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Mapping the indoors: Optimizing cartographic representations for mobile indoor navigation systems

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Kurzfassung

Diese Masterarbeit beschäftigt sich mit der Optimierung von Innenraum-Navigationsanwendungen. Ziel der Arbeit war es, die besten Methoden zur Darstellung von Innenraumkarten, Positions- und Routeninformationen zu identifizieren, um die Benutzerfreundlichkeit und Effektivität von Indoor-Navigationssystemen zu verbessern. Die Vorgehensweise umfasst eine Kombination aus Literaturrecherche, Wettbewerbsanalyse, Prototypenentwicklung und Benutzertests. Die wichtigsten Ergebnisse zeigen, dass im Innenraum aufgrund von anderen Begebenheiten zum Außenbereich zusätzliche kartographische Methoden heranzuziehen sind. Dazu gehören eine angepasste Farbgestaltung, die Visualisierung von speziellen Gebäudestrukturen, die Angabe zu Stockwerkwechseln, das Verwenden von speziellen Landmarken und die Darstellung von Zugängen zu bestimmten Bereichen. Durch die Anwendung angepasster kartografischer Techniken kann die Benutzerfreundlichkeit von Indoor-Navigationssystemen deutlich verbessert werden. Die Arbeit schließt mit Empfehlungen für die zukünftige Entwicklung mobiler Indoor-Navigationssysteme ab.

Abstract

This master's thesis focuses on optimizing indoor maps for mobile navigation applications. The aim of the thesis was to identify the best methods for displaying indoor maps, position and route information to improve the usability and effectiveness of indoor navigation systems. The approach includes a combination of literature review, competitive analysis, prototyping, and user testing. The key findings indicate that, due to the different circumstances indoors compared to outdoor environments, additional cartographic methods need to be employed. These include adjusted color schemes, visualization of specific building structures, indication of floor changes, use of special landmarks, and representation of access to certain areas. By applying adapted cartographic techniques, the usability of indoor navigation systems can be notably improved. The thesis concludes with recommendations for the future development of mobile indoor navigation systems.

Contents

Glossary

2D ..... Two dimensional
3D ..... Three dimensional
e.g. ..... Exempli gratia
GUI ..... Graphical User Interface
HCI ..... Human Computer Interaction
IPS ..... Indoor Positioning System
POI ..... Point of interest
UCD ..... User-Centered Design
UX ..... User Experience
WIMP ..... Windows, Icons, Menus, Pointer

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1 Introduction

Have you ever felt like you were on a scavenger hunt in a large building such as a shopping center, hospital or office building? Finding your way around large buildings can sometimes be difficult. In contrast to navigating outside, we need other tools and tricks inside to find our way around the building easily.

Gotlib (2019) reflected very well that the map serves as a crucial component in any navigation system and highlights the need for improvements in not just the quality of positioning systems, but also in the maps used to represent building interiors. Many of the emerging solutions in this field do not fully utilize cartographic knowledge, and the proper use of cartographic methodology for representing building interiors is still in its early stages of development. Nevertheless, its proper implementation can greatly enhance the overall effectiveness of indoor navigation systems. To achieve this the maps should include recognizable symbols and landmarks, as well as accurate labeling of rooms and buildings. The level of detail should be appropriate for the user's task, and the maps should be designed with user needs in mind.

The information in an indoor map is very different from an outdoor map due to the different properties of indoor space, the higher intrinsic complexity of indoor spaces due to multiple floors, and its connections via lifts and stairs. Despite the increasing demand for sophisticated indoor maps, most existing maps are only simple floor plans that can be unreliable. Cartography is one key to improving indoor navigation. Applying cartographic best practices like symbolization and generalization can turn this data into practical maps, much like traditional outdoor maps. So, developing a consistent set of concepts and terminology can enhance clarity and focus of indoor maps. (Chen et al. 2020: 95-97)

There are only a few studies that deal with the cartographic representation of indoor spaces. Cartographic basic rules for geocommunication can be derived from the cartographic theory. Nevertheless, there is a need for further development of these solutions tailored to indoor spaces. (Gotlib 2019: 164).

1.1 Motivation and relevance of the work

Gotlib and Marciniak (2012) and Puikkonen et al (2009) emphasized the importance of cartographical aspects in the design of indoor navigation systems. Their analysis proved that cartographical methodology is very limited in the process of designing indoor navigation systems. While most research focuses on improving indoor positioning accuracy, the influence of cartographic methods for effective indoor navigation is neglected. In the opinion of the authors, using cartographical methods and techniques could greatly improve indoor navigation systems and speed up their development. Designers of these systems should have a good understanding of cartographical methods.

So, indoor navigation is an area experiencing rapid expansion, offering a wide range of potential applications. These applications span from guiding individuals within expansive public areas to enabling efficient emergency response within hospital settings. The success of indoor navigation systems relies heavily on the accuracy and reliability of the maps and location data provided to users. Currently, there is no universally agreed-upon approach for presenting this information, particularly on mobile devices. Therefore, this study aims to address this gap and explore innovative methods for enhancing the presentation of indoor navigation information.

Understanding which cartographic methods are relevant for the efficiency and user-friendliness of indoor navigation systems can contribute to improve the functionalities and technologies of such applications.

1.2 Objective

The objective of this study is to understand the best way to present indoor maps, position and route information in an indoor navigation application. By understanding the important aspects when designing indoor maps, indoor navigation systems could be improved in their usability.

The process of designing an indoor navigation system involves several tasks. Gotlib and Marciniak (2012) touches the most important features in an indoor navigation app that can be supported by the theory and practice of cartography. These features are to be examined in the thesis:

Presentation of indoor environments: To ensure high-quality map messages, it is important to establish appropriate geovisualization standards for indoor maps. It is essential to consider the user's perception of the interior space and adjust the map message accordingly. Displaying multiple floors of a building in a single map in a user-friendly and practical way is a challenging and uncommon task in current cartographic practices.

Presentation of location/position: The cartographic representation of the position where the user is located should fit harmoniously with the other cartographic symbols, but still stand out from them. This is general for all navigation systems, but especially in indoor navigation is the

representation of which floor the user is currently on or between which floors. (Gotlib 2019: 159)
Location information is rarely perfectly accurate. Visualizing location uncertainty is one option to address this issue. Ranasinghe et al. (2016) found out that the way a position is designed and presented has an impact on how well users understand their location.

Description/Presentation of indoor routes: The quality of route information has a significant impact on how useful and user-friendly an indoor navigation app is. When someone is looking for a shop in a shopping mall or an airport, they need different information compared to a driver navigating through a city. For indoor navigation, it's often helpful to have a general description of the route, such as floor numbers and landmarks, to guide the user to their destination. Sometimes, this type of information is sufficient for reaching the destination.

As current available indoor navigation apps are in a 2D view the study focuses on a 2D view of indoor space presentation for mobile navigation. Chen et al. (2020) argue that the continued prevalence of 2D indoor maps despite the advent of 3D mapping technology is given by that current solutions for indoor positioning systems (IPS) with high accuracy in three dimensions have not yet emerged as a universal solution that is affordable and easy to deploy. Kray et al. (2003) states that 3D visualizations can be even more demanding in terms of technical resources than 2D maps. While 3D visualization can strongly support the recognition of landmarks, and there may be an aesthetic factor that should not be underestimated, it may not necessarily lead to better performance. On the other hand, 2D maps naturally incorporate contextual information, and are a good means to address situations where only imprecise positional information is available. Additionally, they are a well-known tool for navigation and may help an untrained user to familiarize herself with the system. Liao et al. (2017) found that participants using a 3D perspective had an extensive visual search, resulting in significantly longer response time than the 2D participants, which was most probably due to information overload. But the 3D participants performed more efficiently in self-location and orientation at complex decision points than the 2D participants.

1.3 Problem definition

Cartographic theory has not fully kept up with technological progress in this regard (Gotlib 2019). The problem addressed in this research is the lack of comprehensive knowledge about which features, and design variables are relevant when creating indoor maps, showing an indoor position, and provide helpful route descriptions, so that they are understandable and efficient. While previous research has investigated indoor navigation and mapping, there is still a gap in the understanding of which specific design variables and features are most relevant and for mobile phone use cases in indoor positioning. The current research lacks a systematic approach to examining the different features (e.g. symbolization, generalization, scale, projection) that affect the usability of indoor maps and positioning technology in these use cases. In addition, previous studies have mostly focused on one or a few aspects of indoor positioning and mapping, such as accuracy, rather than considering the overall visualization and how cartographical aspects may influence the choice of underlaying technology (Gotlib 2019: 155).

1.4 Research question

The main research question of this thesis is formulated as follows:

How can cartographic methodology be utilized to improve the usability of mobile indoor navigation systems, so that they are efficient and understandable for users?

To answer this main research question, it is broken down into smaller sub-questions:

- What are the strengths and weaknesses of existing indoor navigation apps?
- What cartographic features enhance the usability of indoor maps, and how should these features be specifically designed?
- What are important aspects of position and route information for increasing the usability of indoor navigation systems?

1.5 Methodological approach

Literature review on cartographic theory and studies on the matter: The necessary basics for understanding will first be provided by literature research. Here, the cartographic techniques and models for mobile application visualization will be pointed out. Afterwards, the state of the art in research regarding the visualization of indoor navigation applications will be evaluated and from this it will be derived which requirements are important for such an application. From this, a set of features will be selected, which will be investigated during the user-testing.

Review of existing indoor navigation systems: Furthermore, existing indoor navigation apps will be reviewed in general and evaluated and compared based on the visualization of their map, position, and routing.

User testing of indoor navigation maps*:* The following part of the thesis will describe the implementation of experiments with test persons. For the initial study, three existing indoor navigation systems were selected:

- Apple Maps

- Google Maps
- InMapz

These systems are widely used and employ different cartographic methods for displaying interiors.

To gain an understanding of the strengths and weaknesses of the selected existing indoor navigation systems, user tests were conducted using the common usability method named Thinking Aloud. This already generates an understanding of the challenges users face when using indoor maps. The insights from these initial tests, additional to the literature review, will then be implemented into a newly designed map of the building.

To test the newly designed map and compare it with the existing systems, a questionnaire will be developed. The results of the questionnaire surveys will be evaluated and compared.

Conclusion: In the last part the gained knowledge will be summarized and recorded in a report. The last part will summarize the results and give a recommendation for the further development of mobile indoor navigation apps.

1.6 Structure of the work

This master's thesis is structured into five chapters. The first chapter, the introduction, covers the relevance of the work, the objectives, the problem definition, the research question, and the methodological approach. Here, the importance of the topic is explained and the specific problems that the work addresses are outlined.

The second chapter presents the theoretical background of this work. It examines the relevant literature on cartographic principles and techniques for indoor navigation. Additionally, the theoretical background also deals with significant works on usability, which is important for the user-friendly development of indoor applications.

The third chapter, Methods, describes in detail the methods applied to answer the research questions. These include a competitive analysis of existing indoor navigation systems, the Thinking Aloud method used to collect user impressions, prototyping, and the implementation of questionnaires for data collection.

The fourth chapter, Results, Analysis, and Discussion is the practical part of this work. Here, the test results are presented and then analyzed and interpreted in a discussion.

The fifth chapter, Conclusion, summarizes the objectives and methodology of the entire work, presents the main findings, and answers the research questions. It also provides suggestions for further investigations and possible improvements.

2 Theoretical background

In cartography, there are two important theories: Map symbolization and cartographic communication. In symbolization theory, researchers have studied visual elements and suggested different variables like dynamic variables. As maps evolved from analog to digital and web-based visualizations, additional variables such as screen variables, view variables, and interaction variables have been proposed. The study of cartographic communication theory started in the 1960s. At this time the initial model was published for map communication. Since then, several other models for cartographic communication have been suggested. Figure 1 shows a typical example created by Kolacny. (Zhilin Li, Peichao Gao, Zhu Xu 2021: 2)

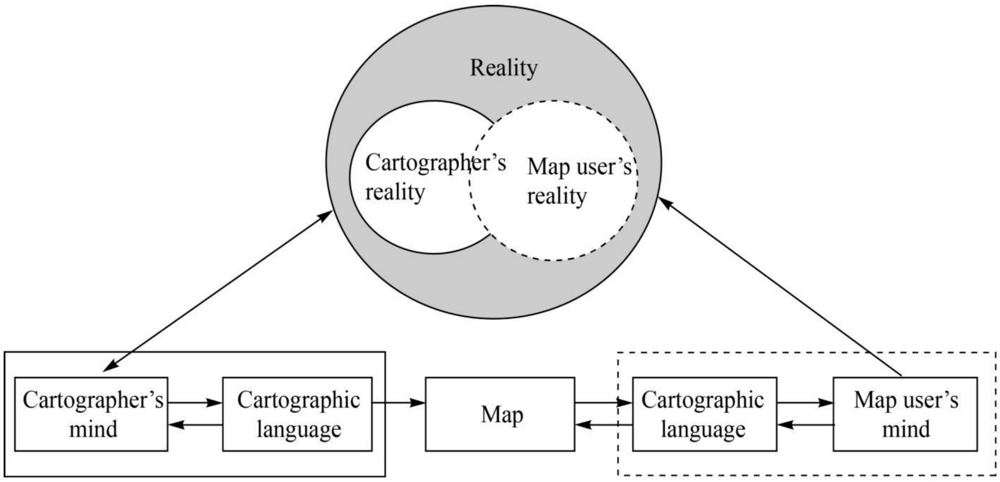

Figure 1: The cartographic communication model by Kolacny (Zhilin Li, Peichao Gao, Zhu Xu 2021: 2)

2.1 Cartography for mobile (indoor) navigation

Navigation is a coordinated movement towards a specific destination. It involves both planning and executing movements. According to Montello (2005), navigation can be divided into two components:

- **Wayfinding** pertains to knowing where we are going and how to get there. This is the planning part of navigation and is goal oriented. The destination is usually outside of the local environment. Through orientation, we solve problems like choosing a route, heading towards a landmark, or selecting shortcuts.
- **Locomotion**, on the other hand, refers to the execution of the wayfinding process, which means successfully moving our body towards the destination without encountering obstacles.

Successful navigation, therefore, means reaching our destination efficiently. To ensure this, we require information about our surroundings, and this information should be accurate, comprehensive, and up to date (Montello and Sas 2006: 3). So, a key factor in the ability to navigate through a physical environment is to represent the spatial characteristics of that environment (Sorrows and Hirtle 1999: 2).

By using cartographic multimedia data, navigation systems can cater to the needs of pedestrians by presenting information in their preferred format. To facilitate navigation tasks, it's not only the map itself that matters, but also the deliberate combination and design with other media, which is a crucial factor for user-friendliness. Furthermore, landmarks are a valuable addition to pedestrian navigation systems, but their wide variety makes it challenging to effectively integrate them into guidance instructions. (Gartner, Cartwright, and Peterson 2007: 301-302)

In his book, Muehlenhaus (2014) emphasized the importance of the user ability to interact with the map. Under map interactions, several key functionalities enhance the user experience:

- **Panning** allows users to shift the map view, especially valuable when the map features a zoom function or when the map size exceeds the screen. Care must be taken to prevent panning beyond the mapped area to avoid confusion. On mobile touchscreens, the touch-and-drag approach is intuitive for panning.
- **Zooming** is another popular feature, though not always necessary. It should be implemented thoughtfully to avoid hindering information delivery. Different methods like zoom bars, buttons, and pinch-to-zoom on touchscreens offer flexibility.
- **Map rotation** is essential for orientation maps, with automatic and user-initiated options. Guidelines include indicating orientation, starting with north at the top, ensuring smooth rotations, avoiding upside-down text, and aligning maps with the user's direction.

Gotlib (2019) focused on the features that mobile indoor navigation systems should have. He provided a literature overview and summarized the following elements:

- **Egocentrism:** The application's information should adapt to the user's behavior. For example, the map's orientation should change as the user changes their direction.
- **Multimediality:** The application should use multiple media to describe the route, which can increase its usefulness and understandability.
- **Multi-scalability:** Since displaying an entire building on a mobile screen while maintaining readability is challenging, users should have the option to zoom in on specific areas.

- **Polymorphism:** The application should offer various display options. For instance, users could choose between different color schemes (e.g., greyscale) or switch to a 3D view.
- **Contextuality:** This element is closely related to egocentrism, meaning that the content of the application should adapt to the specific location and user. For example, a technician in a shopping center will need different information than a shopper.
- **Dynamism:** Maps should change based on the zoom level. For instance, displaying object names should dynamically adjust and take up the appropriate space depending on the scale.
- **Interactivity:** This is a common feature in mobile map applications, especially in indoor navigation, it's essential to have the ability to switch between floors.
- **Universality:** The application should be usable on various mobile devices.
- **Self-explaining:** Avoid using complicated architectural plans. Represent the building with simple cartographic symbols that users can relate to the real world.
- **Glanceability:** Users should be able to understand and use the application's content and instructions quickly.
- **Optimality:** A precise building model is often unnecessary for navigation. The cartographer should offer a suitable selection of content and media for the user.

2.1.1 Mobile map

The map is the most crucial means of presenting spatial information (Gartner, Cartwright, and Peterson 2007: 303; Kray et al. 2003: 119; Bauer and Ludwig 2019: 1; Montello and Sas 2006: 9). It provides users with an overview of the spatial environment. To create effective maps on mobile screens, it's crucial to understand the user and how they interact with digital maps (Gotlib 2019:157).

During their user study, Nivala, Brewster, and Sarjakoski (2008) provided guidelines for map visualization:

- The map should be visualized according to the properties of the computer screen.
- The map should be optimized for viewing on the computer screen.
- Maps should be simple and intuitive and pleasant to use. Colors should be in harmony.
- Each map scale should be considered separately: What information should be included and how it should be visualized at each of the scales.
- Information about data accuracy and validity should be provided.

In user tests, Stefanakis et al. (2006) discovered that the north direction plays a significant role in people's mental maps, whereas in indoor maps, this is not the case. Instead, the direction in which the individual entered the building is more commonly used for orientation. Additionally, it can be observed that efficiency in handling a navigation task is increased through an egocentric view of the map. This means that people orient themselves more quickly when the orientation of the map matches the forward direction of the route, and when left and right on the map correspond to left and right in the real world. People tend to orient a map in a way that eliminates the need for mental rotations, because these processes require cognitive effort. Montello and Sas (2006) suggest that an application should have both options available. This means having an egocentric perspective and one with a fixed map orientation that users can adjust as they prefer. There are some individuals who prefer the north orientation. Additionally, a fixed orientation can help users acquire knowledge about spatial structures, thereby facilitating the formation of cognitive maps.

For maps intended for navigation, extremely precise metric information such as distances and directions can be omitted (Montello and Sas 2006: 10). As long as topological relationships are evident on the map, accuracy doesn't need to be overly emphasized (Evans 1980: 266). Additionally, it is discovered that when users are familiar with the environment, they prefer a schematic map (Stefanakis et al. 2006: 385). This raises the question of how much detail on the map is truly necessary for the user to efficiently reach their destination. While topographical maps may contain too much information for wayfinding purposes (Mackaness, Ruas, and Sarjakoski 2007: 206), schematic maps appear less ideal due to their lack of information. Therefore, it is recommended to use a highly simplified topographical map that includes only the specific details crucial for navigation (Stefanakis et al. 2006: 388; Gartner and Radoczky 2005: 3). Furthermore, it's important to have the ability to change the scale. This can be done either to get an overall view of the surroundings or to closely examine a specific area in detail. (Gartner, Cartwright, and Peterson 2007: 303; Ian Muehlenhaus 2013: 35)

It is essential for navigation that the map contains sufficient information about the surroundings but not too much, as an excess of information can distract the user from the relevant details necessary to reach their destination (Montello and Sas 2006: 3). Dillemuth (2013) explored how spatial information can be effectively represented on a mobile device. This involved comparing and evaluating two maps with different levels of detail. User tests, in the form of a navigation task, were conducted for this purpose. One map was a photorealistic aerial view, while the other was a generalized map created in a GIS (Geographic Information System). The assumption was that the aerial view, due to its realistic representation, would be more popular with users, as it makes interpretation easier, for example through color comparisons, and helps users orient themselves more effectively. Conversely, it was argued that an aerial view contains unnecessary information and, especially on a small screen, could lead to cognitive overload for the user. The ability of a generalized map to focus on the features relevant to the navigation task should not be underestimated. The results show that the generalized map performs better than the aerial view. This is evident in the time users took to complete the task, the fewer zoom levels they required during the task, and how often they paused to orient themselves. The high level of detail in the aerial view necessitates users to zoom in closer to orient themselves. The generalized map reduces the complexity of objects but requires more cognitive effort to associate symbols with reality. Additionally, in cases with challenging or hard-to-recognize routes, the additional information from the aerial view can be helpful for finding the way. Combining a generalized map with an aerial view is worth considering in such scenarios.

As we move into the indoor environment, several questions remain unanswered regarding how much information is crucial for the user to support wayfinding:

„*Mobile maps can differ in scale, content, and style. As a result, the effectiveness of different types of maps (ranging from sketch or schematic map to topographic map or other detailed map) for indoor route communication should be evaluated. However, little work has been done on that.* “- (Huang and Gartner 2010: 10)

Bauer and Ludwig (2019) delved into the question of whether schematic maps with less detail are more efficient than topographic maps. To investigate this, they conducted user tests using a mobile navigation system in a real indoor environment scenario. Additionally, the participants' gaze behavior was analyzed using an eye tracker. It was found that participants using the topographic map spent more time looking at the text instructions and the map, resulting in a longer orientation time. However, in the questionnaire filled out by the participants after the experiment, there was no difference in user satisfaction and self-assessed workload. The time difference between the participants using the topographic and schematic maps for task completion was minimal. Nevertheless, it can be said that the schematic map is slightly more efficient in terms of time, while topographic maps also serve as good navigation aids. The main advantage of the schematic map is that users have more visual resources to observe the actual environment. However, this study did not reveal a significant difference in gaze behavior toward the real environment between the two types of maps.

Sarot et al. (2018) conducted a study where the usability of indoor mobile maps was tested. There were two groups, one that performed the task with a floor plan, the other with a schematic map. In the schematic map, rooms were represented as points and corridors as lines. One of their main findings was that users with the floor plan spent more time reading the map. Since some preliminary studies show that users have a better understanding of the interior when using a schematic map, it is necessary to confirm this in further studies (Delazari et al. 2019: 184).

Ohm et al. (2016) found that the efficiency of a map also depends on user characteristics. User tests revealed that participants with a strong sense of orientation benefit from a highly generalized map, whereas for those with a poor sense of orientation a more detailed map is more suitable.

In the context of coloring a map, this is more challenging in indoor settings compared to outdoor environments. While in outdoor settings, it's generally straightforward to assign grey to roads, brown to ground, and green to vegetation, the appearance of buildings indoors can vary significantly. Therefore, it is essential to pay close attention to color consistency between the map and reality. Hence, it is advisable to conduct some on-site design work during the map creation process. (Puikkonen et al. 2009: 4)

2.1.2 Floor plans

One important difference between the indoor and outdoor environment is that in the indoor area we have to deal with several floors. To represent a complex building and its structures, it's necessary to depict their different levels. Floor plans share similar characteristics with outdoor maps, but the visualization techniques must be adapted to the indoor environment. For example, color-coded symbology aims to enhance recognition within the building. It's particularly important to ensure clear representation when transitioning between different floors. To make this understandable on the map, pictograms such as stairs, elevators, or escalators can be used for symbolism. (Gartner, Cartwright, and Peterson 2007: 304)

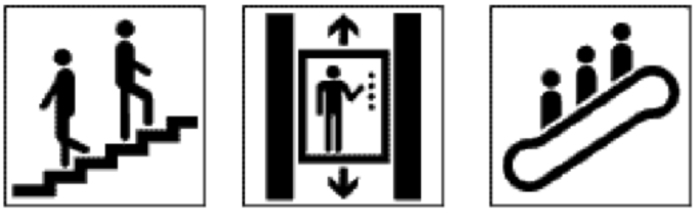

Figure 2: Symbols for stairs, elevators and escalators (Gartner, Cartwright, and Peterson 2007: 305)

Nevertheless, representing the transition between different floors is not an easy task. In this case, Gotlib (2019) recommends using an axonometric representation. The user's position should be clearly visible in three dimensions, even when they are between two floors. The area that would typically be hidden can be depicted using invisible walls.

Nossum (2011) developed a new representation of indoor spaces, called "Indoor Tubes." This style is derived from classic subway maps. In this case, as with a schematic map, the corridors are represented only by lines. This allows all floors to be displayed at once. The lines then have different colors to distinguish between the floors.

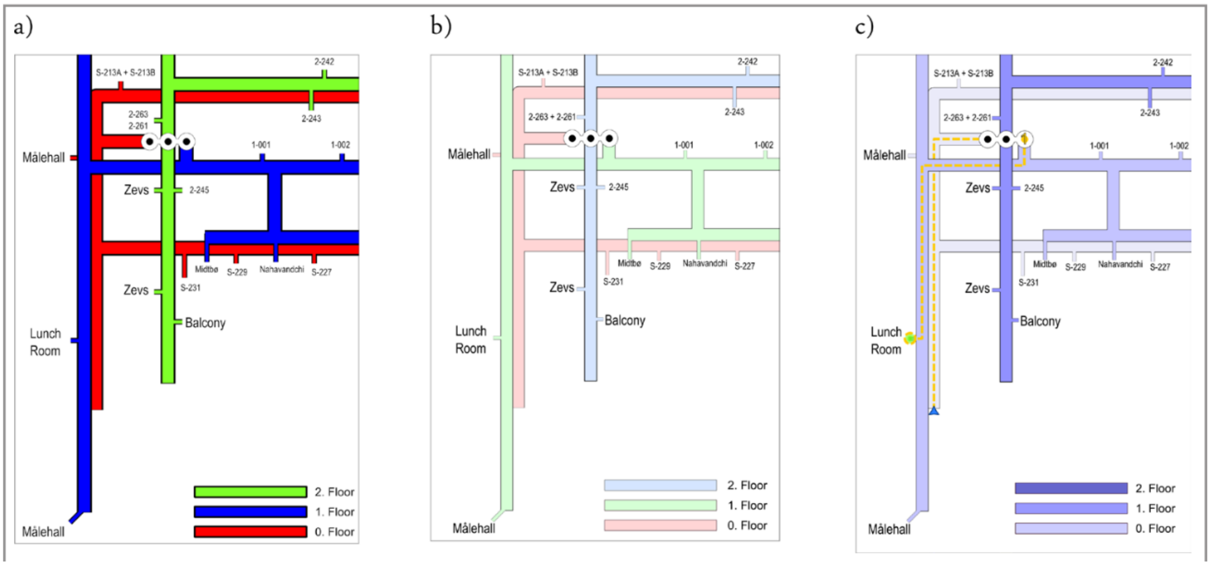

Figure 3: Different color schemes for floor visualization (Nossum 2011: 198)

2.1.3 Routes

Routes are representations that guide users in unfamiliar spatial environments to reach a desired location. They have a starting and ending point and may include additional multimedia data to facilitate wayfinding. The need for a different type of route instruction may vary at decision points (Cock et al. 2019: 1).

At the beginning of a map's route representation, the user should first see the entire route, for instance, in a small-scale view. This provides the user with an overview of the entire route, which can be helpful. Once navigation begins, the map can then switch to a larger scale that depicts the current surroundings. Additionally, it's beneficial to provide the user with further information about the route, such as its length and expected travel time. Junctions where the route direction changes should be clearly identifiable. Furthermore, multiple possible routes should also be displayed (e.g., the shortest, the most scenic, etc.), allowing the user to choose the route that best suits them. (Stefanakis et al. 2006: 387).

In route planning, it's also essential to consider the user's cognitive resources. For instance, an unexperienced tourist is more likely to get lost compared to someone familiar with the surroundings. Therefore, the computer should take this into account during route calculation and provide a route suitable for such situations. (Kray et al. 2003: 118)

Puikkonen et al. (2009) particularly recommend reducing cognitive load and the need for self-localization as much as possible, especially in indoor environments. Therefore, route instructions should always be given in relation to the user's current location. For instance, if the destination is a shop on the fourth floor, the user must know which floor they are currently on, which requires self-orientation. In this case, the instruction could be that the shop is one floor up.

Furthermore, it's advisable to avoid specifying distances in route descriptions. In indoor settings, there are often more obstacles, such as other people, compared to a road for cars. Estimating distances or steps can be challenging. Therefore, it is recommended to provide instructions that describe the surroundings where the user should turn, rather than specifying distances in meters (e. g. "Turn right after the elevator."). (Gotlib 2019: 158)

Textual and verbal guidance of routes

In addition to the map and the route marked on it, further guidance in the form of text or audio can provide the user with additional assistance. Cognitive load can be reduced by combining route visuals on the map, such as a right turn, with a spoken instruction like "Turn right onto the main street." However, it is essential to ensure that only necessary information is provided. Repetitions, such as the destination location, should generally be avoided. But the longer a segment of the route is, the longer the user must remember or refer back to spoken or text-based information. Familiarity with the surroundings can also be considered. For a local resident, less information may be necessary compared to a tourist. (Kray et al. 2003: 118)

Verbal communication tools become particularly crucial when users find themselves in situations where they cannot look at the screen, such as during darkness or adverse weather conditions. This allows users to remain independent of the screen and avoids distractions. Textual information offers the advantage that users can read it as many times as needed, and in noisy surroundings, they can rely on this navigation aid. (Stefanakis et al. 2006: 389; Meng, Zipf, and Winter 2008: 35; Huang and Gartner 2010: 10)

And also indoors, voice commands can be inappropriate in some indoor environments. For instance, the noise in a shopping center can hinder the user from comprehending what is being said. Additionally, the audio output may also disturb other people present in the shopping center. (Gotlib 2019: 157)

In their indoor user study, Bauer and Ludwig (2019) observed that most participants spent an equal amount of time looking at the text instructions as they did at the map. From this, it can be inferred that the additional textual and verbal information plays an important role in navigation aids.

Cock et al. (2019) conducted a user study to determine the most suitable types of route instructions in various situations. They investigated this through an online survey involving ten different instruction types, including maps, text, photos, symbols, and 3D simulations in various forms. The results indicated that all instruction types combined with text received the highest ratings. Among all instruction types, users preferred photos the most. Maps received moderate ratings overall but were rated negatively in more complex decision points. In such situations, users preferred 3D simulations.

2.1.4 Positioning

The cartographic symbol representing the user's location and intended route should be prioritized over the other cartographic symbols in use, while also maintaining a harmonious coexistence with them. (Gotlib 2019: 159)

In pedestrian navigation, especially in indoor environments, there are significantly more points where pedestrians must make decisions about which turn to take. Therefore, a higher level of position accuracy is crucial in these situations. However, when this level of accuracy is not achievable for technological reasons, such as signal interference, the question arises of how to best represent inaccurate position information.

Burigat and Chittaro (2011) investigated the effectiveness and user acceptance of different visualizations for inaccurate position information in a pedestrian navigation system. They conducted field user tests, evaluating three variations of visualizations: "just the last known position" (basic visualization), a dynamically resizing circle that represented the location error, and colored street segments. The study revealed that visualizing position inaccuracies can be beneficial in assisting users in wayfinding. Additionally, the street segment coloring and the dynamic circle required less effort in wayfinding than the basic visualization. However, there was no significant difference observed in terms of the position estimated by users among the three visualization methods.

In the context of user testing, Ranasinghe and Kray (2016) embarked on a quest to explore various methods of representing an inaccurate position, how these representations influence users, and which representation is best suited for specific scenarios. They categorized three forms for representing a position: a circle, a cloud, and a colored street segment. These three forms were further divided into four different styles (see figure 4): Border and middle dot, no border but middle dot, border but no dot, and no border no middle dot. The results revealed that users favored the circle as the preferred form for representing position. The cloud came in second place, followed by the colored street segment. The border and middle dot style received the highest rating. Additionally, it was observed that styles with a middle dot were preferred over those with only a border. Furthermore, concerning position accuracy, it was evident that users associated the size of the form with position accuracy. For instance, users perceived a larger circle as indicating a less accurate position, while a smaller circle suggested greater accuracy. The observations made in this study also suggest that in cases of high position inaccuracy, opting for a visualization without a border may be more suitable. Moreover, the cloud seems to be a reasonable choice when dealing with high inaccuracy in position representation.

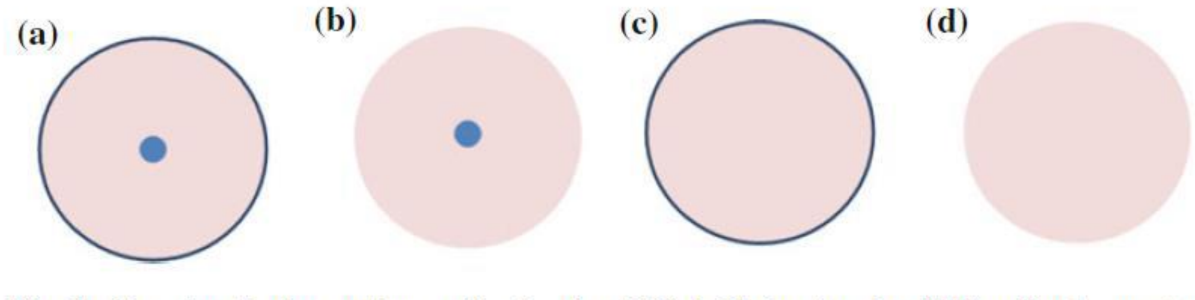

Figure 4: Visualization options for position uncertainty (Ranasinghe and Kray 2016: 319)

Wei et al. (2019) investigated the influence of the viewing field on zoom levels in pedestrian orientation tasks using smartphones. They discuss the design of maps for pedestrian navigation on mobile devices. Their results showed that the "You-Are-Here" point on the map should be positioned at the center of the screen, and not changed during navigation.

2.1.5 Landmarks

In essence, the term "landmark" refers to a point in space that assists people in orienting themselves within an environment (Klippel 2003: 83). Landmarks play a vital role in human wayfinding by providing the structure for mental spatial representations, spatial reference points, cognitive anchors and indicating locations with which to orient (Dubey et al. 2019: 1; Bauer, Müller, and Ludwig 2016: 75).

Sorrows and Hirtle (1999) categorize the term "landmark" into semantic, structural, and visual attributes:

- **Visual landmarks** are primarily recognized based on their visual appearance. These are objects that stand out significantly from their surroundings, possibly due to strong visual contrast or prominence. They are highly recognizable.
- **Cognitive landmarks** are defined by a specific meaning or characteristic. For example, this meaning can be historical or cultural. For instance, a building that may not differ visually from other buildings in the area but holds historical or cultural significance can still serve as a landmark. Cognitive landmarks are inherently personal and may go unnoticed by individuals unfamiliar with the area.
- **Structural landmarks** are formed by objects that are important mainly due to their prominent position within the structure or space. These could include crucial intersections, for example.

However, these three categories are not mutually exclusive. A particularly memorable landmark may possess all three characteristics. In terms of navigation tasks, in unfamiliar environments, users are likely to rely on visual and structural landmarks, whereas in familiar surroundings, visual and cognitive landmarks come into play.

For landmarks to effectively assist in navigation, they first need to be easily recognizable by the user. Just like with the map itself, the level of detail in landmarks should be carefully considered. When an image is significantly reduced in size to fit the map scale, it's likely that certain details may become indistinguishable. Therefore, it can be sensible to simplify the representation of the landmark (Meng, Zipf, and Winter 2008: 44).

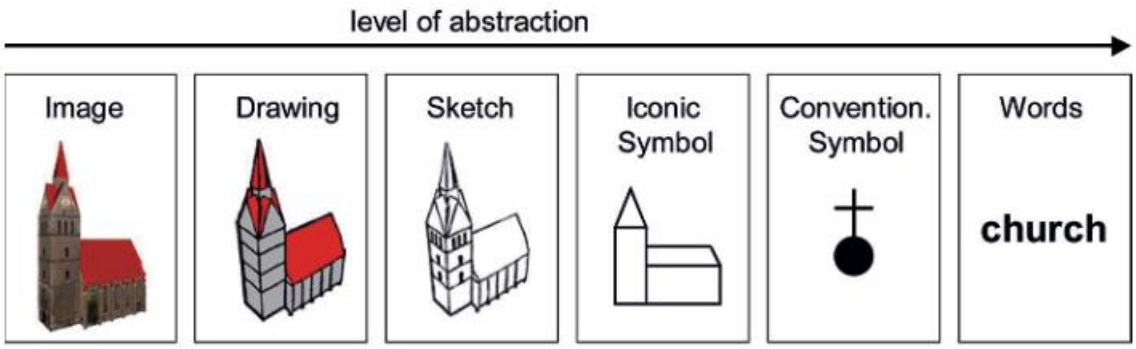

Figure 5: Level of abstraction (Meng, Zipf, and Winter 2008: 44)

To ensure effective communication through map symbols, Muehlenhaus (2014) recommended several strategies for creating map symbols:

- **Keep symbols simple:** Avoid adding details that do not contribute to the recognition of a symbol's meaning. Not only are these details often unnoticed by users, but they can also appear distorted on screens with varying resolutions.

- **Utilize generic symbols:** Design symbols that are representative and recognizable for each class within a category.
- **Leverage people's knowledge of symbols:** Some users may have different perceptions of symbols. For instance, older individuals may have a different idea of what a telephone symbol represents compared to younger individuals, as the appearance of telephones has changed significantly over time.

Regarding symbols, there is also the possibility to embed much more information in a map compared to static maps. Information windows are typically pop-ups that appear when a symbol on the map is clicked. The content within these pop-ups can be multimedia, including text, images, links, or even audio. Information windows can vary in size, offering diverse possibilities. However, as with all map elements, it's important to note that only information relevant to the map's purpose should be included. Striking the right balance of information, not too much and not too little, can be a challenge. If there is an excess of information, providing hyperlinks for interested users to explore further may be an option. Conversely, if there is too little information, it might be better to omit the information window and include labeling on the map. (Muehlenhaus 2014: 42)

Meng, Zipf, and Winter (2008) conducted a user study in which they tested various forms of landmark representations, with a specific emphasis on building landmarks. The test was divided into three parts, where users were questioned about the interpretation, size, and style of the symbols (see figure 6).

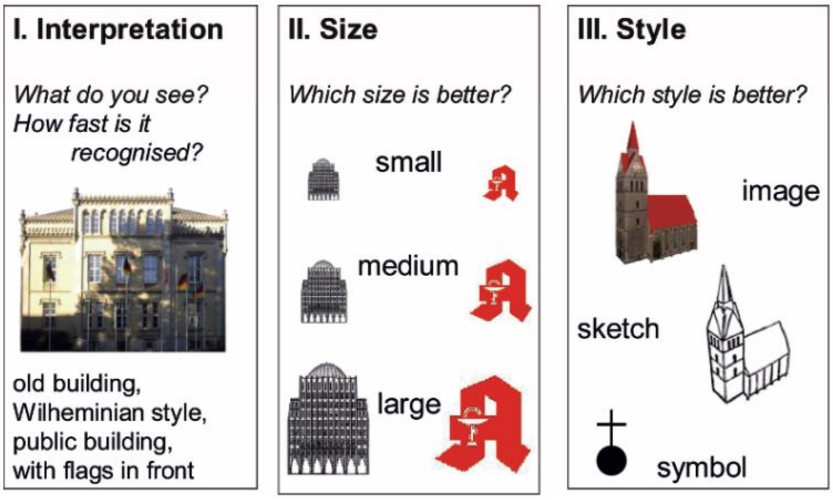

Figure 6: User test outline (Meng, Zipf, and Winter 2008: 50)

During this study, users were presented with images on a mobile display. In the first part, focusing on interpretation, each landmark was represented using an image, a sketch, and a symbol. The time it took for users to recognize the landmark was measured. The results clearly indicate that when it comes to shop names (e.g., McDonald's) and shop types (e.g., hotel), users could interpret the landmark the fastest based on the symbol. For building landmarks in the "Function" category, such as a church, users were equally quick to interpret them using an image, sketch, or symbol. For landmarks related to visual aspects of a building, like its color, it was observed that interpretation took a longer time in all three representation forms.

The results from the second part, which focused on users' preferred size for landmarks, showed that users chose the smallest size for the symbol representation. For the image and sketch, they preferred a medium size. Thus, the optimal size varies depending on whether it's a symbol or a more detailed representation that requires more space.

In the third part, users evaluated the three representation forms for different types of landmarks. It was found that for the shop name group, the symbol received the highest rating, and in the business type group, the symbol was also preferred, although the image or sketch was considered acceptable. In the function landmark group, the image received the highest rating. For landmarks with a visual aspect, the sketch was rated as the most suitable representation form.

The spatial structures of indoor areas are different from those in outdoor areas, and therefore, the attributes of indoor landmarks differ from outdoor landmarks (Zhu et al. 2019: 104). When it comes to indoor navigation, there has been limited research conducted to identify indoor landmarks. In her master's thesis, Gangaputra (2017) formulated a definition of indoor landmarks:

„An 'Indoor Landmark' is a distinctive point of interest that is visually, spatially dominant and informative for spatial orientation in the inside of a structure which could be a route maintenance point, an external point of reference or a route decision point that can either help the person to navigate and explore inside an indoor structure or that helps to reach the desired point of interest" – (Gangaputra 2017: 41)

Additionally, through user testing, Gangaputra (2017) identified characteristics exhibited by indoor landmarks:

- **Uniqueness:** The object should possess a distinct and unique shape.
- **Contrast:** The object should stand out from its surrounding objects.
- **Spatial Prominence:** Depending on an object's familiarity, it can become a stronger landmark.
- **Cognition:** The object should hold significance or meaning.

In the indoor environment, where there is no concept of north, and corridors do not have names like outdoor streets, landmarks become even more crucial (Puikkonen et al. 2009: 4). Bauer, Müller, and Ludwig (2016) conducted a user study to determine how many landmarks are necessary for efficient self-localization in indoor environments. They developed two prototypes, each containing a different number of landmarks. The assumption was that a greater number of landmarks would assist users in their orientation since they could be used as reference points. This assumption could not be confirmed. On the contrary, participants who saw only one landmark on the map knew more quickly in which direction to proceed compared to those with four landmarks. The additional landmarks appeared to have a distracting effect on the participants.

