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Development of methodology for designing indoor cartographic visualizations for use in navigation for persons with special needs

Abstract. This study aimed to design a cartographic visualization for mobile navigation applications around indoor spaces, including metro stations, with persons with special needs in mind. The visualization will be used in a dedicated application for mobile devices supporting the navigation of people around the Warsaw metro. The app was developed for any metro users and includes functions that help persons with special needs navigate the metro. It is not possible to meet the needs of persons with every type, degree, or complexity of disability, but the methodology has been developed based on the principles of designing cartographic presentations, accessibility guidelines and existing solutions, taking into account the needs of persons with special needs and the specifics of metro navigation. As a result, it differs significantly from the visualizations that currently exist in the Warsaw metro. The developed methodology was tested by designing a map of the Świętokrzyska metro station and subjected to user testing, including persons with special needs. The types of special needs included mobility disabilities, colour vision deficiency, and persons, who often travel with baby strollers. The results obtained allowed to improve the proposed solution.

Keywords: mobile applications, accessibility, indoor navigation

1. Introduction

The work described in this article is part of a project that aims to create a system that comprehensively supports the movement of persons with special needs inside publicly accessible facilities, such as metro stations or train stations where access may be difficult. It is believed that indoor wayfinding should be facilitated for wheelchair users, blind people, and anyone who is unfamiliar with a new environment (Prandi et al., 2023). The system, which includes components such as a mobile navigation application, a database, and an admin application, is being developed for the Warsaw Metro on a prototype basis.

A solution to make it easier to navigate the metro stations will be a mobile application in which cartographic visualization plays a key role. It is used to present the location of entrances to Warsaw metro stations and the course of the metro lines, as well as to present metro station maps. The cartographic visualization in the form of a metro station map is intended to provide useful information about the facilities located at the metro station, namely entrances and exits, ticket machines, ticket gates, and toilets. In addition, after defining route parameters and generating navigation directions, the user will be able to check the route's graphical presentation. The presentation of the data must be clear and understandable to the user without including detailed descriptions of the objects.

In the process of designing an indoor cartographic visualization, a number of aspects should be kept in mind. It is crucial to depict the change of floors and the installations that make this possible. In the case of a metro station area, those are primarily elevators, stairs, and escalators. Their geometric representation can be point or polygon. The decision should be made considering the application of the cartographic visualization, how the user will perceive it, and what other objects will be included in the visualization. Crucial to visual perception is the scale of the map at which the user will view the cartographic visualization.

Since the cartographic visualization is intended to help passengers move through the metro station, the route to be followed will be included. It is necessary to consider how to present the route symbol so that it harmonizes with other objects included in the visualization and, at the same time, is visible and legible to the users.

Due to the mapped area and the medium on which the cartographic visualization will be displayed, it is essential to simplify the content. It is necessary to select the most important objects and represent them appropriately.

2. Related works

2.1. Cartographic presentation

Mobile applications that use cartographic visualizations should meet the requirements for cartographic presentations. Cartographic presentation defines a set of expressive means that can be used to change the content of a map, as well as the conventions and rules for their use under certain conditions (Gnat, 2020). The means of expression include symbols, which represent the location and form of objects and phenomena on the map; labels, which supplement information on symbols or are separate objects; and other multimedia elements (MacEachren et al., 2012).

Roth et al. (2024) outline five essential dimensions for mobile-first cartographic design: scale and generalization, projections, symbolization and visual hierarchy, toponymy and typography, and user interaction. These dimensions address the specific needs of mobile navigation, such as adapting map details to screen size, ensuring readability in various environments, and optimizing user interactions for touch-based devices. The most critical concern is the purpose for which the solution is being designed. Also important is the medium through which the geovisualization will be presented and under what environmental conditions it will be used. Determining the purpose and medium will essentially guide the form of the visualization and make it easier to define the aspects that will affect the effectiveness of its reception. Determining the types of users who will use the designed solution is also vital. Such information will verify whether or not it will be necessary to apply additional requirements to adapt the visualization, for example, for persons with special needs. When designing a geovisualization, it is also essential to consider the context of its use, the dynamics of content change, and the characteristics of the data model subject to symbolization (Gnat, 2020).

The qualities of cartographic presentations that are adapted to the needs of mobile navigation and localization systems include egocentrism, polymorphism, contextuality, self-explaining, glanceability (perceptibility), and optimality (Gotlib, 2011).

The egocentrism of the presentation stems from its design, which focuses on the user's position and behaviour (Gotlib, 2011). The cartographic sign, which represents the user's position, should be superior to the other signs on the visualization, while fully harmonizing with them.

Next quality, polymorphism means representing the same data on a map in different forms, using different cartographic characters.

Contextuality is a feature that is applied to a cartographic presentation, which must be tailored in terms of the content and form of the cartographic message to a specific place in space, user behaviour, or preferences. Contextuality is closely related to the egocentrism of the presentation (Gotlib, 2011).

The self-explaining of the cartographic presentation ensures that information can be read correctly without the need for a map legend. Glanceability (perceptibility) gives the possibility to read the cartographic message in a very short time in a situation when the user is simultaneously busy with other activities. Optimality in this case means "the best fit for specific conditions and the absence of additional elements that do not serve the primary purpose" (Gotlib, 2011, p. 47). A cartographic presentation should not be over-saturated with content, as this affects its use.

Modern cartographic presentations intended to be useful should have all or most of the above qualities (Gotlib, 2019). Nowadays, it is also crucial to make maps as accessible as possible to a broad spectrum of the public. A reliable body of knowledge on designing accessible maps is the work of Hennig et al. (2017). Making a fully accessible map is not a simple thing to achieve due to the troublesome reading of map content by assistive technologies as well as the cognitive abilities of readers. However, it is possible to develop cartographic visualization to be as readable as possible for most users.

Symbols used on a map should resemble objects in the real world (Jeffrey & Fendley, 2011) and be simple in their form (Harley, 2014). Nonetheless, preparing and including a map legend in the mobile app is advantageous, as this fits in with Web Content Accessibility Guidelines 2.2 (W3C, 2023).

