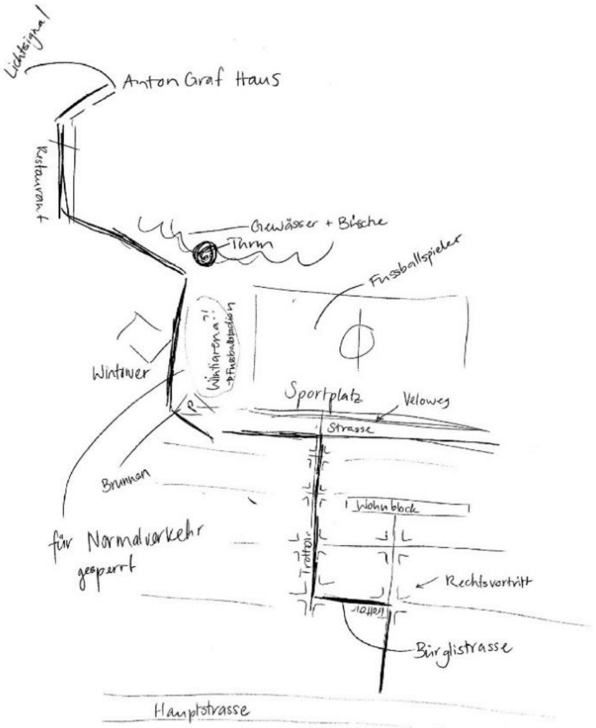
It is quite challenging to make qualitative statements about the sketch maps without immediately interpreting too much into them. Anyway, some characteristics could be observed that have emerged after 36 analyzed sketch maps. Starting with some characteristics of the routes, regardless of which system was used. On average, the participants could remember more local landmarks of TA2 (Oldtown), whereas more global landmarks could be remembered for TA1 (Neuwiesen). Recurring global landmarks from TA1 were the Wintower (point), Schützenwiesen stadium / sports court (area), St.Peter & Paul church (point) and the river Eulach (line). Often used global landmarks for TA2 were the city garden (area), the oldtown (area), the city church (point), the central station (area / line) and the tree avenue at Oberer Graben (line). Since both areas were tested with both systems, these characteristics balance each other out when it comes to the analysis based on other components. Coming to the comparison between the participants themselves. In general, the quality differences of the sketch maps between the test users varied a lot. Whereas some sketch maps are very concise and simple, some of them are very accurate and show many details. However, these differences do not influence the comparative analysis at the system level either. The sketch map pairs from all participants can be categorized into three classes: (1) Low-detailed (with small differences between them), (2) rich in detail (with small differences between them) and (3) apparent differences in the level of detail between the two sketch maps. Two examples of the third category can be seen in *Figure 31*. Since sketch map pairs from the first and the second class with only small differences in detail have no significant influence on the comparison on the system level, sketch map pairs from the third category will be examined in more detail.

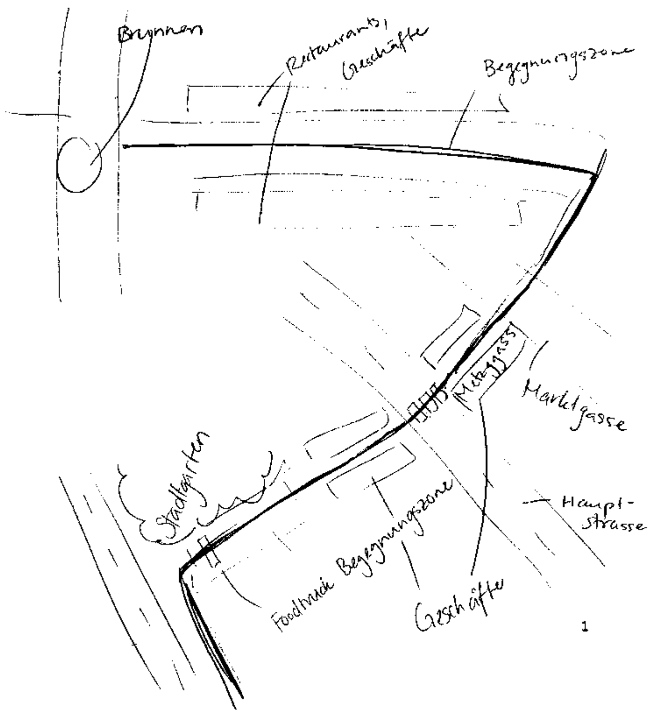
If a clear difference in quality could be found among the sketch map pairs, the quality of the map after using the PPA-System was better in all cases. The phenomena could be observed for both cases when the PPA-System was used for TA1 or TA2. The differences in quality start with the overall shape of the route containing all turns with more or less correct directions. The second feature which could be remembered better were the local and global landmarks, not only along the route or at decision points but also distant landmarks or continuous landmarks away from the route. Another difference between the two systems was the labelling of streets in the sketch maps. Although *Google Maps* shows labelled streets on the map interface and the PPA-System shows a clean base map without labelled





PPA-System – TA2: Oldtown *Participant 9* RL:6 | SL: 6 | OL: 12	***Google Maps* – TA1: Neuwiesen** *Participant 9* RL:3 | SL: 3 | OL: 6





PPA-System – TA1: Neuwiesen *Participant 3* RL:6 | SL: 6 | OL: 12	***Google Maps* – TA2: Oldtown** *Participant 3* RL:6 | SL: 2 | OL: 8

Figure 31: Sketch maps from two different participants

The two sketch map pairs are from two participants, one for each testing area and system. The example show sketch couples, where the route- (RL), survey- (SL) and overall likeness (OL) where better for the PPA-System than for Google Maps.

streets, more participants could remember street names of the test areas after using the PPA-System. Six participants included labelled streets in the sketch maps after using the PPA-System, whereas only three participants included street labels after using *Google Maps*. The lack of street labels in the PPA-System was not criticized by the test users.

Users of the PPA-System included on average more local and global landmarks on their sketch maps than users of *Google Maps*. Whereas dominant point global landmarks such as the Sulzer Tower in TA1 were also included in many sketch maps of *Google Maps* users, linear or planar global landmarks such as the river Eulach, the Oldtown or the city park were included much more often in sketch maps of PPA-system users. Since the latter named types of global landmarks were not visualized more prominently in the PPA-System than in *Google Maps*, the explanation of this phenomenon cannot be found in the visualization of the landmarks. Users of the PPA-System seem to build up more survey knowledge during navigation, which is then reflected in large-scale global landmarks that were included in the drawn sketch maps.

Furthermore, it could be observed that the process of drawing differed according to which system was used. Users of *Google Maps* often tried to draw the whole route first and then added all landmarks to the map which could be remembered. The process of drawing the map after using the PPA-System was more step by step. When drawing the route, landmarks were often drawn simultaneously. This means that landmarks and other characteristics along the route were stronger coupled with the route itself. Therefore, the acquisition of route- and survey knowledge is coupled to each other more intensively either. The traversed route could be embedded better into the environment since the participants had to engage with the surrounding environment along the route more actively during the use of the PPA-System.

7.4. Perceived Demand

The participants rated their perceived overall task load on average slightly higher on the PPA-System (29.5) than on *Google Maps* (24.4). Again, the average NASA tlx scores were tested for significant differences by the help of a Mann-Whitney-U test. The overall task load scores of the two systems showed scarcely any significant difference (with a *p-value* of 0.066). Looking at the different subscales, mental demand, physical demand, effort, frustration but also performance were rated higher for the PPA-System, whereas temporal demand was rated higher for *Google Maps*. The only subscale with a significant difference in its rating is mental demand with a *p-value* of 0.034.

In the questionnaire about the overall user experience (from which the results will be presented later on) some participants mentioned the alignment and the lack of rotation of the map as a primary reason for the high mental demand when using the PPA-System.