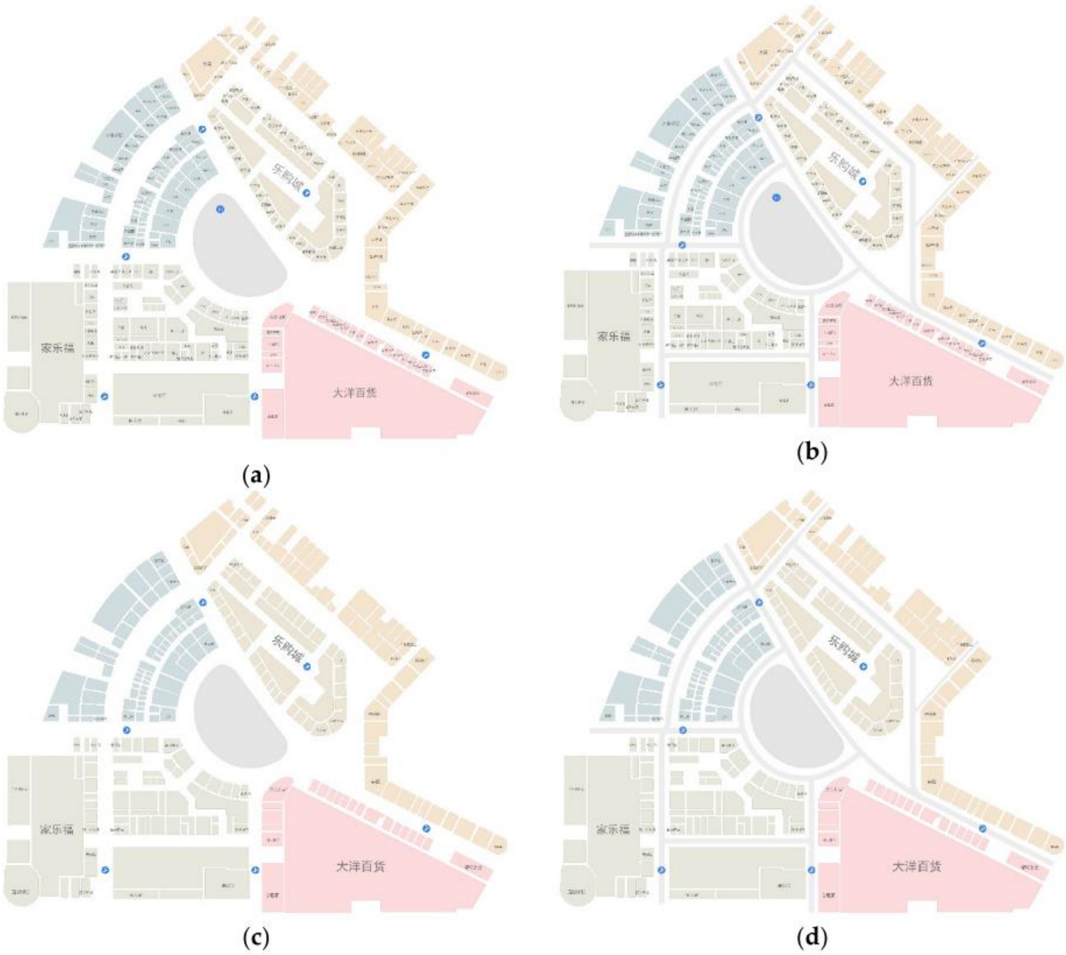

Figure 7: (a) The full-landmark map without highlighted paths, (b) the full-landmark map with highlighted paths (c) the key-landmark map without highlighted paths and (d) the key-landmark map with highlighted paths (Fang et al. 2020: 7)

Fang et al. (2020) examined the efficiency of navigation and cognitive load with four different indoor maps: full landmarks without highlighted paths, full landmarks with highlighted paths, key landmarks without highlighted paths, and key landmarks with highlighted paths. Key landmarks refer to only selected essential landmarks for navigation, while full landmarks represent all reference points. Highlighted paths refer to the drawing of lines along corridors that one can traverse (see figure 7). Efficiency was measured based on the time it took for users to complete the navigation task. Participants with full landmarks took significantly more time compared to those with only key landmarks. Efficiency among participants with key landmarks increased by 40%. Participants with highlighted paths were significantly quicker in solving the navigation task compared to those without highlighted paths. Here, efficiency increased by 25%. In terms of cognitive load, it was found that there was no significant difference between key and full landmarks, but there was a significant difference with highlighted paths. The cognitive load of the group without highlighted paths was significantly higher than that of those with highlighted paths. The map with highlighted paths was able to reduce the cognitive load of participants by 27%.

Zhu et al. (2019) conducted two experiments in two different indoor environments to identify the most significant landmarks for users. The first user experiment took place in a shopping mall. The participants had to follow a route and afterwards describe the route they had taken in as much detail as possible. The fifty indoor objects encountered were categorized into four groups: Shops (e.g., restaurants, clothing stores), Function (e.g., stairs, elevators, doors), Furniture (e.g., seating, sculptures), and Information (e.g., posters, map guides). After weighting the objects based on the criteria mentioned above (visual, cognitive, and structural), it was found that shops were the most noticeable to users, followed by function, furniture, and information. However, it should be noted that this experiment was conducted in a shopping mall.

In the second experiment conducted by Zhu et al. (2019), previously calculated landmarks were tested using the eye-tracking method, which observes users' gaze behavior while walking the route. This time, the experiment took place in a university building. Participants paid more attention to functional landmarks, as there were hardly any commercial landmarks in the university building. The objects that received the most fixation were stairs and doors, while radiators and flowers were the least noticed. Objects that were strongly focused on were at eye level, raising the question of whether they were landmarks or simply within the line of sight. The study by Ohm, Müller, and Ludwig (2015) confirmed the finding that functional landmarks receive the most attention from users.

2.1.6 Catalog

With reference to the literature overview provided, we can now summarize the cartographic features for each category that are relevant when developing an indoor navigation application.

Table 1: Map and Floor features

Feature	**Description**	**Results from various studies**
Egocentric view / static view	This feature describes the orientation of the map. It can remain constant, such as facing north. However, the map's orientation can also adapt to the user's behavior, so the user doesn't have to perform mental rotations.	People orient themselves more quickly when the orientation of the map matches the forward direction of the route (Stefanakis et al. 2006: 382. Montello and Sas (2006) suggests having both options, that the user can choose.
Map interaction	Here, it's about features that allow the user to interact with the map. These functions can include actions like zooming in and panning across the map, but also menu buttons.	Users should be able to scale the map so they can get an overall view of the surroundings or closely examine a specific area in detail (Gartner, Cartwright, and Peterson 2007: 303; Ian Muehlenhaus 2013: 35). In indoor navigation, it's essential to have the ability to switch between floors. (Gotlib 2019: 162)
Level of detail	Here, we're exploring the question of how much detail is necessary on a map for successful navigation. When it comes to creating maps, there are various approaches, each with its own strengths and characteristics. Two common ones are schematic and topographic maps, and they serve different navigation needs.	A highly simplified topographical map that includes only the specific details crucial for navigation is recommended. Too much information distracts the user from the essential, while schematic maps may have too abstract and little information for some users. (Stefanakis et al. 2006: 388; Gartner and Radoczky 2005: 3; Mackaness, Ruas, and Sarjakoski 2007: 206)
Colored / greyscale / realistic	The choice of colors plays a significant role in creating maps. It can greatly influence how users interpret the map. The selection of colors can impact the user's understanding and perception of the map's information. It is essential to choose colors thoughtfully to ensure that the map effectively communicates its intended information.	The application should offer various display options. For instance, users could choose between different color schemes. (Gotlib 2019: 160) Users orient themselves easier when colors on the map match the real world (Dillemuth 2013: 287). Ensuring color consistency between the map and the real world is vital. Especially for indoor spaces, it's recommended to perform on-site design work while creating the map. (Puikkonen et al. 2009: 4)

Floors	When navigating indoors a huge difference to outdoors is that users move between multiple floors.	A clear representation when transitioning between different floors is crucial (Gartner, Cartwright, and Peterson 2007: 304).
Map perspective	A map can be displayed in both 2D and 3D views. In a 2D view, the map is flat and shows information on a single plane, like a piece of paper or a computer screen. In a 3D view, the map adds depth and perspective, making it look more like the real world with different elevations and heights.	The users should be able to switch to a three-dimensional view (Gotlib 2019: 156).
Symbol	Symbols in cartography are visual representations used to convey information on maps. The design of symbols considers factors like size, shape, color, and orientation to ensure they effectively communicate information without cluttering the map.	Points of interest (POI) should be symbolized with icons (e. g. stairs, elevators, and escalators, shops). Avoid using complicated architectural plans. Represent the building with simple cartographic symbols that users can relate to the real world (Gotlib 2019: 163).

Table 2: Landmarks

Feature	**Description**	**Results from various studies**
Landmark symbol and abstraction	Abstraction of landmarks on maps is the process of simplifying and representing real-world landmarks in a more stylized and cartographic form.	Just like with the map itself, the level of detail in landmarks should be carefully considered. Depending on map scale Landmark should be simplified (Meng, Zipf, and Winter 2008: 44).
Recognition	This feature concerns the recognizability of landmarks, which refers to how quickly a user can identify a landmark. It measures the time it takes for a user to recognize a landmark.	Landmarks should easily be recognizable by the user by uniqueness and contrast (Muehlenhaus 2014: 42)
Spatial prominence	The spatial prominence of a landmark, as the name suggests, relates to its familiarity. The familiarity of landmarks can vary among different users.	Depending on an object's familiarity, it can become a stronger landmark. (Gangaputra 2017: 42)
Cognition	Objects on a map can also hold special significance in terms of content. Examples of this include historical or cultural characteristics.	The object should hold significance or meaning. (Gangaputra 2017: 42)

Table 3: Positioning

Feature	Description	Results from various studies
Positioning symbol	The symbol representing your current location in a navigation system plays a crucial role. This symbol is typically represented by an icon, such as an arrow, dot, or other distinctive shape, and it moves as you navigate, providing real-time feedback on your location.	Positioning symbol should stand out over the other cartographic symbols in use, while also maintaining a harmonious coexistence with them (Gotlib 2019: 159)
Visualization of inaccurate position	This involves representing any uncertainties in the device's location data on the map. For example, this can be achieved by using a circle around the user's position symbol to indicate the probable location range. The larger the circle, the greater the uncertainty in the device's positioning.	Visualizing position inaccuracies can be beneficial in assisting users in wayfinding (Ranasinghe and Kray 2016: 331)

Table 4: Routes

Feature	Description	Results from various studies
Relational / absolute instruction	A relational instruction considers the user's current position. For example, an absolute instruction might state that the destination is on the fourth floor. But if the user is already on the third floor, a relational instruction would advise going up one floor.	Especially in indoor environments route instructions should always be given in relation to the user's current location. (Puikkonen et al. 2009: 3)
Metric / qualitative Information	Route instructions can be provided in metric terms, such as instructing the user to turn right in xy meters. However, they can also be described qualitatively, as in turning right after the elevator.	Provide instructions that describe the surroundings where the user should turn. (Gotlib 2019: 158)

2.2 Human Computer Interaction (HCI)

The concept of HCI is closely linked to the introduction of computers and machines. This is because most advanced machines are useless if people cannot operate them effectively. This fundamental argument emphasizes the key concepts that should be considered in designing HCI: Functionality and user-friendliness. The methods by which people interact with computers have evolved significantly over time. This evolution continues as new technologies and systems are developed daily, and research in this field has grown substantially over the past few decades. (Sinha, Shahi, and Shankar 2010: 1-2)

This results in the following definition of HCI:

"Human Computer Interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" - (Sinha, Shahi, and Shankar 2010: 1)

2.2.1 Human-Map-Interactivity

With the transition from printed to digital maps, former map readers have become map users. Now they can influence and interact with the maps directly. The map responds to the user's activity, for example, by changing its field of view. The Graphical User Interface (GUI) simplifies the Human-Computer Interaction. From the 1980s, the WIMP (windows, icons, menus, pointer) interface evolved for computers. "Window" represents the frame in which the program operates, "icons" are buttons that execute specific tasks, and the "pointer" is the visual indicator showing the mouse's current position. Subsequently, the post-WIMP user interface emerged, introducing touchscreens. With touchscreens, the mouse is no longer present, and different factors came into play, such as zooming in and out through pinching, panning with finger gestures, rotating the map, and designing user interfaces suitable for touch input, even for larger fingers. While traditional map elements remain essential for effective map communication, modern times have introduced new elements that enhance interactivity. (Muehlenhaus 2014: 21)

The way we develop mapping products needs to change. Instead of viewing them as isolated tasks, we should adopt a more holistic approach that takes into account both technological and social advancements. This underscores the importance of research focusing on the utilization and evaluation of mapping products. (Schobesberger 2015: 147-148)

Moreover, to create impactful designs, it is crucial to identify the users of these map applications and gain a comprehensive understanding of their needs, requirements, as well as their cognitive and perceptual limitations. This knowledge allows us to tailor the map design accordingly. (Çöltekin et al. 2020: 234; Roth, Ross, and MacEachren 2015: 262; Griffin et al. 2017: 91; Roth 2017; Ottley 2020: 47)

2.2.2 User-Centered-Design

Mobile map apps are gaining popularity in various aspects of our everyday lives, catering to both professional and personal users. These versatile apps serve multiple purposes and are accessible to users of diverse demographics, varying levels of digital or spatial literacy, and different cultural backgrounds and nationalities. The design of map applications holds significant importance in ensuring a positive user experience for all individuals and intended functionalities. Therefore, adopting a User-Centered Design (UCD) approach is essential in guiding the design of the application to align with user requirements. (Roth, Ross, and MacEachren 2015: 263-264)

According to Dix et al. (2005), the philosophy of UCD originates from the field of Human-Computer Interaction. To ensure UCD, the practice of Usability Engineering is often employed, which will be described in more detail later. Jokela et al. (2003) analyzed the ISO Standard 13407 and provided guidance on user-centered design. In essence, it can be derived that the main concept of UCD is to consider the needs, desires, and limitations of end-users at every stage of application development. UCD aims to ensure high quality, utility, and user-friendliness of the end product by actively involving users, aligning application features with user requirements, and using an iterative design process. In this way, UCD aims to reduce support and training costs, enhance user satisfaction, and increase productivity.

The question now arises: how can we measure the success of such an efficient interface? How can we determine if our mobile map service is working for users? The two main criteria for measuring interface success are utility and usability (Robinson, MacEachren, and Roth 2011: 192). While utility focuses on whether the functionality of the system can do what is needed, usability applies to the aspect of how well user can use that functionality (Nielsen 1993: 25). Often, utility is more critical for applications used by experts, such as in professional work, than for applications with public access, where usability is especially important. However, usability and utility mutually reinforce each other (Grinstein et al. 2003: 1-2).

2.2.3 Usability

"*High usability is thus desirable, but it does not magically appear just because we want it. To ensure the usability of interactive computer products, we must actively include usability concerns in the software development process. Of course, nobody deliberately sets out to design an unusable interface, but only a systematic usability effort using established methods can qualify as usability engineering. Good intentions are not enough*." - (Nielsen 1992, 12)

The term "usability" is often understood as describing the quality criteria of a product. These quality criteria can encompass the arrangement of user interface elements, the number of clicks required to reach a desired goal, or the comprehensibility of displayed tools. However, usability also must always be considered in context. For example, a user interface may meet the quality criteria mentioned above, but it may not be rated positively if the user is still unable to easily learn or efficiently use the application. So, usability doesn't solely describe the characteristics of a product but also its suitability for a specific purpose. A hammer designed for driving nails may have high usability in that context. However, it would not be well-suited for screwing purposes. Therefore, usability is about how well the user can employ this tool to accomplish a specific task and how effectively the tool supports them in doing so. (Richter and Flückiger 2013: 4)

According to the ISO 9241-11 standard, the usability of a product is assessed through the following measures (Mond 2007: 11; Ecker 2015: 9):

- **Effectiveness:** The accuracy and completeness with which users achieve a specific goal.
- **Efficiency:** The effort invested by users in relation to the accuracy and completeness of achieving a specific goal. (Mental and physical stress, working hours, materials, use issues)
- **Satisfaction:** Freedom from disruptions and a positive attitude towards using the product. (The willingness to recommend the product, and the absence rate since the product's introduction)

So, to measure effectiveness, we compare the users' goals with the accuracy and completeness of their results. Efficiency depends on how effectively they achieve their goals relative to the resources they use. User satisfaction is evaluated based on their attitude toward using a product. This satisfaction is subjectively measured, often using rating scales.

To assess usability, we need to capture specific information. One factor that influences the measures described above is the context of use. The context of use describes the circumstances in which a product is applied and is therefore not an inherent product attribute. The context of use should be defined before the development of a product to better accommodate the specifics of use during development. The factors to be defined concerning the context of use are the user, the tasks, the tools, and the environment. The *user* can be characterized by their knowledge, skills, experiences, and education, as well as personal characteristics such as age and gender. *Tasks* refer to the goals to be achieved during the use of the product. *Equipment* encompasses the necessary hardware and software to perform a task. The *environment* is defined by the physical and social surroundings in which the use occurs, including factors like workplace conditions, cultural considerations, and other technical aspects. The more precisely these factors are defined in advance, the better they can support the product design process. (Mond 2007: 15-16)

This results in a usability application framework, which is illustrated in the following figure:

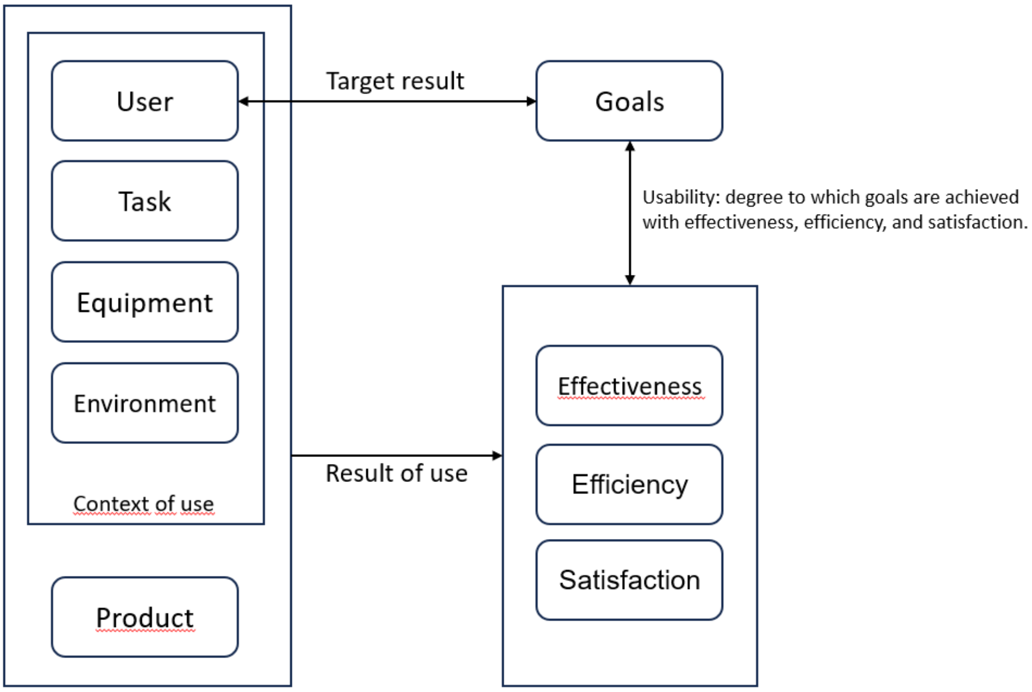

Figure 8: Application framework for Usability by ISO9241-11 (Mond 2007: 16), modified representation

Further approaches for a framework and definition for usability can be found in the literature. For example, Nielsen (1994) identified five main goals or attributes for the Usability of interfaces:

- **Learnability:** In this context, the focus is on ensuring that a system is easy for users to grasp. The system should have a steep learning curve, allowing users to understand

and use it effectively within a short period. This can be measured by the time it takes for users to achieve a certain level of proficiency in using the system. A user has mastered the system when they can successfully complete a specific task with it or handle multiple tasks within a minimum timeframe. It's crucial to establish this performance level before measurement, keeping in mind that users often don't need to learn the entire system before they start using it.

- **Efficiency:** Efficiency revolves around maintaining a consistent level of user performance once the initial learning curve has been overcome. After users have acquired proficiency in using the system, it should facilitate efficient and productive use. This can be measured by defining a desired "user experience", having representative users perform typical tasks, and measuring the time required.

- **Memorability:** This aspect is particularly important for users who occasionally use a system, those who have already learned it but only use it infrequently. They shouldn't have to relearn the system from scratch but should be able to recall how to use it. Memorability is closely linked to learnability, as users tend to remember systems they've learned easily. However, it's essential to consider them separately since memorability often depends on other factors, such as specific associations with meanings. There are two methods for measuring memorability: using a representative group of occasional users to perform typical tasks with the system or conducting a memory test related to the system (e.g., explaining its commands or naming them). While the memory test is easier to administer, in many cases, it's not necessary for users to actively remember the system; instead, the system should prompt the user. Studies have shown that users often do not remember the tools on the user interface but can use them effortlessly when in front of the system.

- **Errors:** Users should make as few errors as possible when using an application. An error is defined as an action initiated by the user that does not contribute to achieving a desired goal. Errors are quantified by their frequency and can be measured alongside other usability attributes during experiments. However, simply counting errors during an experiment does not account for their impact on task execution. Hence, it's important to categorize errors. Some errors are immediately recognized by the user and only affect the duration of task completion, which is factored into efficiency measurements. Errors that go unnoticed by the user are more serious as they lead to incorrect results.

- **Satisfaction:** Subjective satisfaction can be a highly significant attribute when it comes to usability, particularly in leisure settings. It relates to how enjoyable it is for users to use a system. This subjective satisfaction can be assessed through user surveys. To maintain consistency, surveys often employ questionnaires with a point-based scale or semantic differential scales featuring opposing terms. Questions should be carefully reviewed to ensure users interpret them correctly.

The ISO 9241-11 standard does not explicitly include the terms Learnability, Memorability, and Errors as distinct attributes of usability, as defined by Nielsen (1994), but these attributes are indirectly incorporated within the definitions of Effectiveness and Efficiency

Harrison, Flood, and Duce (2013) introduced a new usability model that builds upon existing usability models but aims to make the combined attributes from various studies specifically applicable to mobile devices. In essence, the model encompasses all the attributes defined by Nielsen (1994) and the ISO standard, but it includes an additional attribute: cognitive overload. Harrison, Flood, and Duce (2013) argued that in the context of mobile devices, where screens are typically small, this factor should not be disregarded. Cognitive overload is defined by the cognitive processing required by the user to utilize an application. Most usability studies assume that users are only handling a single task, but with mobile devices, it's often the case that users must manage an additional task as well. One example of this is pedestrian navigation. The user needs to pay attention to walking and the surrounding environment while simultaneously using the navigation app. For this reason, it's essential to consider how operating the mobile device influences the task. Schildbach and Rukzio (2010) observed a decline in performance and an increase in workload among users who were using a mobile device while walking to complete a task. Furthermore, they found that this negative effect could be compensated for symbols through enlargement, but when it came to text-based information, enlargement did not lead to improvement.

Furthermore, concerning the usability attributes of Learnability and Memorability as defined by Nielsen (1994), Flood et al. (2012) discovered that users do not dedicate more than five minutes to learning a mobile app. If they cannot comprehend the application within this timeframe, they opt for an alternative. Additionally, the attribute of Memorability appears to be a significant factor in mobile applications. The study revealed that most mobile applications are irregularly used, with half of the users employing the tested applications only once a month.

Weichbroth (2020) conducted a systematic literature review of usability studies and sought a clear definition of usability and its attributes for mobile devices. In essence, no specific definition for usability in the context of mobile devices could be identified. However, he found that 88% of the authors referred to the ISO 9241-11 standard when defining usability. Therefore, it is evident that this standard is widely accepted. The most common attributes used to analyze the usability of mobile devices were efficiency (70%), satisfaction (66%), and effectiveness (58%), which originate from the above definition. Subsequently, less frequently considered attributes included learnability (45%), memorability (23%), cognitive load (19%), errors (17%), simplicity (13%), and ease of use (9%).

2.2.4 User-Experience

The term "User Experience" (UX) frequently comes up in discussions of usability. However, it's essential to distinguish these terms clearly. According to the ISO 9241-210 standard, the term "User Experience" is defined as the *perceptions and responses of a person resulting from the actual and/or expected use of a product, system, or service*. While usability can be observed during the use of a product, user experience refers to what users feel before, during, and after use (Becker 2015, online).

So, this is not about the functional aspects of a product, ensuring that a user reaches their goal correctly and as quickly as possible. Instead, it's about optimizing the overall experience when using a product. It increasingly involves emotional factors related to aesthetics and the pleasure derived from using a system. To enhance the user experience of a product, we need to delve deeper into product design, such as the user interface and the associated processes (Richter and Flückiger 2013: 156).

2.2.5 Usability Engineering

Usability Engineering is a process that involves defining goals, measuring, and improving the usability of a specific product. The advantage of Usability Engineering is that it provides quantitative results that can be directly compared to usability goals and subsequently provides a better understanding of the user. There are various methods used in Usability Engineering, such as surveys, interviews, observation of users in a field study, user participation in the context of use analysis, brainstorming, evaluation of an existing system and so on (Nivala, Tiina Sarjakoski, and Sarjakoski 2007: 785). These methods can be applied to entirely new products or new versions of existing products. The choice of methods to assess the usability of a product is typically tailored to the development environment and budget constraints. (Wixon and Wilson 1997: 654)

An important factor for successful Usability Engineering is to precisely define the criteria by which a product should be tested for its usability. The most suitable testing of these criteria is based on the user themselves and their interaction with a system. To conduct a meaningful measurement of an application, not only the physical interface itself but also the functional architecture of the system should be considered. (Dix et al. 2005: 237)

Furthermore, the question of usability does not end when a product, for example, is no longer on the market. The decision of interface designs also influences future products. Therefore, we need to consider not only which design currently matches the user's abilities but also whether it can be expanded for later interfaces (Nielsen 1992: 13).

Good et al. (1986) outlined the following steps for successful Usability Engineering:

- define usability through metrics,
- set planned levels of usability,
- analyze the impact of design solutions,
- incorporate user-derived feedback,
- and iterate until the planned usability levels are achieved.

Nielsen (1992) extensively described in his work how the design process of interactive computer applications should look like, to achieve maximum usability. This is crucial because users are usually unwilling to use interfaces that are difficult to learn. Consequently, such applications are used less frequently. The figure below illustrates the elements of Nielson's (1992) complete Usability Engineering Model.

0. Consider the larger context
1. Know the user
   - Individual user characteristics
   - The user's current task
   - Functional analysis
   - Evolution of the user
2. Competitive analysis
3. Setting usability goals
4. Participatory design
5. Coordinated design of the total interface
   - Standards
   - Product identity
6. Guidelines and heuristic analysis
7. Prototyping
8. Empirical testing
9. Iterative design
   - Capture the design rationale
10. Collect feedback from field use

Apply metamethods throughout

Prioritize the usability methods

Figure 9: Elements of the usability engineering model (Nielsen 1992: 13)

At the beginning of every product development, a thorough understanding must be generated about the target audience and the tasks these individuals need to accomplish, as well as how they accomplish them (Travis 2011: 1; Schobesberger 2015: 151). This ensures that valid design decisions can be made. If the design process is rushed at the outset, unnecessary features may be developed, leading to many changes later to meet the users' wishes and recommendations. Therefore, it is crucial to gather as much insight as possible before starting software development.

The following questions should be answered (Nielsen 1992: 14; Schobesberger 2015:153):

- **Who is the user?** - The term "user" should be clearly defined to encompass all individuals who will use the product. For instance, the product might be intended solely for a specific department within a company, such as system administrators. For products with diverse user types, it is possible to consider a few representative users for each type.
- **What are the characteristics of the user?** - Characteristics include experience, educational level, age, social context, and so on. This knowledge allows for the anticipation of learning difficulties to some extent and enables the adjustment of the interface's complexity.
- **What is the user's goal?** - A thorough analysis of the tasks that need to be accomplished with the product should be conducted. It is essential to consider precisely what the user requires to master a task.

In the second phase of the development process, competitor analysis takes center stage. Existing products can be analyzed for their usability elements and empirically tested. Subsequently, these existing products can serve as prototypes for the new software. If multiple products have already been fully implemented, they can be compared, their different approaches analyzed, and their strengths and weaknesses evaluated. The objective here is to achieve a better outcome based on this comparison. In pursuing the main usability goals, prioritization becomes essential. For instance, high learnability would hold significant importance when a product is constantly used by new users. In general, the usability goals should be more precisely specified than the five main goals mentioned. Clearly defining these objectives can greatly assist in the design process. (Nielsen 1992:14-15)

Now, the design process begins with two main objectives: creating a prototype that aligns with the previously established principles and ensuring that this prototype is tested by real users to confirm that it includes the necessary features. Even though we have already defined the user group, we cannot predict all the problems that may arise during task execution (Dix et al. 2005: 241). Users often raise questions that developers might not have thought of on their own. Hence, involving users during the design process is recommended (Lidwell, Holden, and Butler 2003: 118). However, since users are not professional designers, we should not solely rely on their design suggestions but rather observe their reactions to specific features (Nielsen 1992: 15). Prototyping is an iterative process. This means that several rounds of testing, adjustments, expert interviews, and repeated testing take place. The results of prototype testing should be continually compared to the usability goals. In the early stages of the design process, when functional prototypes are not yet available, paper models or some screen mock-ups can engage users in discussions. (Nielsen 1992:15; Travis 2011: 1; Schobesberger 2015:153)

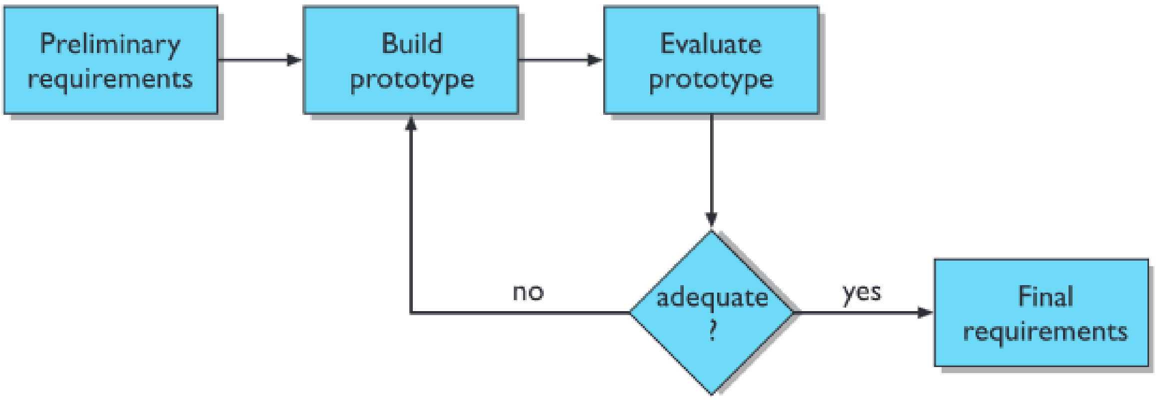

Figure 10: Iterative design of prototyping (Dix et al. 2005: 242)

Following the idea of consistency, things are easier to use and learn when similar parts are presented in similar ways. Consistency helps people pick up new information faster and concentrate on the important parts of a task. There are four types of consistency: how things look (aesthetic), how they work (functional), how they are organized inside (internal), and how they relate to other things (external). So, having a coordinated design is crucial. This means that all media (e.g., documentation, help, tutorials) related to the software should be consistent. (Lidwell, Holden, and Butler 2003:46)

It is also possible to follow predefined standards and guidelines, which are especially valuable in heuristic analysis. Official guidelines are usually published and can be found in journals or books. A concise set of rules and guidelines can then be used for evaluation. The advantage of heuristic analysis is that it can be applied very early in the design process. These guidelines can be classified as follows (Nielsen 1992:16):

- **General guidelines:** applicable to all user interfaces

- **Category-specific guidelines:** specific to the type of system being developed (e.g., navigation system)
- **Product-specific guidelines:** tailored to the individual product.

After the empirical test, a series of usability problems become evident. However, not all of these problems need to be solved immediately. Prioritization is crucial, based on which problems have the most significant impact on task performance, how many users are affected by the problem, and how much time is consumed by it. Additionally, a cost-benefit analysis should be conducted, as some solutions for addressing usability issues may be more expensive and time-consuming than others. Once design problems have been identified through empirical testing, a new version of the product can be developed. This brings us to the iterative process. Through further testing, including heuristic analysis and expert interviews, additional potential issues are likely to arise. These iterations provide an excellent opportunity to evaluate and enhance design ideas. The more frequently these processes are repeated, the higher the likelihood of creating a successful product. In the post-design phase, when the product is already on the market, the goal is to gather more data for the next version of the product. This means the current product serves as a prototype for the next iteration. (Nielsen 1992: 18-20)

Schobesberger (2015) analyzed 26 usability studies in his work and developed a framework for the design process of a Web-Map Application (see figure 11).

Furthermore, in the analysis of 26 usability studies Schobesberger (2015) identified common usability issues, some of them are as follows:

- Problems with the intuitiveness of menu structure, functions, and icons.
- Problems with the position, size, and function of the search box.
- Missing help, tutorials, and/or tooltips.
- Problems with the legend which was either missing or unreadable.
- Map window sizes were too small.
- Problems with the map quality. Maps were missing detail.
- Maps were overloaded and unreadable.
- Some interfaces had consistency problems (language, style, fonts).
- Problems with the position and selection of landmarks and with their iconic representation.
- Confusion about the map-orientation when users were standing still or maps were not adapting themselves to the direction.

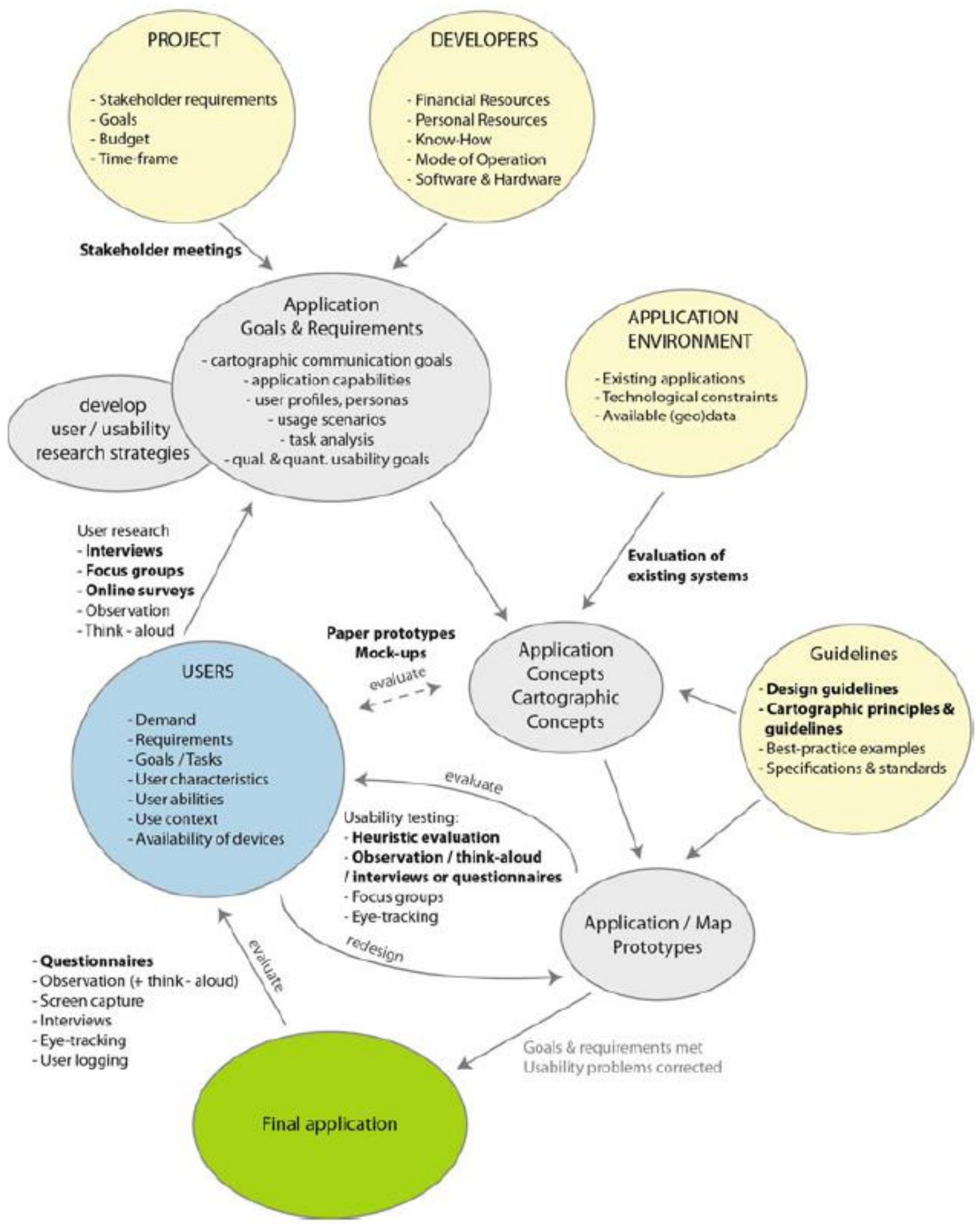

Figure 11: Intergrated framework for the user centered design and evaluation of Web-mapping applications (Schobersberger 2015: 152)

2.2.6 Usability studies on mobile map applications

Dewi and Hadi (2018) conducted a usability study for Google Maps Indoors in one of the largest shopping malls in Indonesia. Participants were required to navigate to a specific store within the mall. After completing the task, each participant filled out a standardized usability questionnaire (System Usability Scalability), which assessed their satisfaction with the Google Maps Indoors app. The results are depicted in the figure below.

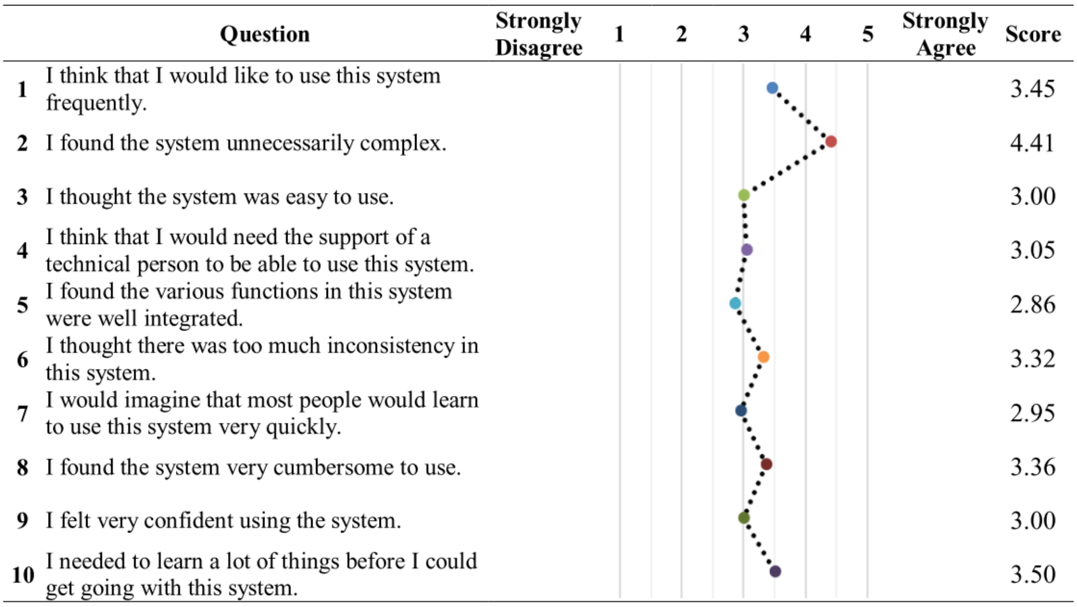

Figure 12: System Usability Scalability scores of Google Maps Indoors (Dewi and Hadi 2018: 4)

When comparing the usability score with other applications like Excel, Gmail, and iPhone, it appears to be relatively low. Despite the young participants (aged between 20-22) who are familiar with mobile devices, they found it challenging to navigate the app and considered the system unnecessarily complicated. In general, this suggests that there is room for improvement in the Google Maps Indoors application. Based on observations during the navigation task, Dewi and Hadi (2018) suspect that usability issues mainly stem from low positioning accuracy, ineffective landmarks, weak information organization and wrong route recommendations.

3 Methods

3.1 Overview

Usability testing essentially involves conducting experiments with the user at the center of the experiment (Hom 1998: 35). This allows the product to be viewed from the perspective of the actual user and identify user's needs (Nivala, Tiina Sarjakoski, and Sarjakoski 2007: 785; Riihi-aho 2018: 258).

Selecting appropriate evaluation methods raises a central question: Which method is the most productive? Sarodnick and Brau (2011) emphasized that the results of such studies are contradictory, which can be attributed, for example, to different testing situations. But overall, according to Sarodnick and Brau (2011) usability testing with real users performing tasks is an effective method to ensure that an application functions well in the real world and meets the needs of users. It allows you to gain targeted insights into the user experience and improve usability.

After a comprehensive examination of the definition, significance, and structuring of usability and user experience in Chapter 2.2 of Human-Computer Interaction, the following chapter discusses the methods that will be applied to achieve the highest possible usability of a Indoor-Navigation-App. Such investigations typically focus on the user, but experts can also contribute to achieving maximum user-friendliness (Nielsen 1992:15). In Chapter 2.2.5, Usability Engineering, the process of creating a user-friendly product was already explained. Common methods and approaches to ensure the usability of a product were introduced. However, there are many other methods and approaches listed and described in detail by Hom (1998). These broadly include examining, reviewing, prototyping, and testing, with several sub-methods for each category.