Object categories such as roads or buildings should be differentiated using visual variables (Bertin, 1983) for instance colour (Jenny & Kelso, 2007) and have a high contrast between them (Fowler, 2011; Jenny & Kelso, 2007). Similarly, different types of Points of Interest should be marked using different icons and colours (Jenny & Kelso, 2007).

An accessible mobile navigation application should have the option to choose the basemap, for example: basic, satellite, and with increased contrast. If buttons are placed on or around the map area, they should be relatively large and have a high enough contrast ratio between the text on the button and its background (Hennig et al., 2017).

The issue of cartographic visualization of indoor space is, at this point, little discussed in scientific articles and research papers, as highlighted in an article by Gotlib, Wyszomirski and Gnat (2020). However, different types of maps of interior spaces have been around for thousands of years (Abrahami, 2016; Chen, 2018). Nowadays, they continue to provide essential spatial information for spaces such as train stations, underground railway systems, airports, and office buildings. These maps often feature unique cartographic symbols, such as the “You Are Here” markers (Montello, 2010), and are tailored for specific applications.

When it comes to outdoor maps, buildings might be depicted as solid rectangles on a coarse scale or a detailed map, whereas indoor maps usually take the form of a basic floor plan or a blueprint with unknown accuracy (Chen & Clarke, 2020). Cartographic visualization is a crucial component of navigation systems, especially in the context of mobile applications. In this case, the use of a basic diagram, such as an architectural plan of a building, is not an appropriate solution due to its complexity and content of redundant elements. The building plans made available to users are usually a highly simplified form of architectural plan prepared by graphic designers.

Various objects can be identified in database models of interior spaces, such as reference data representing room layouts, traffic routes, time-varying objects, address data, or points of interest. The reference data model can include rooms, windows, doors, fixed fixtures, installations, or landmarks. Essential objects are access points, such as building entrances or public transportation stops (Gotlib & Marciniak, 2013). In creating the solution described in this article, the authors took into account both the proposal contained in the paper by Gotlib and Marciniak and the literature review cited by Gotlib and Marciniak.

2.2. Accessibility

Thanks to increased social awareness of the needs of persons with disabilities and special needs, documents have been developed that compile guidelines for digital accessibility. They serve as a very good indicator of how to create products that meet the needs of the broadest possible spectrum of users.

The most important document on digital accessibility is the Web Content Accessibility Guidelines 2.2 (W3C, 2023). It defines how to adapt web content to make it more accessible to persons with disabilities. The WCAG guidelines can be applied to content on desktop computers, laptops, tablets, and mobile devices. In creating the guidelines, a wide range of disabilities were taken into account, including vision, hearing, movement, speech, cognitive limitations, and hypersensitivity to light. However, it is essential to remember that it is not possible to meet the needs of persons with every type, degree, or complexity of disability. The WCAG guidelines can also be used to create content for older people whose overall ability changes with age, as well as for all other users. Each guideline criteria are given a priority of A, AA, or AAA. Recommendations marked A must absolutely be met for a service to be considered accessible at a basic level. Priority AA specifies recommendations that should be met, while AAA indicates the highest level of accessibility and includes recommendations that can be met.

In Poland, the principles of WCAG 2.2 are further reinforced by national legislation. The Act on Digital Accessibility (Ustawa, 2019) contains guidelines equivalent to the WCAG standard at the AA level.

While meeting legal requirements is important, it's just as essential to follow the principles of universal design when creating an accessible solution. The principles are (Story, 2001):

1) Equitable Use,
2) Flexibility in Use,
3) Simple and Intuitive Use,
4) Perceptible Information,
5) Tolerance for Error,
6) Low Physical Effort,
7) Size and Space for Approach and Use.

2.3. Examples

Existing solutions among transportation facility maps and navigation applications are a good source of knowledge and inspiration. Their review aims to identify both their advantages, which can be used in the designed visualization of metro stations, and potential disadvantages, which are worth avoiding. Among them, applications offering indoor navigation were singled out, with airport navigation applications being the main area of interest in this category due to their similarities to metro stations as indoor, transportation-oriented environments, as well as the limited availability of mobile applications that provide navigation within metro stations. The following description focuses on applications available free of charge, but it is also of interest to analyse commercial applications, such as Station Master and Exit Strategy NYC Subway Map, among others.

2.3.1. Schemes and maps

As the cartographic visualization is implemented on the example of the Warsaw Metro, the schemes of Warsaw Metro stations were analysed in more detail (Figure 1). These schemes show the approximate shape of the stations, but the distances and proportions are not drawn to scale. Nevertheless, they provide sufficient information about the layout of the stations. The schemes show a given station's various levels, where the mezzanine and platform levels are the most common. Notably, they are differentiated by colour to emphasize the difference in levels. To depict where the levels overlap, dashed light grey lines are drawn from a point on the mezzanine to the corresponding point on the platform. This is a good solution, but the line style itself may stand out too faintly in the scheme. Unique areas in the metro station are the ticket zones. In order to distinguish them on the diagram, they have been marked with a red border, which effectively makes them stand out. In addition, the place where the ticket gates are located is depicted with a dashed line.

Large symbols are used to depict the stairs so that they are clearly visible at a glance. The elevators are marked with a slightly smaller symbol. Those installations that come to the surface from the mezzanine level have the necessary location information. The access side of the stairs is indicated by an arrow sign. In addition, stairs descending to the platform or exiting from the platform to the mezzanine are demarcated by a thicker line on the sides where there is no stair access. Meanwhile, the direction of the stairs is depicted using appropriate icons depending on whether the stairs lead down or up (Figure 2). Such a differentiated representation of the direction of the stairs seems unnecessary. In the case of stairs and elevators going down to the platform, they are marked with an additional sign in the form of a blue square with the label M1 or a red square with the label M2, depending on which platform line the installation goes down. This indication is hardly noticeable and does not immediately suggest the direction of the elevator.