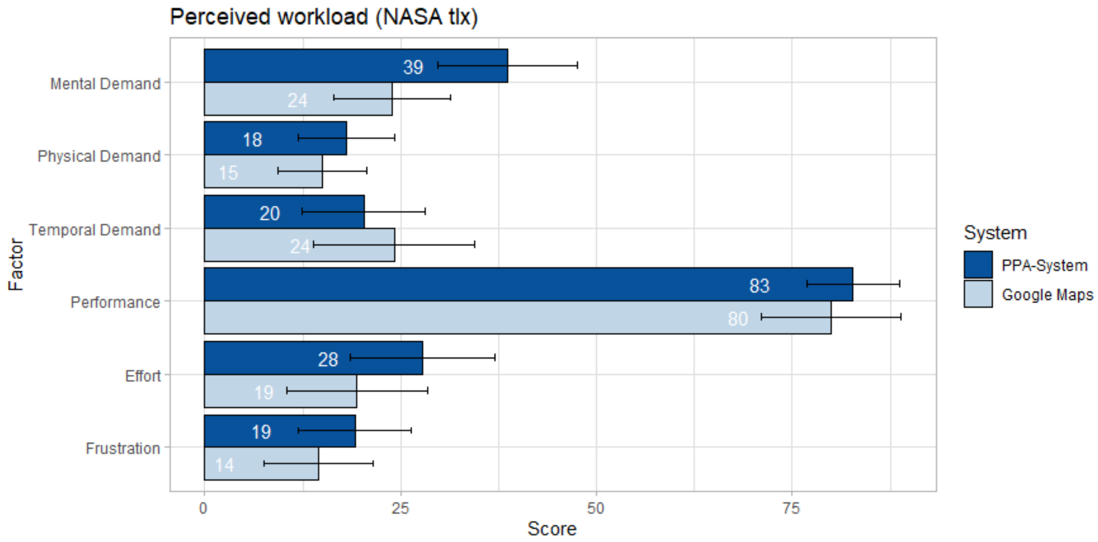


Figure 32: NASA tlx scores for each system by subscale

7.5. System Usability

The system usability of the PPA-System with a score of **85.6** was rated significantly lower (*p-value* = 0.045) than of *Google Maps*, which was rated with a score of **90.5**. However, both scores lie forcefully above the practical value of 67, from which on the usability is rated as 'good'. The most significant differences in the rating can be found at points 3, 9 and 10 (*Figure 33*). It is not by chance that the PPA system was rated worse at these three points: Point 10 states '*I needed to learn many things before I could get going with this system*', point 3 states '*I thought the system was easy to use*' and point 9 states '*I felt very confident using the system*'.

Since all the participants used the PPA-System for the first time, while 14 of 18 test users already were familiar with *Google Maps*, the level of confidence was already higher for *Google Maps* and the usage of the PPA-System had to be learned first. This was mentioned by the participants themselves as well. In the questionnaire about the overall experience, some participants stated that the level of confidence would probably be higher for the PPA-System when they would use it a second time.

Point 1 '*I think that I would like to use this system frequently*' and point 5 '*I found the various functions of this system were well integrated*' were rated with a higher degree of agreement for the PPA-System. The factor *Fun* is further examined in the evaluation of the overall user experience (*Chapter 7.6*). Concerning point 5, many test users stated that there was an overload of components in the interface of *Google Maps* and the automatic rotation was not always accurate and therefore had a disturbing effect on the users.

Beside point 4 '*I think that I would need the support of a technical person to be able to use this system*', which was rated the same for both systems, the other points were rated slightly better for *Google Maps*.

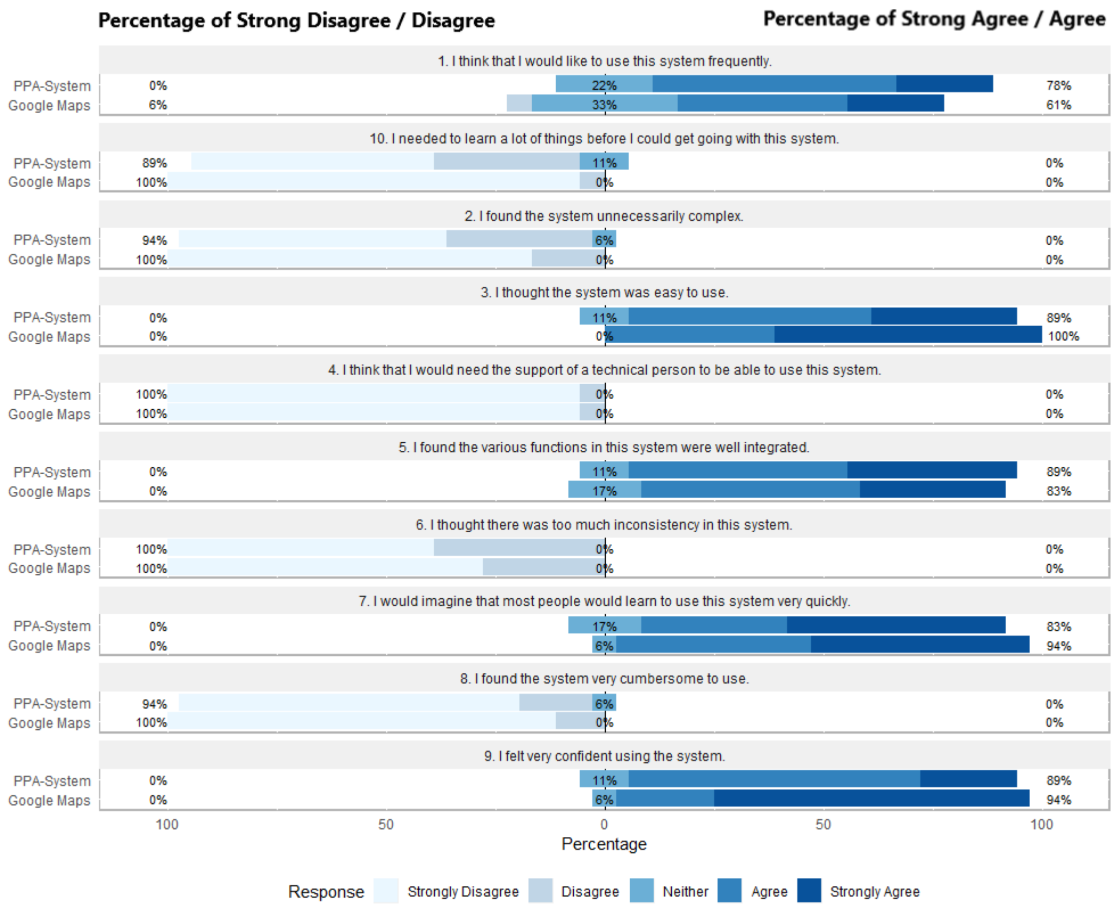


Figure 33: SUS scores of the two systems

7.6. Overall User Experience

The overall user experience was assessed with a Likert-questionnaire by asking three further questions. Additionally, the participants received some space to justify their answers. The Likert scores of the three statements are visualized in *Figure 34*. The average values of both systems were further examined for significant differences. Since the values are not normally distributed and the measurement series are independent of each other, the *Mann Whitney U* test was used. For the first statement '*I felt safe and on the right way*' the participants agreed with an average score of **4.94** for *Google Maps* significantly higher (*p-value* = 0.0002) than for the PPA-System (average score = **4.22**). However, a score of 4 still equals to 'Agree', whereas a score of 5 equals to 'Strongly Agree'. The statements of reasons were then divided into categories according to keywords. The reasons, given for a worse rating of the PPA system than *Google Maps*, can be grouped into two categories: (1) Insecurity / Lack of habit and (2) Lack of alignment of the map. At the same time, a lack of habit leads to uncertainties. Many test users also wondered whether they were on the shortest path to the endpoint of the route, although it was not the goal of the task at all. This misconception is in turn due to a lack of habit. The lack of orientation of the map also posed a problem for some test users, which in turn led to some uncertainties. For the second statement '*The degree of guidance was sufficient and enjoyable'* the participants agreed with an average score of **4.67** for the PPA-System significantly higher (*p-value* = 0.023) than for the PPA-System (average score = **3.94**). Again, the reasons for a better rating of the PPA system compared to *Google Maps* were divided into categories: (1) Freedom and (2) serenity. As the most frequently cited reason for the better score of the PPA-System, the participants stated that they liked the freedom and the opportunity to have a say in the