Usability evaluation is generally divided into formative and summative evaluation. In formative evaluation, the product is assessed during the development process, allowing usability issues to be identified and resolved during development. A classic method to do formative evaluation is Thinking aloud. Summative usability evaluation, on the other hand, takes place after the product development is completed and tests a finished application. A classic method to do summative evaluation is a measurement test. (Bekavac, Schneider, and Schweibenz 2011: 11; Richter and Flückiger 2013: 79; Nielsen 1994: 170).

This master's thesis focuses on the usability of indoor navigation systems concerning cartographic communication.

3.1.1 Aim and process

At the beginning of each usability test, there is the planning phase. In this phase, it is necessary to determine the general objective of the usability test and what information should be collected about the product to achieve this goal (Hom 1998: 35). There is a primary goal that the application ensures a certain level of usability. Within this primary goal, more specific objectives can be formulated for each usability attribute. The specific objectives should be well-defined to ensure that each attribute is genuinely evaluated during the evaluation (Riihiaho 2018: 258).

The main goal of the usability testing in this work is ***to enhance the usability of mobile indoor navigation apps through the use of cartographic communication methods.***

The following process steps are applied to achieve this goal:

1. **Competitor Analysis:** Identifying and describing common indoor navigation systems
2. **Thinking Aloud:** Thinking Aloud test on already existing Indoor systems (Apple Maps, Google Maps, InMapz), to gather specific information from users about various aspects of these maps
3. **Prototyping of a map:** Based on the Thinking aloud test results and considerations of the theory an Own Map is designed
4. **Questionnaire:** Finally, an online questionnaire shall then test all four maps to see which maps and features are preferred by users in different categories

A shopping center in Vienna called "Lugner City" was chosen as the study area because of the availability of data. None of the three existing indoor navigation applications that were chosen for the Investigation in this work have implemented Lugner City in their application yet. To ensure comparability, it was important to use the three different map visualizations for the same study area in all tests. Therefore, the map design of each existing indoor application was imitated by the author of this work for the building of Lugner City.

By combining the Thinking Aloud method during the examination of paper maps and online surveys with graphical evaluations, this study aims to gather comprehensive feedback on the usability and cartographic effectiveness of the tested indoor navigation applications. This iterative process will contribute to developing best practices in indoor cartographic communication. The methods employed to achieve this are described in the following in detail.

3.2 Competitor Analysis

Existing systems that have already been implemented often serve as the best prototypes. To develop a product that is superior to its predecessors, it makes sense to analyze and test existing systems for their strengths and weaknesses. Therefore, it is advisable to heuristically analyze existing products according to established usability guidelines and to conduct empirical user tests with these products. Users can perform real tasks on the competing system, which can determine how well its functionalities support the tasks that the planned new product should also handle. If multiple competing products are available for analysis, a comparative analysis of their different approaches to the various user interface design questions of the product type under investigation can be conducted. This provides ideas for the new design and a list of ad-hoc guidelines for approaches that work and those that should be avoided. In this way, better solutions can be developed by analyzing the strengths and weaknesses of existing designs. (Nielsen 1994: 79)

3.3 Thinking Aloud

The Thinking Aloud method is a common tool in usability testing (Boren and Ramey 2000: 261) and according to Nielsen (1994) "*may the single most valuable usability engineering method*". With this method, the test subject speaks out their thoughts during a given task and thus verbalizes them. This collects data about their perception, thoughts, and feelings during a learning process. It is important that the test subject speaks directly of what comes to mind, without structuring and interpreting their thoughts in advance. Loud thinking can occur in three different ways: *Introspection, immediate retrospection, and delayed retrospection.* Here, *Introspection* is the immediate verbalization, the *delayed retrospection* follows the Introspection temporally, and the *delayed retrospection* which happens directly or even a few days after the task is completed. (Konrad 2010: 476-477)

Verbalizing thoughts allows understanding how the test subject sees and interprets a product. This in turn leads to quickly uncovering major problems and possible misunderstandings of a system. Therefore, this method is well suited to be used with prototypes at an earlier stage of development (Nielsen 1994: 195). However, one disadvantage of the Thinking Aloud method is that many test participants find it unnatural and tiring to speak their thoughts out loud for a long time (Rubin and Chisnell 2008: 205).

Van Someren, Barnard, and Sandberg (1994) described in their book the practical process of the Thinking Aloud method to conduct a test as error-free as possible and thus generate high-quality data. This process is summarized as follows (van Someren, Barnard, and Sandberg 1994: 41-48):

- **Setting**: An atmosphere of trust and ease should be created so that the test person feels comfortable and confident speaking their thoughts aloud. Among other things, the room where the test is conducted should be quiet and the test person should sit comfortably. It is important to explain the purpose of the study and inform the test person that their personal data will be treated confidentially.
- **Instructions:** The essential instruction is that the test person should perform the task while trying to say everything that comes to mind. "Tell me what you are thinking" should be avoided, as this instruction might make test persons think they are being asked for their opinion or evaluation, thus hindering free thought flow. The instruction should be brief and clear to avoid misinterpretations.
- **Warming up:** Some test persons may find Thinking Aloud difficult and need training before starting to get used to Thinking Aloud. This also gives the opportunity to correct the test person if they interpret their thoughts instead of verbalizing them. The test should not start until the test person feels comfortable with the method.
- **Behavior of the experimenter and prompting:** During the test, the experimenter's task is to be reserved. Intervening in the test situation should only occur if the test person stops speaking. Usually, a simple "Keep talking" is enough.
- **Recording:** The session is usually documented with audio or video recordings. It is also advisable to record the instructions to check afterward if they were given correctly.
- **Transcription of the protocol:** Everything that was said or happened during the session should be typed up in the protocol. Every sound like "uh" or "hmm" should be typed as truthfully as possible. Pauses during speaking are also important to transcribe. Remarks from the test person that are off-topic can indicate a block in the thought process. If some sentences were incomprehensible, this should also be noted. An action column in the protocol can be used to note the test person's behavior while speaking.
- **Review:** It can be very helpful to go through the protocol with the test person afterward to generate additional information and better understand the protocol. These additional comments and explanations are then the retrospectives and must be treated differently.

3.3.1 Test procedure

Three different existing indoor maps (Google Maps, Apple Maps, InMapz) are to be tested using the Thinking Aloud method. One test is conducted per map. Consequently, there are three test persons who will each think aloud using one map. The test person will be given the corresponding indoor map in the form of a sheet of paper. Then there are three tasks to be completed in order:

1. **Navigation task:** The test person should find the fastest route from point A to point B in the shopping center.
   Description: "You are at the Austrian Post. Your goal is to find the fastest way to Media Markt."
2. **Information search:** The test person should filter specific information from the map. *Description:* "You are interested in electronic products and telecommunications. Find corresponding stores where you can find these."
3. **Exploration task:** Explore the map and identify all available services (e.g., toilets, elevators, emergency exits).
   Description: "Look at the entire map and identify all available services like toilets, elevators, and emergency exits. Thinking Aloud and describe how you find this information on the map and what you notice."

3.4 Prototyping

Nielsen (1994) emphasized in his work the importance of prototyping in the software development process as an effective alternative to the traditional waterfall model. He highlights those early prototypes, either as "vertical" prototypes with limited but in-depth features or as "horizontal" prototypes offering a wide user interface without actual functionality can be developed faster and more cost-effectively, enabling the evaluation of the user experience at an early stage. These prototypes allow for the testing and iterative improvement of design and usability under realistic conditions before the full system development begins.

3.5 Questionnaire

Questionnaires often serve as a complement to other usability evaluation methods and are an important way to gather information from a larger number of people. Questionnaires provide us with two types of information. Firstly, about the user themselves, such as demographic information or familiarity with technical devices. Secondly, questionnaires also provide information about the usability of a system. This can involve using simple, self-designed questionnaires, but also methodically validated usability standard questionnaires. (Richter and Flückiger 2013: 88)

To ensure that the results of a questionnaire match reality, the design of the questionnaire must be carefully considered. The questions must be formulated in such a way that they are clearly interpretable since users may not think the same way as the questionnaire creator, and thus, their responses may be distorted. Furthermore, questions should not be phrased in a manner that could potentially influence the user's opinion. The length of a questionnaire also plays an important role. For example, if a questionnaire is too long, the respondent may give up before even looking at it. In general, the rule can be observed that questionnaires for teenagers and adults (aged 13 and above) should not exceed five pages, and the time required to complete the questionnaire should not exceed fifteen minutes. (Valli 2016: 16-17)

To conduct a successful study, the objectives and research questions of the study must be clearly defined (Breakwell, Wright, and Barnett 2020: 347). The questions in the questionnaire should then be formulated based on these objectives. To achieve this, it is advisable to formulate hypotheses (Richter and Flückiger 2013: 90). Since the survey in this study is intended to inquire about user preferences, it seems unnecessary to establish if-then hypotheses. Because of that the basis for the questionnaire in this work is based on the defined objectives below.

Likert-type scale questions

For the following questions select the number that best describes you.

Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
5	4	3	2	1

1. I am very satisfied with the conversations I have with my coworkers.
2. I like talking with my coworkers at the office.
3. The conversations I have with my coworkers are very rewarding.
4. I do not enjoy talking with the people I work with.
5. I hope to have more conversations like the ones I have with my coworkers.

Figure 13: Likert scale question type (Gournelos, Hammonds, and Wilson 2019: 126)

Questionnaires can include both open-ended and closed-ended questions. Open questions allow participants to provide details about their perceptions and experiences. Closed-ended questions, on the other hand, are usually categorical or scaled and have a fixed set of responses. Scaled questions are used to assess the user's attitude towards a specific aspect. The Likert scale is the most commonly used scale for this purpose and is primarily used to test hypotheses. (Gournelos, Hammonds, and Wilson 2019: 125)

Another important scale for questionnaires is the semantic differential scale. This uses the polarity of two terms, such as "good" and "bad." These are then opposed, and test subjects should decide where they stand within this scale. (Gournelos, Hammonds, and Wilson 2019: 126)

Semantic differential question		
Your romantic partner is		
Safe	____ ____ ___ ___ ____	Dangerous
Candid	____ ____ ___ ___ ____	Deceptive
Straightforward	____ ____ ____ ___ ___	Tricky
Respectful	____ ____ ____ ___ ___	Disrespectful
Considerate	____ ____ ____ ___ ___	Inconsiderate
Honest	____ ____ ___ ___ ____	Dishonest

Figure 14: Semantic differential question type (Gournelos, Hammonds, and Wilson 2019: 127)

Another scale is the so-called visual analog scale, which is often used to assess pain. It consists of a 10-centimeter line on which a participant can mark the degree of the queried value, such as pain. This allows for a much more precise capture of opinions and subjective phenomena from the participants. The entry on the line can then, for example, be measured with a ruler. The numeric rating scale is also an analog scale, differing from the visual analog scale in that it is divided into numbers from 0 to 10. (Krause 2008: 35)

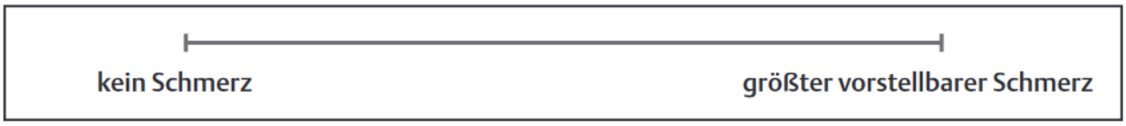

Figure 15: Visual analogue scale question type (Krause 2008: 35)

3.5.1 Aim of the questionnaire

The questionnaire for this study aims to collect insights and data to understand the various aspects of cartographic design in indoor navigation systems. It seeks to gather specific information from users of such systems to better understand their needs, preferences, and requirements. The precise objectives are outlined as follows:

- **Capturing user preferences**: Gathering preferences on different representations of indoor maps, positioning, and route instructions. This aims to understand which cartographic approaches and representations are preferred in indoor navigation, leading to informed recommendations for designing such systems.
- **Evaluating strengths and weaknesses of indoor navigation systems:** Providing feedback on the representation methods of existing indoor navigation systems. This

gathers information on how users experience them, and which aspects might need improvement.

- **Identifying opportunities for improvement:** Collecting users' suggestions and ideas for enhancing current indoor navigation systems. This helps uncover weaknesses and develop new approaches to cartographic design to better meet user needs and requirements by identifying improvement opportunities directly from the user perspective.

3.5.2 Questionnaire creation process

Based on the objectives outlined in chapter 3.5.1 and the theoretical background the questionnaire was developed. To ensure the questionnaire was concise and thus avoid demotivating the participants (Valli 2016: 16-17; Hug et al. 2020: 165), it was decided that a maximum of 10 questions would be focused specifically on the map. Similarly, for questions related to the visualization of routes and positions and other aspects, a maximum of 10 questions was established. Consequently, the questionnaire is intended to comprise a total of 20 questions and is estimated to take about 5-10 minutes to complete. This questionnaire will be conducted online using ArcGIS Survey123 Connect. With ArcGIS Survey123 Connect, a wide variety of question types can be created, and the survey can be enhanced with media such as graphics ("Quick reference—ArcGIS Survey123 | Documentation" 2024). This capability is crucial for this survey since all questions are directly related to graphics, making ArcGIS Survey123 particularly suitable for this survey.

After engaging in several discussions with individuals from the author's personal environment and a thorough feedback session with the supervisor of this master's thesis the questionnaire was developed.

Capturing user preferences

To achieve the goal of the questionnaire, which is to capture preferred visualization methods, the following questions were formulated:

- **Landmarks for orientation**: To ascertain which types of information are most utilized for orientation on the map, the participants are asked which information they find most useful. Several response options are provided, including floor plans, shop symbols, and symbols for stairs, elevators, and escalators in a ranking question. To ensure that additional orientation aids, which may be important for the participants, are not excluded, a text field was added in addition to the ranking question where the participants can write additional comments.
- **Position and route visualization***:* The primary objective here is to ascertain participants' preferences regarding the design and presentation of such information. To

facilitate this, various graphics depicting different visualization options were prepared and are displayed beneath each corresponding question. To capture not only the most preferred visualization but also to gauge preferences for the second, third, and least preferred options, a ranking format was selected. This format requires the participants to order the visualizations according to their preference, providing a clear hierarchy of choices.

- **Textual versus graphical route descriptions:** This question investigates whether participants prefer textual or graphical route descriptions. The participants are asked to rate their preferences to better understand which representation is most intuitive and helpful for users.
- **Metric versus qualitative route descriptions:** Here, the participants are asked whether they prefer metric (e.g., distances in meters) or qualitative (e.g., "turn right after the elevator") route descriptions. They are to rate these options from most to least preferred to gain further insights into their navigation preferences.
- **Different floor visualizations:** Three different floor visualizations are displayed: consistent coloring across all floors, color gradation across floors, and different color per floor. The participants are asked to rate in a ranking question which visualizations are most understandable and helpful for them, especially in terms of navigating across multiple floors.
- **General map design:** Four maps are displayed: the Own Map, Apple Maps, Google Maps, and InMapz. Participants are asked to rank these maps according to their preferences in a ranking question.
- **Atrium visualization:** Three different atrium visualizations are displayed: individual line pattern, hatched, and an empty polygon. The participants are asked to rate in a ranking question which visualizations they prefer for the depiction of an atrium.
- **Continuation of the route to another floor:** The question aims to determine whether users prefer that parts of the route which continue on another floor are also displayed for clarity of the route course.

Evaluating strengths and weaknesses

To identify strengths and weaknesses of the maps, questions regarding their comprehensibility and readability were formulated:

- **Clarity of spatial representation:** This question aims to generate an understanding of how clearly and understandably users perceive the different spatial room divisions on the map, such as whether restaurants are clearly distinguishable from shops. Assessment is carried out using a Likert scale. To avoid neutral responses, only four categories were used on the Likert scale.

- **Recognizability of symbols and their meanings:** By inquiring about the recognizability and clarity of the symbols, we evaluate the strengths and weaknesses in the use of these symbols. Evaluation is also conducted using a Likert scale. To avoid neutral responses, only four categories were used on the Likert scale.
- **Atrium recognition:** This question aims to investigate whether the atrium polygon is recognized as an atrium. It is a yes-no question. In the survey, a condition was set that if the participant clicks "yes," a text field appears where they can specify what this polygon represents, ensuring that the participant truly recognizes it and not just thinks they do.
- **Map detail level**: The participants are asked how they rate the level of detail on the map. This helps us understand the preferred type of information density on the map by the users. This leads directly to a better understanding of which approach to detailing on the map is favored for indoor maps. Responses are gathered using a Likert scale.

Identifying opportunities for improvement

Users are not only encouraged to rate certain aspects of the map but also have the opportunity to provide suggestions for improvement:

- **Improvement suggestions:** Through an open-ended question, users can offer suggestions for enhancing the map. This allows for the collection of diverse ideas that could be considered in future developments.
- **Aesthetic appeal:** This factor also contributes to a user-friendly map. How appealing users find the visual design provides feedback on their aesthetic perception. It was decided that more accurate insights into the participants' subjective perceptions could be gathered using a numeric rating scale (Krause 2008: 35). Accordingly, this scale, ranging from 0 (least visually appealing) to 10 (most visually appealing), was incorporated. This grading scale was also explained in detail within the context of the question to ensure clarity.
- **Comprehensive information:** This question pertains to the information content of the map and asks whether all necessary information for navigating indoors is included. This is formatted as a yes-no question, thus a single-choice question. A condition was added that if a participant clicks 'no,' an additional text field appears where they can write in what information they are missing.
- **Unnecessary details:** This question helps identify which information is considered unnecessary or even obstructive, which is valuable for reducing superfluous elements on the map. It is structured as a yes-no question, thus a single-choice question. A condition was added that if a participant clicks 'yes,' an additional text field appears where they can write in what information they find unnecessary.

- **Direction for changing floors:** This question aims to determine whether the participants find it helpful to have directions indicated by arrows for stairs, escalators, and elevators. It is a single-choice question: either the symbol with or without arrows.

Other considerations

In addition to the content-related questions of the questionnaire, further considerations were made to improve the quality of the questionnaire and thus achieve better results.

- **Wording:** The questionnaire was crafted in German, considering all the respondents are from German-speaking regions. Notably, the German language offers two distinct forms of address individuals: formal and casual. The questionnaire employed a casual tone. The reason behind this stems from the belief that a casual tone fosters a more relaxed atmosphere, thereby making the participants feel more at ease, which is likely to encourage more honest responses. Furthermore, minor modifications in phrasing were implemented to simplify the questions and make them more straightforward. For example, the phrase "Wie bewertest du…" was transformed into "Wie findest du…," which is less formal.
- **Format:** To inform the participants about what the survey is about and how long it will approximately take, an introductory text was written. To ensure a complete data set, all questions were set to *required*. Only the open-ended questions were optional to avoid deterring participants and preventing dropouts. To ensure the participants could easily navigate through the questionnaire, a numbering of the questions was implemented. This way, the participants always know how far along they are with each question. For ranking questions, it was written in parentheses that the ranking works via drag and drop. This prevents participants from becoming frustrated because they do not know how to technically perform the ranking
- **Demographic data:** To improve the response rate and avoid early participant fatigue, demographic data were collected at the end of the questionnaire. This strategic placement helps in preventing any initial annoyance that might deter participants from completing the survey, as demographic questions are generally perceived as uninteresting compared to the main content of the survey. Demographic data were asking about age, gender, and occupation, which provide valuable personal characteristics. Names were not asked as they are not essential for the study's purposes and might deter some participants from taking part.

The final questionnaire is located in the appendix of this thesis.

3.5.3 Test persons

According to Sarodnick and Brau (2011), the test persons should ideally be representative of the actual future users of the product. This implies that individuals who participate in usability tests should possess similar characteristics to the target audience that will ultimately use the final product. However, in practice, it often presents a significant challenge to accurately identify and include all relevant user groups in these tests. This difficulty arises because user groups can be incredibly diverse, especially when targeting broad audiences. For this study, the user group is defined as individuals frequenting shopping centers. This group is not easily delineated, as shopping centers attract people from a wide array of backgrounds, including various origins, age groups, and social statuses. The heterogeneity of this group complicates the process of drawing a representative sample that mirrors the entire user base effectively.

The recruitment of test participants is executed through both the author's professional and personal networks. A total of 135 participants engaged in the online survey. As the survey evaluated four different maps, attention was given to ensure that an equal number of questionnaires were completed for each map. The detailed distribution of survey participants per map is displayed in table 5. This structured approach ensures that each map is evaluated with an equal number of participants, facilitating a balanced comparison across all tested designs.

Table 5: Distribution of survey participants per map

	Own Map	Apple Maps	Google Maps	InMapz
Participants	34	36	31	34

The first ten questions of the questionnaire specifically focus on the map itself. The remaining ten questions are standalone queries related to visualizations of positions and routes, and as such, they are consistent across all four versions of the questionnaire. Therefore, the sample size for these particular position and route questions stands at 135 participants.

Demographic data, including age and gender, were provided by 128 out of 135 participants. The age distribution is illustrated in Figure 16. The chart clearly shows a significant concentration in the distribution within the age groups of 24-34 and 35-44. All other age groups are very minimally represented. This distribution indicates that the interests of the age groups 0-14, 15-24, 55-64, and 65+ are underrepresented in this sample, which might influence the representativeness of these user groups. The gender distribution among the participants is relatively balanced, with a total of 63 female participants and 65 male participants.

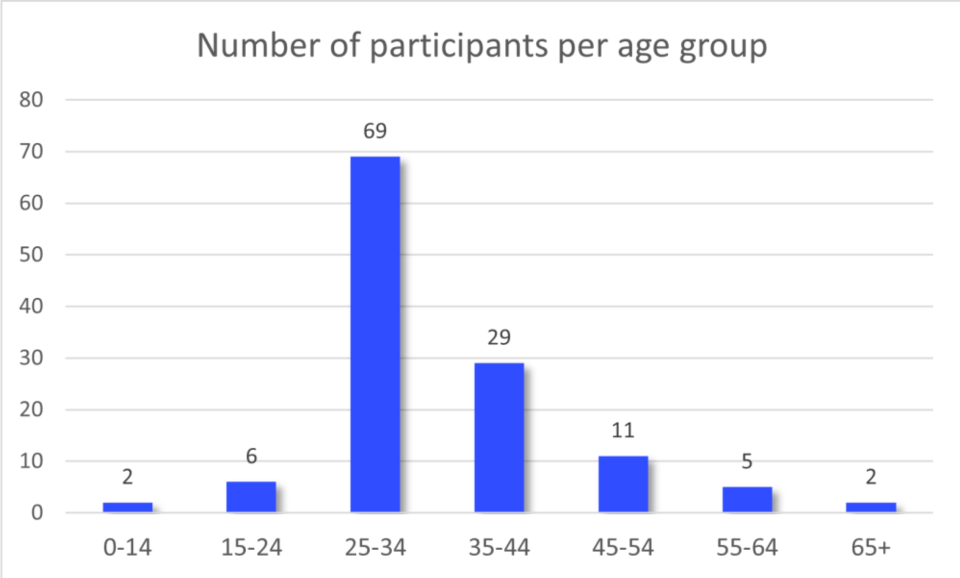

Figure 16: Age distribution of the test persons in online survey

Although the number of surveyed users does not represent statistical significance, the preferences of the participants can nonetheless be identified from the responses they provided. These early insights enable the formulation of interpretations. Given the limited resources, both financial and temporal, that were available for this project, a so-called trade-off between time, effort, and quality had to be made (Richter and Flückiger 2013: 112). In such situations, Nielsen (1994) discusses the concept of Discount Usability Engineering. This approach aims to achieve usable results with minimal effort and low costs. Even though this method may not yield the best possible outcome, it can still uncover significant usability issues. This pragmatic approach allows for valuable improvements to be made to the product despite the constraints on resources, thereby optimizing the overall user experience.

4 Results, analysis and discussion

4.1 Competitor Analysis

In this chapter, the existing indoor navigation apps will be described and analyzed. Through internet research, four mobile apps that already offer indoor navigation at certain locations were identified.

4.1.1 Google Indoor Maps

Google Maps is one of the most widely used and influential mapping and navigation platforms in the world. Google Indoor Maps is a feature offered by Google Maps that provides detailed maps and navigation assistance for the interiors of various buildings, such as shopping malls, airports, museums, and more. Google Maps only provides information about the countries where Google Indoor Maps are available. There is no explicitly listed inventory of buildings equipped with indoor maps. Therefore, in the app, searches were conducted for well-known buildings in Vienna. Indoor maps were found for Vienna International Airport, some buildings of the University of Vienna, Donauzentrum Shopping Center, and Shopping City Süd.

To display the indoor map, you need to zoom in into the building. Then, a new button appears where you can switch between the floors. Especially in large buildings, it becomes evident that there is no overall view of the interior of a building. As soon as you zoom out far enough to see the entire building on the screen, the indoor function disappears. Therefore, users cannot get an overview of the entire building but only a small section at a time. As a result, it could be more challenging for users to orient themselves. It also seems that some information is missing, such as certain shops. There is no indoor map available for the old part of Vienna International Airport that is still in operation.

Another thing noticeable is that some points of Interest (in this case, restaurants) don't disappear when you switch between floors, even though they definitely aren't on both floors (see figure 17).

The left side of figure 17 shows the entire airport complex. It is challenging to distinguish what is a building and what is not. When looking at the Google Maps satellite image, it can be seen that the white area represents roads or asphalt. The rest of the area is grey. However, not all of the grey area is the airport building. So, in this case, there is no differentiation between the airport building and its surroundings. Therefore, it could be difficult for the user to know exactly where to zoom in when they want to use the indoor function.

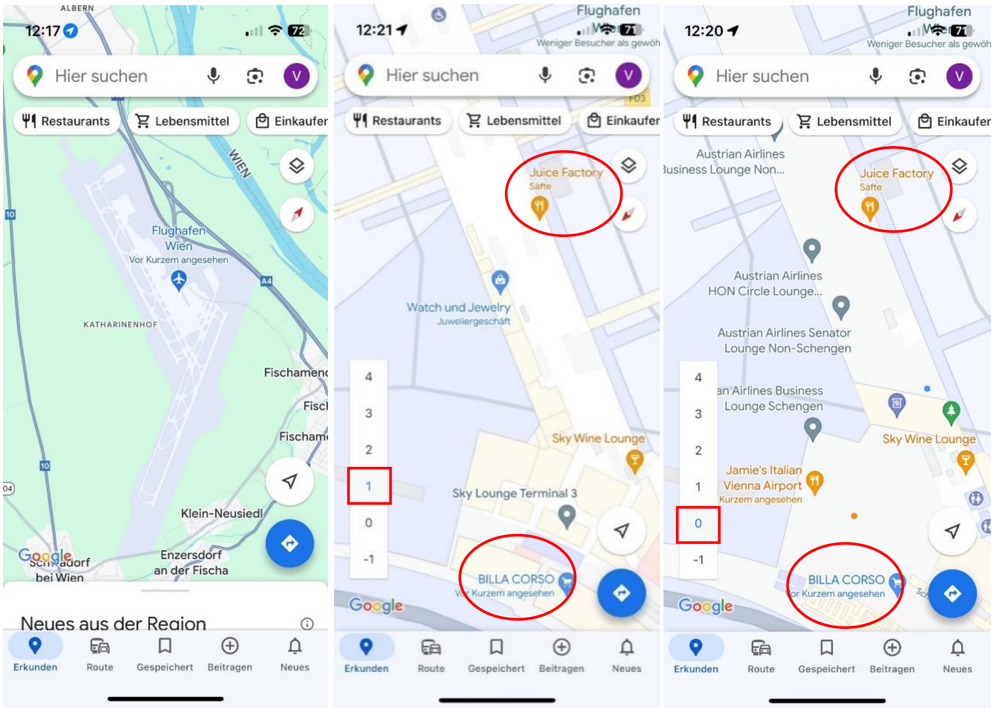

Figure 17: Google Maps Indoor map of the Vienna International Airport

When entering a desired destination at Vienna International Airport, it's not possible to specify a gate or a restroom as the destination, which could be considered problematic for an airport. This means users can only calculate a route to shops and restaurants. Since most points of interest are visible on every floor, it also becomes challenging to calculate a route. When specifying a route where there is actually a floor in between, this is not indicated in the route description, making it incorrect. The route also goes through a barrier that you cannot actually pass through.

The Google Indoor map of Shopping City Süd works better in this regard. Here again, the same shops can be found on multiple floors. However, during testing a route, textual instructions described that the user needs to go up one floor (see figure 18). But on the map, there is no symbol for an escalator within the route. Again, here, you can only specify restaurants and shops as destinations.

When we look at the indoor map of the New Institute Building at the University of Vienna, there are no restaurants and shops, as expected. Here, the rooms are labeled with numbers and categories like offices and lecture halls (see figure 18). Once again, we encounter the situation where these categories cannot be clicked on and therefore cannot be specified as a destination in the search. It is only possible to manually enter the destination on the map.

However, to do so, the destination, for example, a room number, must be searched for on the map. This could be inconvenient for the user, especially with 7 floors to navigate.

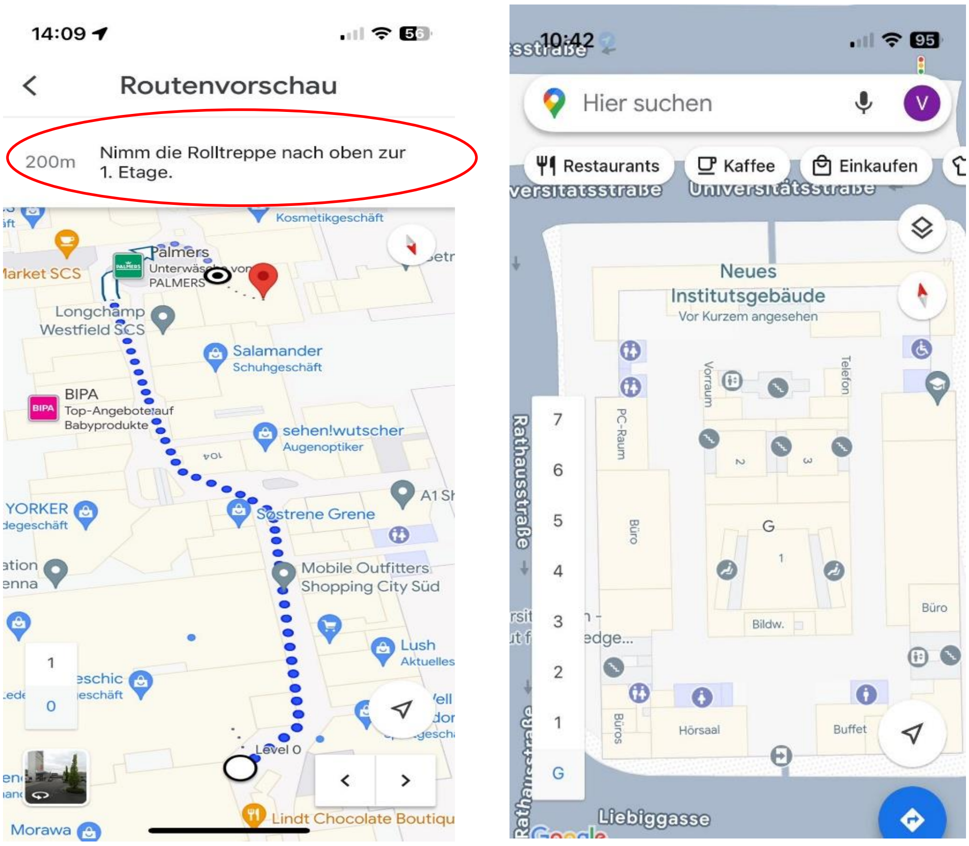

Figure 18: Google Maps Indoors, left: Route descriptions, right: University building in Vienna

In the following, we will focus our attention on the catalog of Chapter 2.1.6 and describe Google Indoor Maps based on it.

Map

The Google Indoor Map features essential map interactions such as zooming, panning, and map rotation. These functions work smoothly and are intuitive to use. The base map is a topographic map that displays the ground plan of individual rooms or objects that is slightly to not generalized. There is some detailed information about room structure and small objects that are unnecessary for navigation tasks. Depending on the type of object, these ground plans are labeled with text or marked with symbols. Symbols for toilets, stairs, elevators, and others are visually associative but small and therefore the icon is not always easy to recognize. In symbolizing shops, Google Maps only distinguishes between grocery stores and all other shops. All other shops have a shopping bag as a symbol, while grocery stores have a shopping cart. The colors are kept very simple, with rooms in yellow and corridors in grey. But colors are not contrasting, making it a bit more challenging to distinguish between different areas. There is an option to switch the map to a dark mode, but a realistic color scheme is not available for the user to choose. Floor selection is done through buttons on the left side of the screen, displaying all floors simultaneously. The map is presented in a 2D view.

Landmarks

In general, Google Maps uses landmarks, especially for sightseeing attractions and large buildings. Within the indoor map, such prominent landmarks were not found. However, even small shops can serve as landmarks. When zoomed in closely enough, every shop name is displayed. This means there isn't really a selection of shops that are more important for navigation itself. What I found particularly noticeable, though, is that McDonald's, unlike other shops, has received a logo. As a result, it is much easier to recognize and thus acts as a stronger landmark.

Figure 19: Google Maps Indoors, Use of landmarks

Positioning

Google Maps uses a blue dot as the position symbol. The user's direction is represented by a cone. Once a route is initiated, the position display changes to an arrow pointing in the same direction as the user is facing. The accuracy of a position is shown in Google Maps by a circle around the blue dot.

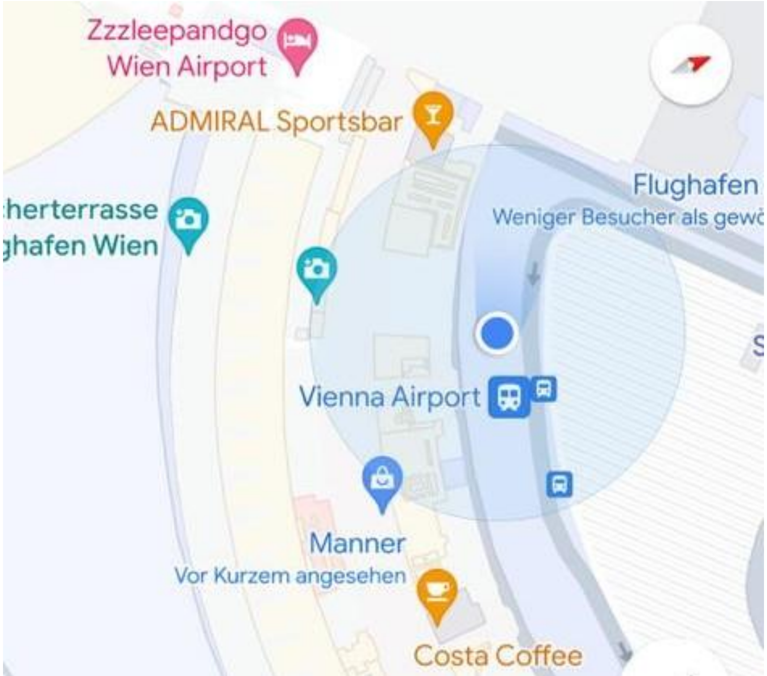

Figure 20: Google Maps Indoors, Visualization of position and position uncertainty

Routes

Google Maps uses a dotted line to depict the route for pedestrians. When a destination is entered, the map automatically zooms out to display the entire route on the screen. Once the route starts, it switches to an egocentric view of the map. Both text and verbal route descriptions are available, and the verbal route description can be muted if desired.

4.1.2 Apple Indoor Maps

Like Google Maps, Apple Indoor Maps is a feature that extends the functionality of Apple Maps to help users navigate indoor spaces seamlessly. Apple provides a precise list of airports that have indoor navigation within the app. As for shopping centers, only the countries are listed. Therefore, a search was conducted for the same buildings in Vienna as before in Google Maps. The availability of indoor maps in Vienna appears to be somewhat limited. Indoor maps were only found for the shopping center Donauzentrum and the Shopping City Süd.

Similar to Google Maps, here you also need to zoom into the building to activate the indoor function. However, the indoor function appears much earlier here. While with Google Maps, you have to zoom in so much that you only see a small part of the building, with Apple Indoor Maps, you can view a larger section of the building with the indoor function.

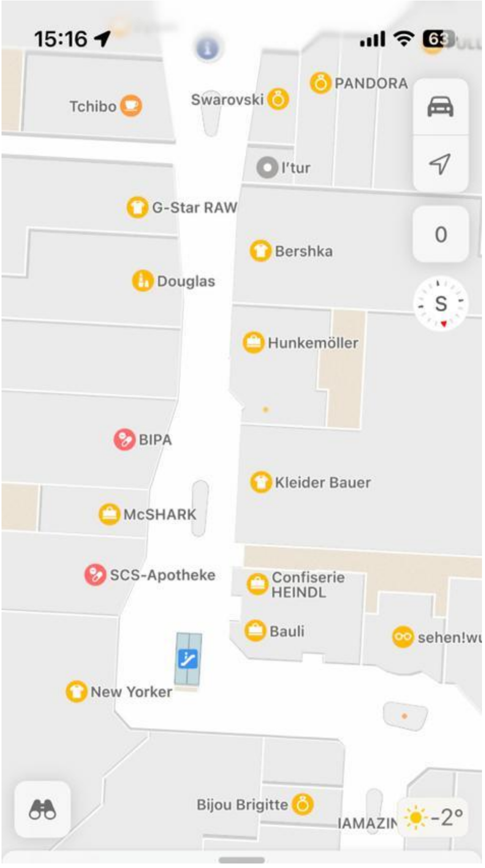

Figure 21: Apple Maps Indoors of the Shopping City South

In Apple Indoor Maps, Points of Interest such as toilets, stairs, elevators, and escalators are stored as features on the map rather than being static drawings. This means they can also be selected as destinations and are clickable with a pop-up.

Map

Here, you have the essential map interaction options once again. The base map is a simplified topographic map that displays the ground plan of objects. Apple Indoor Maps' map is more generalized, which makes the overall map look more coherent. The map, in general, looks cleaner and more organized. A direct comparison of the same map extent between Google Indoor Maps and Apple Indoor Maps can be seen in Figure 22. Here, the rooms are marked with symbols, each representing the function of the object. The symbols of toilets escalators and elevators are also quite similar to those in Google Maps. Regarding store symbols, Apple Indoor Maps distinguishes between various categories of stores which have different symbols, such as children's clothing, opticians, toy stores, pharmacies, and more. The colors are kept simple: grey for rooms, white for corridors, blue for toilets, elevators, and escalators. There is no option to customize colors as desired. Switching between floors is done through a button on the right side of the screen, indicating the current floor level. Clicking on the button displays all the building's floors.

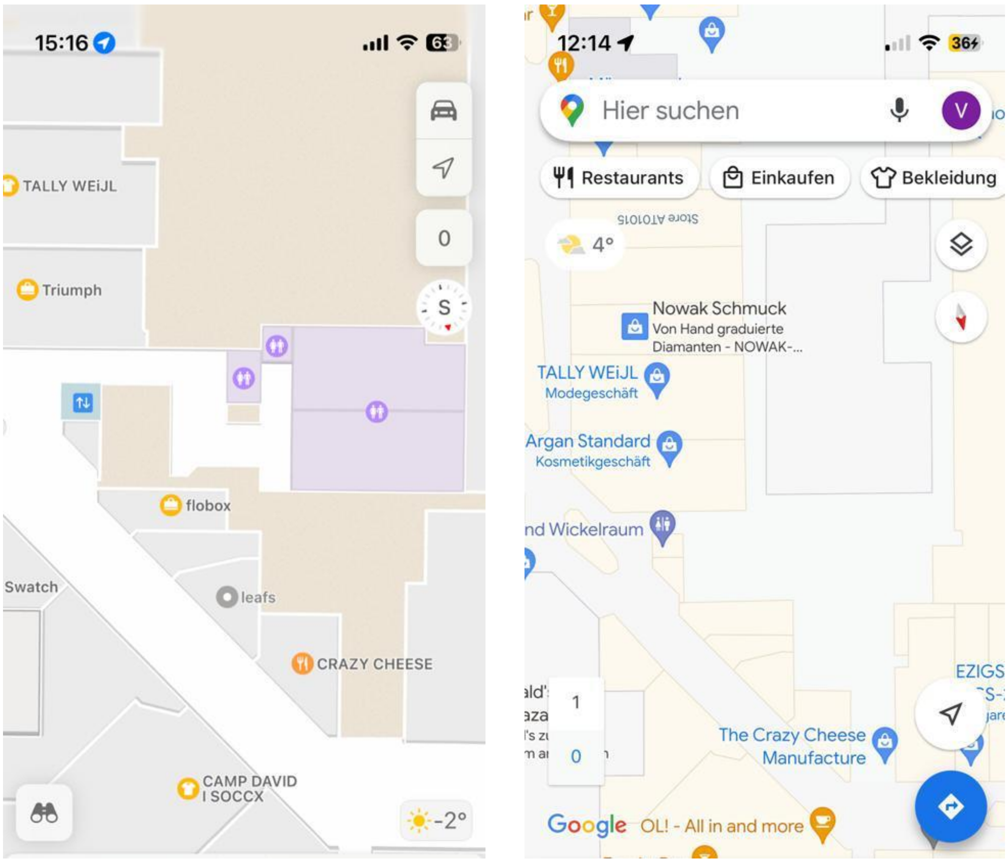

Figure 22: Apple Maps Indoors (left) and Google Maps Indoors (right), Comparison of the same spatial extent

A feature of Apple Maps Indoors is a partial 3D view. The user cannot view their position completely vertically, but a slanted view is possible (see figure 23). This is also available in Google Maps Indoors.