In addition to the aforementioned key facilities to help navigate the station, the schemes also show the locations of ticket machines, ATMs, toilets, and Passenger Service and Information Points, if any, at the station. The listed facilities are depicted with signs the same size as those representing elevators. Signs presenting ATMs and ticket machines need improvement, as they are too similar to each other and may be difficult for some passengers to distinguish.

Another example is the map of Washington-Dulles Airport. It presents a solution on how

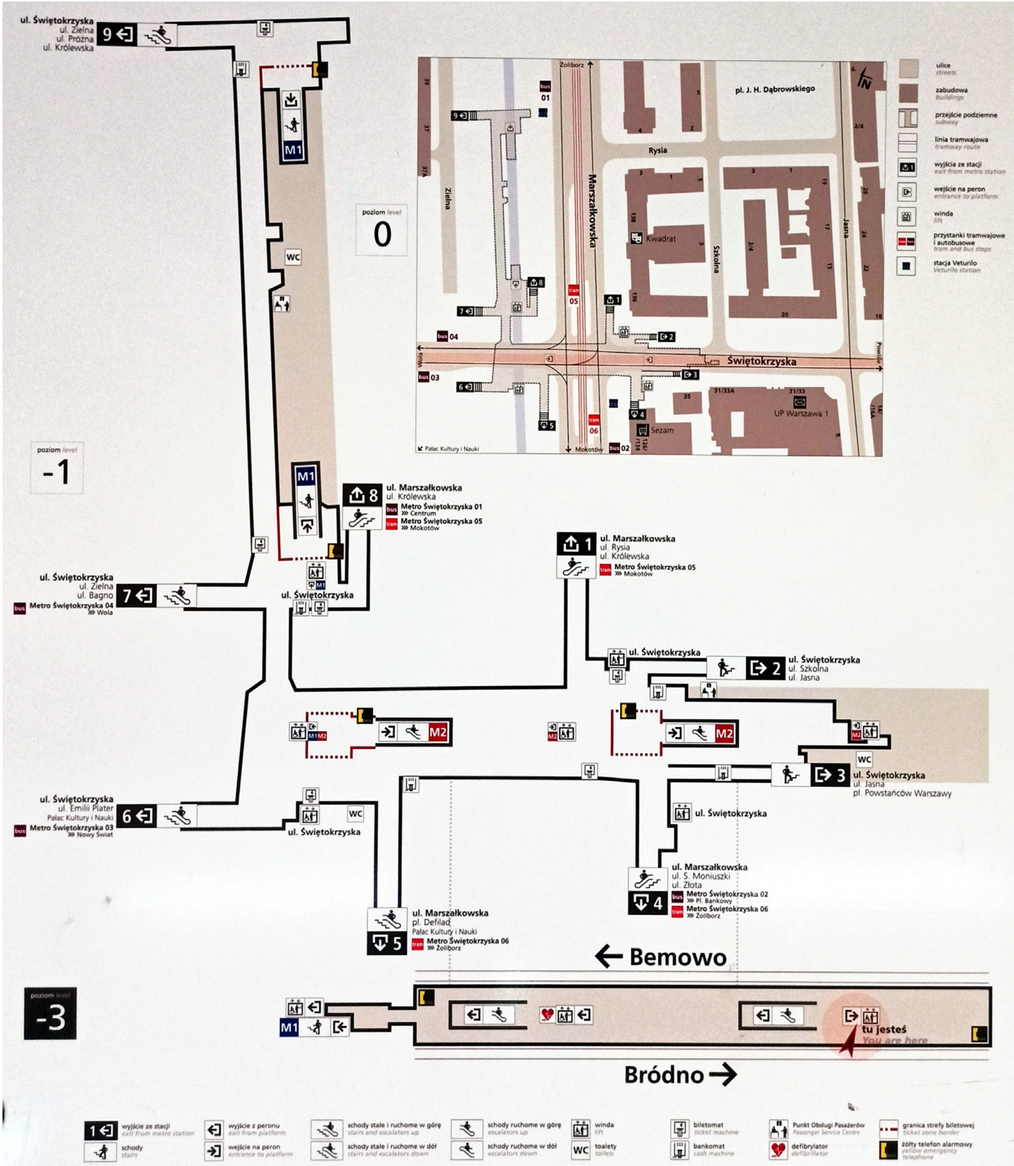


Figure 1. Świętokrzyska metro station scheme on the M2 metro line, where M1 and M2 metro lines cross (source: photo by authors)

to represent the difference in levels in 2D. Two levels are included in the diagram – the arrivals level and the departures level. They have been presented at an angle to give the effect of a 3D view, preserving the 2D dimension. The diagram includes all the essential facilities that are located at the airport. These include the check-in areas of the various airlines, security checkpoints, restrooms, stairs, and elevators.

To show the change of levels and indicate where the levels overlap, bright green arrows have been drawn in place of stairs and elevators, which serves a clear presentation. This lets

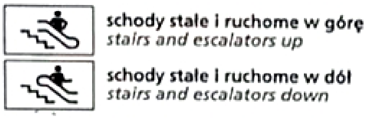


Figure 2. Differentiation between stairs leading up and down on a scheme of a metro station in Warsaw (source: photo by authors)

passengers know where they will exit using a particular installation.

The waiting areas in front of the aircraft exit gates are depicted in an orthogonal projection, and thus in a different way than the rest of the airport. Presumably, it was implemented this way because local transportation is organized between these facilities, which is easier to visualize in such a projection. At first glance, the presentation of the connection of the terminal level to the gates is not fully understood and requires a moment of analysis.