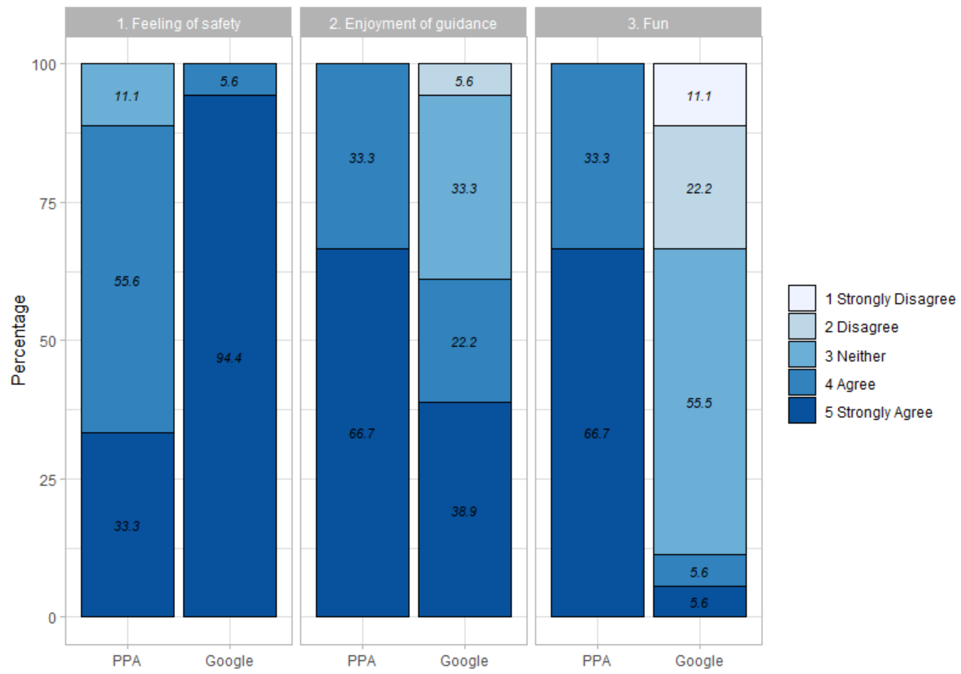


Figure 34: Overall user experience Likert-questionnaire

wayfinding process when using the system. Many test users found the guidance of *Google Maps* too restrictive. The second reason mentioned was that the process of locomotion while navigation was perceived as more pleasant and calmer. Additionally, it was negatively mentioned that the participants had to look more often at the display of *Google Maps* to always turn correctly. The third statement '*I had fun using the system*' was rated with an average value of **4.67** significantly higher (p-value of $1.4*10^{-6}$) than *Google Maps* with a value of **2.72**. The reasons given are summarized as: (1) Playful through participation, (2) way according to preferences and (3) higher engagement with the environment. The participants liked above all the scope the system gave them during the process of wayfinding. Since every intersection is a potential decision point for the wayfinders, much more active engagement with the environment took place. So, the participants were able to estimate which way they liked the most. Reasons given among others for individually choosing paths were '*paths in the green instead along a main street*', '*paths with shadow*' and '*paths with a wide walkway*'.

7.7. Evaluation of the Components

Although it was not the goal to test a single isolated component but a complete system, the test users got the possibility to evaluate the individual components and rank them according to their importance to the system. This would allow someone to determine which components should be retained, improved, or omitted if the system is to be continued. The rating of the different components, including the average score (Less = 1, ..., Very Strong = 4) is visualized in *Figure 35*. The potential path area and the off-screen arrow pointing to

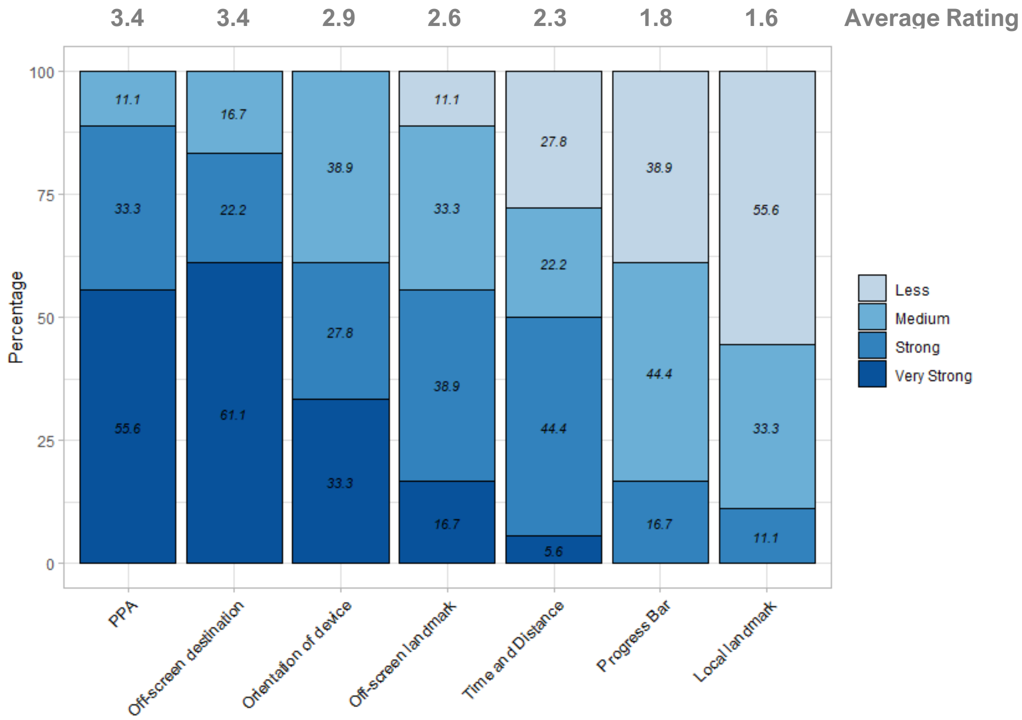


Figure 35: Rated importance of the different components of the system

the direction of the destination got an average rating between *strong* and *very strong*. The current position marker indicating the direction of the device, the off-screen global landmark and the information about time and distance to the destination were rated between *medium* and *strong*. The progress bar, as well as the local landmarks, got an average rating between *less* and *medium*.

The participants got some further space to justify their rating. One participant stated for the PPA "*As long as you stay in the bright area, you can't take a wrong turn, but you still don't get lost.*". This emphasizes the importance of the PPA nicely and at the same time shows its advantages. It was also mentioned that the PPA is a delightful tool to assess whether an alternative route is useful. The PPA also gives the user the opportunity to look at preferences or to take evasive action if a particular path is blocked. Whereas some of the participants found the current location marker indicating the direction of the device very helpful, some other test users would have preferred a rotating map having the direction of travel always at the top. On the other hand, some users found the rotating map of *Google Maps* too irritating and preferred a static map as it is provided from the PPA-System. The global landmarks were primarily perceived as helpful by the participants. They helped the test users to make a connection between the map on the device and the real environment. Additionally, the global landmarks were used as an aid when they had to do the direction pointing exercise. For some users, on the other hand, the GL was not very helpful, since due to the narrow streets it can only be seen to a limited extent in TA2. The local landmarks were less used as orientation aids by the participants. While some of them did not even take notice of them, some would have preferred a labelling of them, e.g. the names of the restaurants. One user stated: "*They didn't help to orientate, but I could remember them better from the real environment when drawing the sketch map*.". Most of the participants fount the progress bar not very useful and did not take any notice of it. Many test users stated that the information about the time and distance to the destination is enough.