Figure 23: Apple Maps Indoors, 3D view

Landmarks

While Google Maps uses McDonald's as a landmark, Apple Indoor Maps does not. In general, I could not find any distinct landmarks in the indoor area. However, the symbols of shops and other spaces can also serve as landmarks, but there is no clear distinction here regarding which objects can be considered landmarks and which cannot.

Positioning

Like Google Maps, a blue dot is used to represent the user's position in this app. The user's direction is also indicated by a cone. However, Apple Maps does not display the position inaccuracy.

Routes

Route calculation within the building is not yet available in Apple Indoor Maps.

4.1.3 InMapz

InMapz is a software company based in California that develops mapping technologies for the built environment. Their goal is to enhance building management, visitor experience, and site security. The app already provides access to indoor maps for many locations. Currently, in Vienna, only Vienna Airport is available. InMapz creates maps for airports, shopping centers, municipalities, universities, schools, hospitals, churches, parks, trade conferences, and corporate campuses. Therefore, there is no outdoor navigation function in the app. The map view in the app cannot be shifted to an outdoor area. When the app is opened, a facility can be searched for or selected from the list. After clicking on a facility, you will be directed to it on the map, and the indoor map will be visible.

Map

Essential map interactions like zooming, panning and map rotation are also given in InMapz. The map starts with a north orientation. Once again, it's a simplified topographic map where ground plans and other objects are depicted. These rooms are simplified, and clearly distinguished from one another. One notable feature, distinct from Google Indoor Maps and Apple Indoor Maps, is the use of arrows to mark entrances. This can serve as a valuable point of reference for users, providing them with an initial orientation point from which they can navigate. InMapz employs a color-coded system to categorize various spaces. Shops are represented in pink on this map, while other spaces such as toilets, escalators, information desks, luggage services, and more are denoted in yellow. Security control areas are highlighted in orange. These color variations ensure a clear differentiation between different points of interest and spaces. Through the high contrast of the colors, it is easy to distinguish between different areas. There is no option to customize the color scheme. Each object or space is associated with a specific symbol. In contrast to Google Maps and Apple Maps, InMapz uses the respective logo as the symbol for each shop. However, symbols for toilets, elevators, and escalators are again very similar. One noteworthy aspect regarding symbols is their size. InMapz utilizes different sizes for various symbols. For example, the symbol for security is notably larger than the others. As depicted in the illustration, floor transitions can be executed through a drop-down button. There is no provision for a 3D view.

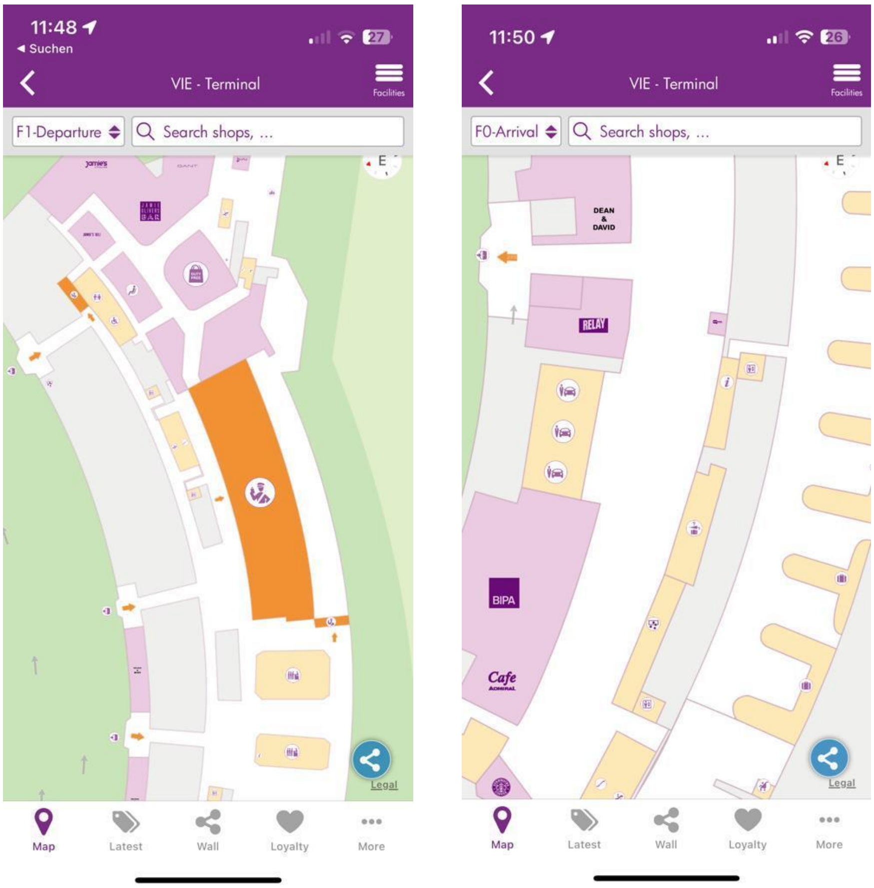

Figure 24: InMapz, Vienna International Airport

Landmarks

Here, all the shops are displayed with their logos. Therefore, these can be considered as landmarks. The symbols that are larger than the others can be seen as stronger landmarks.

Positioning

Unlike Google Maps and Apple Maps, InMapz uses only a pin as a positioning symbol (see figure 25). The direction in which the user is facing with their mobile device is not visualized with a cone or any other representation. The user also does not receive information about position inaccuracy.

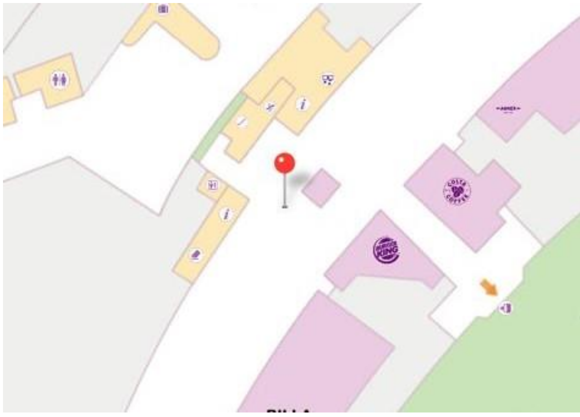

Figure 25: InMapz, Position symbol

Routes

In the InMapz app, the route is represented as a chain of arrows (see figure 26). Here, we do not have route descriptions in textual or verbal form. The route description is presented through a bar that describes each section of the route using symbols. When a symbol on this bar is pressed, the map view changes so that this section of the route is drawn on the map.

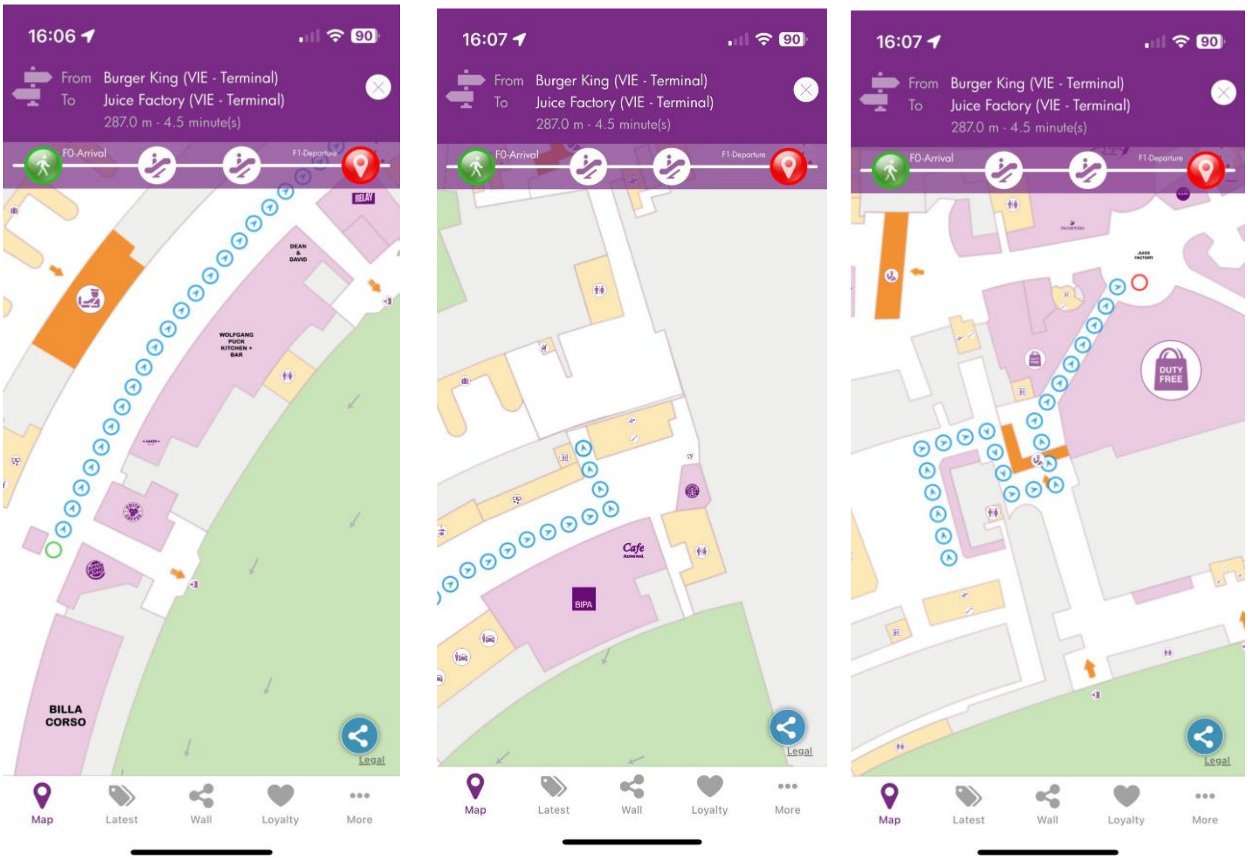

Figure 26: InMapz, Graphical route descriptions

4.1.4 Explorer AMNH nyc

The Explorer AMNH NYC app is a mobile indoor navigation app designed exclusively for the American Museum of Natural History. So, consequently the indoor map was specifically created for use within a museum. When the app is opened, you immediately see the museum's map.

Map

Here, the user once again has the ability to view the map using essential map interaction tools such as zooming, panning, and map rotation. The map's orientation is based on the entrance. This means the map is displayed in the direction that the building is seen by the user when they enter through the entrance. In comparison to the previously described indoor maps, we now have a completely different design. Essentially, the map looks more like an architectural plan but highly simplified. The map's colors are limited to grey and white. So, there is only one differentiation of two types of spaces. As there is no map legend it is not very clear which color represents which type of space. Different exhibitions within the museum are represented by circular images. For example, North American Mammals is indicated with corresponding images of such animals. These images are quite large and, especially on a smaller scale, cover a significant portion of the map. Symbols for other points of interest, such as elevators, stairs, and toilets, are much smaller but larger and more noticeable compared to the apps analyzed earlier. There is a layer symbol on the upper right side of the screen. When clicked, a pop-up window opens, allowing users to switch between floors. A 3D view is not available.

Figure 27: Explorer AMNH nyc

Landmarks

Here, there are pictures representing various exhibitions in the museum. These can be used by the user as reference points. The other symbols for stairs, elevators, toilets, and others are weaker landmarks in this case, as they are not as prominently displayed on the map.

Positioning

As this work is being written in Vienna, and the app does not offer positioning or route calculation unless you are inside the museum, this cannot be verified firsthand. However, in the app preview on the App Store, it can be seen that the positioning symbol of the Explorer AMNH NYC app is a blue dot with a cone indicating the user's viewing direction. Whether the position inaccuracy is visualized is unknown.

Routes

In the preview, it can be seen that routes are displayed with a blue line, and at a junction, an arrow is additionally drawn on the route itself. Furthermore, it can be inferred from the preview that route instructions are provided in the form of textual information.

Figure 28: Explorer AMNH nyc, Route visualization

4.1.5 Summary

In the following tables, the criteria from the catalog of section 2.2.6 will be analyzed and assessed using a color-coded rating system with red, yellow, and green. This system allows for the evaluation of each criterion in different Degrees. Red indicates 'The criterion was not met.' Yellow indicates 'The criterion was partially met, but there are significant deficiencies or issues.' Light green indicates 'The criterion was mostly met, but there are some minor deficiencies or areas for improvement.' Dark green indicates 'The criterion was fully met.' The fulfillment of a criterion is based on the insights gained from the literature review.

Table 6: Map, Competitor Analysis

Feature	**Google Indoor Maps**	**Apple Indoor Maps**	**InMapz**	**Explorer AMNH nyc**
Egocentric / Static view	During route egocentric	During route egocentric	Static	//
Map interaction	Yes	Yes	Yes	Yes
Level of detail	Topographic map, slightly to not generalized, with some unnecessary details	Simplified and generalized topographic map	Simplified and generalized topographic map	Strongly simplified and generalized topographic map, no clear differentiation of different areas
Color	No contrast, dark color scheme available	Dull, contrast, clear differentiation of rooms and spaces, no other color scheme available	Contrast, clear differentiation of rooms and spaces, no other color scheme available	Only two colors and no clear differentiation between different types of spaces trough colors, no other color scheme available
Floor switch	Yes	Yes	Yes	Yes
2D / 3D	2,5D	2,5D	No	No
Symbols	Symbols are associative, but small, in case of shops there is no further differentiation in symbolization	Symbols are associative, but small	Symbols are associative, but partly small	Symbols are associative and good to see

Table 7: Landmarks, Competitor analysis

Feature	Google Indoor Maps	Apple Indoor Maps	InMapz	Explorer AMNH nyc
Landmark symbol and abstraction	Yes	Yes	Yes	Exhibition land-marks are non-ab-stract, others are abstract
Recognition	Less recognizable	recognizable	Strongly recogniza-ble	Strongly recogniza-ble
Spatial promi-nence	No	No	No	No
Cognition	Yes	Yes	Yes	Yes

Table 8: Positioning, Competitor analysis

Feature	Google Indoor Maps	Apple Indoor Maps	InMapz	Explorer AMNH nyc
Position symbol	Blue dot	Blue dot	Pin	Blue dot
Showing users direction	Yes (Cone)	Yes (Cone)	No (Cone)	Yes (Cone)
Visualization posi-tion uncertainty	Yes (Circle)	No	No	No

Table 9: Routes, Competitor analysis

Feature	Google Indoor Maps	Apple Indoor Maps	InMapz	Explorer AMNH nyc
Route symbol	Dotted line	Solid line	Arrow chain	Solid line
Relational instruc-tion / Absolute instruction	Absolute	//	No	//
Metric / qualitative Information /	Both	//	No	Both
Written / verbal guidance	Both	Both	No	Written

4.2 Thinking Aloud

Three Thinking Aloud tests were conducted. For each of the three existing indoor navigation applications (Google Maps, Apple Maps and InMapz), a paper map was created for the shopping center Lugner City, mimicking the visualization of each application. The Lugner City was chosen as the study area because of the availability of data. None of the three indoor navigation applications have implemented Lugner City in their application yet. To ensure comparability, it was important to use the three different map visualizations for the same study area in all three tests.

Before testing, a training session was conducted with the test participants so that they could get used to Thinking Aloud. The training included tasks like:

"Which public transport could you use to get from Stephansplatz to Vienna Airport?"
or
"You plan to walk through the city and want to pass as many green spaces as possible. How do you proceed?"

Each participant was given three maps of Lugner City (one map for each floor of the building, with each map labeled with its respective floor). Each participant was given a different map visualization. As soon as the map was presented, the testing began. The test consisted of three tasks which are described in Chapter 3.3.1.

The Thinking Aloud tests lasted between 10-15 minutes and were documented using an audio recording. The audio file was then transcribed using AI (Otter-AI), which specializes in transcriptions. The transcripts were then reviewed against the audio recordings. The transcripts were read several times, noting special interesting situations and key moments, which are listed and discussed below.

4.2.1 Test 1: Apple Maps

The maps that the first test person had in front of them during the test execution are shown in figures 29, 30 and 31. The following important observations were made during the Thinking Aloud test.

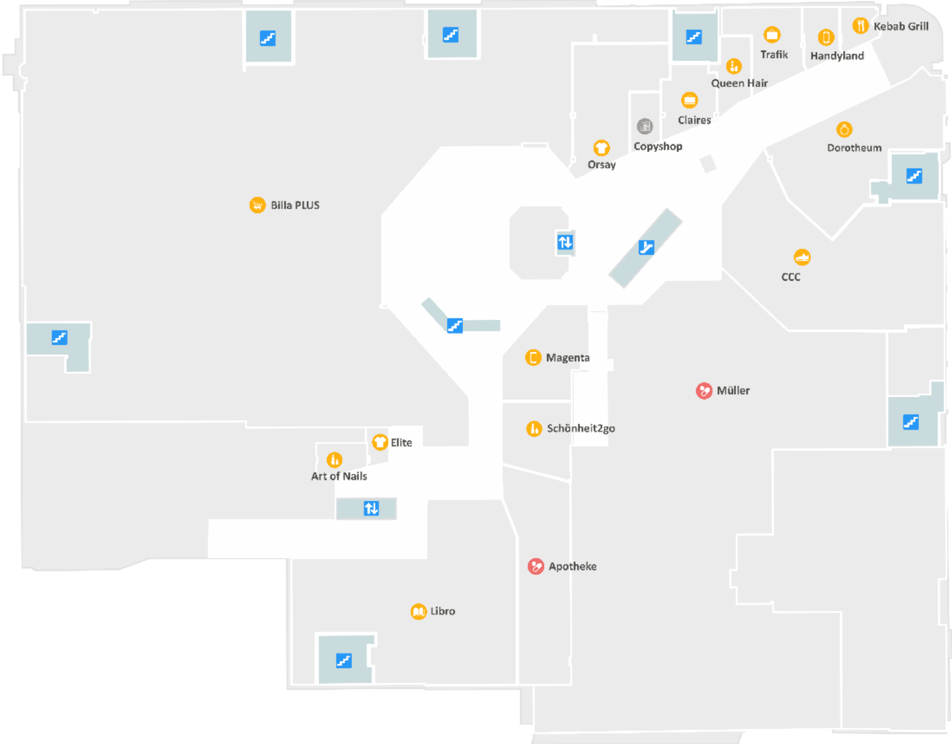

Figure 29: Apple Maps, Basement floor

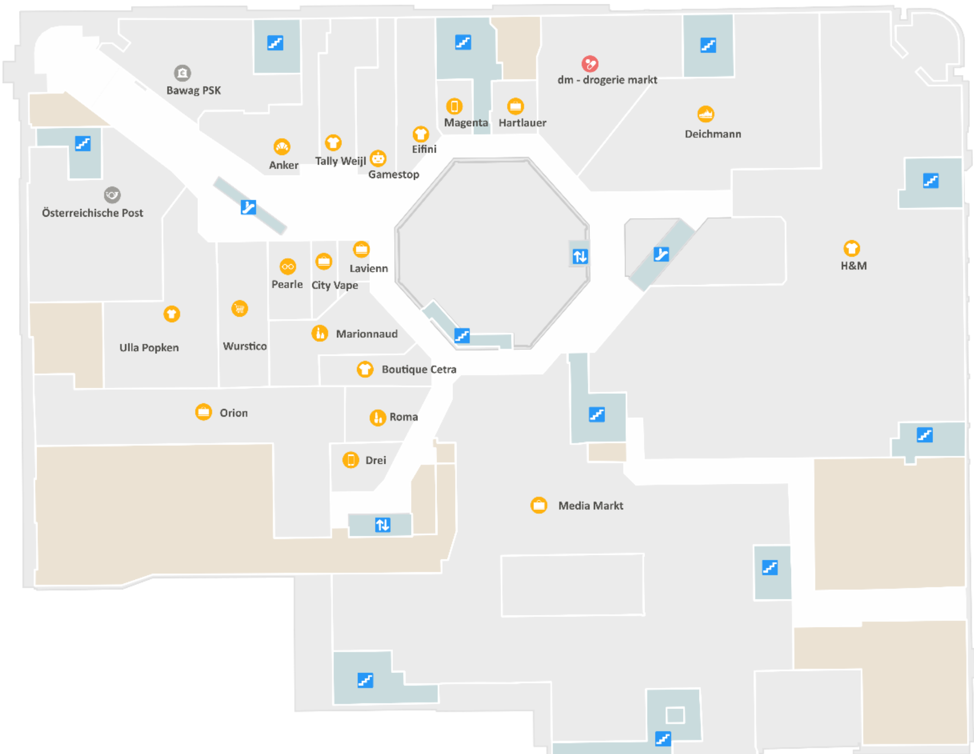

Figure 30: Apple Maps, Ground floor

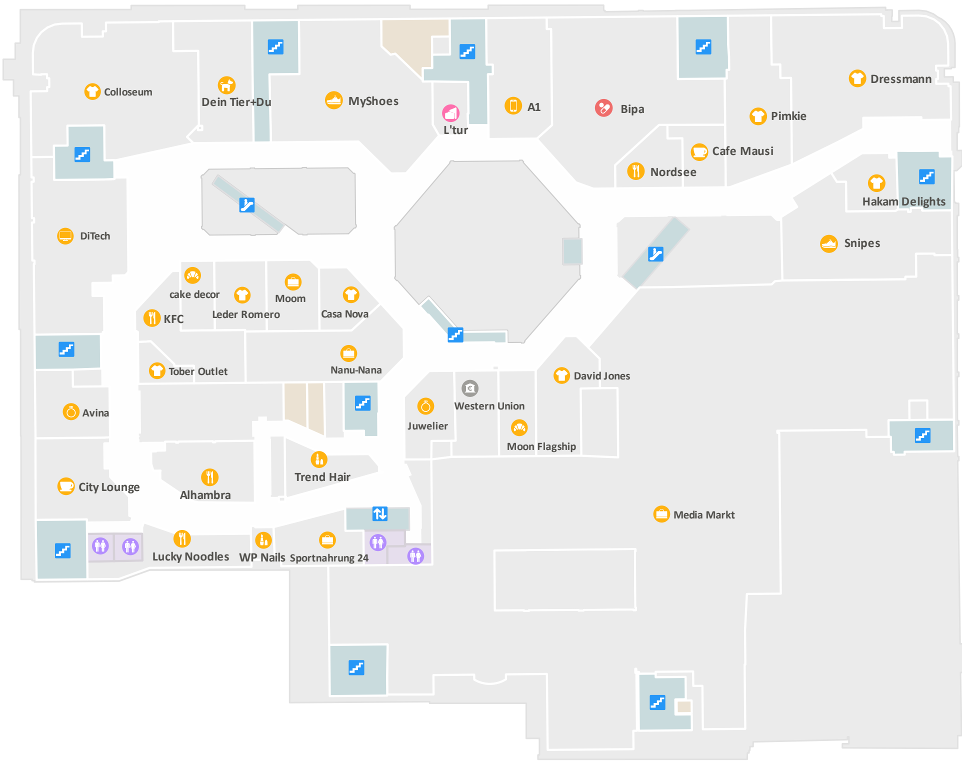

Figure 31: Apple Maps, Upper floor

Task 1

Navigation and orientation:

- In the first step, the Austrian Post and then the tobacco store on the maps were searched for problem solving.
- The test person had difficulties finding the Austrian Post. They began by analyzing all symbols by color to determine what symbol the Post might have, assuming that the Post should also be yellow. However, they expressed surprise about why the "dm drogeriemarkt" is red.
- 91 seconds time span to find both locations.
- In the next step, a connection between these two locations and floors was sought and described.

User experience and impressions:

- The test person found the grey symbols for banks and post offices unappealing because they did not stand out well, especially against the grey background, which made them less noticeable compared to other colors.
- The test person was familiar with the shopping center and was aware of the atrium but expressed the opinion that the atrium should not be the same color as the stores, as this might lead someone to mistakenly assume it is also a store.

Missing information:

- Confusion about whether the stairs or escalator actually go down to the lower floor or perhaps up to the upper floor – Then check whether the stair symbol is also on the other floor to make sure it goes to the right floor.

Task 2

Shop information:

- It took 10 seconds until the first electronics store was found.
- The test person primarily focused on the text of the shop names.
- The test person indicated that they only found Media Markt because the shop was familiar to them.
- The test person found all the electronics stores.

User experience and impressions:

- The test person suggested that it would be helpful if electronics stores and food service establishments (generally different shop categories) were also in a different color, because of that drugstores are marked with a different color.
- The test person noted that black lettering is effective and stands out and that it is not the same color as the symbol.

Task 3

User experience and impressions:

- The test person was surprised by the high number of restrooms on the upper floor compared to other levels.
- The test person emphasized that restaurants are not distinguishable from other shops but noted that restaurants or cafés are marked with a cup or fork and knife icon.
- The test person did not recognize the jeweler shop symbol as a jeweler and is confused about what it could represent.
- The test person highlighted that the optician's shop symbol did not clearly indicate an optician—without knowing the shop by name, they would not have realized it was an optician.

4.2.2 Test 2: InMapz

The maps that the second test person had in front of them during the test execution are shown in figures 32, 33 and 34. The following important observations were made during the Thinking Aloud test.

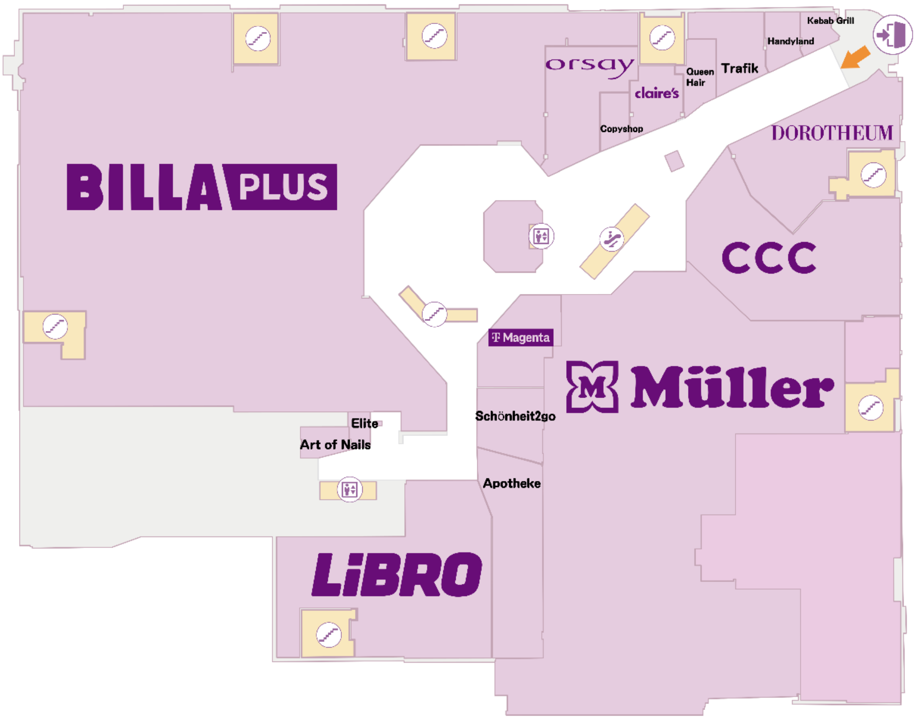

Figure 32: InMapz, Basement floor

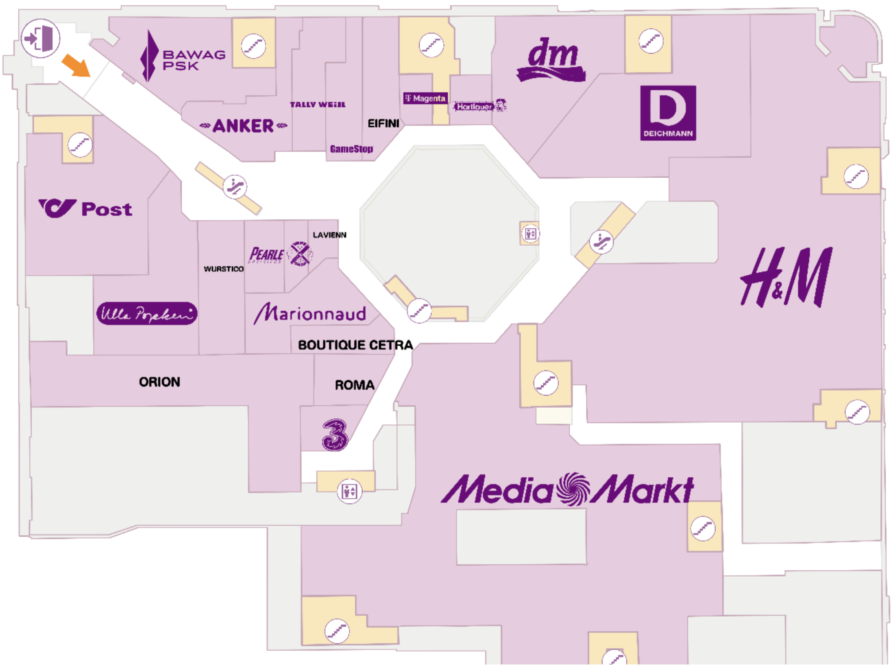

Figure 33: InMapz, Ground floor

Figure 34: InMapz, Upper floor

Task 1

Navigation and orientation:

- In the first step, the Austrian Post and then the tobacco store on the map were searched for problem solving.
- 5 seconds time span to find both locations.
- In the next step, a connection between these two locations was sought.

Missing information:

- The test person searched for doors to the shop entrances (at both locations), which are not drawn on the map.
- Wonders whether the tobacco store is also accessible via the staircase in the rear area of the tobacco store (however, it is assumed that the doors face the corridors).

Task 2

User experience and impressions:

- The test person was not interested in electronic products and was not familiar with shops that sell such products.

Shop information:

- Difficulties in identifying electronics stores, since stores were marked only with a logo (test person was not familiar with electronics stores) and contained no additional description.
- Still, "Media Markt" and "DiTech" are associated with electronics stores by the shop name.
- 16 seconds until the first electronics store was found.

Navigation and orientation:

- Confusion about stairs in the rear area of the "Media Markt" store, as these are not accessible via the corridor.
- The test person did not make any assumptions that the store is multi-floor.

Task 3

Navigation and orientation:

- "Octagon" (Atrium) was regarded as the center and orientation point in the building.
- The stairs in the Atrium area were only noticed at that moment.
- Confusion about the entrance/exit being on the left on the ground floor and on the right in the basement floor.

Shop information:

- Known restaurant chains like "Anker", "Nordsee" and "Billa Plus" were immediately recognized by their logo.
- Restaurants / Cafés without a logo were in black font with their names indicated: Test person only recognized these shops as a restaurant whose names already suggested it (Kebab Grill, Wurstico, City Lounge, Café Mausi).
- Restaurants that did not have a suggestive name (Alhambra) and restaurant chains where the logo was not known were not mentioned.
- Large stores were immediately noticeable.

Missing information:

- Confusion about what function the "Octagon" has (still the correct assumption that it was an airspace)

4.2.3 Test 3: Google Maps

The maps that the third test person had in front of them during the test execution are shown in figures 35, 36 and 37. The following important observations were made during the Thinking Aloud test.

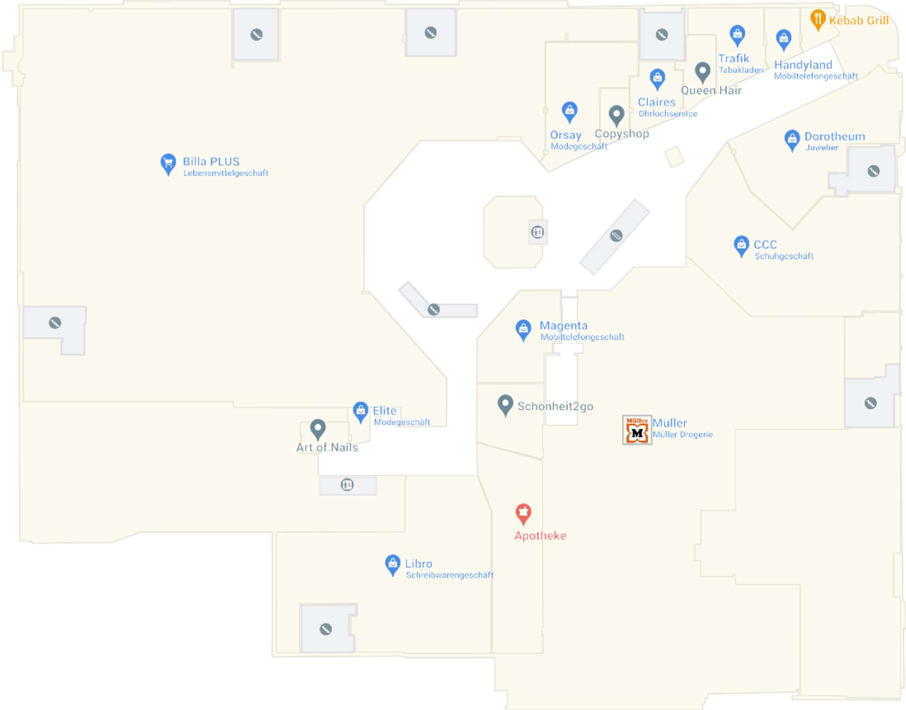

Figure 35: Google Maps, Basement floor

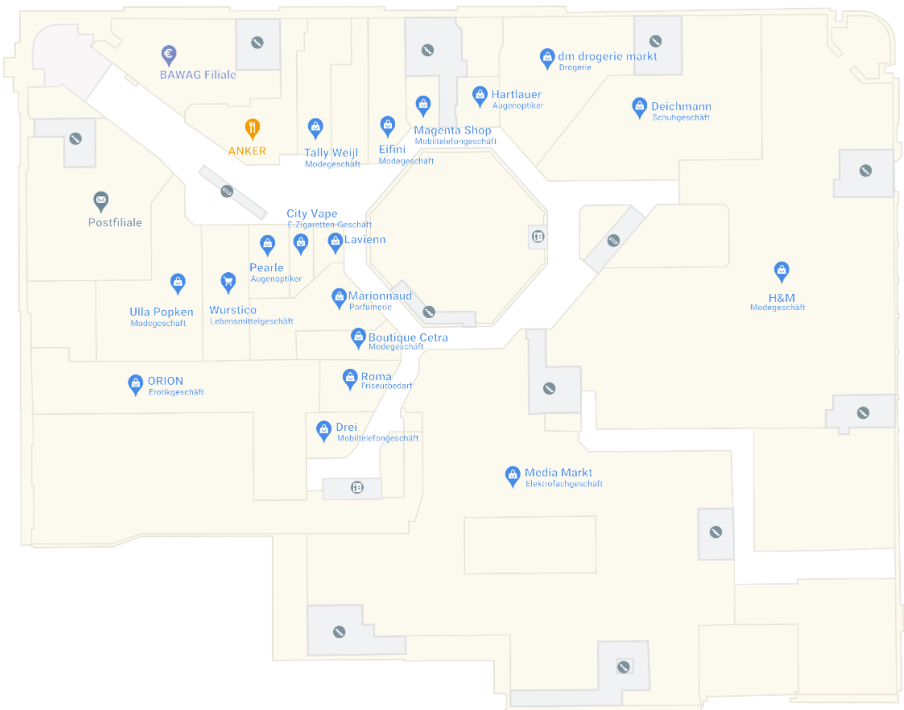

Figure 36: Google Maps, Ground floor

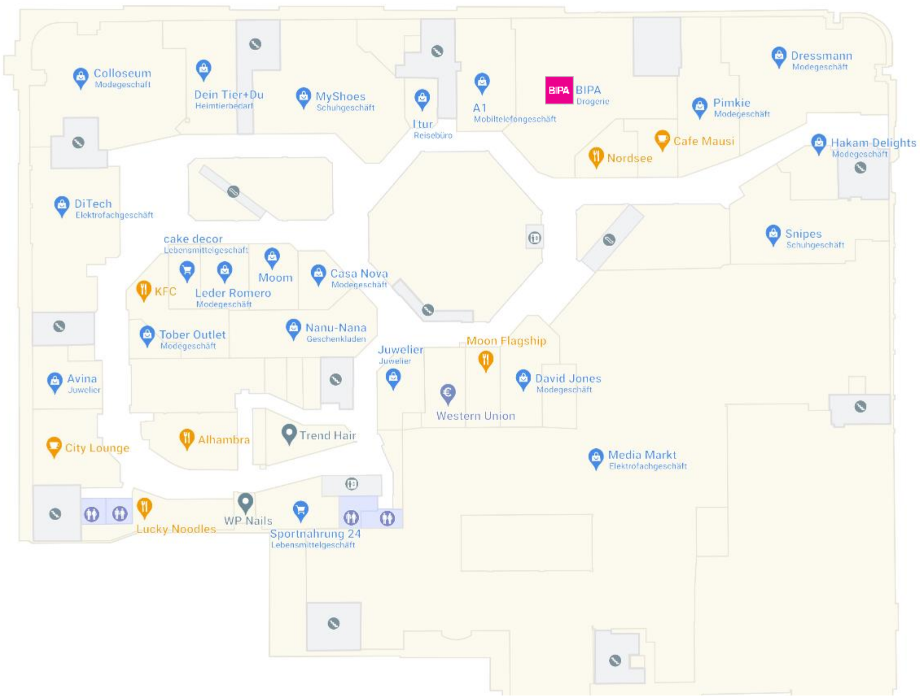

Figure 37: Google Maps, Upper floor

Task 1

Navigation and orientation:

- In the first step, the Austrian Post and then the tobacco store on the maps were searched for problem solving.
- Primarily the test person looks for the blue text information on the map to find desired locations.
- 57 seconds time span to find both locations.
- In the next step, a connection between these two locations and floors was sought.

Missing information:

- Confusion about whether the stairs or escalator actually go down to the lower floor or perhaps up to the upper floor – Then check whether the stair symbol is also on the other floor to make sure it goes to the right floor.

Task 2

Shop information:

- The test person only paid attention to the blue text and checked if the description below mentions "electronics" or looked for a shop name they recognize – stated that they first looked at the upper text to see if they recognize the shop. If not recognized, then they looked at the lower text, which is harder to read.

- 26 seconds until the first electronics store is found.
- The test person recognized the store "Hartlauer" by name and thought that it sold electronic products but saw the label "optician" below and then decided against going there.
- The test person found all available electronics stores.

User experience and impression:

- The test person noted that the "Media Markt" store is relatively large.

Missing information:

- The test person noticed that there is no difference in the icons for the various stores.

Task 3

User experience and impression:

- The test person noted that stairs, escalators, and restrooms are clearly visible in grey, and the stores are well-distinguished from the corridors by color, with the blue text being easily readable.
- Restaurants stand out due to a different color and icon—stated that cafes / restaurants are easily distinguishable from stores because of this.
- The test person mentioned that individual stores are difficult to differentiate from each other—there is no categorization of different shops in the symbol.
- Test person is confused that the copy shop and beauty services have the same icon – but is assuming that it is because both are services

Missing information:

- The test person pointed out that the entrances to the shops were not marked on the map. This was particularly noticed at the "Media Markt" store, which is quite large and extends over a large area in the shopping center, making it unclear where the entrance might be.
- Confusion about "Anker," noting that the shop floor appears narrow at the back – the test person cannot imagine that the shop actually looked like this.

4.2.4 Summary

In the following tables, the most important results of the Thinking Aloud testing per task are summarized.

Table 10: Task 1, Navigation

App Map	Navigation	Missing information	User impressions	Time span to find locations
Apple Maps	The test person paid attention to the symbols but had difficulties in finding desired location due to color coding.	Confusion about whether the stairs or escalator actually go down to the lower floor or up to the upper floor	Color confusion about why the bank is depicted in grey and why the atrium has the same color as the shops.	91 seconds
InMapz	Test person found desired location at first glance, because of the prominent logos.	The test person searched for doors to the shop entrances	//	5 second
Google Maps	The test person mainly focused on the blue text labels to find the locations, as the symbols otherwise provide no information.	Confusion about whether the stairs or escalator actually go down to the lower floor or up to the upper floor	//	57 seconds

Table 11: Task 2, Information search

App Map	Information search	Missing information	User impressions	Time span to find first electronic shop
Apple Maps	The test person focused mainly on the text of store names and found all electronics stores.	Suggestion to differentiate electronics stores and restaurants by color.	Black text was perceived as effective.	10 seconds
InMapz	Difficulties in identifying electronics stores due to unfamiliar logos, Media Markt and DiTech were identified as electronics stores by name.	Shop categories since the test person is not familiar with logos. Confusion about the stairs at the back of the Media Markt shop from where they are accessible.	//	16 seconds
Google Maps	The test person only focused on the blue text and checked if the description mentioned "electronics" or searched for known shop names.	No differentiation in the symbols for different stores.	//	26 seconds

Table 12: Task 3, Exploration

App Map	Exploration	Missing information	User impressions
Apple Maps	//	Restaurants are not distinguishable from other shops.	Test person found symbols for jewelry and optician not intuitive.
InMapz	Known restaurant chains were easily recognized by logos. Unknown restaurants were only recognized when they had a suggestive name.	Confusion about the function of the "Octagon" but assumed correctly it was an atrium.	Used the “Octagon” (Atrium) as a central orientation point.
Google Maps	Identified stairs, escalators, and restrooms clearly, shops and restaurants were easily distinguishable by color.	No differentiation between various store icons, entrances to shops were not marked, particularly noticed at the large "Media Markt" store.	Test person found individual shops difficult to differentiate like shops and services.

4.2.5 Discussion

Efficient navigation in buildings using indoor maps often poses a challenge, particularly when it involves interpreting navigation symbols. The accurate interpretation of these symbols is crucial for quick and frustration-free orientation.

Stairs and escalators

During the Thinking Aloud tests with indoor maps on Google Maps and Apple Maps, the participants expressed uncertainty about the direction of stairs and escalators. They couldn't clearly see whether these went up or down. This uncertainty led to delays and possible frustration in finding routes. For instance, if a participant wants to go to the ground floor and finds the nearest stair symbol, it's useless if the stairs only lead to the upper floor. Indeed, at the stairs located at the back of the Media Markt store, the stairs only function between two floors and merely connect the two sales areas of Media Markt. The information on which direction the stairs lead is not shown with the stair or escalator icon. To solve this problem, the participants then checked the floor they wanted to reach to see if there was also a stair or escalator symbol at the same place on the map of the other floor. Then they were sure that the chosen route would lead to their destination. However, this still means a delay in route finding and the user might feel annoyed by this.