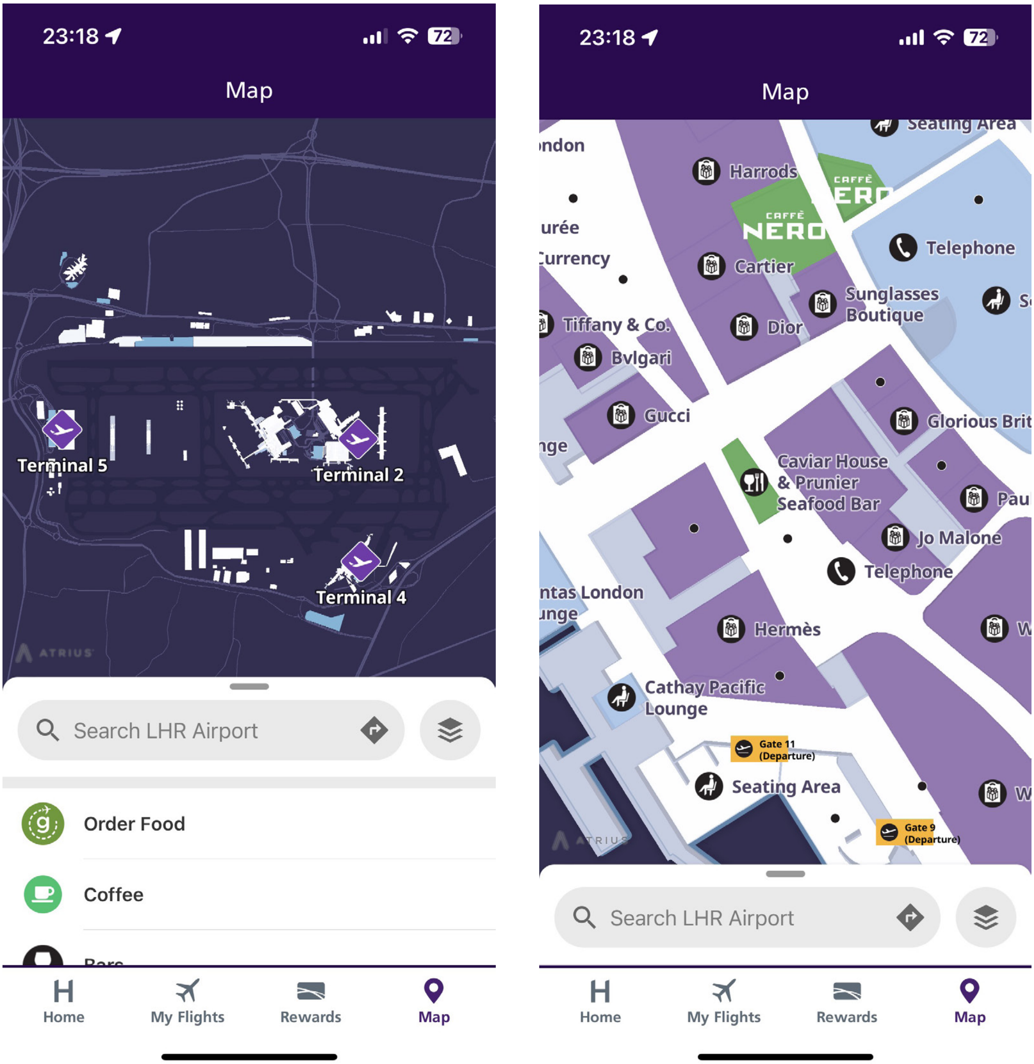


Figure 3a. Screenshots of the Heathrow Airport mobile application: (a) Main map view, (b) Close-up map view

2.3.2. Mobile navigation applications

The London Heathrow Airport has its own app – LHR London Heathrow Airport (*Mobile apps*, n.d.), which includes a navigation component (Figure 3). On the map base, all the buildings that make up the airport are displayed (Figure 3a), as well as individual rooms and objects in the buildings (Figure 3b). Users have the option to navigate the airport, and the generated route is displayed on the map and takes the form of a continuous line in purple (Figure 3c). If the route leads through a security check, its colour changes to red. In terms of adapting the navigation component to the needs of persons with special needs, the app's developers have added an accessible route generation mode that avoids obstacles such as fixed stairs or escalators (Figure 3d).

Like the Heathrow Airport, Rome also has an app – Rome Airports with a map component for its airports (Figure 4). A system map is used