7.8. Summary

In the following, the tested variables of the user study for both systems are summarized.

Starting with the **task completion time**, users of *Google Maps* needed on average slightly less time for both test tracks than users of the PPA-System. However, the differences in the time required for both routes are less than 10 percent. The PPA-System has been programmed to achieve a maximum detour of 20 percent. Thus, the differences lie within the defined framework. There was no statistically significant difference between the systems.

After completing the navigation task, the participants were tested for their **acquired spatial knowledge**. As a first task, the test users had to perform a direction estimation task and determine the direction to the starting point of the route. For both test areas, the average degree deviation of the estimate was smaller after using the PPA-System. Test users of the PPA-System indicated that the global landmark in the field of view helped estimate the direction to the starting point. Statistically, however, no significant difference could be found between the two systems. Furthermore, the participants had to draw a sketch map of the route and its surroundings they had taken. The maps were evaluated regarding their route and survey likeness, as well as examined based on the number of local and global landmarks included on the map. Sketch maps of PPA-System users were rated better on average for all examined variables. In particular, the survey likeness and number of global landmarks included were significantly higher. This shows that the users of the PPA-System perceived their environment more actively and were able to acquire more survey knowledge during the navigation task.

Regarding the **user experience**, on the one hand, the test users had to fill out the two broadly used questionnaires *NASA task load index* and *System Usability Scale*. By the help of the NASA tlx questionnaire, the perceived demand in different categories was examined. Higher demand has been attributed to the PPA-System on average, even though with no significant difference. Only in one subscale, the mental demand, a significant difference could be observed. The system usability was rated slightly, but significantly higher for *Google Maps*.

In the last questionnaire, the **overall feeling** of the participant using the two systems was evaluated. The test users stated, that they felt slightly safer and more certain about being on the right way when using *Google Maps*. However, the test users liked the degree of guidance of the PPA-System more than of *Google Maps*. Notably, the freedom to choose routes according to personal preferences was perceived as very enjoyable. Also, the fun factor when using the PPA-System was rated significantly higher than for *Google Maps*.

8. Discussion

8.1. RO1: System Design

Before starting with the conceptual design of the application, the existing literature had to be studied profoundly. The aim was to explore approaches and concepts that already exist and at the same time find gaps in the state of the art research. For the first research objective of this work, the focus was on the question of how a navigation system for pedestrians can be designed without restricting the user to a pre-defined route.

The used approach was to design a system right from the start without using a conventional navigation system as a template and isolating and modifying individual components. The first decision that was made was to have a blank YAH map and an additional space for further information about the route as two fundamental elements of the application. Additionally, the existing concepts of local and global landmarks were embedded in the system. Global landmarks, in particular, have not yet found a place in conventional navigation systems, despite positive results from scientific publications. However, the core concept of the application is the potential path areas, which were developed in the context of this work. The idea of these areas is derived from the concept of time geography, where detours within defined time limits are accepted and the user is presented with his possible paths to the destination as an area. This allows the user to choose his path within certain limits according to his personal preferences.

After an initial design of the interface was created, it was discussed with a focus group to collect feedback from potential users of the system. Inputs, which were confirmed by a majority of the discussion group, were implemented. The system was then tested in a user study according to the acquisition of spatial knowledge and the user experience. Regardless of how the system has performed regarding the acquisition of spatial knowledge, in the following, it is discussed which components of the system worked well and were well integrated into the system and which of them were not. The key aspects of the first research objective are summarized below:

- **Map Rotation and Street Labelling:** While some users pointed out that the orientation of the device indicated at the location marker was helpful, some users would have preferred a rotating map itself with the direction of travel at the top. On the one hand, this can be explained by the different preferences of the users when navigating, on the other hand, it has to do with the orientation and

navigation skills of a user. People who are used to navigate with paper maps and also have an interest in navigation itself had no problems with the static map in the application and even preferred it over a rotating map since they experienced it as too irritating when using *Google Maps*. For people who did not have such strong orientation skills, the static map was more challenging to use in the application, as the map of the application sometimes had to be turned by hand or mentally in the head to be aligned to the real environment. The evaluation shows that the needs of the users are different. When further developing the application, a rotating map should be integrated as a function of the base map, so that the user can choose between a static and a rotating map.
As it turned out, the street labelling on the map was not decisive for its internalization. Users of the PPA-System, in which the streets on the base map were not labelled, could remember more street names when drawing the sketch maps. Furthermore, it did not result in more orientation problems during the navigation task. For the participants, the lack of labelled streets on the map was not a problem, even in a conscious sense; not a single test user complained about it after using the system. The idea behind this is that through the labelling the user's attention focuses too much on the application itself. It could result in test users unconsciously using the street labelling on the map to accomplish the task of wayfinding. Therefore, it is suggested not to label the streets in a further revision of the application.

- **Local Landmarks:** The evaluation of landmarks has yielded interesting results. Whereas the majority of the test users stated, that they did not even take notice of the local landmarks or did not use it to orientate themselves, many users could remember them when it came to the sketch map exercise. The local landmarks, therefore, influence the acquisition of spatial knowledge, especially route knowledge. Some users also stated that the local landmarks should have been described with the names of the restaurants or shops. Local landmarks, therefore, have an essential role to play and should be taken into account when further developing the system. A more attractive use is proposed. One possibility could therefore be, that the user can decide in advance which categories of local landmarks he would like to have represented (e.g. only bars and cafes).

- **Global Landmarks:** The global landmarks were perceived as very helpful. In retrospective, they even fulfilled two tasks: First, they helped users to orientate themselves and generate spatial knowledge. Some users said by the help of the global landmarks they could link the map of the application to the real environment. Other users made use of the GLs when doing the direction estimation task. This shows that the global landmarks are an important point of focus of their created mental map. Secondly, the users stated that they liked the GLs because they led them to exciting and nice places on the route. Therefore, a more attractive usage of global landmarks is proposed as well. They could be used to lead users to some points of interest between the start and endpoint of the route. A possibility would be, that the system suggests a set of possible GLs when the start and endpoint of the route are defined. The users would then have the possibility to choose their desired global landmarks / points of interest.

- **Potential Path Areas:** The test users all agreed that the PPAs provided a great deal of added value. The usage of the PPAs as a guidance tool could be learned fast and then be used very intuitively. Generally, they especially like the freedom when it came to the task of wayfinding. Additionally, the test users intuitively perceived the environment stronger and more apparent, as they could decide at each intersection whether they wanted to make a turn or not.
  In the case of a possible further development of the application, the focus should lie on the calculation and computation of the areas. In the framework of this research project, the PPAs were calculated and loaded into the system in advance. With a real-time calculation of the areas within the application, the start and endpoints of a route could be freely selected, and the system would be applicable to an extensive area (depending on the road network data). The underlying road network would not have to be stored locally but could be loaded online into the system from an external database. However, the calculation of the PPAs would have to be integrated into the application as a function. The computation complexity of the applied k-shortest paths algorithm is not much higher than a simple shortest-path calculation since it is just a repetition of the latter named algorithm within a loop until a threshold value of the length of the route is reached. After the k-shortest paths are computed, a convex hull with a buffer is calculated. This results in one specific potential path area.
  The frequency at which the areas are to be calculated would have to be tested before it came to a second experiment with test users. Major changes in the PPAs take place mainly at decision points, which is why the area calculations can also be reduced to these points. In order to prevent abrupt changes in the areas, the calculation could also take place more frequently. The function could theoretically be called every time the device receives a GPS signal. However, this is certainly not necessary but is subject to be tested before doing a second user study.