This issue primarily occurs when only a map is available. With a complete indoor navigation system, the route description would already indicate whether a user should go to the upper or lower floor. Thus, the question of which direction a stair or escalator leads would become irrelevant.

To prevent this uncertainty in users, one possibility would be to represent the direction of the stairs through the symbol itself. In this case, a stair leading to an upper floor would be depicted in the symbol as going from the lower left corner to the upper right corner. For stairs going to a lower floor, the stair symbol would go from the upper left corner of the symbol to the lower right corner (see figure 38).

Stairs to upper floor: Stairs to lower Floor:

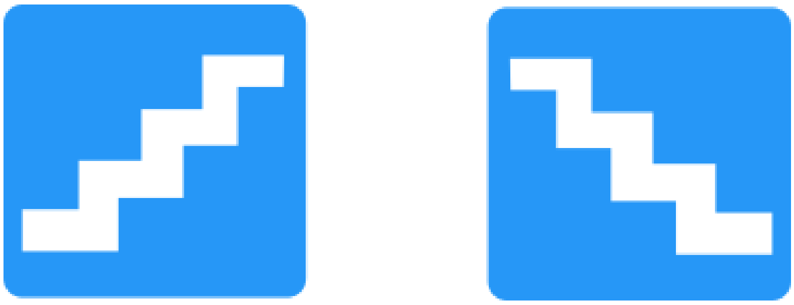

Figure 38: Visualization of stairs direction

One disadvantage of this solution proposal is that where stairs lead to both the upper and lower floors at a location, two symbols would need to stand next to each other to correctly display the information. However, this could lead to the map becoming cluttered and it might also confuse the user if two stair symbols are adjacent.

Additionally, there is also the question of how understandable and intuitive this representation is for the user. It might be necessary for the user to receive an introduction to the meaning of the symbols to understand this depiction.

Another way to represent whether stairs lead to the upper or lower floor would be to use arrows. (see figure 39)

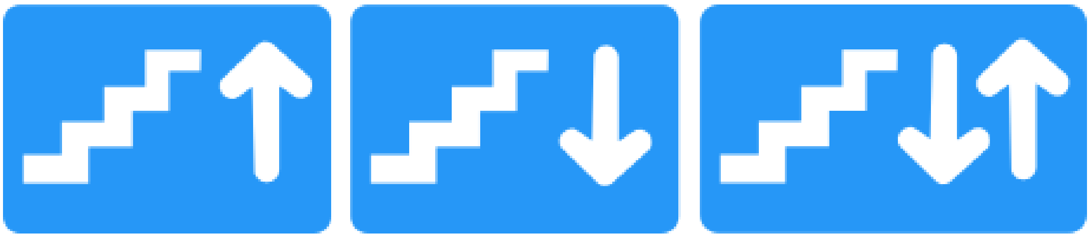

Figure 39: Visualization of stairs direction with arrows

The approach of using a stair symbol combined with arrow symbols provides a clear visual indication of the stair direction, which facilitates navigation. This method does not require additional textual instructions, making it particularly user-friendly. Overall, this symbol offers an effective way to display the directional information of stairs or escalators. The challenge lies in implementing the symbol so that it is intuitive, consistent, and does not clutter the map.

Establishment-Symbols

The map with the InMapz style, unlike the other two map visualizations, uses establishment logos to represent the functions of spaces within the shopping center. Additionally, the establishment symbols do not always have the same size as in the other two versions. The symbols adjust to the polygon size of the room unit. As a result, shops, services, and restaurants with a large floor area stand out very quickly. If the establishment logos are familiar to the user, they also catch the eye quickly because they are immediately recognized at a glance. In the first task of the Thinking Aloud testing, the test person with the logo map also took significantly less time to find the two shops they were looking for than the testers with the other maps. However, the Thinking Aloud testing also showed that users have different interests when it comes to shopping or eating. While some are familiar with the electronics shops at the market and their logos, these are not known to other users. And very likely, there are few users who know all existing shop or restaurant logos. Therefore, the target user group should be well considered. Especially if it is an international location where users unfamiliar with the local establishment logos are present, a logo representation would probably not make much sense. In shopping centers mainly visited by locals, this could be an advantage if the shops are immediately recognized, as it requires less effort for the user to find a desired location. Another aspect is that establishment logos are always different in size and shape. Some have a round shape, others are more elongated. Therefore, it is not possible to create a uniform image for the establishment symbols, which, however, does not necessarily have to be disruptive. Generally, the testing shows that logos can be helpful, but also have the disadvantage that they do not offer much to the user if the respective logo or shop is not known to the user. A variant in map visualization that considers advantages and disadvantages could be that abstract symbols are generally used for representing the functions of spaces, but logos are only used in those spaces where they are international shop or restaurant chains. It can be assumed that large international establishment chains are recognized by most users and can thus also serve as landmarks.

The map style of Google Maps makes hardly any difference in the symbolism of space functions. Color-wise, there is only one difference between shops, restaurants, and services. The clear color distinction between restaurants and shops was found very helpful by the test person. The color of services was rather confusing for the test person, as they initially did not understand why a nail salon and a copy shop should have the same symbol color. During the testing, the test person mentioned that there was no further categorization among the shop symbols but remained rather neutral regarding their feelings about this. During the tasks, the test person also indicated that they only read the textual information next to the shop symbols. Here, they proceeded by first reading the upper text of a symbol (shop name). If they did not know the shop name, they read the text below (shop category). Thus, information on shop categorization turns out to be extremely important. For example, if a user is not familiar with shop names but is looking for a shop that sells electronic products, the shop category is a very important piece of information. The Thinking Aloud testing also showed that the test person, who did not get this information on the map (InMapz), did not find all the electronics stores, unlike the other test persons. At Apple Maps, the shop categorization is represented with the shop symbol itself. However, there were uncertainties regarding these symbols during this testing. For example, the test person did not recognize the jeweler symbol as such. They were also unsure about the optician symbol. Therefore, with this method of presenting shop categories, there is a risk that the symbols will not be understood the same by all users. With textual information of shop categories, it is clearly understood, but the user has to read for that.

Based on the discussion and the Thinking Aloud testing, a mixed representation form of the symbols might be most advantageous. This means that logos are used only for internationally known shop or restaurant chains. Regarding the abstract symbols, the shop categorization could be provided both in the symbol itself and as textual information. Additionally, it helps the user if the symbols for restaurants, shops, and services are displayed in different colors to enable quick visual differentiation.

Atrium

Another aspect that came up during the Thinking Aloud testing is the representation of the atrium. One test person (InMapz) initially did not know what this was supposed to represent but guessed that it might be an airspace. Another test person (Apple Maps) wondered why this area has the same color as the shops. The atrium is indeed an airspace. In shopping centers, it is not uncommon for buildings to be constructed in such a way that it is possible to see from one floor to another. Therefore, it is important to consider how such airspaces are depicted, so that their representation on the map is clearly understandable and thus confusion among users is avoided. Since air is transparent, it cannot really be represented with a color, which complicates the depiction.

An approach to improve the representation of atria could involve using specific symbols or hatching that make it clear that it is not a walkable space. For example, a special symbol (such as a individual line pattern) could help highlight these areas on the map and distinguish them from walkable spaces. (see figure 40 and 41)

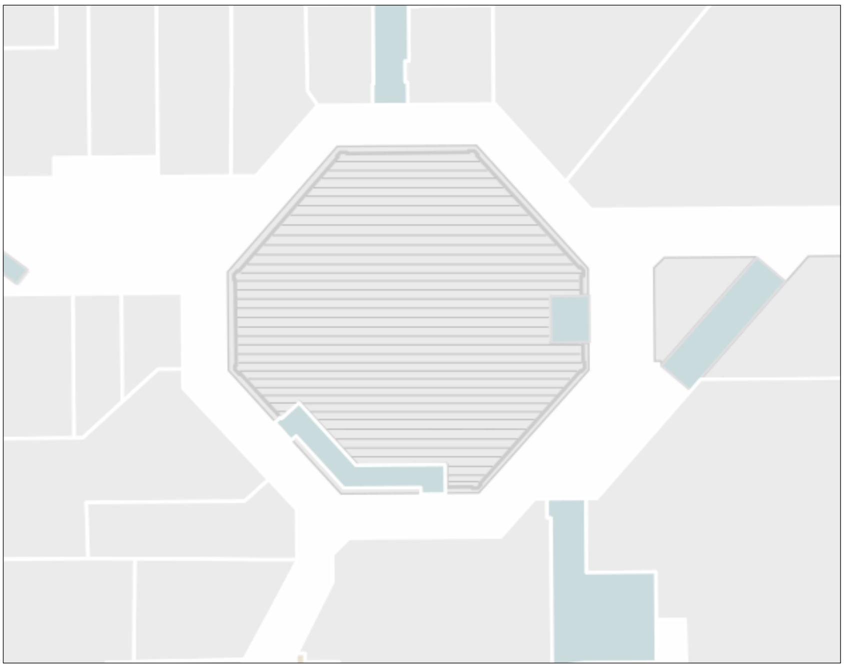

Figure 40: Atrium visualization, Hatched pattern

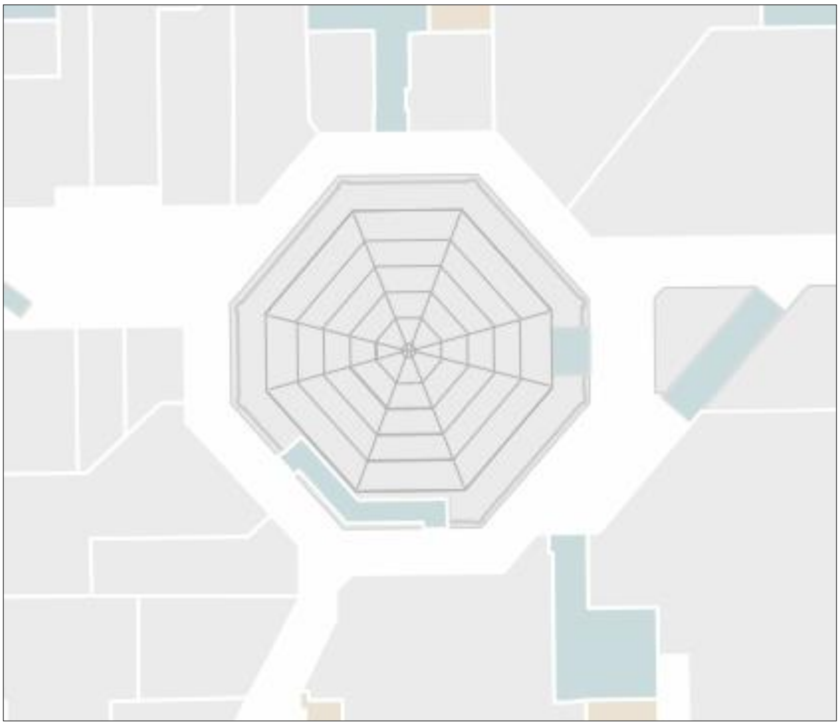

Figure 41: Atrium visualization, Individual pattern

Another approach could involve coloring the atrium polygon in the same color as the polygon from the lower floor that is visible from the atrium area. This color alignment could help establish a visual connection between the floors. Visitors might thereby more easily understand that the atrium represents an opening to an underlying area. However, this could also create potential confusion for the user, as they might think it is a walkable space. Additionally, the user must also know what is on the lower floor to make this connection. In the case of Lugner City, the lower area would be a corridor. Accordingly, this would appear as shown in figure 42.

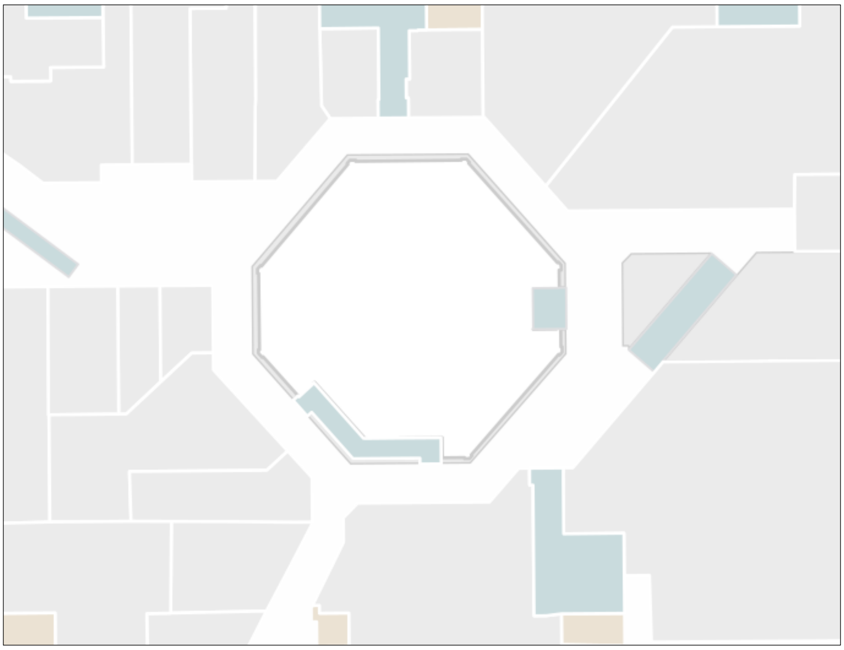

Figure 42: Atrium visualization, Color fill with lower floor area

To master the problem of representing airspaces on indoor maps, a combination of both approaches could be used. The atrium could have the same base color as the visible lower floor but be supplemented by transparent patterns or a slight transparency to indicate its non-walkability.

Shop entrance

Two test persons mentioned during the testing that they were missing the entrance doors to shops. In one case, it was about knowing whether a shop could be accessed via stairs or if the shop was only accessible through the corridor.

Figure 43: Unclear area of access

In the other case, it involved a shop with a large sales area, where its front extends over a wide part of the corridor. Here, it was unclear exactly where the entrances were located, leading to confusion when planning the fastest way to the shop. This can be especially problematic in large shopping centers, where stores often have multiple entrances or extensive fronts.

However, adding entrance doors to every shop visualization could visually overload the maps and make them more complex, which could lead to new orientation problems for some users. A possible solution approach would be the selective representation of entrance areas. Instead of marking every single entrance, only the main access points or particularly important accesses could be highlighted.

4.3 Prototyping

Based on the theoretical foundations in Chapter 2.1, the competitor analysis in Chapter 4.1, and the results of the Thinking Aloud testing in Chapter 4.2, considerations were made regarding the design of the Own Map.

The goal was to integrate as many details as possible in the map that are important for orientation within the building, while still maintaining a good overview on the map. This can be ensured through a clean map design and a harmonious and intuitive choice of colors (Nivala, Brewster, and Sarjakoski 2008: 134).

Nossum (2013) and Montello and Sas (2006) emphasized the importance of carefully considering which information should be displayed on the map and which should not, as the density of information in indoor environments is often much higher than in outdoor areas. Therefore, the author of this work initially considered which information is essential for orientation in a shopping center. This includes shops, landmarks or important orientation points, information on floor change facilities (stairs, escalators, and elevators), sanitary facilities, and the marking of different usage areas in the building.

Gotlib (2019) proposes several qualities that should be met by indoor maps. One such quality is being "self-explaining," which involves ensuring that the symbols and colors on the map are related to the real world. To ensure this in the Own Map, abstract symbols were used to represent shop categories. Most of the shop symbols were adopted from the Apple Maps map, as in the author's opinion, they are very intuitive. To make the colors intuitive (Puikkonen et al. 2009: 4), grey was chosen for non-walkable areas in the building. The color grey can be associated with emptiness and is additionally unobtrusive, thereby receding into the background, which are suitable characteristics for non-walkable areas. For a clean appearance, the same color was used for all establishment areas. Care was taken to ensure that the color is easily recognizable and distinguishable from other colors on the map, but not too prominent so that the symbols that lie over it are well highlighted. For a clear representation of walkable areas, such as corridors, the color white was chosen.

Another feature defined by Gotlib (2019) is the "glanceability" of a map, which refers to how quickly the content of the map can be understood. To ensure this, care was taken not only to ensure that the symbols are intuitive but also that they are large enough to be easily recognizable. To quickly distinguish between different facilities, different symbol colors were chosen for shops, restaurants, and services. In addition to the shop symbols and shop names, it was decided to include a textual description of the shop category. This proved to be helpful in the Thinking Aloud tests from Chapter 4.2.

Gartner, Cartwright, and Peterson (2007) emphasized the importance of clearly depicting stairs, escalators, and elevators, recommending that they be represented as pictograms. However, during the Thinking Aloud tests from Chapter 4.2, the aspect of indicating the direction of these objects in the building emerged. Test participants wondered whether a staircase leads to an upper or lower floor. Therefore, the author of this work decided to indicate direction using arrows next to such symbols. Several colors were tested for the stairs, escalator and elevator symbols. Red and green were initially tried. However, the author of this work found the color red to be too dominant. Green symbols appeared like emergency exits. It is essential to highlight stairs, escalators, and elevators, but it should not be too dominant. Ultimately, a blue color was chosen.

By providing spatial reference points and cognitive anchors, landmarks play an important role in human wayfinding (Dubey et al. 2019: 1; Bauer, Müller, and Ludwig 2016: 75). Zhu et al. (2019) found that in shopping centers, the shops are the landmarks that users pay the most attention to. Shop logos are highly recognizable and therefore well suited for landmarks. However, the Thinking Aloud testing from Chapter 4.2.2 also showed that only displaying shop logos can hinder orientation for users who are not familiar with the logos. Therefore, only relatively large and well-known shops (H&M and MediaMarkt) were selected, which are additionally represented by their logos and thus used as landmarks. Care was taken to ensure that this representation does not deviate from the design of other shop displays and that uniformity is maintained despite the logos being shown only for individual stores.

The atrium of the building studied in this work is a prominent feature in the shopping center. During the Thinking Aloud testing, it was not clear to the participants what this area was supposed to represent. Given the prominence of the atrium in the shopping center, it could potentially serve as an important landmark. Therefore, the author of this work considers appropriate visualization of the atrium as important. For this, individual line patterns were created to reflect the shape of the sky dome. Grey was again chosen for the area coloring because it represents an airspace, and the area is therefore not walkable.

The marking of doors and access points to shops and stairs was also an aspect that emerged during the Thinking Aloud testing. In some areas of the building studied in this work, these were not always clear, and the participants indicated that this marking would be helpful in route finding. However, to avoid cluttering the map, the author of this work decided against including doors on the map.

Overall, the Own Map is a combination of the existing indoor mapping systems (Apple Maps, Google Maps, and InMapz) and further developed features from the theoretical background (Chapter 2.1) and the Thinking Aloud tests (Chapter 4.2), which makes use of the positive attributes of each map and further. The resulting map is shown in figure 44.

Figure 44: Self-designed indoor navigation map (Own Map)

4.4 Questionnaire

The four maps that were tested with the questionnaire are shown in figure 45.

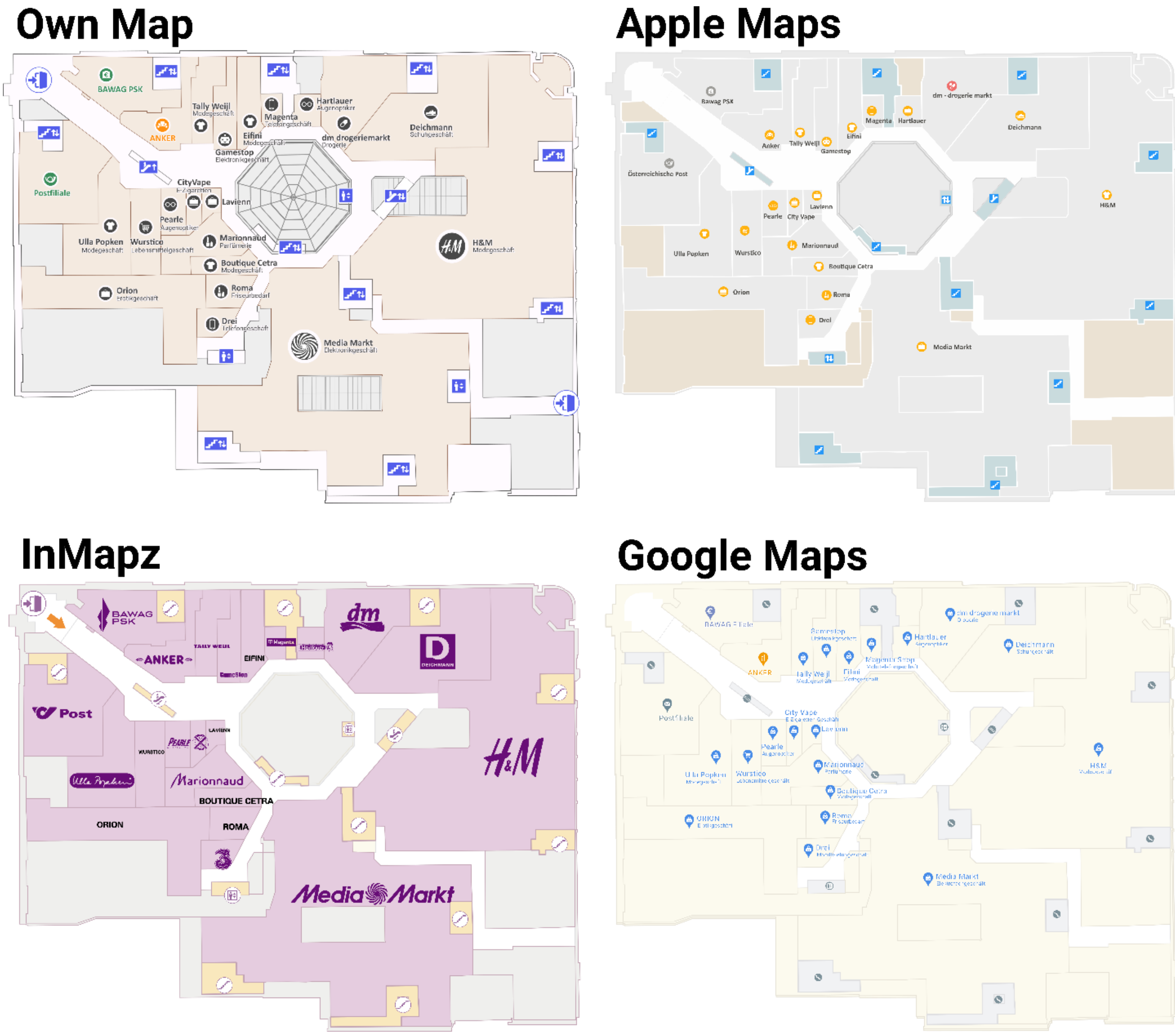

Figure 45: Tested maps

There are several ranking questions in the questionnaire. To account for all ranks in ranking questions, a weighting is carried out. Each rank is evaluated differently: For rank 1, +2 points are awarded per participant and map, for rank 2, +1 point, for rank 3, -1 point, and for rank 4, -2 points. This results in the following formula for each map:

$$S = (N_{Rank1} \times 2) + \ (N_{Rank2} \times 1) + \ (N_{Rank3} \times (-1)) + \ (N_{Rank4} \times (-2))$$

Where N_{Rankx} is the number of mentions in rank x.
Utilizing a weighted scoring system allows for a more nuanced and precise evaluation of preferences, as it accentuates the significance of higher and lower rankings much more than the pure average score.

4.4.1 Results of the questions

Question 1 – How do you find the level of detail on the Map?

The data analysis of question 1 of the questionnaire is shown in figure 46.

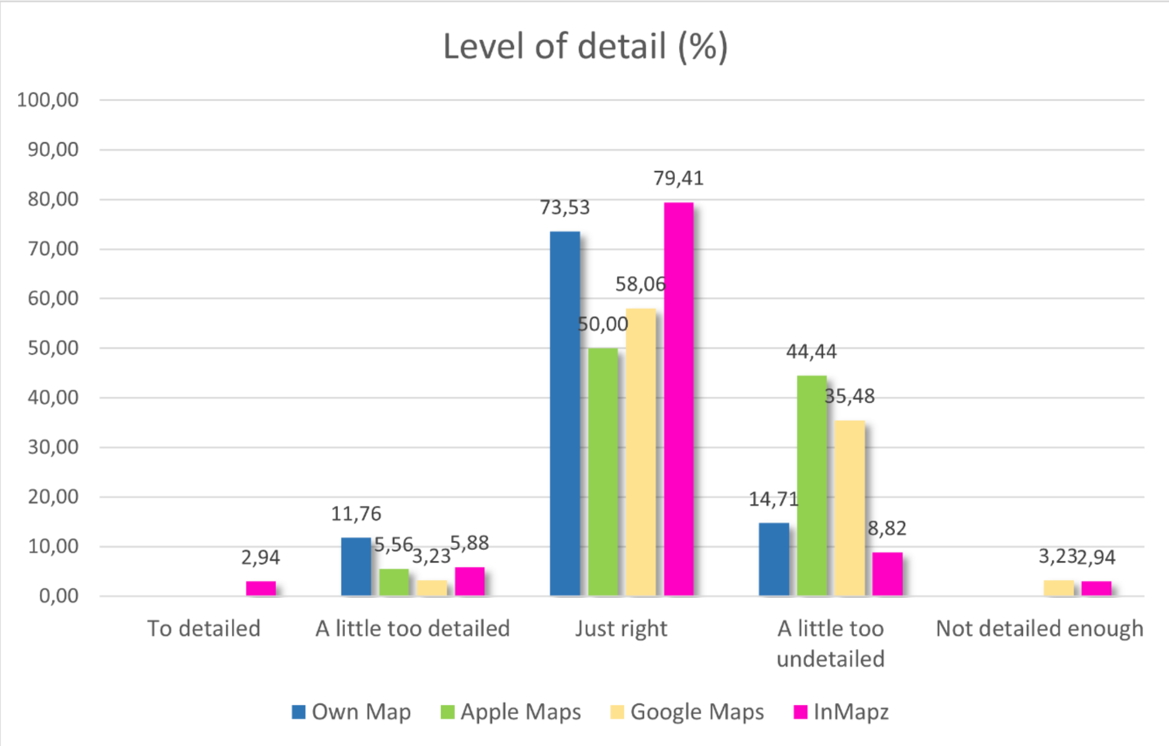

Figure 46: Results of question 1, Level of detail

Own Map:

The results show that the majority of the participants (73.53%) rated the level of detail on the map as “just right”. 14.71% of the participants found the map a bit too undetailed. 11.76% of the participants felt the map was a “bit too detailed”. None of the participants found the map too detailed or not detailed enough.

The Own Map ranks second best among the other maps in terms of level of detail, in the "just right" category. Compared to the other map, it has the highest overall information.

Apple Maps:

The majority of the participants (50%) felt the level of detail of Apple Maps was “just right”. However, a significant portion of the participants (44.44%) found the map a bit too undetailed. A smaller group of the participants (5.56%) felt the map was a bit too detailed. No participants found the map too detailed or not detailed enough.

The Apple Maps map has the highest percentage in the "a bit too undetailed" category compared to the other maps, and the lowest percentage in the "just right" category. When the map is compared, regarding the symbols, with those of the Own Map and the Google Maps map, the map contains no additional textual description of the shop categories. This could be a reason for this rating. Additionally, the shop symbols on the Apple Maps map are smaller compared to the Own Map, which could have made it more difficult for the participants to recognize information from the map, and for this reason, the map was rated as "a bit too undetailed". Furthermore, there are areas on the map that are not marked or labeled, which could also lead to this result. However, these areas are not marked or labeled on the InMapz map either, which nevertheless achieved the best result in terms of level of detail.

Google Maps:
The majority of the participants (58.06%) rated the level of detail of Google Maps as just right. Again, a larger percentage (35.48%) of the participants found the map a bit too undetailed, and 3.23% not detailed enough. A small percentage (3.23%) felt the map was a bit too detailed or not detailed enough. No participants rated the map as too detailed.

The Google Maps map ranks second worst in terms of level of detail compared to the other maps. When considering the symbols, it can be assumed that this might be due to the fact that there is no distinction in the shop symbols. They are all the same and thus cannot be differentiated. The Apple Maps map has different shop symbols, but no text descriptions of shop categories. Furthermore, in the Google Maps map, all areas, except for stairs, escalators, and elevators, are colored the same. Therefore, there are some areas that contain no symbols and are also not distinguished from shop areas by color, leading to a lower information content.

InMapz:
A majority of the participants (79.41%) found the level of detail of InMapz just right. A small number of users (8.82%) found the map a bit too undetailed. 5.88% of users rated the map as a bit too detailed. A small percentage (2.94%) found the map either too detailed or not detailed enough.

The InMapz map has the best rating compared to the other maps regarding the level of detail, even though it contains no shop categorizations, only the logos of the shops. The logos are displayed very large and thus quickly catch the eye, and the participant does not need long to get an overview of the building. This could be a reason for the good rating, although this map actually has the least information content. One information that is displayed in contrast to the Apple Maps and Google Maps map is the marking of entrances and exits.

Question 2 - What types of information do you find most useful for navigating indoors on the map?

Question 2 is a ranking question. This means that the participants indicated the importance of each feature from rank one (most important) to rank 3 (least important). Figure 47 shows the results.

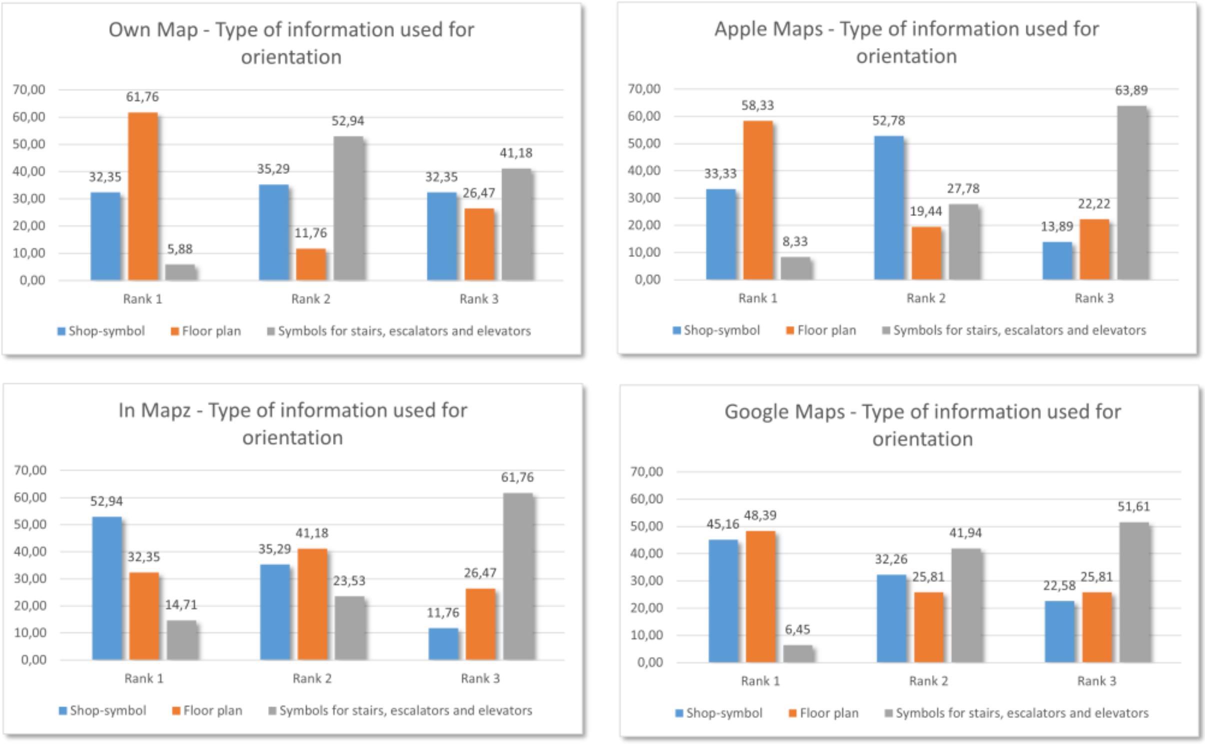

Figure 47: Results of question 2, Types of information

In the first rank, most of the participants of the Own Map, Apple Maps map and Google Maps map placed the floor plan as the most important information for orientation. For the InMapz map, the majority of the participants placed the shop symbols in the first rank. When looking at the InMapz map, this seems plausible as the logos of the shops are very prominent, easily recognized, and thus stronger points of orientation.

In the second rank, there is more variation in the responses and no clear trend can be discerned. This variation indicates that the usefulness of the information varies depending on individual needs and usage scenarios.

In the third, or last rank, it is clear to see that the majority of the participants have placed the information about stairs, escalators, and elevators on all the maps. These are thus considered less important for orientation compared to the floor plan and the shop symbols by the participants.

Overall, it can be said that floor plans and shop symbols are preferred as aids in orienting within buildings. The results suggest that the usability of indoor maps can be improved if the display of floor plans and easily recognizable shop symbols is prioritized.
In addition to setting the ranking, the participants had the opportunity to specify additional aids in a text field below this question. This field was optional to fill out and was only completed by some participants. These answers are thematically categorized and analyzed in the following:

Table 13: Own Map (Question 2)

Category	**Number of comments**
Sanitary facilities	4
Entrances to stores	4
Floor information (e.g. basement)	2
Current position	5
Emergency exit	1
Color differentiation shops/restaurants	1

Table 14: Apple Maps (Question 2)

Category	**Number of comments**
Sanitary facilities	4
Entrances to stores	4
Floor information (e.g. basement)	1
Current position	2
Emergency exit	1
Building entrance	2
Subway stations/streets	1

Table 15: Google Maps (Question 2)

Category	**Number of comments**
Sanitary facilities	3
Floor information (e.g. basement)	4
Current position	3
Building entrance	3
Parking spaces	1
Subway stations/streets	1
Staircase access	1

Table 16: InMapz (Question 2)

Category	**Number of comments**
Sanitary facilities	7
Floor information (e.g. basement)	1
Current position	5
Building entrance	1
Emergency exit	2
Color differentiation shops/restaurants	1
Smoking area	1
Shop logos in color	1
Map color matches color in reality	1

The results show that additional orientation aids such as current position, floor, and sanitary facilities were indicated by the participants in all maps. Since it is a prototype, this is not displayed on the map, but in the final product, the position would obviously be displayed. Sanitary facilities were not displayed on the map because there are none on this floor in reality. The information about the floor was not displayed since only one level was depicted, but this would also have been valuable information for the participants. In the final product, it should be clearly and distinctly displayed on which floor the participants are located. This orientation aid was also discussed in the theoretical part of this work (Chapter 2.2.2) by Gartner, Cartwright, and Peterson (2007).

Other frequently mentioned additional orientation aids were entrances to shops, building entrances, and emergency exits. The aspect of shop entrances also appeared during the Thinking Aloud testing in Chapter 5.2.3. Through these additional comments from the questionnaire participants, it was confirmed that this information should not be neglected on indoor maps and serves as important information. Especially for larger shops, it is not always clear where the entrance is located. However, it is often the case with large stores that the front facing the corridor is an entire entrance. It must be considered where it makes sense to draw entrances. Regarding stair access, a participant wrote that these are missing. Specifically, in this building, it would make sense to draw stair access since it is not apparent from the stair polygons. For example, the stair polygon borders several shops, making it unclear whether the user can access the stairs through all the adjacent shops.

Building entrances are not displayed on the Google Maps map and Apple Maps map, where most comments regarding this were written. A participant also indicated this on the InMapz map, although the building entrance is actually marked here.

The assumption, which already emerged from the Competitor Analysis (Chapter 5.1) and Thinking Aloud testing (Chapter 5.2), that there should be a clear and colorful distinction between restaurants and shops, was confirmed by some comments from the participants. Further comments from the participants were the indication of adjacent streets to the building, subway stations, and parking garages. Additionally, a participant of the InMapz map criticized that the logos should be displayed in their original color. This would probably make the logos even quicker to recognize, although this approach could also overload the map and disturb the color harmony.

An interesting aspect, which was mentioned by a participant as an idea, was that the colors on the map could be aligned with the colors in reality. For example, if the floors in the building corridors are yellow, these could also be yellow on the map. This aspect was also addressed in the theoretical part (Chapter 2.2.1). Dillemuth (2013) found that users orient themselves more easily when the colors on the map reflect the colors in reality. However, these tests were not indoors but outdoors. Puikkonen et al. (2009) also recommend color consistency between the map and reality. Since buildings are all different, this approach could not create a uniform terminology of guidelines for indoor maps. Moreover, it could be difficult to maintain color harmony on the map. The approach that the colors on the map and reality match could be valuable for virtual reality applications.

Question 3 - How clearly and understandably can you distinguish the different rooms and areas within the building? (e.g., shop areas, restaurants, corridors...)

The data analysis of question 3 of the questionnaire is shown in figure 48.

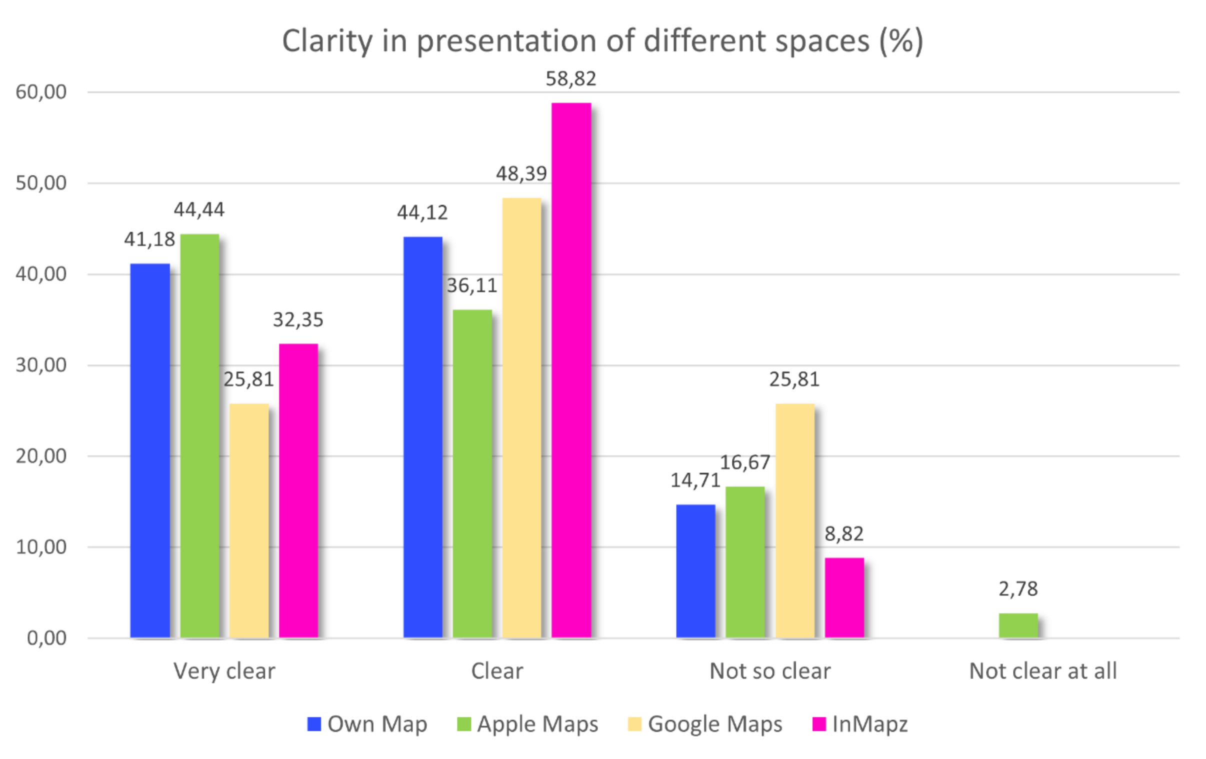

Figure 48: Results of question 3, Presentation of different areas

Own Map:

The majority of the participants found the map to be "clear" or "very clear" in terms of the demarcation of different areas and rooms within the building, summed up 85.3%. A smaller part (14.71%) of the participants indicated that the different rooms and areas are "not so clear".

Apple Maps:

The Apple Maps map has the highest proportion of the participants who chose the "very clear" category overall, but if the "very clear" and "clear" categories are summed up, it ranks narrowly in third place with 80.55%. A smaller part of the participants (16.11%) indicated that the various rooms and areas within the building are "not so clear."

Google Maps:

The Google Maps map performed the worst in this question compared to the other maps. With 25.81%, it has the lowest percentage of the participants who perceive the various rooms and areas of the building as "very clear". Also, with 25.81%, it has the highest proportion of the participants who perceive the various rooms and areas as "not so clear". Comparatively, however, a high percentage of the participants (48.39%) chose the "clear" category. If the "very clear" and "clear" categories are summed up, 74.2% of the participants find the various rooms and areas in the building to be clearly depicted.

InMapz:

If the "very clear" and "clear" categories are summed up, the InMapz map shows the best value in terms of the clarity of different rooms and areas within the building with 92.17%. However, the "very clear" category is weaker compared to the Own Map and the Apple Maps map, with 32.35%. The majority of the participants (58.82%) chose "clear" and 8.82% indicated that they find the various rooms and areas to be "not so clear."

Summary*:*

Overall, it can be said that the Own Map, Apple Maps map, and InMapz map performed similarly in this question, and no clear differences can be discerned. There are variations in the categories, but these relatively balance out when summed up. In contrast to the Google Maps map, it is evident that here, compared to the other maps, the fewest chose "very clear" and the most chose "not so clear." All in all, the InMapz map was rated the best in this question, followed by the Own Map, Apple Maps, and finally Google Maps.

Question 4 - In the middle of the map, an octagonal polygon is depicted. Can you recognize what this polygon represents?

The data analysis of question 4 of the questionnaire is shown in figure 49.