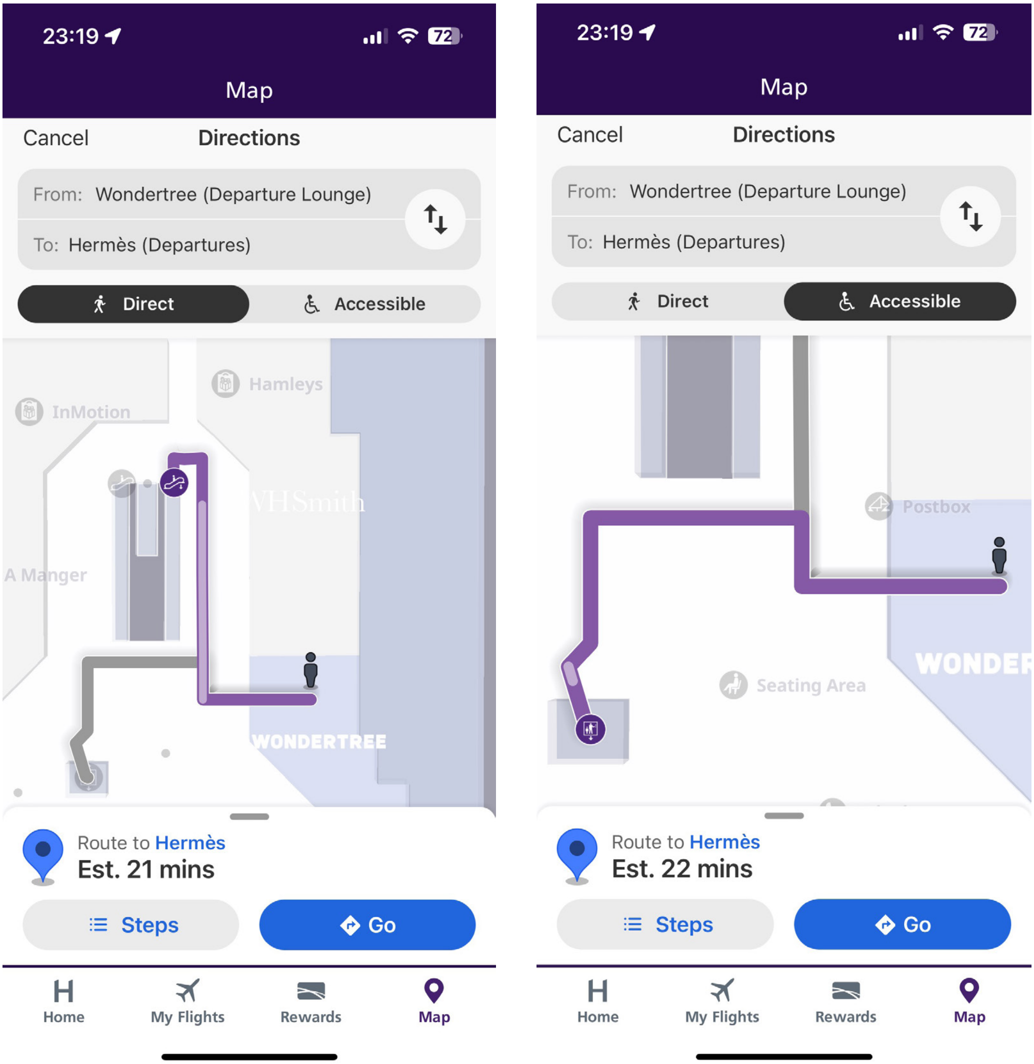


Figure 3b. Screenshots of the Heathrow Airport mobile application: (c) Direct route, (d) Accessible route

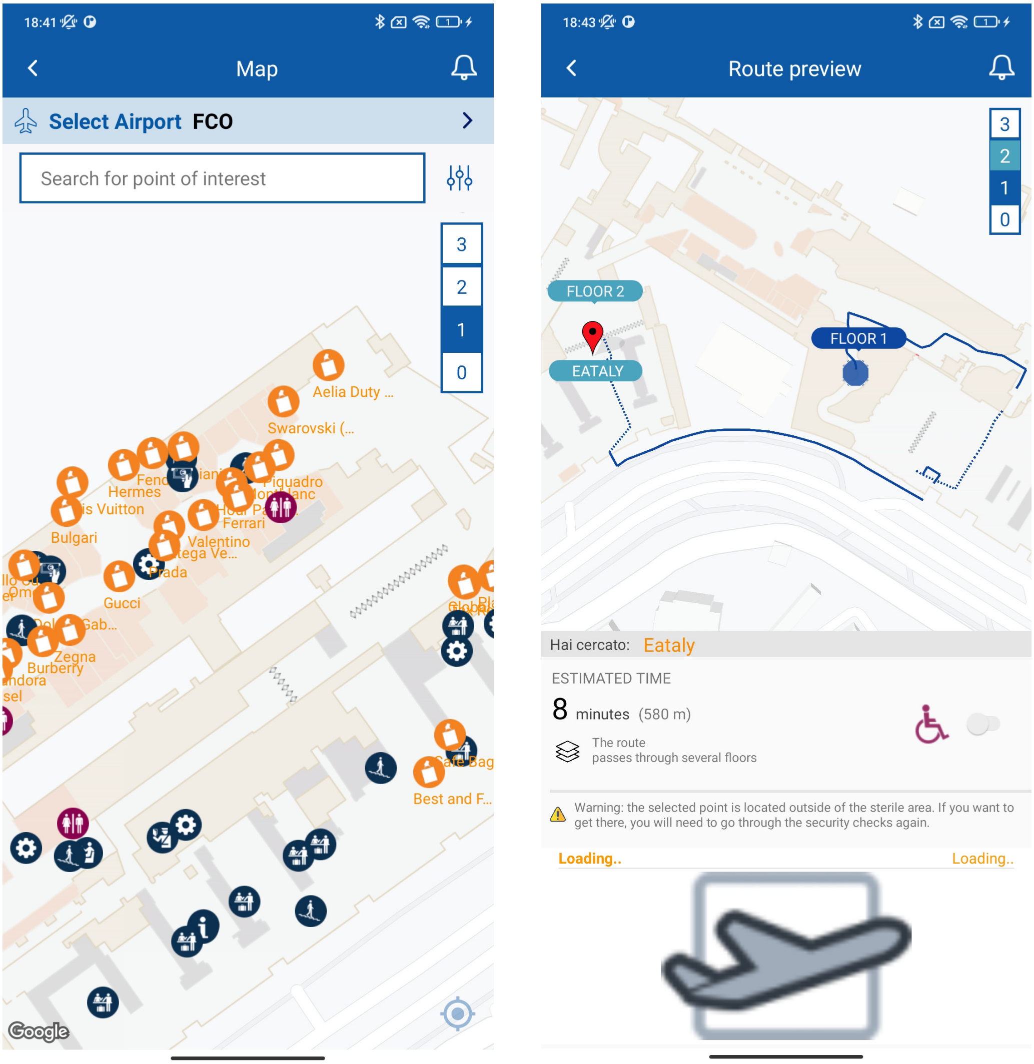


Figure 4a. Screenshots of the Rome Airports mobile application: (a) Close-up map view, (b) Direct route

as the map base: Google Maps for Android and Apple Maps for iOS. Markers are added to the map to denote the location of specific facilities within the airport (Figure 4a). In the case of service establishments, their name is also added. Regarding navigation, the generated route is displayed on the map, and the estimated time of the route is indicated. The path has the form of a dark blue continuous line if the route is carried out on the level where the starting point is located (Figure 4b) and a dashed line if there is a change of levels on the route. If the user selects an accessible route, its colour changes to maroon (Figure 4c). This type of route avoids fixed stairs and escalators, but the path is not generated as the shortest one.