- **Additional Information:** The test users agreed that the progressive bar, in particular, did not add any value to the system. Most users stated that they were only looking at time and distance to the destination. If the system design is revised, another focus group would have to discuss whether the progress bar should be omitted. In addition, different design variants should be developed for the 'further information' area. The user experiment has shown that this area tends to receive little attention. Therefore, this area should probably be reduced in size in order to create more space for the map-based part of the interface.

These are the most essential points that have arisen in relation to the system design after going through all steps of the workflow within the framework of this Master's Thesis. Decisive for the further development of the system are the results concerning the acquisition of spatial knowledge and the user experience. These will be discussed in the next section. If a further development is recommended, the key points worked out above would have to receive attention when it comes to the second time going around the workflow diagram.

8.2. RO2: Performance of the System

The second research objective deals with the question '*How does this system perform compared to a turn-by-turn system in terms of spatial knowledge acquisition and the user experience?*' The system was therefore tested in a user study against the existing app *Google Maps*. In order to assess the acquisition of spatial knowledge, the participants had to do a direction pointing task and to draw a sketch map of the covered route after each navigation task with the two different navigation systems. To assess the user experience, all participants had to fill out a comparative evaluation of the two systems and their usage after finishing both navigation tasks.

Spatial Knowledge Acquisition

The results of the direction pointing task have shown that the participants achieved better results after using the PPA-System even though the difference is not significant. Since there were outlier values in both groups, the variances were quite high. Larger test groups would have been desirable in order to find a possible significant difference. Nevertheless, participants who used the PPA-System had a more structured approach to solve the exercise. A lot of those participants tried to orientate themselves with the help of the visible global landmark and tried to find the direction of the start point in relation to the direction of the global landmark. Participants who have used *Google Maps* had more problems to find orientation points to do the exercise. Therefore, by the help of global landmarks, the users get fixed orientation points in the environment which they can put into relation with other points. The sketch map exercise revealed some significant differences between the two systems. The drawings were analyzed regarding their route- and survey likeness and the number of drawn local and global landmarks. In all assessed categories, the sketch maps after using the PPA-System got significantly higher scores on average. This can be traced back to various reasons. First, the users of the PPA-System engaged more actively with their environment when using the navigation system. Since every crossroad is a potential decision point, the users automatically have a look at their different possibilities and can then decide afterward if they want to make a turn or not. The users have to make decisions and actively contribute to the process of wayfinding. Many participants themselves noted this behavior in the evaluation. The second reason is that the PPA-System gives the users components like the GLs which they can link from the interface to the real environment and therefore actively draws the users' attention to the real environment.

The PPAs work the same way; without looking at the environment at possible decision points, the areas alone make no sense. When following a predefined route using e.g. *Google Maps,* the users do not even have to look around coercively and can just 'blind' follow the route. Additionally, the sketch map drawing task showed, that landmarks and other characteristics along the route were stronger coupled with the route itself when using the PPA-System. Therefore, the acquisition of route- and survey knowledge is coupled to each other more intensively either compared to the acquisition of spatial knowledge during the usage of *Google Maps*.

User Experience

The user experience has been assessed using three different questionnaires, whereas the first dealt with the perceived demand, the second addressed the system usability and the third one evaluated the feeling when using the different systems. The perceived demand was rated slightly but significantly higher when using the PPA-System than when using *Google Maps*. Additionally, *Google Maps* got a slightly but also significantly higher score in the system usability. These two categories are related in many ways. Certain components of the PPA-System which got a bad score in the system usability (such as the static map) had an influence on the (higher) mental demand. Due to the first use of the PPA-System, some questions such as *'How much did you have to learn before you could use the system?'* were automatically rated worse in the questionnaire of the system usability.

Basically, the idea was to create a system with which the user has to engage more actively with the environment and contribute to the process of wayfinding. As discussed above, these objectives have been achieved, and therefore the perceived demand during the usage of the system is higher as well. In comparison to a firmly established and powerful system like *Google Maps*, the PPA-System could already achieve good scores. Nevertheless, in the event of a possible further development of the system, it is necessary to increase the system's user-friendliness. Thus, the perceived demand, which is caused by lousy system properties and inconsistencies, can be minimized. The last questionnaire revealed the following three statements:

- Users of *Google Maps* felt slightly safer and on the right way than users of the PPA-System.
- The degree of guidance was rated more enjoyable for the PPA-System than for *Google Maps.*
- The test users had more fun using the PPA-System than when using *Google Maps*.

Many test users stated that due to the first usage of the PPA-System it was quite unusual not being restricted to a pre-defined path. This made users of the PPA-System feel less secure. On the other hand, this feeling can be minimized or possibly even eliminated by more frequent use. Concerning the degree of guidance, the participants emphasized the freedom of decision and at the same time felt too restricted when using *Google Maps*. Due to personal preferences, the process of locomotion could be enjoyed more, and thus the usage of the system was more fun as well.

Many participants stated that if you have time and want to explore an unfamiliar environment, they would prefer using the PPA-System. For example, in the tourism industry, the application could be very well received. On the other hand, *Google Maps* is more a means to an end and probably the better alternative if you want to reach your destination as fast as possible.

8.3. Critical Evaluation of the Study

In the following, the methodology of the user study is critically reflected, which should also be considered when interpreting the results.

A first point that must be considered when interpreting the results is the limitation in the choice of test areas. Richter *et al.* (2010) have observed different results in the acquisition of spatial knowledge for two different test environments in their study and therefore state, that the complexity of a test environment must be considered when interpreting results concerning spatial knowledge acquisition. When choosing the two test areas for this user study, care was taken that both test areas show an equal amount of complexity. Nevertheless, the two test areas have some small differences in length and visibility of the environment that can influence the acquisition of spatial knowledge. Since the streets in TA2, the city center and old town, are narrower than the streets in TA1, the global landmark can be seen more often in TA1.

Secondly, the group of participants can lead to limitations in the study as well. The number of participants could be a reason for missing significant differences. A higher number of participants would always be desirable for studies like this one. Nevertheless, I am very grateful for all participants who have agreed to participate in the study and a much higher number of participants would have gone beyond the scope of this Master's Thesis. Another limitation concerning the participants of the user study is the existing spatial knowledge about the test areas before the study. Care was taken, that no participant lived in the city of Winterthur and is not familiar with the test areas. However, it could not be avoided that some participants already knew certain parts of Winterthur a bit. Many of these biases were already known prior to the study and had to be accepted due to a lack of resources.

9. Conclusion

9.1. Major Findings

The work aimed to develop a pedestrian navigation system that does not restrict the user to a predefined route. In a further step, the developed system should be tested against the conventional turn-by-turn navigation system *Google Maps*. The research project has led exemplarily through the individual steps of a user-centered design approach.

The first research objective of this work dealt with the **design of the application**. In the design phase, the components of the navigation system were developed and discussed with a focus group and adapted afterward. It has been shown that the use of a YAH map and local and global landmarks are well suited for the system. However, the participants would have appreciated a more attractive presentation of the landmarks. For example, users could select different categories of local landmarks, which would then be displayed on the map. As another essential component of the system, the potential path areas have been developed. At every potential decision point, these areas show the user all alternatives in which he will reach the goal within a specific time limit. The concept of the PPAs met with great popularity among the test users. Particularly the opportunity to participate in the process of wayfinding and to choose the route on the fly according to one's preferences were considered as very valuable.