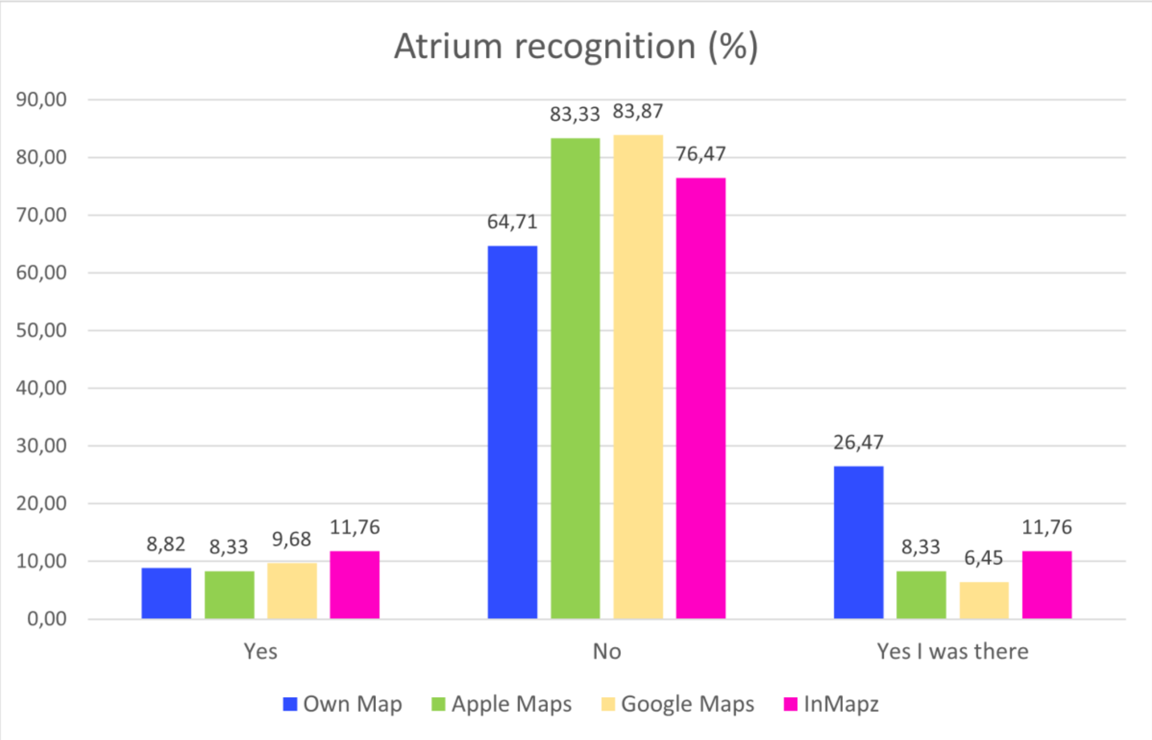

Figure 49: Results of question 4, Atrium recognition

Across all maps, there were no significant differences in recognizing the atrium. For Apple Maps, Google Maps, and InMapz, the atrium polygon was simply an empty space. On the Own Map, a line pattern was displayed that reflected the shape of the skylight dome. However, the results show that this line pattern did not significantly contribute to the polygon being interpreted as an atrium.

Question 5 – Is there any information on the map that you consider unnecessary?

The data analysis of question 5 of the questionnaire is shown in figure 50.

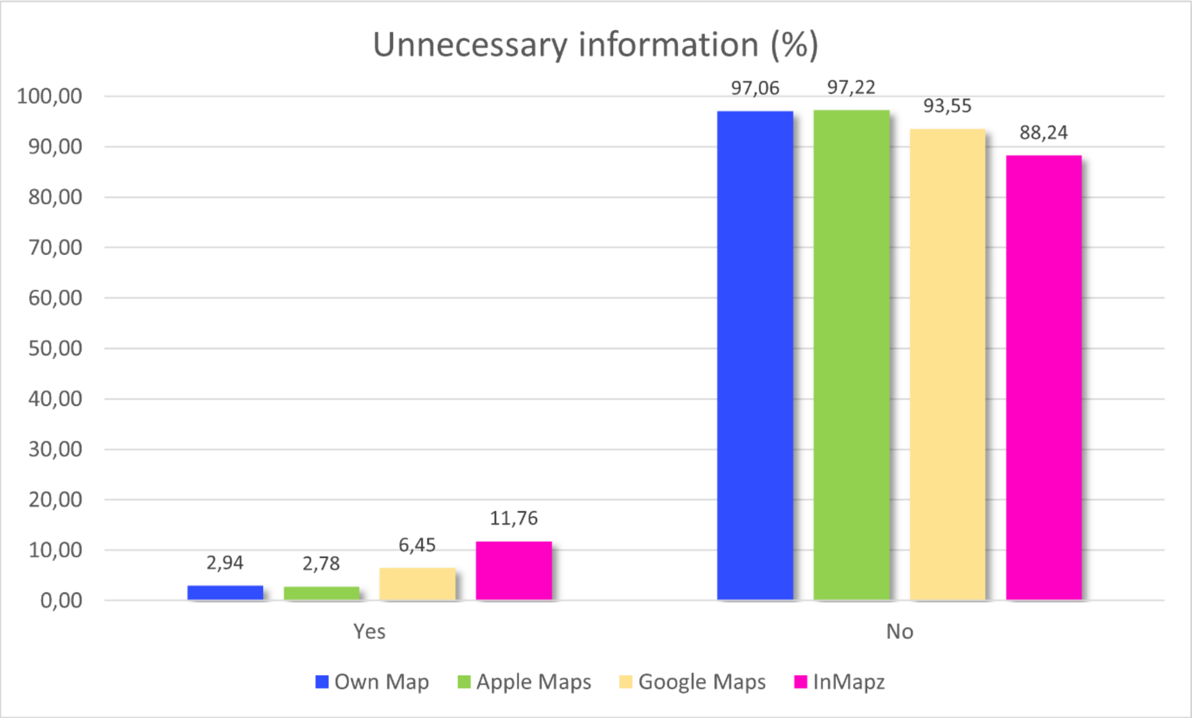

Figure 50: Results of question 5, Unnecessary information

Own Map:

Among the Own Map, 1 out of 34 participants indicated that they found some information unnecessary. Additionally, the participants had the opportunity to write a comment describing which specific information they found unnecessary. The participant wrote that the shop boundaries are too detailed and should be more generalized. The same participant also suggested that textual shop categories could potentially be omitted.

Apple Maps:

Similarly, with the Apple Maps map, 1 out of 36 participants felt that some information was unnecessary. This person criticized that there are too many different symbols for the shop categories.

InMapz*:*

With the InMapz map, 2 out of 34 participants stated that they found some information unnecessary. One participant found the depiction of the floor plan around stairs, escalators, and elevators unnecessary. However, it should be noted that the floor plan is already represented by the adjacent polygons. Another participant mentioned that the shop boundaries are too detailed.

Google Maps:

For the Google Maps map, only 1 out of 31 wrote a comment on this question. The comment specified that there are many different shops, yet the same symbol is used for all.

Summary*:*

Generally, very few participants across all maps felt that any information on the map was unnecessary. In the case of the Apple Maps map, one person felt that the precise categorization of shops by symbols was excessive. Conversely, for the Google Maps map, a participant noted the opposite issue, where there was too little distinction between the symbols. Two participants (one from the Own Map and one from the InMapz map) mentioned that the shop boundaries were too detailed and that the lines could be simplified.

Question 6 - How easily can you recognize the different symbols on the map?

The data analysis of question 6 of the questionnaire is shown in figure 51.

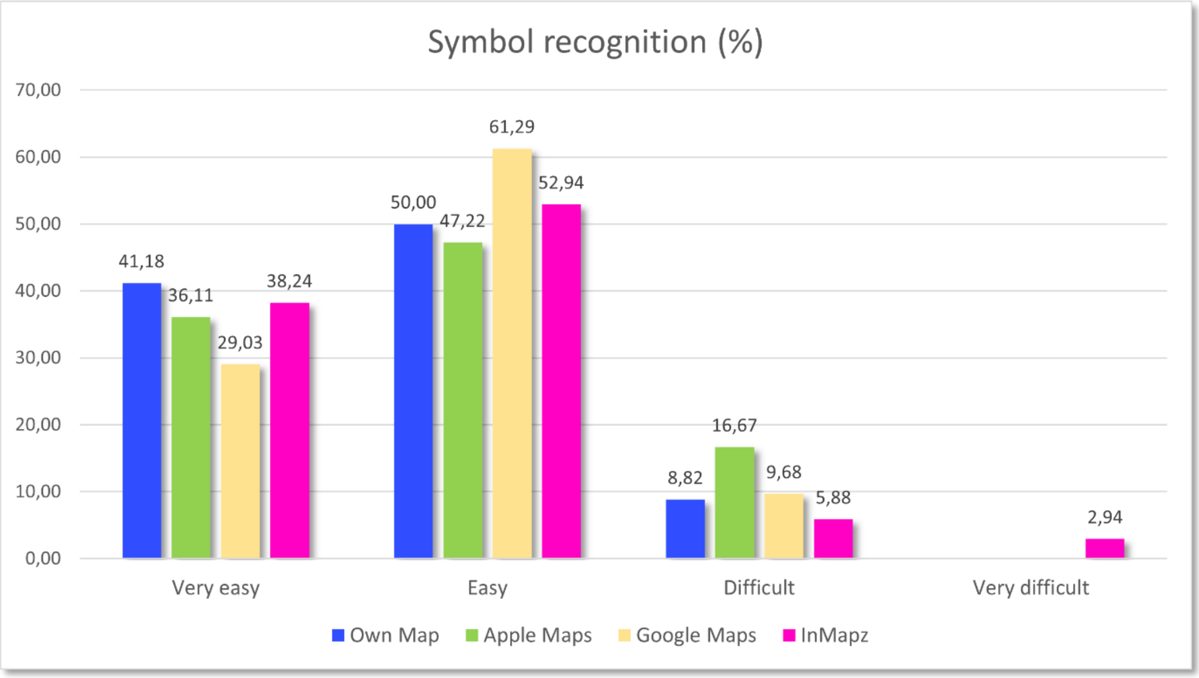

Figure 51: Results of question 6, Symbol recognition

Own Map:

In terms of recognizing the various symbols on the map, the Own Map performed the best overall. In the "Very Easy" category, the Own Map has the best value compared to the other maps with 41.18%. In the "Easy" category, the map shows a value of 50%. Only a small part of the participants (8.82%) found the symbols hard to recognize.

Apple Maps:

The majority of the participants (47.22%) of the Apple Maps map stated that they recognized the different symbols easily. However, it also has the highest proportion of the participants (16.67%) who stated they find the symbols "hard" to recognize among the other maps. In the best category "Very Easy," the Apple Maps map ranks just behind the InMapz map in third place compared to the other maps with 36.11%.

When looking at the Apple Maps map, the shop symbols stand out well in color from the background. Different categories of symbols have different colors and are easily distinguishable. An explanation for the poorer rating compared to the other maps could be the size of the symbols. If the symbol size is compared with the Own Map and the InMapz map, they are rather small and could therefore not be recognized as easily.

Google Maps:

The Google Maps map has the worst value in the best category "Very Easy" in terms of recognizing different symbols overall with 29.03%. However, in the "Easy" category, the Google Maps map has a high proportion of the participants with 62.29%. If the first two categories, where the participants can recognized the symbols on the map "Very Easy" or "Easy," are summed up, the Google Maps map is in second place after the Own Map with 90.32% and is generally rated positively. A small part of the participants (9.68%) finds the symbols "hard" to recognize.

Looking at the Google Maps map, this result seems surprising. Compared with the other maps, the Google Maps map has small symbols. Especially the symbols for stairs, escalators, and elevators are very small. Additionally, the symbols for stairs, escalators, and elevators are colored grey, which can be considered a rather inconspicuous color. A reason for the still positive result in this question could be user experience. Google Maps is a widely used mapping service and is therefore likely known to most participants. As a result, they are already familiar with the map design and find it easy to recognize its symbols.

InMapz:

The majority of the participants (52.94%) stated that they recognized the symbols on the map "easily." In the "Very Easy" category, the InMapz map reached 38.24% and is thus in second place in this category. A small part of the participants (8.82%) stated that they find the symbols on the map "hard" or "very hard" to recognize.

The good rating for the InMapz map is understandable as the shop symbols are displayed very large on the map and thus immediately catch the eye. However, it must also be considered that the shops are represented by their logos, and well-known logos generally have a high recognition value.

Question 7 - Is the meaning of the various symbols on the map clear to you?

The data analysis of question 7 of the questionnaire is shown in figure 52.

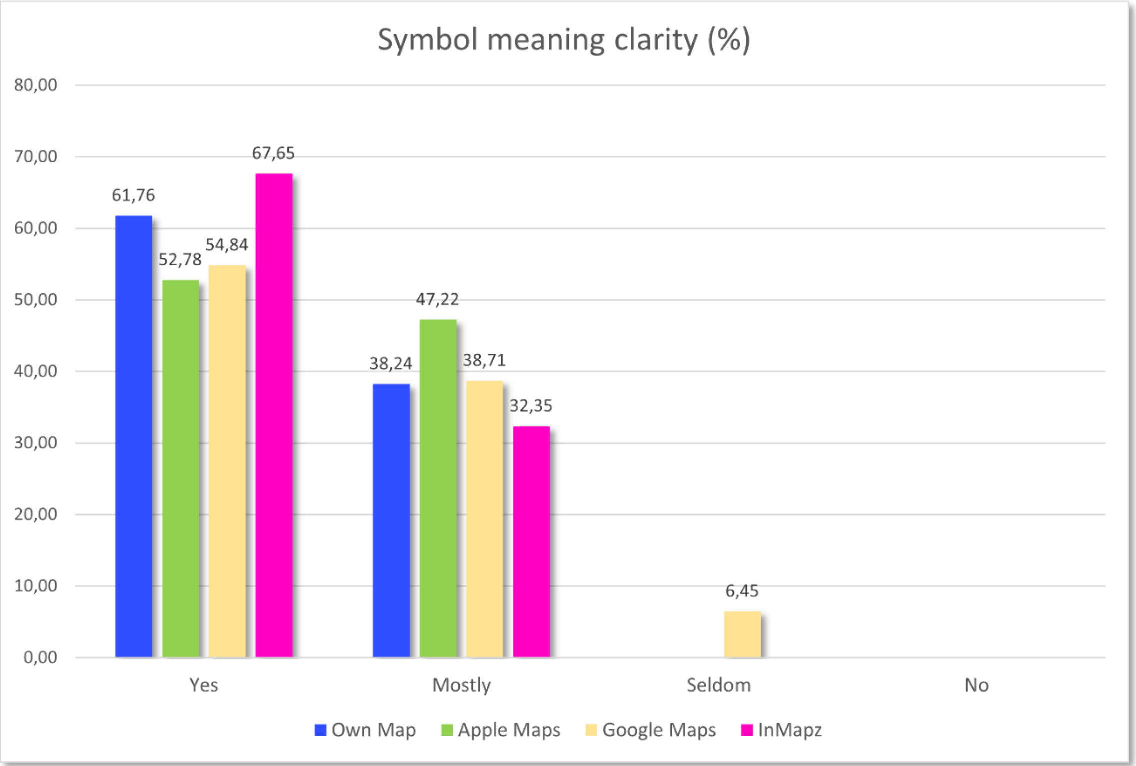

Figure 52: Results of question 7, Symbol meaning clarity

Own Map:

The majority of the participants (61.76%) stated that the meaning of the symbols on the map is always clear. 38.24% of the participants chose the category "Mostly." No participants selected the categories "Seldom" or "No," indicating high clarity in the meaning of the symbols.

Apple Maps:

Compared to the Own Map and InMapz map, fewer participants (52.78%) of the Apple Maps map chose the category "Yes." Instead, 47.22% of the participants chose "Mostly." No participants indicated understanding the symbols "Seldom" or "No". Even though the clarity of symbol meaning is slightly less than that of the Own Map and InMapz map, it can still be considered a positive result.

InMapz:

In comparison to the other maps, most participants of the InMapz map (67.65%) reported always understanding the meaning of the symbols. 32.35% indicated "Mostly," and no participant chose "Seldom" or "No". However, it should be noted that the symbols on this map are primarily the logos of shops, which limits the variation in different symbols compared to the other maps.

The Participants either recognized the logos or they didn't, but there were not many abstract symbols to interpret.

Google Maps:

54.84% of the participants of the Google Maps map chose the category "Yes". 38.71% chose "Mostly". Compared to the other maps, 6.45% of the participants stated that the symbol meaning is "Seldom" clear.

Question 8 - How appealing do you find the visual design of the map?

For this question, the participants were asked to rate the visual appeal of the map displayed in their questionnaire on a scale from one to ten. The average score for each map is shown in figure 53.

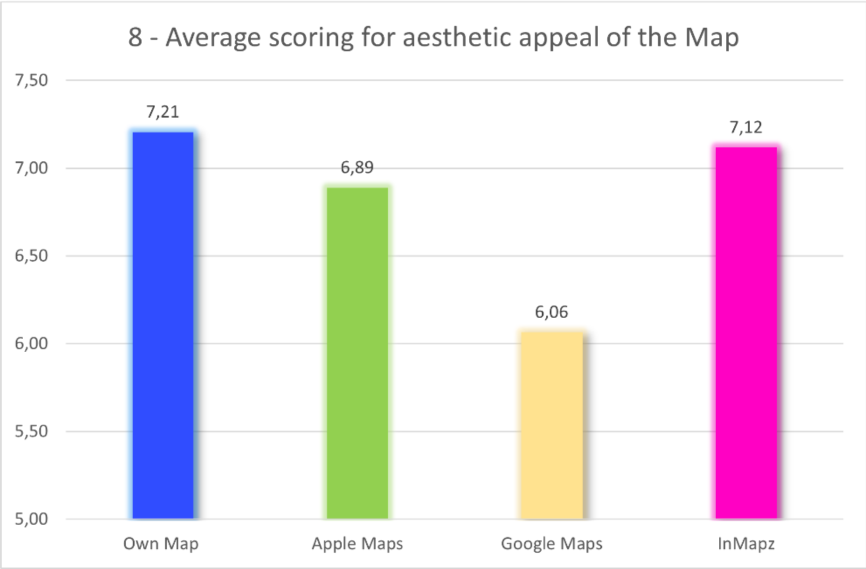

Figure 53: Results of question 8, Aesthetic appeal

The evaluation by the participants shows that the Own Map is the most aesthetically appealing, closely followed by the InMapz map. These two maps are still very different. The InMapz map uses exclusively the respective logos to mark the shop areas and contains significantly less information compared to the Own Map. The Apple Maps map ranks third, and the Google Maps map is in last place.

Question 9 - Does the map contain all the information you need for orientation?

The data analysis of question 9 of the questionnaire is shown in figure 54.

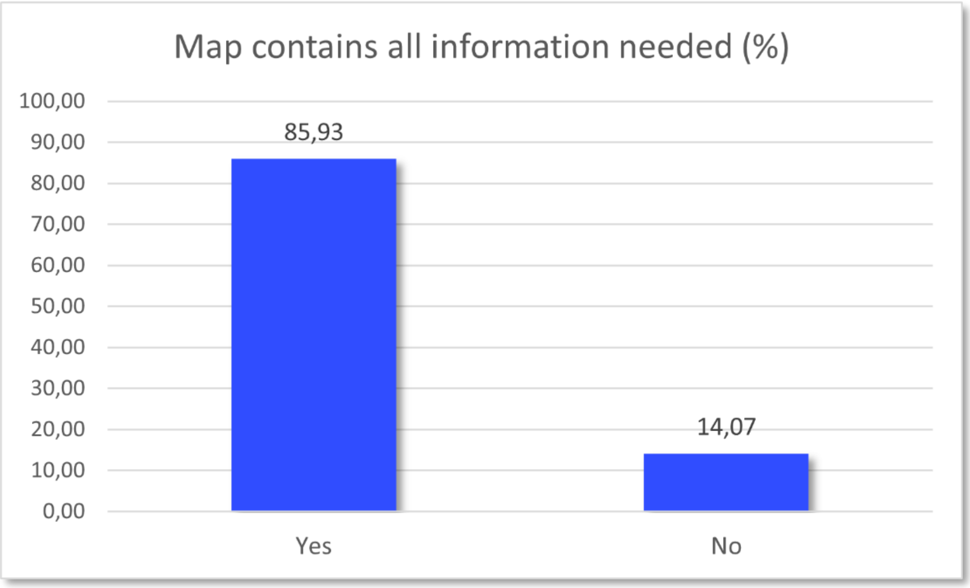

Figure 54: Results of question 9, Information needed

In this question, similar textual comments appeared as in Question 2, where the participants indicated which additional information, they find helpful for orientation. Comments regarding the indication of one's own position or the indication of sanitary facilities and floor information were removed here, as this involved a prototype in which the position symbol and floor level were not displayed. Sanitary facilities were not shown on the map because there were none on this floor of the building.

Since the same comments recur across all maps and only very few comments refer specifically to the map itself, similar comments from all maps will initially be summarized. The individual comments that relate specifically to the map itself will be discussed separately afterward.

Table 17: Additional information needed

Category	Number of comments
Cardinal direction	4
Escape routes	2
Entrances and exits (Apple Maps and Google Maps)	5
Unclear areas of empty polygons	5
Direction of stairs and escalators	3

On the InMapz map, there was a comment regarding the shop designations that do not display a logo. The participant commented that there is confusion as to why some stores are marked with logos and others with black text. This was because no logo existed for that store. However, it is clear that the altered representation of the shop can lead to confusion among users. Another comment referred to the Own Map. Here, the participant commented that it was unclear what the line patterns of the atrium representation meant.

Question 10 - If you could make a suggestion for improving this map, what would it be?

The comments written by the participants were summarized into thematic categories and are presented in the following tables.

Table 18: Own Map, Suggestions for improvement

Category	**Number of comments**
Legend	4
Color difference between different usage areas	4
Stronger color contrast/boundaries	3
Text/symbols too large	2
Entrances to shops and stairs	2
Display of surrounding streets outside the building	1

Table 19: Apple Maps, Suggestions for improvement

Category	**Number of comments**
Legend	2
Color difference between different usage areas	6
Labeling of unlabeled polygons	1
Text/symbols too small	3
Entrances to shops and stairs	4
Display of surrounding streets outside the building	1
Display direction of stairs/escalator	3
Display entrances of building	3

Table 20: Google Maps, Suggestions for improvement

Category	**Number of comments**
Color difference between different usage areas	3
Text/symbols too small	6
Higher color contrast	5
Display direction of stairs/escalator	2
Unappealing colors	2
Unappealing symbols	2

Table 21: InMapz, Suggestions for improvement

Category	Number of comments
Color difference between different usage areas	3
Shop-Logos too big	1
Higher color contrast	2
Display direction of stairs/escalator	1
Unappealing colors	3
Display of surrounding streets outside the building	1
Legend	1

Based on user comments about different indoor navigation systems, several common suggestions for improvement that can enhance usability have been identified.

A frequently mentioned issue concerns color differences between different usage areas. Users desire clearer color distinctions to better differentiate between various areas. This was commented on a total of 16 times. Another common problem concerns the size of texts and symbols on the maps. Especially with Google Maps (6 comments) and Apple Maps (3 comments), texts and symbols were found to be too small, making them hard to read. The representation of shop entrances and stairs is another important aspect, commented on a total of 8 times. Users want a clearer display of these entrances.

In summary, the most frequent comments call for improving color differences, adjusting text and symbol sizes, enhancing color contrast, and clearly displaying entrances.

Question 11 - Please rank the following route visualizations according to your preference

The participants were able to rank the route visualizations shown in figure 55. This means placing the preferred route visualization in first place and then descending to the least preferred route visualization.

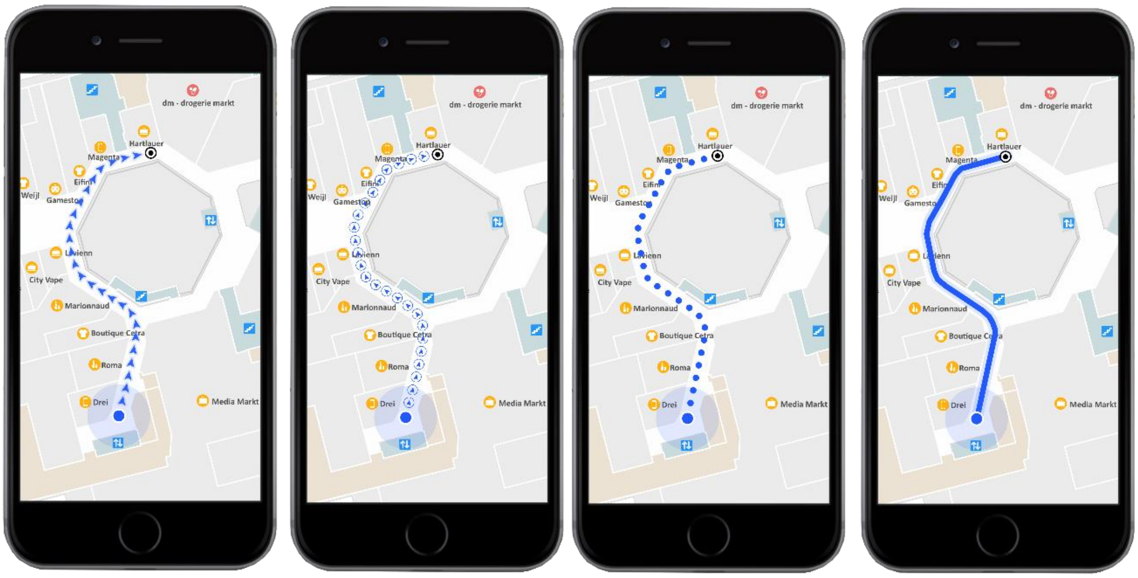

Figure 55: Route visualization options in the questionnaire

Figure 56 shows the results of the ranking.

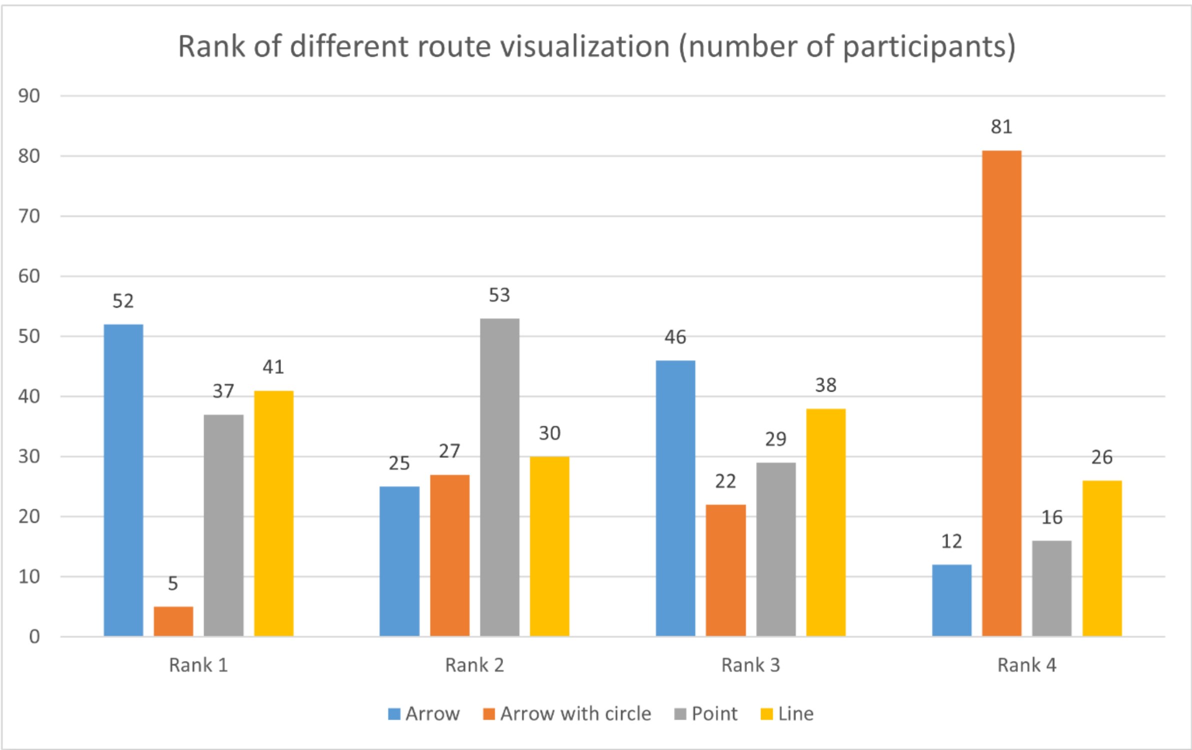

Figure 56: Results of question 11, Route visualization

The results show that most of the participants preferred the arrow visualization of the route. However, it is also often ranked third. The point visualization was most frequently placed in the second rank, but also often in the first rank. The line visualization was the second most frequently placed in the first rank, but it also has the second highest number of votes in the fourth rank. The arrow visualization is clearly the least preferred with 81 mentions in the last rank.

The weighting of the values from Question 11 results in the following table:

Table 22: Route visualization

Visualization	Rank 1 (x2)	Rank 2 (x1)	Rank 3 (x-1)	Rank 4 (x-2)	Total points
Arrow	52 (104)	25 (25)	46 (-46)	12 (-24)	104 + 25 – 46 – 24 **= 59**
Arrow with circle	5 (10)	27 (27)	22 (-22)	81 (-162)	10 + 27 – 22 -162 **= -147**
Point	37 (74)	53 (53)	29 (-29)	16 (-32)	74 + 53 – 29 -32 **= 66**
Line	41 (82)	30 (30)	38 (-38)	26 (-52)	82 + 30 – 38 – 52 **= 22**

When the results are weighted, it turns out that the point visualization of the route is overall the most preferred, followed by the arrow visualization, then line visualization, and finally the arrow visualization with a circle.

Question 12 - Please rank the following additional route descriptions according to your preference

The participants were able to rank the route descriptions shown in figure 57. This means placing the preferred route description in first place and then descending to the least preferred route description.

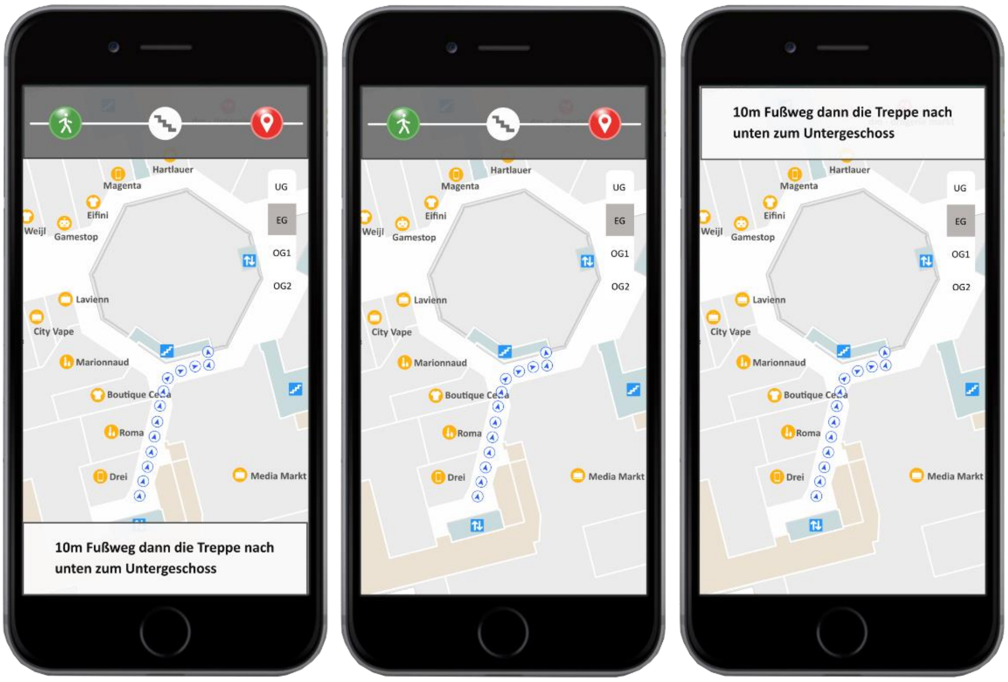

Figure 57: Graphical versus textual route description

Figure 58 shows the results of the ranking.

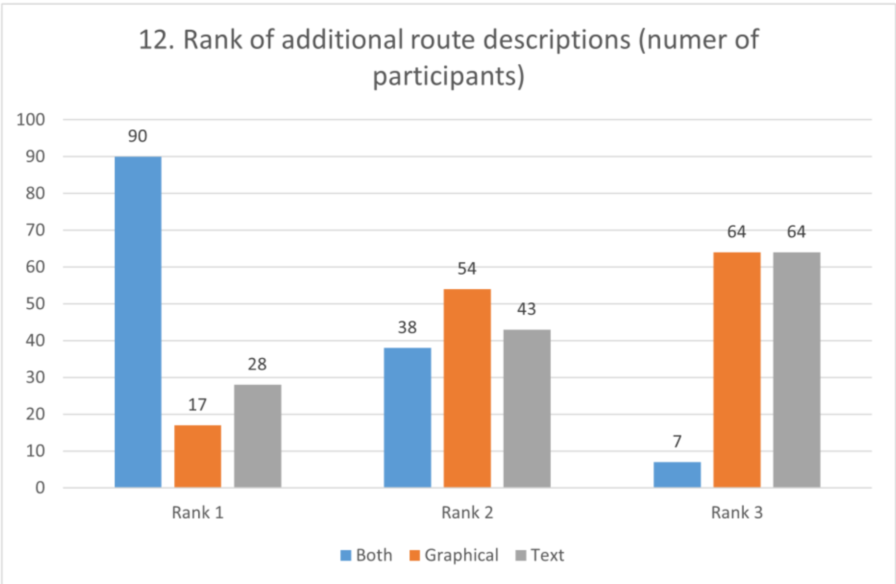

Figure 58: Results of question 12, Graphical and textual route descriptions

The results show that most of the participants preferred a combination of graphical and textual route description. When looking at the first rank, the textual route description has the second most mentions and the graphical route description the least mentions. In the second rank, the graphical route description received slightly more mentions than the textual one and is generally rated positively. Last rank, the textual and the graphical route descriptions received the same number of mentions. A small portion of the participants placed the combination of textual and graphical route descriptions at the third and last rank.

In this case, since there are only three ranks, the weighting is distributed such that the second rank gives 0 points, the first rank gives +1 point, and the third rank gives -1 point.

Table 23: Route description (Graphical versus textual)

Description	Rank 1 (x1)	Rank 2 (x0)	Rank 3 (x-1)	Total points
Both	90 (90)	38 (0)	7 (7)	90 – 7 **= 83**
Graphical	17 (17)	54 (0)	64 -64)	17 – 64 **= -47**
Text	28 (28)	43 (0)	64 (-64)	28 – 64 **= -36**

When the results are weighted, the combination of textual and graphical route descriptions was clearly placed more often in the first rank. This is therefore the preferred variant. There is a smaller point difference of 11 points between the textual and graphical route descriptions. However, in contrast to the graphical, there is a preference for the textual route description.

Question 13 - Please rank the following textual route descriptions according to your preference

The participants were able to rank the textual route descriptions shown in figure 59. To evaluate purely textual route descriptions, different forms of textual information were also surveyed. From the literature review (Chapter 2.2.3), it emerged that Gotlib (2019) recommended qualitatively describing textual route descriptions. The participants were able to rank qualitative descriptions, metric descriptions, and a combination of both according to their preferences.

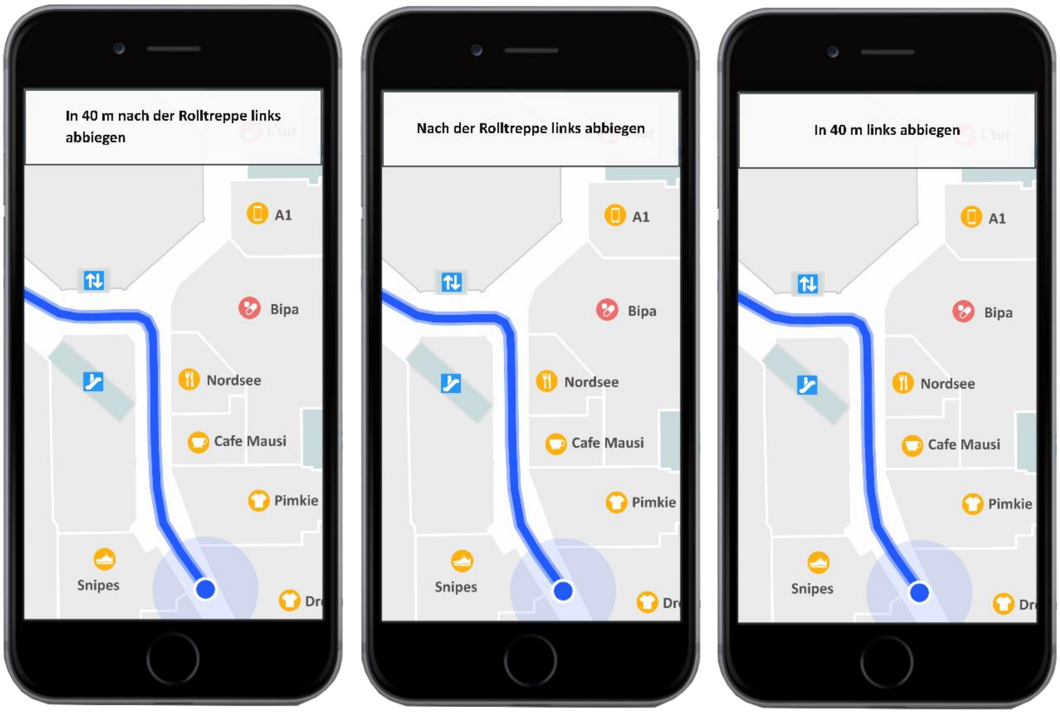

Figure 59: Qualitative versus metric route descriptions

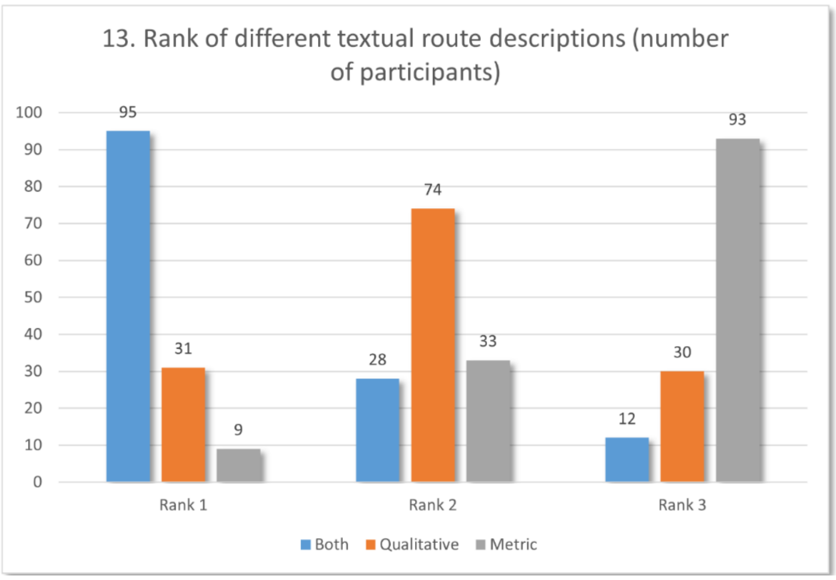

Figure 60: Results of question 13, Qualitative and metric route descriptions

The results show that in the first rank, the combination of qualitative and metric route descriptions is clearly preferred with 95 mentions. In the first rank at second place is the qualitative route description, followed by the metric one. Even in the second rank, it is evident that the qualitative description was clearly preferred.

Here again we have only three ranks. The same weighting procedure as in question 12 applies. The weighting results are shown in table 24.

Table 24: Route descriptions (Qualitative versus metric)

Description	Rank 1 (x1)	Rank 2 (x0)	Rank 3 (x-1)	Total points
Both	95 (95)	28 (0)	12 (-12)	95 – 12 **= 83**
Qualitative	31 (31)	74 (0)	30 (-30)	31 – 30 **= 1**
Metric	9 (9)	33 (0)	93 (-93)	9 – 93 = **-84**

In the weighting, it is also clear that the combination of both descriptions clearly performed best, followed by the qualitative description of the route. The metric route description ranked third with a significant point difference of -85 points.

Question 14 - On map a), the continuation of the route to another floor is included. How do you assess the usefulness of this depiction compared to map b), which only shows the route within one floor?

This question investigated whether participants prefer the depiction of a route continuation on another floor or if the route should only be displayed within the same floor. The visualization options are shown in figure 61.

Figure 61: Visualization of route continuation

The results are shown in figure 62.

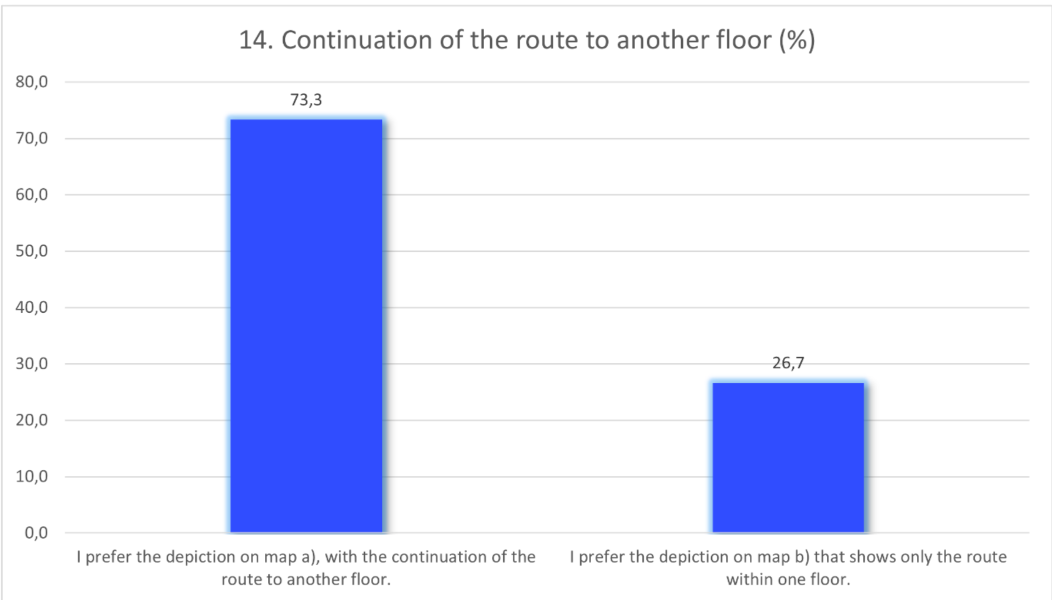

Figure 62: Results of question 14, Route continuation

The results show that the majority of the participants (73.3%) preferred the depiction of the route with its continuation on a different floor. 26.7% of the participants preferred the route to be displayed only within the respective floor.