3. Methodology

Based on a comprehensive review of existing literature, best practices and requirements for accessible indoor cartographic visualizations have been identified. These requirements were distinguished based on user needs, accessi-

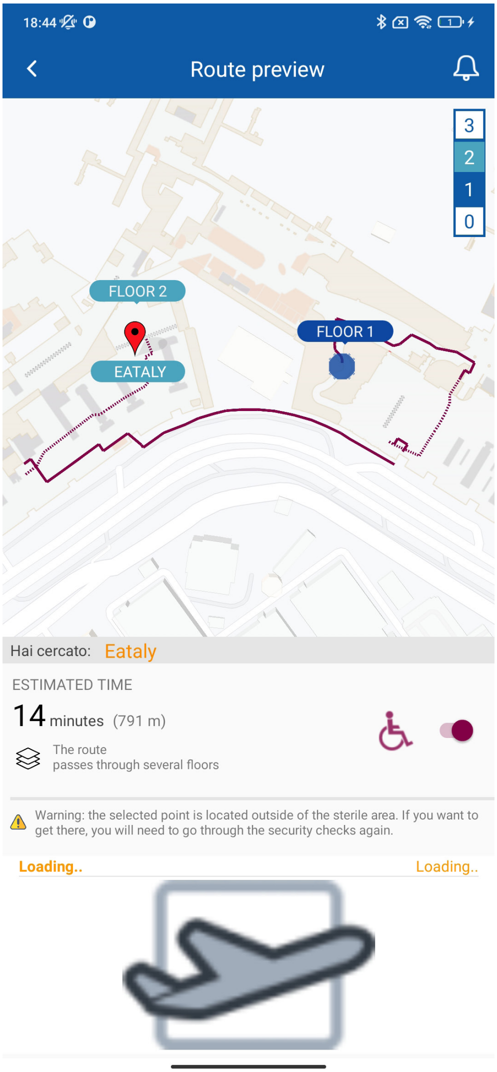


Figure 4b. Screenshots of the Rome Airports mobile application: (c) Accessible route

bility standards, and established principles of cartographic presentation. Key considerations include the selection of colour palettes, icons, geometry types, and objects. Given that the geovisualization is focused on the Warsaw metro system, the cartographic elements from maps located at Warsaw metro stations served as the primary inspiration, ensuring familiarity for potential users. The initial proposal of the geovisualization was created using QGIS with a Google Maps basemap and Adobe Illustrator.

As stated by Lobben et al. (2015, p. 96): “The map user plays a crucial role in the design process”. It’s important to take into account that the research was conducted from the beginning with the participation of people with special needs. Their verbal comments and accompanying discussions made it possible to develop a metro station map. The final surveys conducted as part of this work are only a part of a larger evaluation process.

A review of the use of colour on different schemes of indoor spaces was carried out to select appropriate colours for the cartographic visualization of metro stations. The analysis covered a selection of shopping centres and airports. The adopted methodology assumes that colours creating a higher contrast with the background are used for objects that are the first to draw the user’s attention. In the case of the designed geovisualization, it was necessary to select a colour and shade that did not blend in with the Google Maps basemap and simultaneously harmonized with it. The key to visual perception is legibility. Initially, the authors intended for the space fill to be semi-transparent so that the user would have a direct reference to the ground surface. However, such a solution would interfere with the legibility of the geovisualization.

In the database, each space separated by different types of doors is considered a distinct object. However, metro passengers often do not notice when they pass through doors, especially when it comes to areas like the corridor and the space in front of the ticket gates, which are separated by constantly open glass doors. To achieve a smooth transition between spaces, doors should be represented with a polygon that colour matches the space in which they’re located, creating an open-door effect in the cartographic visualization. This representation is crucial for passengers to understand the space, as they may not realize they are passing through doors or changing areas.

In the case of installations such as stairs or escalators, there are several options for presentation, and the selection of the right one was preceded by trials. First of all, due to the fact that the stairs occupy a large area within a metro station, the chosen approach involves presenting them as a polygon. This kind of geometry allows users to orient themselves better in the space. In schemes of other spaces, such as shopping malls, stairs are usually represented by a point. As for the appearance of the stairs, the original idea was to create a texture on their surface that mimics the individual steps. Nonetheless, the texture of the steps would interfere with the legibility of the scheme.

It also proved problematic to adequately represent the side of the stairs entrance, which is particularly important for platform-level stairs. The authors decided that the best solution would be to take inspiration from the schemes of Warsaw Public Transport, where the stairs are demarcated by a thick dark line on the sides from which they cannot be accessed.

The most challenging case was how to present the change of levels on the metro station scheme. The issue to consider was how to present the staircase when the levels change – fully or partially. In a situation where the mezzanine level is not directly above the platform, it is possible to present the entire staircase at both the mezzanine and platform levels. However, when the mezzanine runs centrally over the platform, such a presentation is impossible due to overlapping the stairs object on the mezzanine corridor area. It can also be problematic to present the stairs on the platform level, especially when the stairs are far from the ends of the platform, and there is a space underneath them where passengers can walk. As a result, the authors decided that the staircase connecting the mezzanine and the platform would be presented in partial form, with only half of it shown at the corresponding level.

Another aspect was to distinguish between stairs leading downward and those leading upward. Such a situation is most common at the mezzanine level, where some flights of stairs lead out to the ground level and some down to the platform. To simulate the impression that the objects located lower down are darker, the authors suggest using different shades of the same colour for the corresponding direction.

When it comes to ticket gates, they can be represented using a separate symbol for each gate or be generalized, and a single symbol can be used for a group of gates. To ensure clarity on the geovisualization, the authors suggest using one generalized symbol. The dilemma arose regarding the representation of wide ticket gates, primarily intended for wheelchair users, people with luggage, or those with bicycles. Due to the ambiguous purpose of these gates, it was a challenge to select an appropriate symbol to be part of the sign representing the wide gate. At metro stations, in place of these gates is a sign representing each person who can use them. Unfortunately, due to the fact that the geovisualization on a smartphone screen will reach an insignificant size, it was necessary to select one simple sign.