Within the second research objective of the thesis, it wanted to be found out, **how the system performs** compared to a conventional tbt navigation system. In a real-environment user study, two different routes with one of the two systems each had to be completed in Winterthur by every participant. After completing the navigation tasks, the test users had then to do two exercises concerning the acquisition of spatial knowledge and to fill out some questionnaires relating to the user experience. It could be shown that the acquisition of spatial knowledge was significantly higher when the PPA-System was used. When using the PPA-System, the user is much more concerned with his environment. Every intersection is a possible turning point at which the user can decide whether he wants to make a turn or not. Therefore, the user has to engage much more intensively with the environment. Due to the global landmarks, the system also directs the user's attention automatically to the real environment. This, on the other hand, leads to a higher perceived demand. However, there are also unintentional things that have increased the perceived mental demand. Small inconsistencies in the system or for example the missing rotation of the map led to a poorly rated system usability for individual participants. Due to the first use of the system, certain functions of the system were also described as unusual and therefore more difficult to understand. In an open questionnaire about the overall user experience, the test users rated the feeling of safety and being on the right way slightly but significantly higher for *Google Maps*. However, many participants said that this feeling would probably increase for the PPA-System as well when they would use it more often. On the other hand, the degree of guidance was rated with a significantly better score for the PPA-System because the guidance of *Google Maps* restricts the users too much. The test users liked especially the freedom in choosing routes on the fly according to their preferences. Also, the fun factor of using the PPA-System was rated significantly higher than for *Google Maps*. *Google Maps* is a means to an end when you want to get to the destination as fast as possible. If you want to explore an unfamiliar environment, the PPA-System has much potential in some application areas as for example the tourism industry.

9.2. Future Work

It could be shown in the user study, that the developed PPA-System performed well and generated good results concerning the acquisition of spatial knowledge and the user experience. Since the research project follows an iterative UCD approach, it would make sense to repeat the steps proposed in this paper. The results of this study must be incorporated into the revision of the system and the planning of the user study.

In general, there are many interesting questions that can be asked after this work: Can the results be confirmed in an independent study? Can the results be improved with a revised system? In all steps of the workflow, the design phase, the implementation and the user study, some things can be improved. The results of this study should be taken as the most crucial point of reference in the design phase. Nevertheless, one must also ask oneself whether there are other possible components to which no attention was paid in this study. The second initial design should again be discussed in a focus group. Therefore, it would make sense to discuss the design in the second focus group with participants of the first user study since they can give inputs on the basis of their experience doing the first user study. When implementing the revised system, care should be taken to eliminate all inconsistencies mentioned in this study. Thus, system usability can be further increased. In order to test whether the system is usable for a broad target audience, a real-time calculation of the PPAs should be tested.

Thinking about the user study, there are many things that can be done differently. However, many of these things also depend on how many resources are available. First, with a higher number of participants, significant differences could be better identified on one hand and random differences eliminated on the other. Secondly, the testing areas could be chosen to have fewer differences according to the length of the route and its immediate surroundings. Additionally, there are many other interesting things which could be studied. For example the question 'What influence does the size of the interface have on the acquisition of spatial knowledge and the user experience?' could be further investigated. The interaction between the user and the navigation system is also a very interesting aspect that could be further explored. Possible questions are: 'How much do the users interact with the PPA-System compared to other systems such as *Google Maps?*' or 'Which system components can be used to make the user navigate more independently of the system?'.

Another suggestion for future work on this project would be to do a stakeholder analysis. As a first step, all individuals, organizations or institutions whose interests may be affected as a result of the PPA-System have to be identified. Possible cooperation could thus be clarified and potential application areas could be identified.

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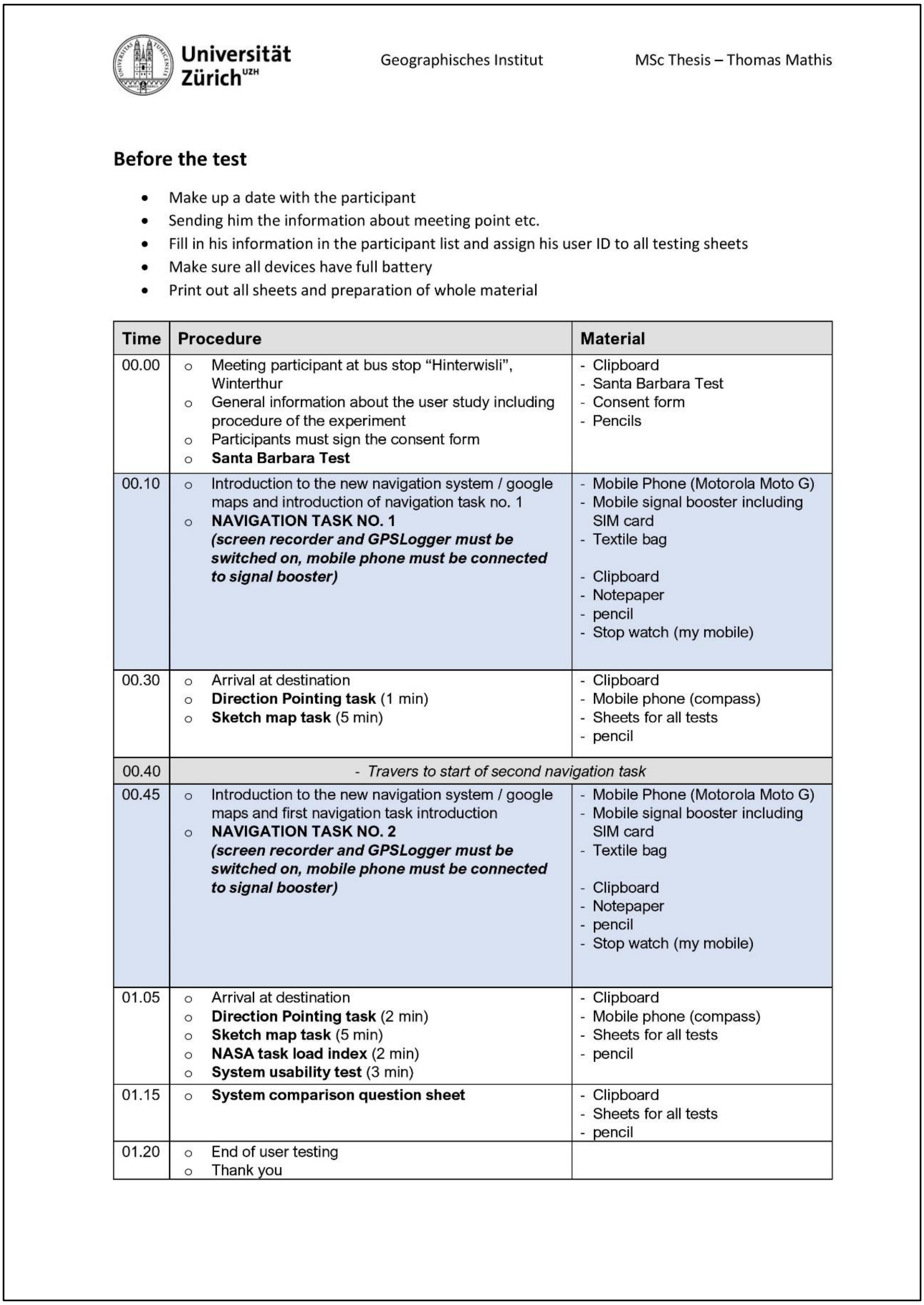
Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Place and date:	Signature:
Zurich, 30.09.2019	Thomas Mathis

Appendix

A Schedule of the User Study



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Before the test

- Make up a date with the participant
- Sending him the information about meeting point etc.
- Fill in his information in the participant list and assign his user ID to all testing sheets
- Make sure all devices have full battery
- Print out all sheets and preparation of whole material