This indicates that a complete view of the route is preferred, although it does not always pertain to the respective floor. This allows participants to get a comprehensive view of the route and reduces the need to switch between different floor views.

One reason for participants preferring the depiction of the route only within one floor might be that they find it simpler to view the progression of the route separated by floor. Additionally, continuing the route within one floor could lead to an overload of the map.

Question 15 - Please rank the following position symbols according to your preference

This question examined the participants' preferences regarding different position symbols on maps. The five different symbols are: blue dot, blue dot with direction, arrow, pin, and cross. The participants were able to rank the different position symbols shown in figure 63.

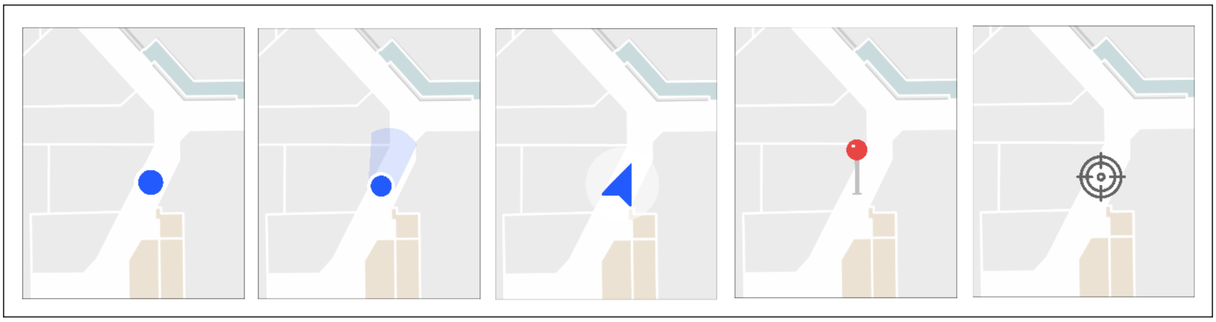

Figure 63: Visualization options for position symbols

Figure 64 shows the results of the ranking.

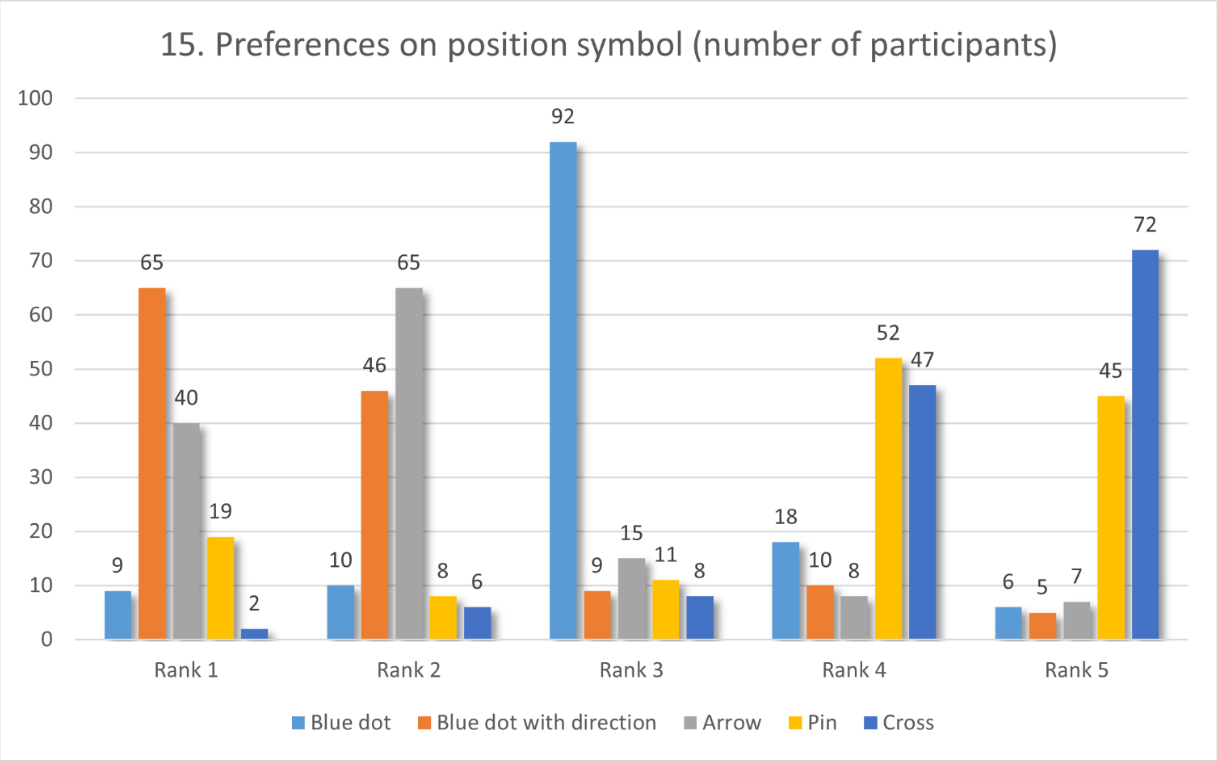

Figure 64: Results of question 15, Position symbol

In the first and second rank, it is clear that the Blue Dot with Direction Indicator and the Arrow have received the most mentions. This indicates that symbols which provide information about the user's direction of view are preferred. In the third rank, the simple blue dot received the most mentions, although it, like the Cross and Pin, does not indicate a direction. The Cross and the Pin clearly have the most mentions in ranks 4 and 5. A reason for the better rating of the simple blue dot could be that it is more intuitive, as this type of position representation is already widely used and thus familiar to users.

In this case, since there are five ranks, the weighting is distributed such that the first rank gives +2 points, the second rank gives +1 point, the third rank gives 0 points, the fourth rank gives -1 point and the fifth rank gives -2 points. The weighting results are shown in table 25.

Table 25: Position symbol

Visualization	Rank 1 (x2)	Rank 2 (x1)	Rank 3 (x0)	Rank 4 (x-1)	Rank 5 (x-2)	Total points
Blue dot	9 (18)	10 (10)	92 (0)	18 (-18)	6 (-12)	18 + 10 – 18 – 12 **= -2**
Blue dot with direction	65 (130)	46 (46)	9 (0)	10 (-10)	5 (-10)	130 + 46 – 10 – 10 **= 156**
Arrow	40 (80)	65 (65)	15 (0)	8 (-8)	7 (-14)	80 + 65 – 8 - 14 **= 123**
Pin	19 (38)	8 (8)	11 (0)	52 (-52)	45 (-90)	38 + 8 – 52 – 90 **= -96**
Cross	2 (4)	6 (6)	8 (0)	47 (-47)	72 (-144)	4 + 6 – 47 – 144 **= -181**

When the results are viewed with weighting, they show a similar pattern. The preferred representation is the blue dot, followed by the arrow with a small point difference. The simple blue dot is in third place. Regarding the cross and the pin, it is clear to see that the cross is the least preferred by a significant margin of -85 points compared to the pin.

Question 16 - In the case of an imprecise position, should the area of uncertainty be displayed with or without a position symbol?

In this question, the participants could choose between two different visualizations of positional inaccuracies. One visualization showed the area of uncertainty with an additional "more precise" position symbol, while the other visualization showed the area of uncertainty alone.

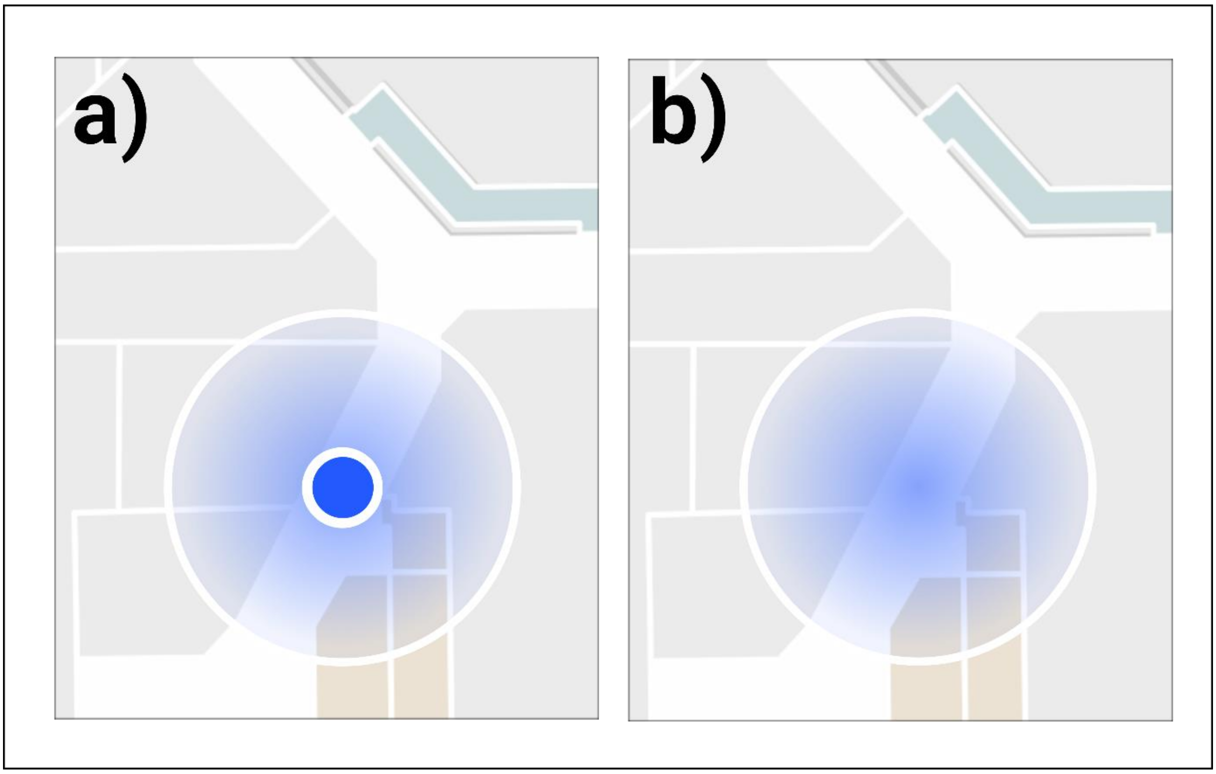

Figure 65: Visualization options for position uncertainty

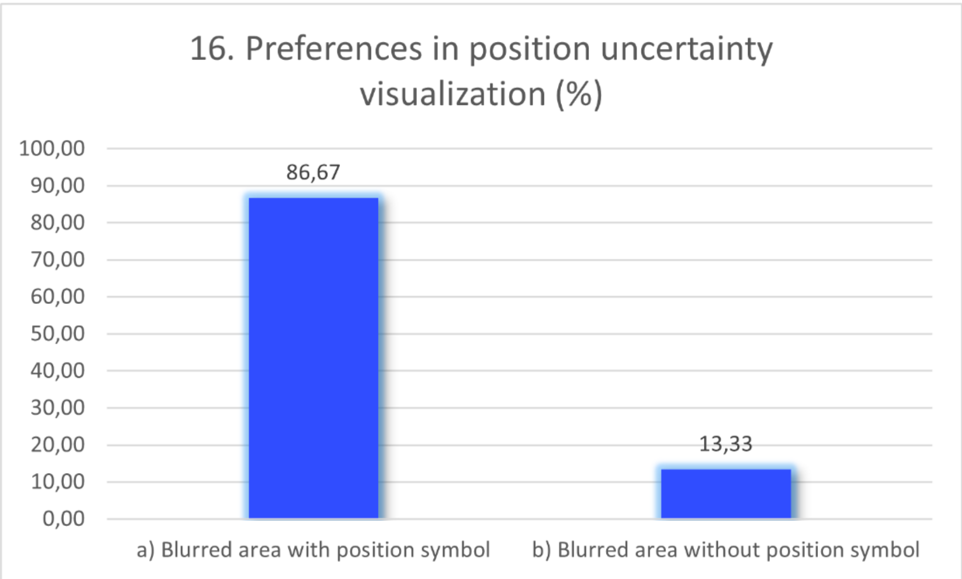

Figure 66: Results of question 16, Position uncertainty

The results show that the majority of the participants, with 86.67%, preferred when the area of uncertainty is displayed with an additional position symbol. 13.33% of the participants were satisfied with just the area of uncertainty alone.

A possible reason for this preference may be that even if the additional blue position point might not be accurate, users still have a clear reference point, which helps them better orient themselves and understand their position. Additionally, users might perceive the display with only the area of uncertainty as less informative.

Question 17 - Please rank the following floor visualizations according to your preference

In this question, several ways to visualize different floors were presented. There were three options: a consistent visualization of the various floors, a color gradient between the floors with lighter colors for higher floors, and completely different colors for each floor (see figure 67). The participants were able to rank the different floor visualizations shown in figure 68.

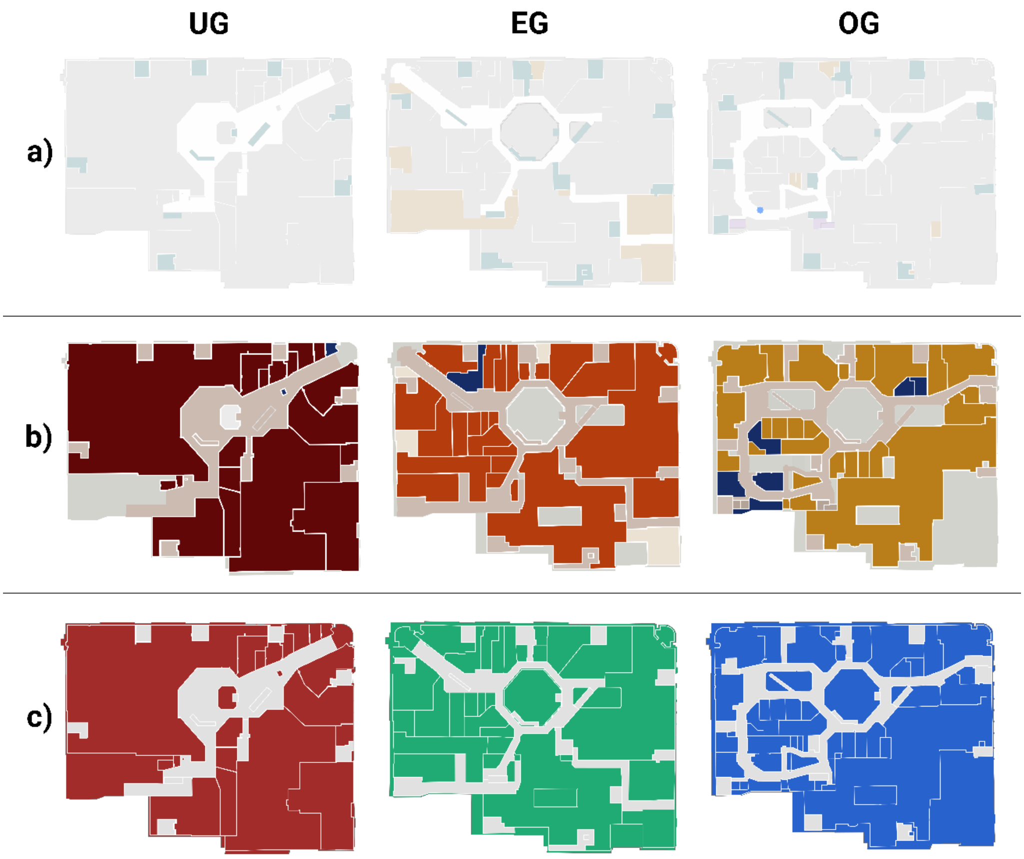

Figure 68: Visualization options for floors

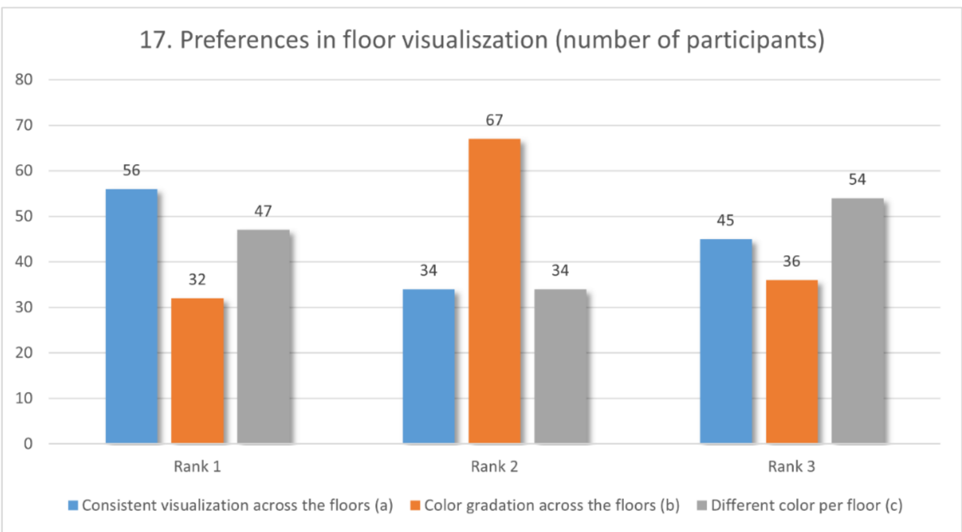

Figure 67: Results of question 17, Floor visualization

The majority of the participants ranked consistent visualization for the first rank, followed by visualization with different colors, and finally the color gradation across the floors. In the second rank, the color gradation received significantly more mentions, suggesting that users generally find this representation helpful. The visualization with different colors per floor received the most mentions in the third rank. A possible reason for the relatively poorer rating of this option might be that users could be confused by too many different colors.

The weighting of the values from Question 17 is shown in table 26.

Table 26: Floor visualization

Visualization	Rank 1 (x1)	Rank 2 (x0)	Rank 3 (x-1)	Total points
Consistent	56 (56)	34 (0)	45 (-45)	56 – 45 **= 11**
Color gradation	32 (32)	67 (0)	36 (-36)	32 – 36 **= -4**
Different color	47 (47)	34 (0)	54 (-54)	47 – 54 **= -7**

Overall, the results show that the ratings of the different visualizations are quite close together, indicating no clear preference. In the weighting, there are no significant point differences. However, the numbers indicate that the consistent floor visualization is preferred, followed by the color gradation across the floors, and then the use of different colors.

An aspect that should also be considered in this question is that cartographic work becomes more complicated with a non-consistent visualization of the floors. Unlike consistent visualization, care must be taken to ensure that the overall color harmony of the map is maintained despite using different base colors.

Question 18 - Please rank the following airspace visualizations according to your preference

In this question, the preferences of the participants regarding airspace visualizations were investigated. Airspaces are common in buildings, making their visualization important. The question provided three visualization options: individual pattern, hatched polygon, and empty polygon. The participants were able to rank the different airspace visualizations shown in figure 69.

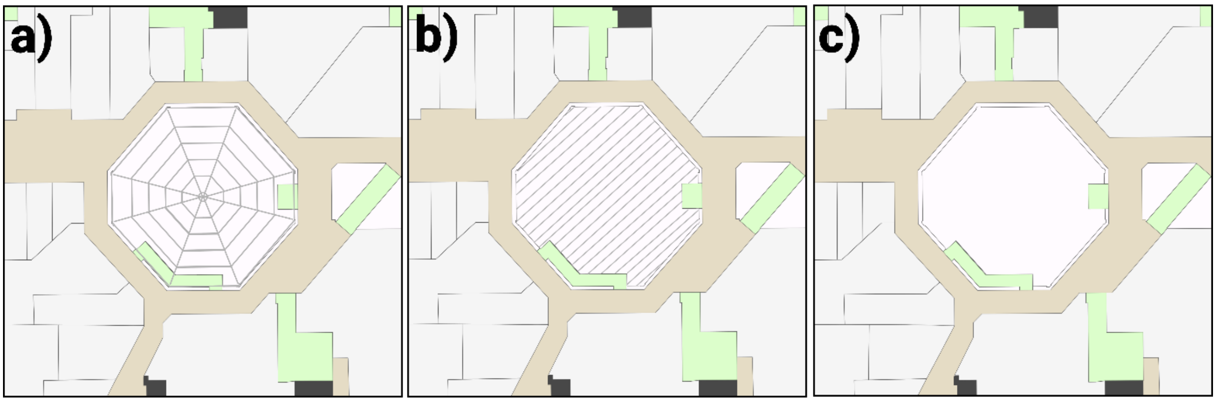

Figure 69: Atrium visualization options

The results of the ranking are shown in figure 70.

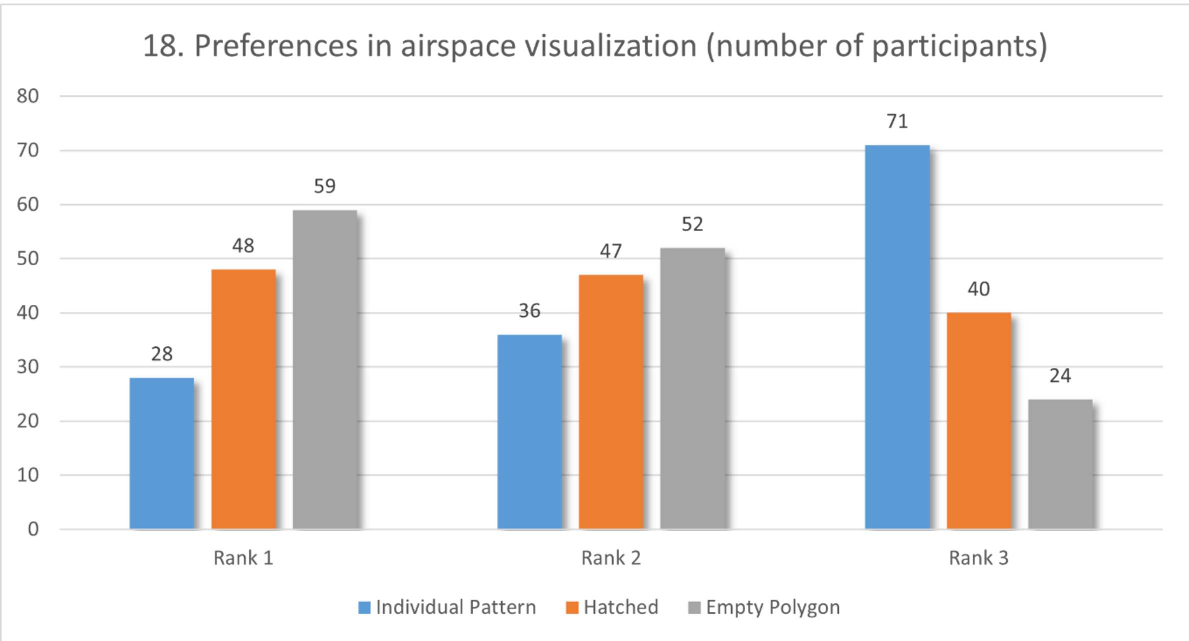

Figure 70: Results of question 70, Atrium / airspace visualization

The airspace visualization with an empty polygon received the most mentions in Rank 1 and Rank 2 and the fewest in Rank 3. The hatched polygon consistently ranked second in each category. Consequently, the individual pattern was least preferred. Participants might have found the individual pattern too distracting or confusing. The results suggest that the participants preferred the empty polygon, although the hatched area is also found helpful in highlighting airspace.

Table 27: Atrium visualization

Visualization	Rank 1 (x1)	Rank 2 (x0)	Rank 3 (x-1)	Total points
Individual pattern	28 (28)	36 (0)	71 (-71)	28 – 71 **= -43**
Hatched polygon	48 (48)	47 (0)	40 (-40)	48 – 40 **= 8**
Empty polygon	59 (59)	52 (0)	24 (-24)	59 – 24 **= 35**

When the results are considered with weighting, they paint a similar picture. The empty area is rated the best, with a relatively larger point difference compared to the hatched area. The individual pattern is rated the worst and has a significant point difference of -51 compared to the hatched area.

Interestingly, the result from question 5 shows that the participants did not know what the polygon represented even when it was an empty area. Similarly, with the map featuring the individual line pattern, no more participants understood what it represented compared to the other maps. Perhaps a completely different approach to airspace visualization should be considered.

Question 19 - Do you prefer a simple stair symbol, or one with a directional indicator that shows whether the stairs go up or down?

For the representation of stairs, the participants had two options to choose from: a simple stair symbol and one with arrows indicating the vertical direction of the stairs (see figure 71).

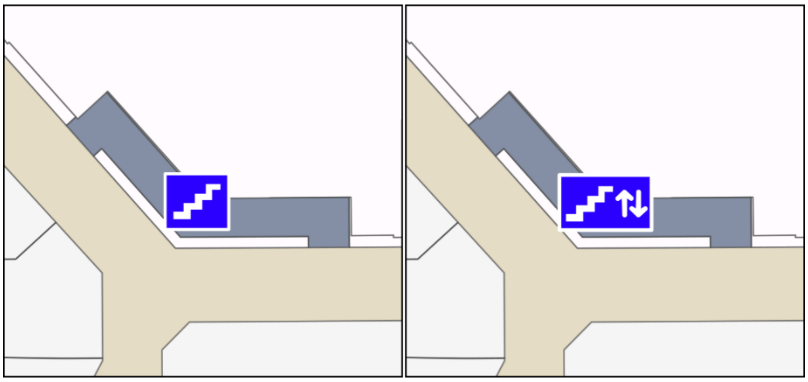

Figure 71: Stair symbol options in the questionnaire

The responses from the participants indicate that there is no clear preference between these two options, however, the visualization with arrows received slightly more mentions (52.59%). The results thus show a slight preference for the representation with arrows, but a considerable portion of the participants preferred the simple stair symbol.

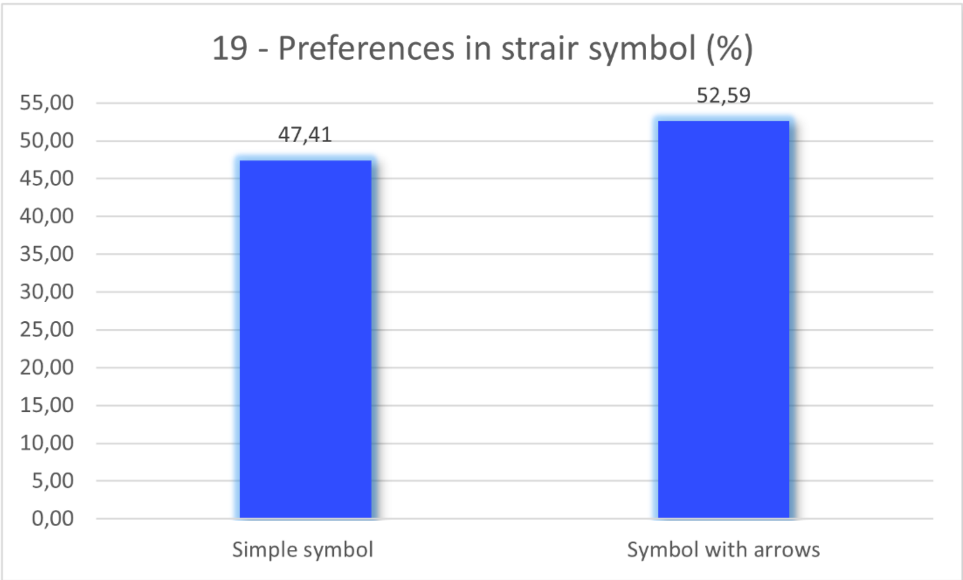

Figure 72: Results of question 19, Stair symbol

Some participants commented in the questionnaire that they did not understand the question, as stairs can always be used in both directions. This comment suggests that some participants may not have understood the question as intended, which could potentially skew the results.

Question 20 - Please rank the maps according to your preference

To draw a comparison between the maps, the last question of the questionnaire displayed all four maps, and the participants were asked to rank the different map designs (see figure 73) according to their preference. The results of the ranking are shown in figure 74.

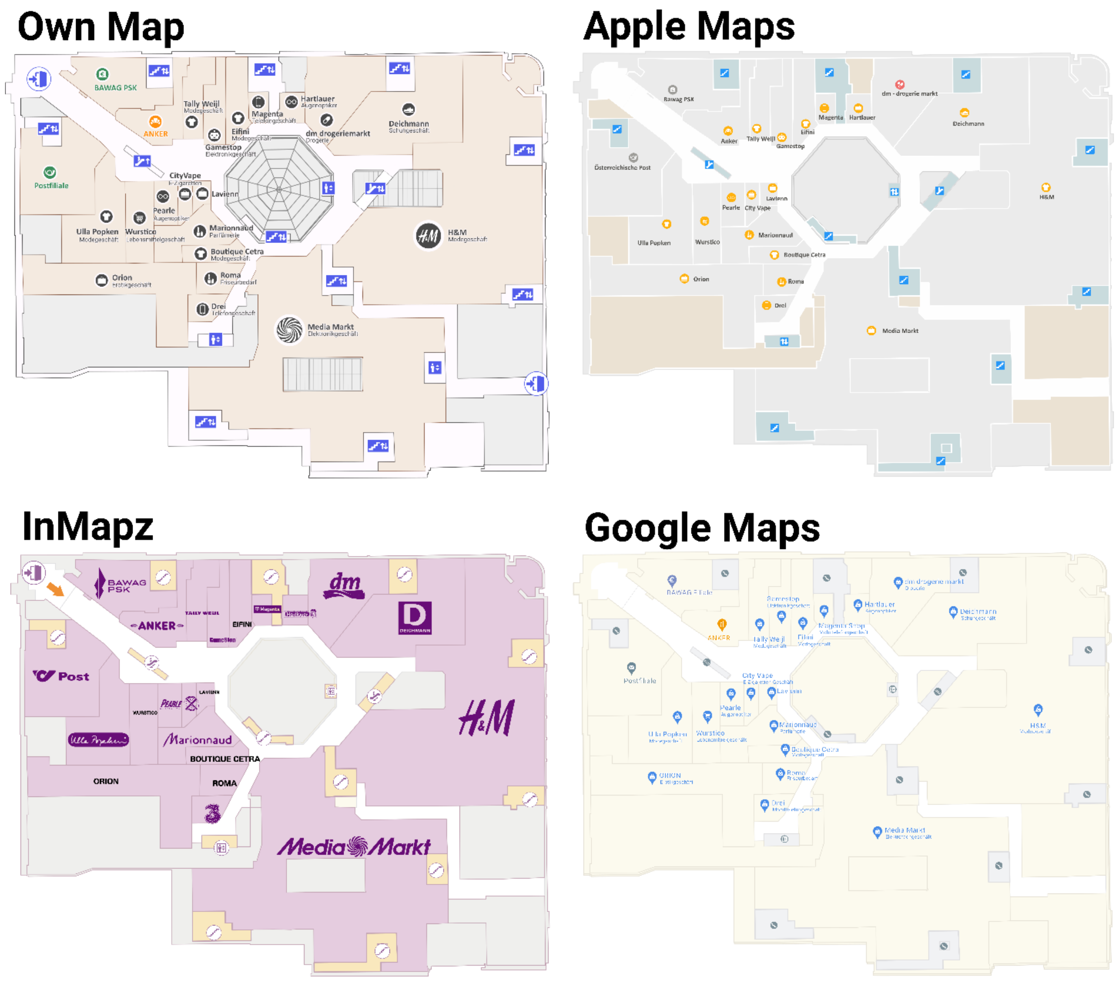

Figure 73: Map design options in the questionnaire

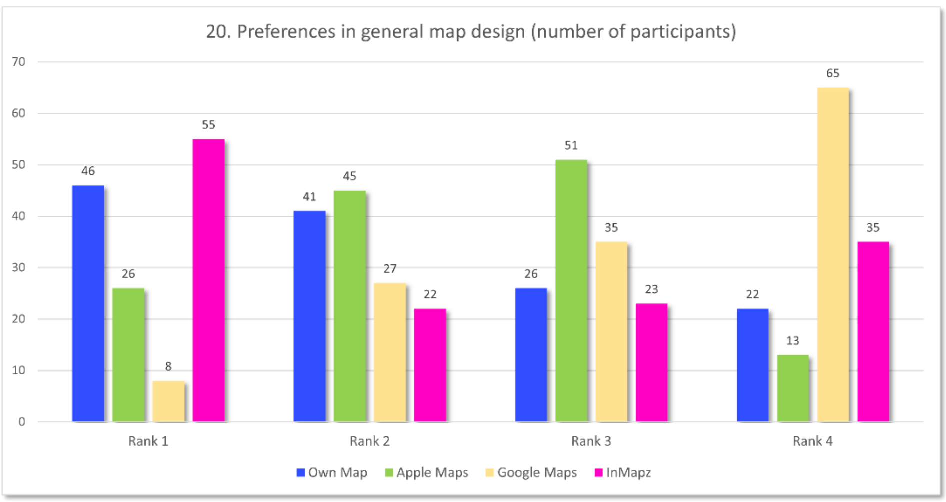

Figure 74: Results of question 20, Map design

When considering the results of the first rank, it is noticeable that the Own Map and the InMapz map were most frequently mentioned by the participants, with the InMapz map received a few more mentions. The Google Maps map received the fewest mentions in the first rank, and as the ranks decrease, the number of Google Maps mentions steadily increases. The Apple Maps map had the highest number of mentions in rank 3, but also a considerable amount in rank 2 and the fewest mentions in rank 4. In the middle ranks, the map mentions are somewhat more evenly distributed compared to rank 1 and rank 4.

The results show a clear preference for the Own Map and the InMapz map, although they follow different cartographic approaches. The Apple Maps map is frequently mentioned in the second and third rank, while the Google Maps map is the least preferred map. To account for all ranks, weighting is also carried out here again.

Table 28: Map design

Map design	Rank 1 (x2)	Rank 2 (x1)	Rank 3 (x-1)	Rank 4 (x-2)	Total points
Own Map	46 (92)	41 (41)	26 (-26)	22 (-44)	92 + 41 – 26 – 44 **= 63**
Apple Maps	26 (52)	45 (45)	51 (-51)	13 (-26)	52 + 45 – 51 -26 **= 20**
Google Maps	8 (16)	27 (27)	35 (-35)	65 (-130)	16 + 27 – 35 -130 **= -57**
InMapz	55 (110)	22 (22)	23 (-23)	35 (-70)	110 + 22 – 23 – 70 **= 39**

When all ranks are compared, the Own Map is generally preferred, even though it ranks second to the InMapz map in the first rank. This is because the Own Map was mentioned significantly more often for the second rank than the InMapz map. Additionally, the Own Map was placed in the last rank less often compared to the InMapz map.

Therefore, when the weighted evaluation is considered, the Own Map is clearly the preferred one among the other maps, with 24 points more than the InMapz map. The Apple Maps map is in third place, and the Google Maps map is last. Generally, it can be said that the participants' preferences regarding the map design go in two different directions (Own Map and InMapz Map). This could be because some users prefer the display with the logos and some not. The Apple Maps map is in the middle and is somewhat less preferred overall, while the Google Maps map is clearly poorly rated.

4.4.2 Discussion

The following summarizes and discusses the main results of the survey. The results are structured into more general topics:

Level of detail

The level of detail of a map is a crucial element that ensures usability. Overall, the Own Map and the InMapz map were rated the best in terms of their level of detail. The InMapz map was rated slightly better. When comparing the two maps, it should be considered that the Own Map has a significantly higher information density. The Own Map represents shop categories, provides direction information for objects of floor change, and marks airspaces. Despite the significantly higher information density, the majority of the participants found the level of detail of the map to be "just right", which indicates a good composition of the information on the map.

Stefanakis et al. (2006), Gartner and Radoczky (2005), and Montello and Sas (2006) emphasized in their work that the map should contain all the information that is crucial for navigation, but not so much that it distracts the user (Chapter 2.1.1). Additionally, Nossum (2013) pointed out the importance of considering which information should be displayed on indoor maps and which should not. If a user, who for example is looking for an electronics store, now uses the InMapz map with the logos, but the logos are not known to this user, he cannot do much with this map. For this user, the map would no longer provide all the information he needs. When both maps are viewed from this perspective, the Own Map offers significantly more information, which is important for navigation and is also additionally rated as "just right" in terms of its level of detail.

The maps Apple Maps and Google Maps are often rated as too less detailed, although they display even more information compared to the InMapz map (shop categories). The author of this work posits that this rating is likely related to the size of the symbols. These are significantly smaller on these maps and are therefore likely to be less recognized. This could lead to an overall general impression of less detail.

Landmarks

Puikkonen et al. (2009) emphasized in their work that landmarks in indoor areas must be assigned greater importance than in outdoor areas. This is due to the fact that there is generally no concept of the north in buildings, nor do corridors have names, as streets in outdoor areas. The results show that the participants, especially, use the floor plan and shop symbols as orientation aids. Apart from the InMapz map, the floor plan was most often placed first in all maps. Considering the InMapz map, this seems plausible since the shop logos are the most striking symbols on the map. Gangaputra (2017) found in her work that landmarks are characterized by their uniqueness, contrast, prominence, and significance (Chapter 2.1.5). If this is applied to the logos, it can be said that they are unique, as each store has its own logo. Prominence refers to the familiarity of an object. So, if the logos are known to the users, they are strongly perceived. Similarly, the significance is clear and memorable when the logos are known. Zhu et al. (2019) also found during their study that in shopping centers, the shops are the most noticed by users (Chapter 2.1.5).

Considering the difference in results from the InMapz map to the other maps, it becomes clear that the orientation aids used by the users also depend on the prominent elements on the map. That is, elements that are quickly and strongly perceived are also more likely to be used as orientation aids. Here it must be considered that logos should be displayed large and prominently. In shopping centers, there are of course also small shop areas where logos cannot be displayed large. If a logo is then displayed small due to the shop area, the question arises as to how reasonable the logo display still is.

The line pattern for the atrium proposed by the author of this work for visualizing an atrium was rated the worst by the participants. Interestingly, the empty polygon was the most popular, although, as evident from Question 4, it also does not provide any information about what this polygon represents. In shopping centers, airspaces and openings in the floor, where one can see into another floor, are common. Therefore, developing cartographic approaches for representing such spaces is important. Since the hatched and the individual pattern were poorly rated, further consideration must be given to how airspaces are represented so that their interpretation on the map corresponds to reality. Perhaps in further study, a dot pattern could be tested. This would not be so dominant and would be more likely associated with airspace. In general, leaving the area empty is not considered effective by the author of this work, as the atrium could then be confused with non-walkable areas, and no distinction would be made between these areas.

Other orientation aids, which were often mentioned by the participants, were the marking of sanitary facilities, shop entrances for large shops, access to stairs, floor information, and building entrance.

Symbols

Gartner, Cartwright, and Peterson (2007) pointed out that pictograms should be used for stairs, escalators, and elevators (Chapter 2.1.2). However, it is not yet addressed that directional information for stairs and escalators is relevant for users. In the open-ended questions, comments from the participants were frequently made, indicating that they do not know whether, for example, an escalator goes up or down. The results clearly indicate that directional information for stairs and escalators is a relevant and not to be neglected aspect for indoor maps.

The marking of shop entrances has not been addressed in existing studies of the theoretical part (Chapter 2.1). However, the results of the questionnaire show that this is an important aspect. This was frequently noted in the open questions by the participants. Especially with large shop areas, it is not clear where the entrance to the shop is located. This aspect is also evident with stairs, as some stairs adjoin several shop areas. Some participants commented that it is not clear from which shop the stairs were accessible from. Drawing doors in unclear areas is an important part of designing indoor maps.

Regarding symbol recognition and meaning, all maps received a good rating overall and there are no clear differences to be seen. However, despite its good symbol recognition rating, the Google Maps map received frequent comments in the later question, where the participants could suggest improvements for the map, that the symbols are too small. This means that the Google Maps symbols are well recognized, but still perceived as too small by the participants. Since Google Maps is a widely used mapping application, this could indicate that the symbols are well recognized by the participants because they are already familiar with the map design of Google Maps. Therefore, the good rating of symbol recognition in the Google Maps map could be due to user habits.

Regarding the recognition of symbol meaning, the Apple Maps and Google Maps map performed slightly worse. This could be due to the symbol size, as these are displayed smaller than on the Own Map and the InMapz map. The fact that the Own Map uses very similar symbols to the Apple Maps map, only that they are displayed larger on the Own Map, underscores this assumption. When the InMapz map is considered, it can be noted that there are fewer symbols to interpret here, as mainly logos are used, while the other maps use abstract symbols for the shops.

Floors

Nossum (2013) uses different colors for different floors in the representation of 'Indoor Tubes' (Chapter 2.1.2). Although a topographic and not schematic map was used for building representation in this work, a similar approach was surveyed in the questionnaire. The participants could choose between three floor visualization options: consistent floor visualization, floor visualization with color gradation, and floor visualization with different colors. When the results are weighted, the consistent floor visualization is generally preferred by the participants, however, a significant portion of the participants also prefer the other two variants. An advantage of the consistent floor visualization is that it ensures color harmony across all floors, while with changing base color of the map, the remaining colors no longer match.