4. Proposal

As an example, the visualization has been prepared for the Świętokrzyska metro station, as it's the most complicated station in the whole Warsaw metro network with two metro lines crossing. The geovisualization of the station is divided into four levels: 0 – ground level, -1 – mezzanine level, -2 – M1 station level, and -3 – M2 station level. They were divided according to the natural position of the levels resulting from the construction of the metro. The only aspect that needed to be deliberated was the division of the space that connects the M1 and M2 levels, mainly due to its L-shaped layout. In addition, this space consists of two levels, including a small mezzanine, so it is crucial to clearly depict this part of the station on the geovisualization. Based on the adopted methodology, it was decided to present the upper part of the connecting space together

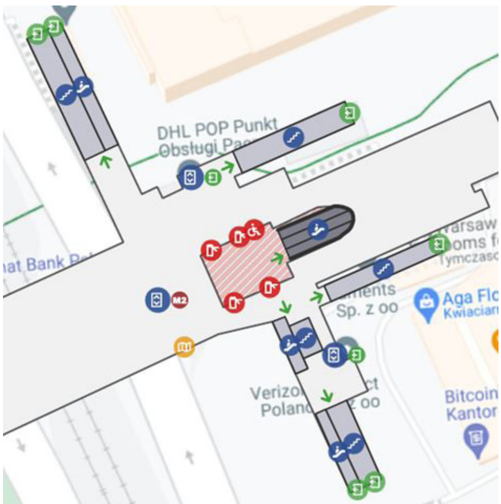


Figure 5. Fill colors used for spaces on the geovisualization (source: Google Maps)

Figure 6. Representation of stairs and elevators on the geovisualization (source: Google Maps)

Figure 7. Ticket machine, ATM, information board, and elevator symbols on the geovisualization (source: Google Maps)

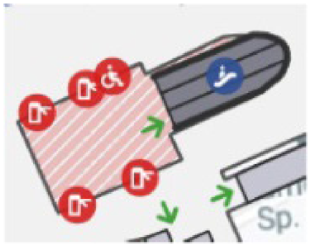


Figure 8. Ticket zone and gates symbols on the geovisualization (source: Google Maps)

with the M1 line platform since both are on the same level and to connect the lower part to the M2 line platform.

The authors considered it worthwhile to use a lighter colour to fill the corridors of the metro station since, in this case, it is the most essential content. A shade of grey, a tad darker than the one used as the primary background in Google Maps, was applied (Figure 5). A dark grey border, that creates a high contrast, was also used to distinguish the station area on the base map and the individual spaces on it. The space that required a special presentation was the ticket zone. This area has been filled with a pale red colour with hatching in the form of white diagonal lines.

Three objects are included as part of the installations: fixed stairs, escalators, and elevators. The presentation of each of these objects differs to some extent. In general, installations on the visualization are represented by a sign with a white icon on a blue background. Additionally, stairs are filled with a solid colour, different from the fill colour of corridors (Figure 6).

To indicate the side of the stairs entrance, the method used in Warsaw metro schemes was applied, but in a more subtle form, using a thinner line, with the addition of green arrows at the entrance to the stairs (Figure 6).

Elevators, unlike stairs, occupy a smaller area, so a simpler approach was chosen for them. They were represented solely by an elevator symbol located at the object's centroid (Figure 6).

To distinguish the direction of the stairs, an exit sign placed at the top of the stairs leading to the surface has been added. Compared to the stairs going up, a darker shade of grey has been used for the stairs leading down.

Figure 9. Train direction symbol on the geovisualization (source: Google Maps)

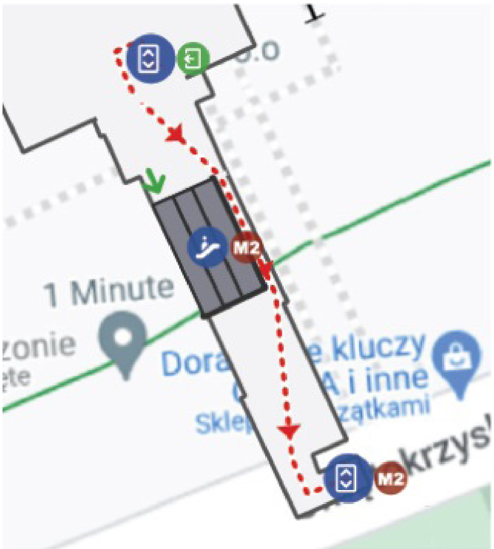


Figure 10. Route symbol on the geovisualization (source: Google Maps)

As for elevators, the direction of their operation was marked with an additional symbol in accordance with the methodology used in station schemes provided by Warsaw Public Transport. Elevators leading to the platform were marked with an M1 or M2 symbol, according to the metro line number, while those leading to the surface were marked with an exit symbol.

Due to their small relative size, objects such as ticket machines, ATMs, or information boards are represented by point symbols. Their representation is in the form of a yellow circle with a white icon corresponding to the object (Figure 7).

In order to highlight the location of the ticket zone boundary, a circular sign with a red background was used to depict the gates (Figure 8). This refers to the station schemes provided by Warsaw Public Transport, where the ticket gate symbol has the form of a red dotted line. A shape reminiscent of the ticket gates found at stations on the M1 metro line was chosen as the

Figure 11. Cartographic visualization of level -1 of the Świętokrzyska metro station (source: Google Maps)

Figure 12. Cartographic visualization of level -2 of the Świętokrzyska metro station (source: Google Maps)

icon placed on the sign. To represent wide ticket gates on the geovisualization, an icon of a person in a wheelchair was used.

Tracks have been added to the platform levels to help users better orient themselves in the space. A sign commonly used on base maps such as Google Maps and Apple Maps was chosen as the symbol for the tracks. In addition, the tracks have been labelled with the name of the end station in a given direction and an arrow sign indicating the exact direction the train is moving (Figure 9).