Time	Procedure	Material
00.00	○ Meeting participant at bus stop "Hinterwisli", Winterthur ○ General information about the user study including procedure of the experiment ○ Participants must sign the consent form ○ **Santa Barbara Test**	- Clipboard - Santa Barbara Test - Consent form - Pencils
00.10	○ Introduction to the new navigation system / google maps and introduction of navigation task no. 1 ○ **NAVIGATION TASK NO. 1** ***(screen recorder and GPSLogger must be switched on, mobile phone must be connected to signal booster)***	- Mobile Phone (Motorola Moto G) - Mobile signal booster including SIM card - Textile bag - Clipboard - Notepaper - pencil - Stop watch (my mobile)
00.30	○ Arrival at destination ○ **Direction Pointing task** (1 min) ○ **Sketch map task** (5 min)	- Clipboard - Mobile phone (compass) - Sheets for all tests - pencil
00.40	*- Travers to start of second navigation task*	
00.45	○ Introduction to the new navigation system / google maps and first navigation task introduction ○ **NAVIGATION TASK NO. 2** ***(screen recorder and GPSLogger must be switched on, mobile phone must be connected to signal booster)***	- Mobile Phone (Motorola Moto G) - Mobile signal booster including SIM card - Textile bag - Clipboard - Notepaper - pencil - Stop watch (my mobile)
01.05	○ Arrival at destination ○ **Direction Pointing task** (2 min) ○ **Sketch map task** (5 min) ○ **NASA task load index** (2 min) ○ **System usability test** (3 min)	- Clipboard - Mobile phone (compass) - Sheets for all tests - pencil
01.15	○ **System comparison question sheet**	- Clipboard - Sheets for all tests - pencil
01.20	○ End of user testing ○ Thank you	

B Consent Form

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ID: ______

Einwilligungsformular

Testnutzung von Fussgänger-Navigationssystemen

Zweck und Ablauf Studie

Diese Studie wird im Rahmen der Masterarbeit von Thomas Mathis durchgeführt. Dabei soll der Einfluss auf die räumliche Wahrnehmung bei der Nutzung von verschiedene Navigationshilfen getestet werden. Die Masterarbeit wird von Dr. Haosheng Huang und Prof. Dr. Robert Weibel vom Geographischen Institut der Universität Zürich geleitet.

Falls Sie sich entscheiden an der Studie teilzunehmen, werden Sie gebeten einen Fragebogen betreffend Ihrer räumlichen Fähigkeiten, Vorlieben und Erfahrungen beim Finden von Wegen auszufüllen. Danach werden Sie zwei Navigationsaufgaben mit unterschiedlichen Navigationshilfen in der Stadt Winterthur absolvieren. Nach jeder Aufgabe werden Tests in Bezug auf Systemnutzerfreundlichkeit und Ihrer räumlichen Wahrnehmung durchgeführt. Das Absolvieren beider Navigationsaufgaben inkl. anschliessender Tests wird ca. 75 Minuten dauern.

Vertraulichkeit der Daten

Jegliche Informationen, welche während der Studie mit Ihnen in Verbindung gebracht werden können, werden vertraulich behandelt und nur mit Ihrer ausdrücklichen Erlaubnis an Dritte weitergegeben. Mit Ihrer Unterschrift erlauben Sie uns, die anonymisierten Ergebnisse des Versuchs mehrmals zu publizieren. Dabei werden keinerlei Informationen veröffentlicht, die es ermöglichen, Sie zu identifizieren.

Einwilligung

Entscheiden Sie sich dazu, an der Studie teilzunehmen, steht es Ihnen jederzeit frei, die Teilnahme ohne Begründung abzubrechen. Sollten Sie Fragen haben, zögern Sie bitte nicht, uns diese zu stellen. Sollten zu einem späteren Zeitpunkt Fragen aufkommen, wird Thomas Mathis (079 382 92 47) diese gerne beantworten.

Unterschrift des Teilnehmers

____

Vor- und Nachname in Blockschrift

____

Ort/Datum:

____

1

C Santa Barbara Sense of Direction Form (SBSOD)

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Fragebogen: Navigation und Orientierung

ID: _______

Erfahrung im Umgang mit digitalen Katen

1. Wie oft benutzen Sie Karten-Apps auf Ihren mobilen Geräten (Smartphone, Tablet oder Navigationsgerät)?

   - ☐ Nie
   - ☐ Selten (2-3 Mal pro Halbjahr)
   - ☐ Gelegentlich (3-4 Mal pro Monat)
   - ☐ Häufig (3-4 Mal pro Woche)
   - ☐ Sehr Häufig (mind. 1 Mal pro Tag)

2. Welche Karten-Apps benutzen Sie auf Ihren mobilen Geräten?
   - ☐ «Google Maps» von Google Inc.
   - ☐ «Maps» von Apple
   - ☐ «Bing» von Microsoft
   - ☐ Andere: _________________

Selbsteinschätzung

Nachfolgende Fragen sind verschiedenen Aussagen über Ihre räumlichen Fähigkeiten, Vorlieben und Erfahrungen beim Finden von Wegen. Nach jeder Aussage sollen Sie einen Kreis um diejenige Zahl ziehen, die den Grad Ihrer Zustimmung mit dieser Aussage am besten ausdrückt. Markieren Sie die „7“, wenn Sie stark zustimmen, dass diese Aussage für Sie zutrifft, markieren Sie „1“, wenn Sie dies stark ablehnen oder markieren Sie eine Zahl dazwischen, wenn Ihre Zustimmung dazwischen liegt. Markieren Sie die „4“, wenn Sie weder zustimmen noch ablehnen.

1. Ich bin sehr gut im Geben von Wegbeschreibungen.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

2. Ich kann mir gut merken, wo ich Dinge liegen gelassen habe.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

3. Ich bin sehr gut im Schätzen von Entfernungen.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

1

4. Mein «Orientierungssinn» ist sehr gut.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

5. Wenn ich über meine Umgebung nachdenke, verwende ich meist die vier Himmelsrichtungen.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

6. In einer neuen Stadt verlaufe ich mich nur selten.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

7. Landkarten lesen macht mir Spass.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

8. Ich habe keine Probleme, Wegbeschreibungen zu verstehen.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

9. Ich bin sehr gut im Kartenlesen.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

10. Als Beifahrer im Auto erinnere ich mich nicht sehr gut an die gefahrenen Strecken.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

11. Ich gebe gerne Wegbeschreibungen.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

12. Für mich ist es wichtig, zu wissen wo ich bin.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

13. Ich übernehme oft die Wegplanung für längere Fahrten.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

14. In der Regel kann ich mich an einen neuen Weg erinnern, wenn ich ihn lediglich einmal zurückgelegt habe.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

15. Ich habe eine gute «innere Karte» meiner Umgebung.

Stimme stark zu 7	6	5	4	3	2	Lehne stark ab 1

D Direction Pointing Form

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Aufgabe: Richtungsschätzung

ID: ______

Strecke	Gradschätzung
Neuwiesen	
Altstadt	

1

E Sketch Map Form

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ID: _______

Aufgabe: Skizzenkarte

System: __________________________

Skizzieren Sie eine Karte der zurückgelegten Route. Die Karte soll zudem die Umgebung zwischen Start- und Endpunkt der zurückgelegten Route so detailliert wie möglich wiedergeben. Dabei dürfen Sie jedoch nur Elemente (Strassen, Häuser, Plätze, etc.) verwenden, die Sie während der Navigationsaufgabe erkennte haben und nicht schon aus Vorwissen bekannt sind. Wie Sie die verschiedenen Elemente Ihrer Skizze darstellen, ist Ihnen überlassen. Eine Strasse darf beispielsweise als einzelner oder doppelter Strich gezeichnet werden, ein auffälliges Gebäude (bekannter Laden, Restaurant, etc.) darf nach Belieben gekennzeichnet werden.

Ästhetische Aspekte spielen keine Rolle! Bei der Auswertung wird nur darauf geachtet, was auf der Skizze vorhanden bzw. nicht vorhanden ist.