Colors and visual appeal

From the Thinking Aloud testing (Chapter 4.2), it was already evident that a color differentiation between different usage areas is helpful, so that, for example, restaurants can be quickly distinguished from shops. This approach is also used by all maps except the InMapz map, but with a color differentiation of the symbols. Some participants mentioned in the open questions that they would find it beneficial if the area had a different color to make this distinction more quickly recognizable. This raises the question of whether the map would become too cluttered if the entire area had a different color and not just the symbol. Therefore, further tests would need to be conducted.

In the open questions, the Google Maps map was often criticized by the participants regarding its colors. The participants found them unappealing and with too little contrast. This is also reflected in the results of Question 8, where the aesthetics of the map were rated by the participants on a scale of 1 to 10. Here, the Google Maps map scored the worst. In contrast, the InMapz map received a good rating, while the color scheme was also criticized in the open comments. The good rating, despite these comments, could be due to the popularity of logos.

Overall, the Own Map was rated the best in terms of visual appeal. And also, in the last question of the questionnaire, where the participants ranked all four maps according to their preference, the Own Map was generally preferred. Overall, the InMapz map also received a good rating, while Apple Maps and Google Maps performed rather poorly.

Routes & Positioning

Regarding the visualization of position, it is clear from the results of the questionnaire that position symbols, which include a direction of view, are preferred. In terms of visualizing position inaccuracy, it became clear that the depiction of the blur area together with a position symbol is preferred over the sole depiction of the blur area. Ranasinghe and Kray (2016), who studied the representation of position inaccuracy (Chapter 2.1.4), came to a similar conclusion. Gartner, Cartwright and Peterson (2007) and Gotlib (2019), emphasized that describing a route using multimedia data, in addition to the map itself, is an important component of navigation and enhances the usability of a system. Cock et al. (2019) found that additional textual information is preferred by users compared to other additional media formats. Bauer and Ludwig

(2019) observed that users in the indoor area look at the textual route description as often as at the map itself. Thus, route descriptions play an important role in the usability of navigation systems. Therefore, different forms of route descriptions and visualizations were tested in the study of this work. Regarding visualization, the dotted route and then the route depicted with arrows were clearly preferred by the participants. A possible reason for this result could be that the participants most likely associate dotted visualizations with walking.

Gotlib (2019) recommended that the description of a route be made qualitatively. For example, the route description should address landmarks and not provide metric distance information. The results of this study clearly show that a combination of both information ("Turn left in 10 meters after the escalator") is preferred by the participants. The ranking type of the question also identified the preference apart from the combination of both pieces of information. It is clear to see, when the choice is only between qualitative and metric, that the qualitative route description is significantly preferred. This suggests a general opinion that qualitative route descriptions indoors are more helpful than metric ones. However, to meet all user needs, a combination of qualitative and metric information is most favored.

Also, in choosing whether a graphical or textual route description is preferred, it came out that a combination of both is the most popular. Apart from the combination, no clear trend is discernible. Some participants prefer the graphical variant, others the textual. Thus, this is about more individual preferences.

Regarding the continuation of the route on another floor, a clear majority of the participants indicated a preference for this visualization. Displaying the continuation of the route on another floor gives users the opportunity to get an overview of the entire route. However, it must also be considered that this depiction only works well as long as the continuation of the route on the other floor does not lead through walls on the current floor. Since shopping centers often have a similar structure on all floors, this can be considered depending on the building structure.

5 Conclusion

The following chapter recaps the objectives, implementation, and results of this work. It starts by addressing the objectives and the methods used to reach them. Subsequently, the key findings of this work are summarized, and the research questions are answered. Finally, an outlook is provided where open questions from this work are discussed.

5.1 Objective and methodology

The aim of this study was to optimize the cartographic representation of indoor spaces and to gather user preferences in position and route descriptions for indoor navigation systems. The goal was to enhance the usability of indoor navigation systems in the future. To achieve this aim, the theoretical part of this study (Chapter 2.1) analyzed existing literature on cartographic theories and techniques for representing indoor spaces. From this analysis, valuable characteristics of indoor navigation systems were identified, which were subsequently used for evaluating and investigating such systems. The next step involved examining widely used existing indoor applications such as Google Maps, Apple Maps, and InMapz through a competitor analysis (Chapter 4.1). The objective here was to compare different visualization approaches for indoor maps and to identify their strengths and weaknesses. The analyzed indoor navigation systems - Apple Maps, Google Maps, and InMapz - were then tested with real users using Thinking Aloud tests (Chapter 4.2). The aim here was to identify initial usability issues with these map applications during orientation and route finding. From the results of the literature review (Chapter 2), competitor analysis (Chapter 4.1), and Thinking Aloud tests (Chapter 4.2), a custom map of the study area was created (Chapter 3.4). An online survey was developed to test the user-friendliness and understandability of the Own Map. To compare the results of the Own Map with the existing indoor navigation maps (Apple Maps, Google Maps, and InMapz), there were four surveys in total, each containing the same questions but referring to a different map. Through this iterative approach using different methods of usability research, valuable insights were generated that can improve the Usability of indoor navigation systems.

5.2 Summary of the results

The results of this study clearly demonstrate the importance of applying cartographic techniques in the design of indoor navigation systems. Efficient navigation within buildings using indoor maps can pose a challenge for users, especially when it comes to interpreting symbols. Therefore, a clear and intuitive presentation of symbols is crucial for frustration-free orientation. One important aspect of symbol design emerged during the Thinking Aloud tests where some participants were unsure whether a staircase on the map led to an upper or lower floor, leading to delays in route finding and potentially causing user frustration. This issue was also highlighted in several comments about Apple Maps, Google Maps, and InMapz in the online survey, underscoring the importance of this information. For the custom map, a solution using arrow symbols was chosen to indicate the direction of stairs, escalators, and elevators.

Regarding the symbols that indicate room functions, different approaches are pursued by the various maps. The results of the Thinking Aloud testing showed that the use of shop logos enables large and prominent shop areas to be immediately seen and recognized, thus serving as strong landmarks, but they can also be limiting for users who are not familiar with the logos. Therefore, the sole display of logos is not suitable for all users. The online survey also showed that while a large part of the users like the logos and generally responds well to them, a similarly large part finds the visualization using logos less appealing. Here, opinions diverge in two different directions. Since logos act as such strong landmarks, their inclusion in indoor maps is reasonable, but too many logos can also overload the map and make it less clear. It is recommended to use a combination of both approaches: Logos for prominent shops and abstract shop symbols for smaller shops. Another important aspect of symbol design that emerged is the color differentiation of room functions. The findings of this study indicate that it helps users when symbols for restaurants, shops, and services have different colors, aiding orientation and speeding up the search for desired locations.

The density of information indoors is significantly higher than outdoors. Therefore, when designing indoor maps, careful consideration must be given to which information should be included and which should not. The results of this work indicate that providing shop categories is important information for users. For example, if shop names are not known, the next piece of information users seek is the category of the shop. The results of the online survey reveal that there are users who prefer graphical information and those who prefer textual information. It is therefore advisable to represent the shop category both abstractly in the shop symbol itself and as textual information.

Another important finding of this work, which emerged both in the Thinking Aloud testing and in the online survey, is the representation of entrances and access points to specific areas. For instance, in the building studied in this work, the stairs border several shop polygons. Here, it was not clear to the test participants through which polygon the stairs were accessible. Moreover, for large shop spaces, which have a wide front facing the corridor, marking the entrances helps the participants. A selective display of important access points could provide a solution without cluttering the map.

During the Thinking Aloud testing, it emerged that the participants were wondering about the atrium area on the map and did not know what it represented. Therefore, for this work's Own Map, a line pattern was created that reflects the shape of the atrium's skylight dome. However, the results of the online survey showed that most participants preferred the empty polygon area, and the line pattern designed by the author of this work was the least preferred. Nonetheless, the approach of using an empty area, as the results indicate, also does not contribute to the atrium being recognized as such. Since atriums and openings in the floor are common in shopping centers, the development of cartographic approaches for depicting such spaces is important. Therefore, the author of this work suggests testing further visualization options for an atrium, such as a dot pattern.

In the investigation of different floor visualizations, it turned out that a consistent visualization across floors was generally the most preferred. However, a significant portion of participants also favored a color gradient or the use of different colors between floors. The results do not show a clear preference among users. Since opinions vary widely, a settings option could be provided in the final product of a mobile indoor navigation app, allowing users to decide which visualization they prefer to use. Using different colors for different floors, of course, also brings the challenge of maintaining the unity and color harmony of the map.

Route descriptions are a crucial aspect of navigation. For indoor route descriptions, different considerations are necessary compared to outdoor environments. The findings of this study revealed that there is a greater emphasis on qualitative descriptions indoors compared to metric ones. However, the most preferred type of route description is a combination of both qualitative and metric information. That means, in addition to providing distance information, it is recommended to describe the user's surroundings (e.g., "Turn left in 10 meters after the escalator"). In the examination of textual and graphical route descriptions, it was found that a combination of both types is desired. When deciding between the two individual options (graphical or textual route description), there is no clear opinion among users evident in the results. Furthermore, it was found that users prefer the continuation of the route to be drawn, even though it is no longer on the same floor. This provides users with an overall view of the route's progression. However, it must be ensured that the different floors have a similar spatial structure, as it would be less useful to display a route that, for example, goes through walls.

Overall, the results of this study demonstrate that by incorporating theoretical foundations and considering insights from Thinking Aloud tests, a map was designed that was rated better in the online survey by participants than the maps of existing indoor navigation systems (Apple Maps, Google Maps, and InMapz). By combining various visualization approaches and adapting to user needs, indoor navigation systems can be made more effective and user-friendly. The findings of this work provide valuable insights and recommendations for the further development and optimization of mobile indoor navigation applications.

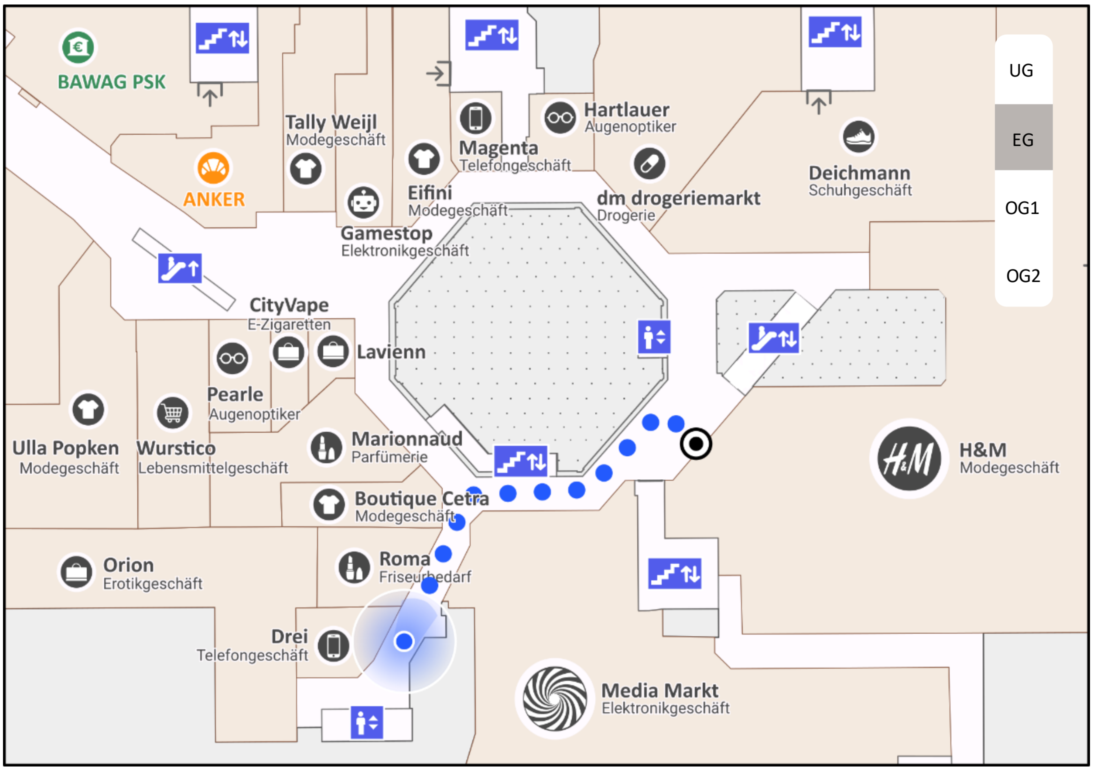

Figure 75: Possible visualization due to the results

Figure 75 presents a design proposal by the author of this work for the indoor map of a shopping center. The position symbol is represented by a blue dot with a viewing cone. The route is dotted. As landmarks, prominent shops are displayed using logos, but in a style consistent with the other shop symbols. Additionally, in unclear areas, in this case some staircases, access is indicated by a door symbol. Furthermore, due to the poor evaluation of the atrium visualization, a more subtle dot pattern has now been created.

5.3 Answer to the research question

The main research question of this thesis is formulated as follows:

How can cartographic methodology be utilized to improve the usability of mobile indoor navigation systems, so that they are efficient and understandable for users?
The analysis of the user studies in this work has shown that several cartographic features significantly improve the usability of indoor maps. The following will detail this by answering the formulated sub-research questions.

What are the strengths and weaknesses of existing indoor navigation apps?
Based on the Competitor Analysis, the feedback from participants of the online survey, and the results of the Thinking Aloud tests, the following strengths and weaknesses of the indoor navigation systems studied in this work are identified:

Table 29: Strengths and weaknesses of existing indoor navigation systems

Map design	Strengths	Weaknesses
Apple Maps	○ Abstract symbol representation for different shop categories ○ Colorful and noticeable symbols for stairs, escalators, and elevators ○ Non-walkable areas in a different color ○ Directional indication in the position symbol	○ No color differentiation between restaurant and shop symbols ○ Small symbols, making them less recognizable ○ No cartographic representation of atriums ○ No textual information on shop categories ○ No directional indication for floor change symbols ○ No use of clear landmarks ○ No information on room access points
Google Maps	○ High recognition and familiarity with the map design ○ Color differentiation between restaurant and shop symbols ○ Directional indication in the position symbol ○ Use of landmarks	○ No differentiation between shop categories in the symbols ○ Unappealing color design ○ No depiction of non-walkable areas ○ No cartographic representation of atriums

	○ Qualitative and metric route description	○ Small symbols, making them less recognizable ○ No directional indication for floor change symbols ○ No information on room access points
InMapz	○ Non-walkable areas in a different color ○ Use of shop logos ○ Well-recognizable symbols ○ Showing building entrances	○ Unappealing color design ○ No color differentiation between restaurant and shop symbols ○ Use of logos only ○ No directional indication for floor change symbols ○ No directional indication in the position symbol ○ No cartographic representation of atriums ○ No information on room access points

What cartographic features enhance the usability of indoor maps, and how should these features be specifically designed?

After analyzing the results, the author of this work identified the following key aspects that enhance the usability of indoor maps and gives following design recommendations:

- **Room symbols**: Symbols should be clearly understandable and categorize the space into categories (e.g., shop categories). For rooms with different functions (e.g., restaurants and shops), a color distinction is helpful to enable quick differentiation of various areas within the building.
- **Atrium/Other unique building elements:** Buildings often have more complex structures than outdoor areas. Elements like atriums frequently appear in buildings. To utilize these elements as important landmarks, visualization techniques should be developed that clearly and unambiguously reflect the spatial features of the building.
- **Landmarks:** In shopping centers, shop logos are very strong landmarks that users can orient themselves by. However, since not all logos are well-known, a selective display of logos from more prominent and noticeable shops in the building is recommended.
- **Floor changes:** Clear indications of stairs, escalators, and elevators, as well as their clear directional signs indicating whether they lead to upper or lower floors, are essential for frustration-free route finding for users.
- **Display of accesses in unclear areas:** In unclear areas, such as adjoining polygons where entrances are not already recognizable from the shape of the room polygon, marking where an access point exists is important.
- **Color design:** A clear and appealing color scheme that also clearly separates different rooms contributes to user satisfaction with the map.

What are important aspects of position and route information for increasing the usability of indoor navigation systems?

- **Display of the direction of the position symbol**: Users prefer position symbols that indicate the user's viewing direction.
- **Combination of qualitative and metric route information:** In addition to distance information, a qualitative description of the surroundings indoors is an important aspect in route descriptions to enhance usability.
- **Inclusion of graphical route descriptions:** Since some users are visually oriented, incorporating graphical route descriptions can provide relief, eliminating the need always to read text.
- **Continuation of the route to another floor:** To give users a general overview of the route, it can be helpful to draw the entire route, even if parts of it are on a different floor.

Figure 76: Design recommendation for routes and route descriptions

5.4 Future work

In this work, several fields have been identified that require further research to continue improving the usability of indoor navigation systems. Initially, different visualizations for marking accesses and entrances should be investigated to depict in unclear areas of a building which front of certain areas are accessible from. This includes the exploration of various symbols or line representations to make these accesses easily recognizable.

Another important topic is the representation of atriums. These pose a particular challenge in indoor cartography. Future studies should focus on finding the most effective methods for depicting atriums so that their representation accurately reflects reality. This could involve experimenting with various visual techniques and perspectives to accurately convey the spatial and visual characteristics of atriums. Through appropriate visualization, atriums can be used as strong landmarks.

Furthermore, in the maps studied in this work, a color distinction in the symbols was used for different room functions. Some participants indicated in the comments that they would find it helpful if the entire area of the room had a different color to distinguish these rooms more quickly. Here, it could be further investigated whether this visualization is indeed preferred by users and whether it does not disturb the color harmony of the map.

Continuing the route across multiple floors also poses a challenge, especially when the spatial structure varies between levels. Future studies should explore alternative methods for displaying entire routes that maintain clarity and comprehensibility, even when moving across different floors.

Finally, further studies on this topic should also deal with other types of buildings. This work examined indoor maps of a shopping mall. Future research could focus on airports, hospitals, or large office buildings, where different conditions prevail.

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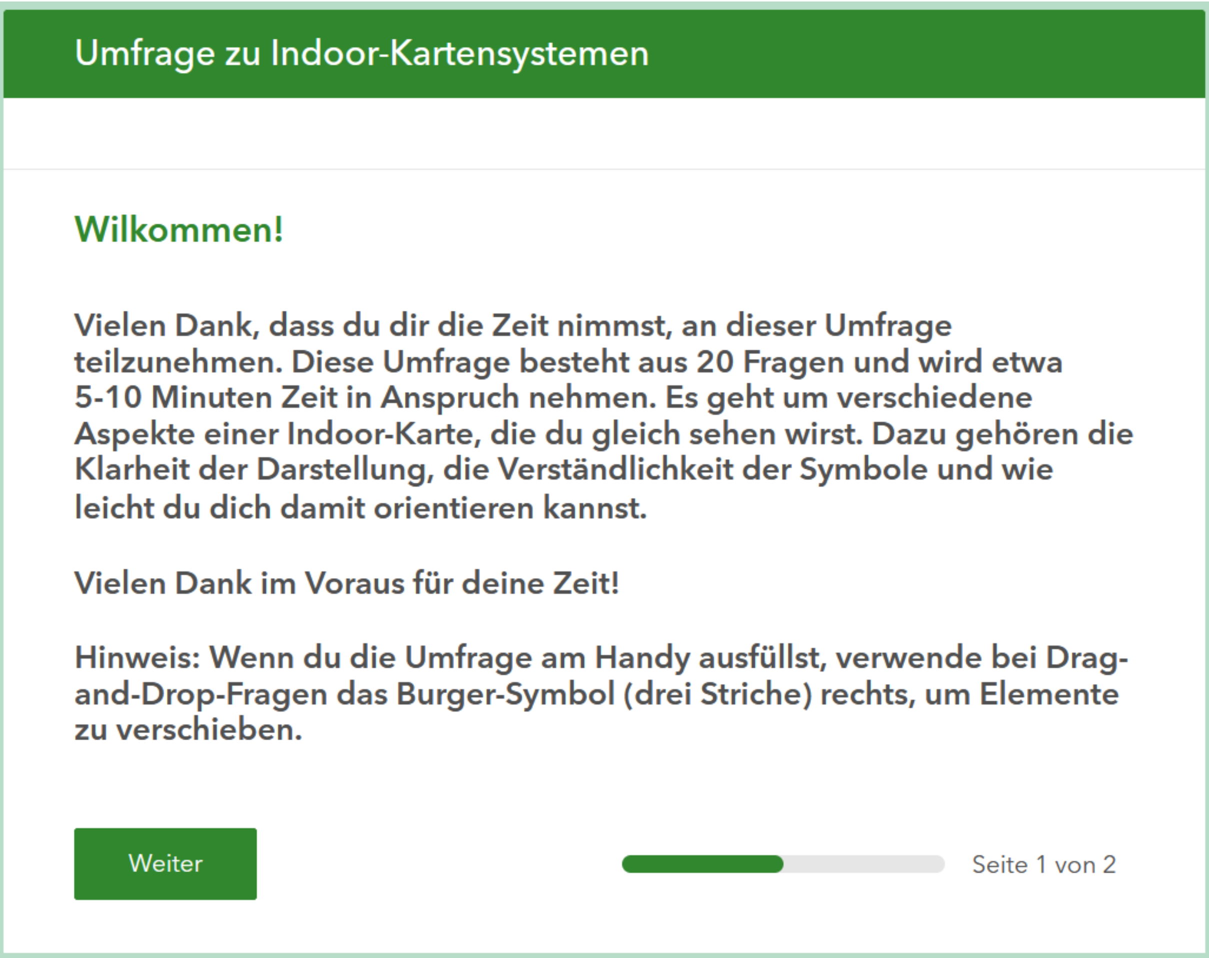
Appendix

Appendix A: Own Map group of the questionnaire



Umfrage zu Indoor-Kartensystemen

Bitte betrachte die Karte:

1. Wie findest du den Detailgrad der Karte?*

- Zu detailliert
- Etwas zu detailliert
- Genau richtig
- Etwas zu wenig detailliert
- Nicht detailliert genug

2. Welche Arten von Informationen findest du beim Navigieren in Innenräumen auf der Karte am nützlichsten? (Reihung per drag&drop)*

- Shop- oder Restaurantsymbole
- Grundrissplan
- Hinweise zu Treppen, Rolltreppen und Aufzügen

Zurücksetzen

Zusätzliche Informationen die beim Navigieren im Innenraum für dich nützlich sind (optional):

3. Wie klar und verständlich erkennst du die verschiedenen Räume und Bereiche innerhalb des Gebäudes? (z.B Shopflächen, Restaurants, Gangflächen...)*

Sehr klar — Klar — Nicht so klar — Gar nicht klar

4. In der Mitte der Karte ist ein achteckiges Polygon dargestellt. Erkennst du, was dieses Polygon repräsentiert?*

- Ja
- Ich bin mir nicht sicher
- Ich weiß es, da ich bereits dort war

5. Gibt es Informationen auf der Karte, die du als unnötig empfindest?*

- Ja
- Nein

6. Wie leicht erkennst du die unterschiedlichen Symbole auf der Karte?*

Sehr leicht | Leicht | Schwer | Sehr schwer

7. Ist die Bedeutung der verschiedenen Symbole auf der Karte klar und eindeutig für dich?*

Ja | Meistens | Selten | Nein

8. Wie ansprechend findest du die visuelle Gestaltung der Karte? (1 = nicht ansprechend, 10 = sehr ansprechend)*

1 10

Zurücksetzen

9. Enthält die Karte alle Informationen, die du zum Orientieren benötigst?*

- Ja
- Nein

10. Wenn du einen Verbesserungsvorschlag für diese Karte machen könntest, welcher wäre das? (Offene Frage)

11. Bitte ordne die folgenden Routenvisualisierungen nach deiner Präferenz, wobei 1 die höchste Präferenz und 4 die niedrigste ist. (Reihung per drag&drop)

*

Pfeil mit Kreis

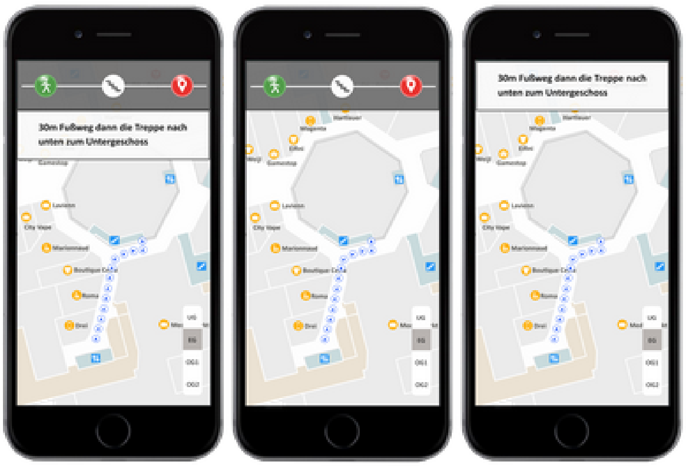
Pfeil

Gepunktet

Linie

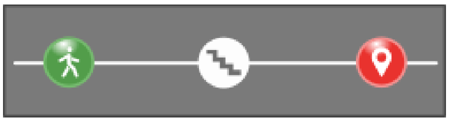
Zurücksetzen

12. Bitte ordne die folgenden zusätzlichen Routenbeschreibungen nach deiner Präferenz, wobei 1 die höchste Präferenz und 3 die niedrigste ist. (Reihung per drag&drop)



*

Grafisch



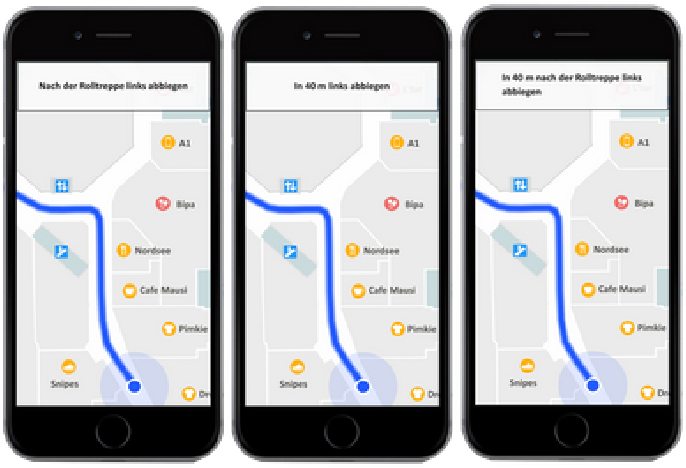
Text

30m Fußweg dann die Treppe nach unten zum Untergeschoss

Kombination Grafik & Text

Zurücksetzen

13. Bitte ordne die folgenden textliche Routenbeschreibungen nach deiner Präferenz, wobei 1 die höchste Präferenz und 3 die niedrigste ist. (Reihung per drag&drop)



*

- In 40 m links abbiegen
- Nach der Rolltreppe links abbiegen
- In 40 m nach der Rolltreppe links abbiegen

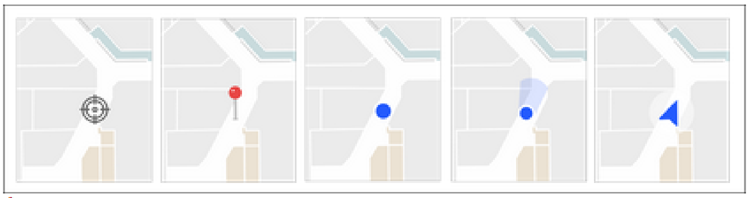
Zurücksetzen

14. Auf Karte a) ist die Fortsetzung der Route in ein anderes Stockwerk mit eingezeichnet. Wie bewertest du die Nützlichkeit dieser Darstellung im Vergleich zur Karte b), auf der nur die Route innerhalb eines Stockwerks angezeigt wird?

*

- ○ Ich bevorzuge die Darstellung auf Karte a), mit der Fortsetzung der Route in ein anderes Stockwerk
- ○ Ich bevorzuge die Darstellung auf Karte b) die nur die Route innerhalb eines Stockwerks zeigt

15. Bitte ordne die folgenden Positionssymbole nach deiner Präferenz, wobei 1 die höchste Präferenz und 5 die niedrigste ist. (Reihung per drag&drop)



*

Blauer Punkt mit Richtung

Blauer Punkt

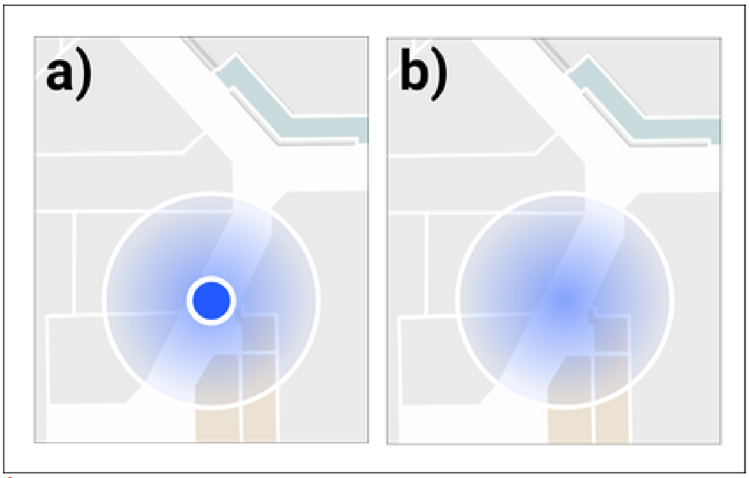
Stecknadel

Pfeil

Kreuz

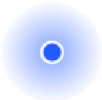
Zurücksetzen

16. Positionsungenauigkeit: Soll im Fall einer ungenauen Position der Unschärfebereich mit oder ohne Positionssymbol dargestellt werden?

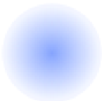


*

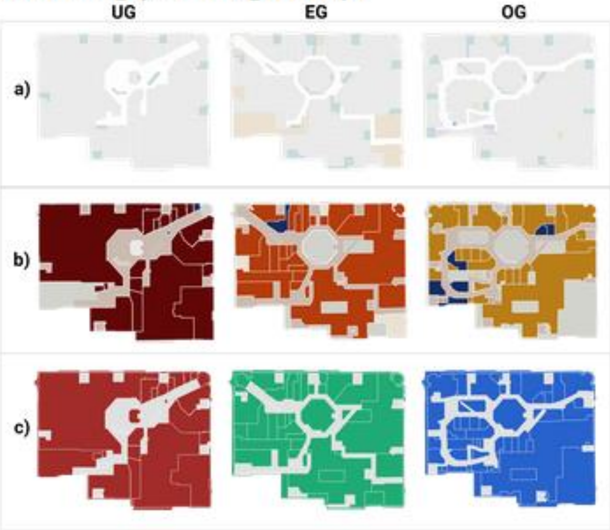
○ a) Unschärfebereich mit Positionssymbol



○ b) Unschärfebereich ohne Positionssymbol



17. Bitte ordne die folgenden Stockwerkvisualisierungen nach deiner Präferenz, wobei 1 die höchste Präferenz und 3 die niedrigste ist. (Reihung per drag&drop)



*

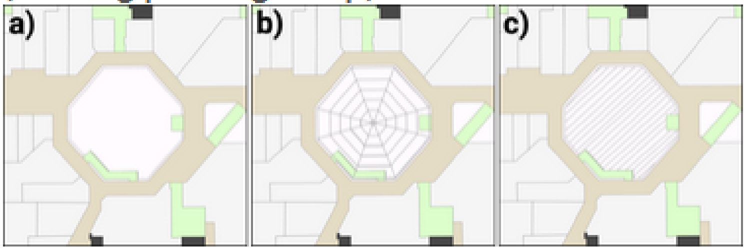
a) Gleichbleibende Visualisierung über die Stockwerke

b) Farbabstufung über die Stockwerke

c) Unterschiedliche Farbe pro Stockwerk

Zurücksetzen

18. Bitte ordne die folgenden Luftraumvisualisierungen nach deiner Präferenz, wobei 1 die höchste Präferenz und 3 die niedrigste ist. (Reihung per drag&drop)

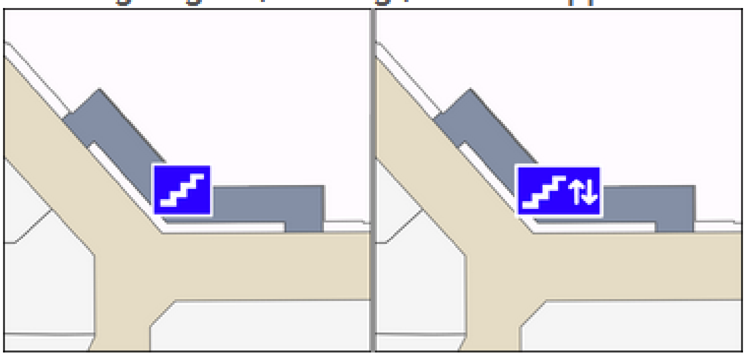


*

- a) Weiße/Leere Fläche
- b) Individuelles Linienmuster
- c) Schraffiert

Zurücksetzen

19. Bevorzugst du ein einfaches Treppensymbol, oder eines mit Richtungsangabe, die zeigt, ob die Treppe nach oben oder unten geht?



*

- Einfaches Symbol

- Symbol mit Pfeilen

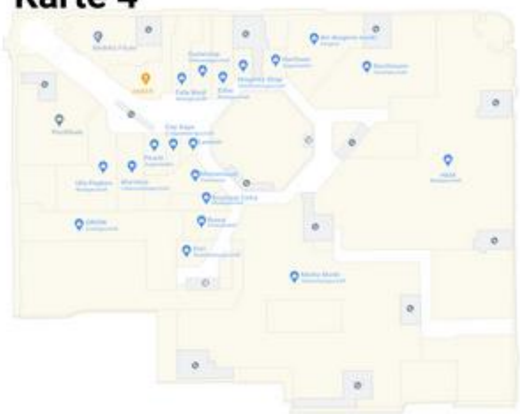
20. Bitte betrachte folgende vier Karten:

Karte 1

Karte 2

Karte 3

Karte 4

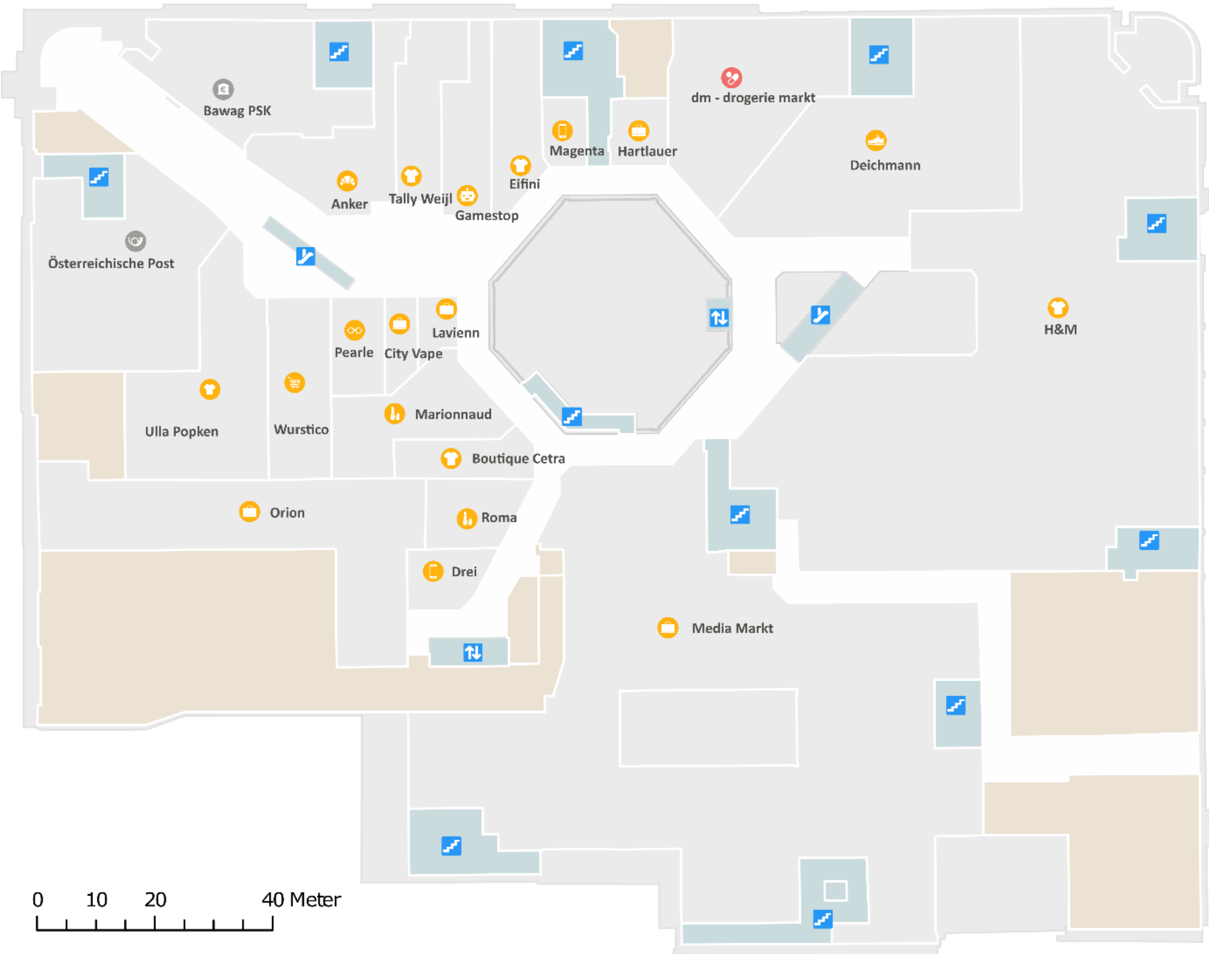


Bitte ordne die Karten nach deiner Präferenz ein, wobei 1 die höchste Präferenz und 4 die niedrigste ist. (Reihung per drag&drop)*

- Karte 1
- Karte 2
- Karte 3
- Karte 4

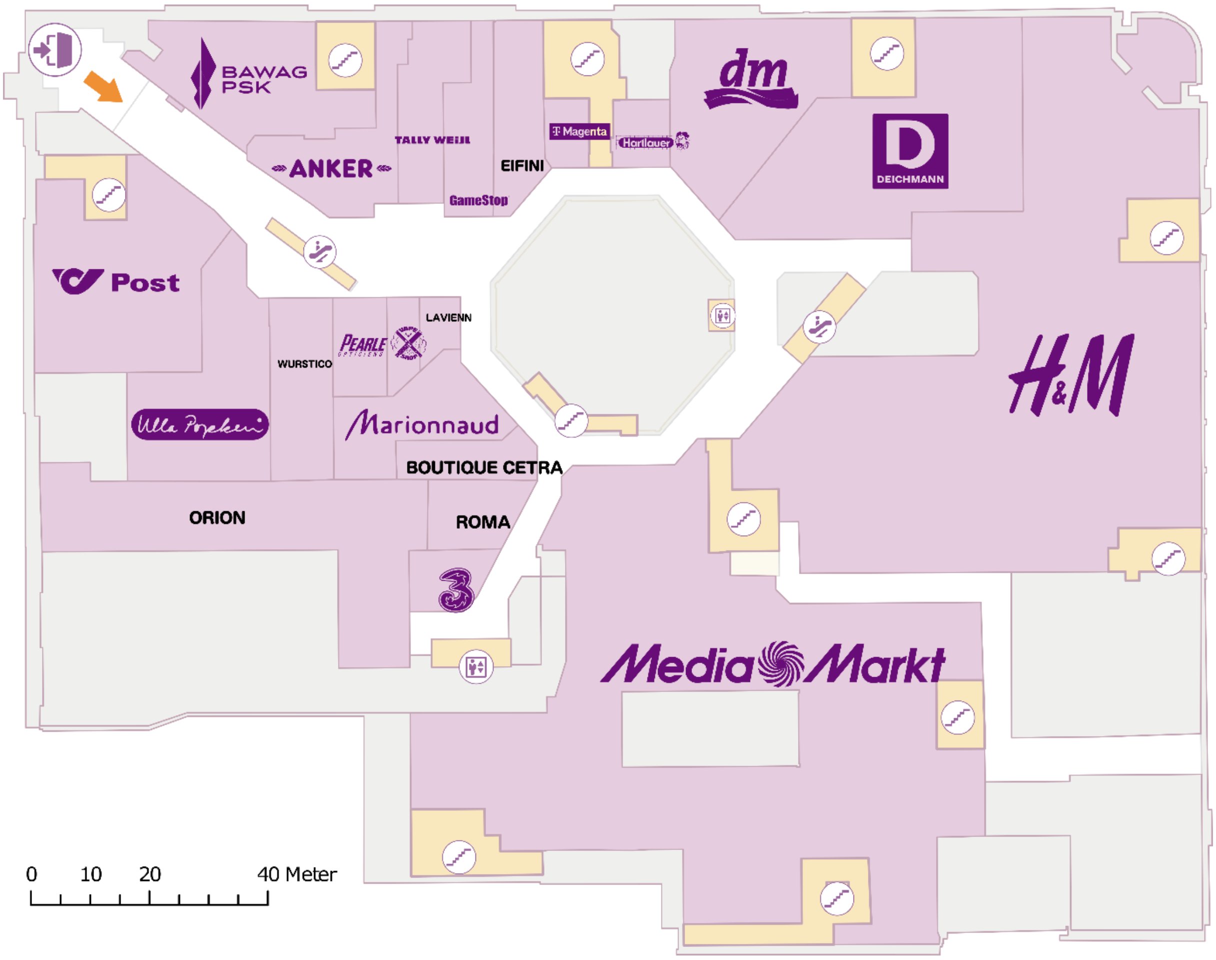
Appendix B: Apple Maps group of the questionnaire

In all four questionnaires, the questions were identical, with the only difference being the displayed map for each. The complete questionnaire is included in Appendix A. For the Apple Maps questionnaire group the following map was displayed.



Appendix C: InMapz group of the questionnaire

In all four questionnaires, the questions were identical, with the only difference being the displayed map for each. The complete questionnaire is included in Appendix A. For the InMapz questionnaire group the following map was displayed.



Appendix D: Google Maps group of the questionnaire

In all four questionnaires, the questions were identical, with the only difference being the displayed map for each. The complete questionnaire is included in Appendix A. For the Google Maps questionnaire group the following map was displayed.