1

F NASA task load index Form

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Fragebogen: Empfundene Beanspruchung

ID: ______

Geben Sie jetzt für jede der untenstehenden Dimensionen an, wie hoch die Beanspruchung für das jeweilige System war. Markieren Sie dazu bitte auf den folgenden Skalen jeweils für beide Systeme, in welchem Maße Sie sich in den sechs genannten Dimensionen von der Navigationsaufgabe beansprucht oder gefordert gesehen haben:

Beispiel:

PPA System
Google Maps
gering   hoch

1. Geistige Anforderung

PPA System
Google Maps
gering   hoch

Wie viel geistige Anstrengung war bei der Navigationsaufgabe erforderlich (z.B. Denken, Entscheiden, Rechnen, Hinsehen, Suchen...)? War die Aufgabe leicht oder anspruchsvoll, einfach oder komplex?

2. Körperliche Anforderung

PPA System
Google Maps
gering   hoch

Wie viel körperliche Aktivität war erforderlich (z.B. Ziehen, Drücken, Drehen, Steuern, Aktivieren,...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?

3. Zeitliche Anforderung

PPA System
Google Maps
gering   hoch

Wie viel Zeitdruck empfanden Sie während der Navigationsaufgabe? Fühlten Sie sich zeitlich unter Druck? War die Abfolge langsam und geruhsam oder schnell und hektisch?

1

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4. Leistung

PPA System

Google Maps

gering — hoch

Wie erfolgreich haben Sie Ihrer Meinung nach die Navigationsaufgabe erfüllt? Wie zufrieden waren Sie mit Ihrer Leistung?

5. Anstrengung

PPA System

Google Maps

gering — hoch

Wie hart mussten sie arbeiten, um Ihren Grad an Aufgabenerfüllung zu erreichen?

6. Frustration

PPA System

Google Maps

gering — hoch

Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Navigationsaufgabe?

G System Usability Scale Form

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Fragebogen: System Benutzerfreundlichkeit

ID: _______

Geben Sie bei jeder Frage Ihren Grad an Zustimmung für jeweils beide Systeme an.

Beispiel:

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System		X			
Google Maps				X	

1. Ich denke, dass ich das System gerne häufig benutzen würde.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

2. Ich fand das System unnötig komplex.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

3. Ich fand das System einfach zu benutzen.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

4. Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

5. Ich fand, die verschiedenen Funktionen in diesem System waren gut integriert.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

6. Ich denke, das System enthielt zu viele Inkonsistenzen.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

7. Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit diesem System sehr schnell lernen.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

8. Ich fand das System sehr umständlich zu nutzen.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

9. Ich fühlte mich bei der Benutzung des Systems sehr sicher.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

10. Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

H System Evaluation Form

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Fragebogen: System-Vergleich

ID: _______

Geben Sie für die drei Aussagen an, wie stark Sie für die beiden benutzen Systeme zustimmen. Überlegen Sie sich die Aussage zuerst für beide Systeme und kreuzen Sie die entsprechenden Felder anschliessend an.

1. Ich fühlte mich während der Navigationsaufgabe sicher und auf dem richtigen Weg.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

Begründung:
……
……
……
……
……

2. Ich fühlte mich in einem angenehmen und genügenden Masse vom System ans Ziel geführt (vs. zu wenig oder zu fest vom System geleitet).

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

Begründung:
……
……
……
……
……

3. Ich hatte Spass beim Benutzen des Systems.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
PPA System					
Google Maps					

Begründung:
……
……
……
……
……

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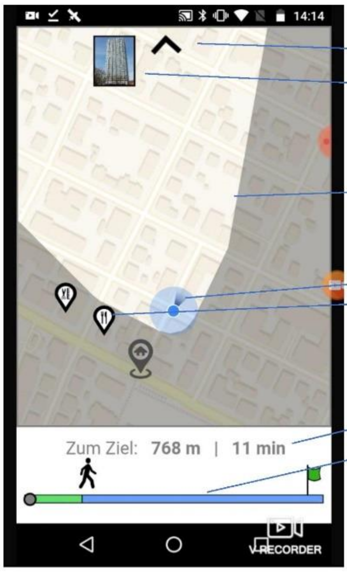
4. Wie stark haben die folgenden Komponenten dazu beigetragen, dass die Navigationsaufgabe mit dem PPA-System erfolgreich absolviert werden konnte?



1. Zielpfeil
2. Globale Landmarke (als Orientierungshilfe)
3. Potentielle Weg-Ebene
4. Ausrichtung des Handys
5. Lokale Landmarken (als Orientierungshilfe)
6. Zeit und Distanz zum Ziel
7. Fortschrittsbalken

	wenig 1	mittel 2	stark 3	Sehr stark 4
1. Zielpfeil				
2. Globale Landmarke				
3. Pot. Weg-Ebene				
4. Ausrichtung				
5. Lokale Landmarke				
6. Zeit und Dist.				
7. Fortschrittsbalken				

Welche Komponenten waren im Vergleich zu Google Maps besonders wertvoll? Welche Komponenten stellten keine grosse Hilfe für die Navigation und Orientierung dar? Warum?

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I Statistical Tests

Task completion time

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
Neuwiesen - PPA	0.965	0.859
Neuwiesen - Google	0.978	0.953
Altstadt - PPA	0.956	0.776
Altstadt - Google	0.847	0.088

Test for sifnigicant Differences - t-Test	t	p-Value
Neuwiesen - PPA / Google	0.814	0.215
Altstadt - PPA / Google	1.415	0.089

Direction estimation

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
Neuwiesen - PPA	0.798	0.069
Neuwiesen - Google	0.847	0.016
Altstadt - PPA	0.927	0.273
Altstadt - Google	0.903	0.453

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
Neuwiesen - PPA / Google	49	0.474
Altstadt - PPA / Google	47.5	0.564

NASA tlx

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.85	0.009
Google Maps	0.94	0.415

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
PPA-System / Google Maps	103.5	0.066

System usability scale

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.905	0.069
Google Maps	0.914	0.102

Test for sifnigicant Differences - t-Test	t	p-Value
PPA-System / Google Maps	-1.741	0.045

Route Likeness

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.808	0.002
Google Maps	0.848	0.008

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
PPA-System / Google Maps	216	0.073

Survey Likeness

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.911	0.089
Google Maps	0.934	0.232

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
PPA-System / Google Maps	224	0.047

Overall Likeness

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.952	0.455
Google Maps	0.933	0.219

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
PPA-System / Google Maps	238	0.016

Local Landmarks

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.894	0.045
Google Maps	0.89	0.039

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
PPA-System / Google Maps	209	0.139

Global Landmarks

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.943	0.325
Google Maps	0.882	0.028

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
PPA-System / Google Maps	232	0.022

Overall Feeling, Q1

Test for normal distribution - Shapiro-Wilk Test	W	p-Value
PPA-System	0.786	0.001
Google Maps	0.257	1.06E-08

Test for sifnigicant Differences - Mann Whitney-U Test	W	p-Value
PPA-System / Google Maps	262	0.0002

Overall Feeling, Q2

Test for normal distribution - Shapiro-Wilk Test		
	W	**p-Value**
PPA-System	*0.601*	*6.88E-06*
Google Maps	*0.833*	*0.005*

Test for sifnigicant Differences - Mann Whitney-U Test		
	W	**p-Value**
PPA-System / Google Maps	*96*	*0.023*

Overall Feeling, Q3

Test for normal distribution - Shapiro-Wilk Test		
	W	**p-Value**
PPA-System	*0.601*	*6.88E-06*
Google Maps	*0.862*	*0.013*

Test for sifnigicant Differences - Mann Whitney-U Test		
	W	**p-Value**
PPA-System / Google Maps	*15*	*1.41E-06*

Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Place and date:

Zurich, 30.09.2019

Signature:

Thomas Mathis