When navigating, users will be able to view the route they need to follow directly on the station visualization. This route should be clear to them, especially when they are on the move. For this reason, the authors used red for the line to make it stand out against the background of other objects. Based on the adopted methodology, the route was given a dashed line style. In addition, arrows were added to the line to tell the user in which direction to move, making it easier to navigate (Figure 10).

Overall, the colours used in the geovisualization were carefully chosen to ensure high contrast between marked objects and the background. Each symbol has a contrast ratio of at least 3.07:1 between the icon and its background, which meets the WCAG guidelines requiring a minimum contrast of 3:1. Widely recognized symbols that correspond to real-world objects were also incorporated. Each object is distinguished by both colour and iconography, which aids individuals with colour vision deficiency as well as those with cognitive impairments. These design choices align with digital accessibility guidelines, enhancing usability for a diverse audience.

The complete cartographic visualization is presented on Figure 11, Figure 12, and Figure 13.

5. Results

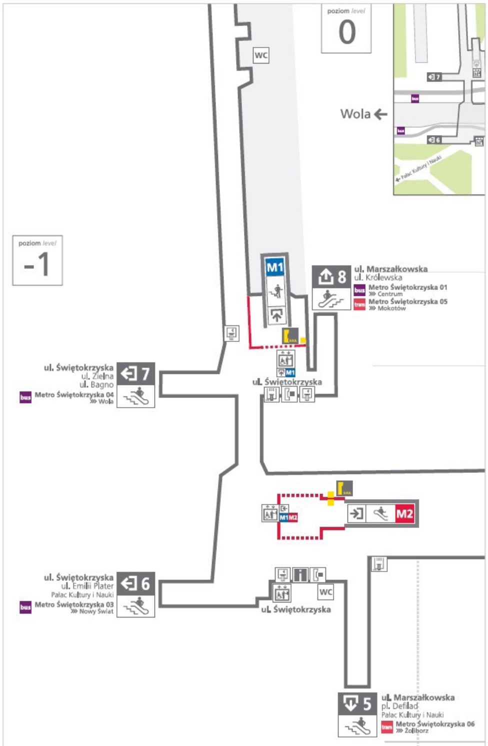
Two types of research – quantitative and qualitative – were conducted as part of this study. However, it should be borne in mind that the parameters studied in the surveys were evaluated in multiple stages, where the surveys were only one of them.

5.1. Quantitative study

A quantitative study in the form of an online survey was conducted to verify the quality and legibility of cartographic visualizations of metro stations. The survey included the complete geovisualization as an attached file for respondents to preview. Respondents were asked to evaluate the readability and aesthetics of the proposed geovisualization, as well as to indicate

Figure 13. Cartographic visualization of level -3 of the Świętokrzyska metro station (source: Google Maps)

Station map 1



Station map 2

Figure 14. Images attached to questions no. 3–6 (source: Google Maps)

their preferred visualization in terms of the specified aspects. Compared with the proposed geovisualization was a metro station map provided by Warsaw Public Transport. Besides the metric questions, respondents were asked the following structured questions with images attached (Figure 14):

1. How do you rate the legibility of the presented fragments of the visualization of a metro station?
2. How do you rate the aesthetics of the presented fragments of the visualization of a metro station?
3. Which metro station map is more appropriate for use in mobile metro navigation applications?
4. Which metro station map displays features such as stairs and elevators more effectively?
5. Which metro station map has a better reference to the ground surface?
6. Which metro station map employs a more effective colour scheme?

Answers to questions number 1 and 2, had the form of a five-level Likert scale, where 1 equals to very poor, and 5 equals to very good.

The questionnaire was completed by 84 people, 35% of whom had experience in cartography or geoinformation. Among the respondents, seven people have a mobility disability, four people frequently use the metro with a baby stroller, and one person has declared colour vision deficiency.

Nearly half of respondents use the metro at least once a week (n = 41). About a third of people (n = 26) use it once a month or once every two weeks, while the rest use it less frequently than once a month (n = 17).

Respondents without geoinformation experience rated the legibility of the metro station visualizations at an average of 3.25, while those with experience rated it at 3.07. Persons who frequently use the metro with strollers rated the legibility at 3.50, users with mobility disabilities at 2.29, and the person with colour vision deficiency at 2.

In terms of the aesthetics of metro station visualizations, respondents with and without geoinformation experience rated it at averages of 3.69 and 3.58, respectively. Frequent metro users with strollers rated the aesthetics at 4.25, users with mobility disabilities at 2.57, and the respondent with colour vision deficiency at 3.

In comparing the proposed cartographic visualization (station map 1) and the Warsaw Metro scheme (station map 2, Figure 15), 66% of respondents with geoinformation experience and 53% of those without experience preferred station map 1 for use in a mobile navigation application. Frequent metro users with strollers showed no clear preference. The respondent with colour vision deficiency preferred station map 1, whereas 71% of respondents with mobility disabilities chose station map 2.

Both experience groups judged similarly which map was better at presenting objects such as stairs or elevators, with 51% of persons without geoinformation experience and 48% of those with experience voting for station map 1. Similar results were obtained for groups of persons with special needs, although 71% of those with mobility disabilities chose station map 2.

Those with experience were unanimous in their opinion that station map 1 had a better reference to the ground surface. 87% of respondents without geoinformation experience also chose station map 1 as more suitable in this aspect. 67% of respondents in the special needs group considered station map 1 to be better related to the ground surface.

Both those with no experience and those with expertise in geoinformation or cartography were more likely to judge that station map 1 makes better use of colours compared to station map 2, with 76% and 59% respectively. However, respondents in the special needs group were equally split in their evaluation of the use of colour between station map 1 and station map 2. This means that for most of those surveyed, the use of colours in station map 1 is better.

5.2. Qualitative study

A qualitative study was conducted with 12 people including two wheelchair users. The study took the form of an in-person interview. This provided detailed responses and opinions about the developed geovisualization. Each

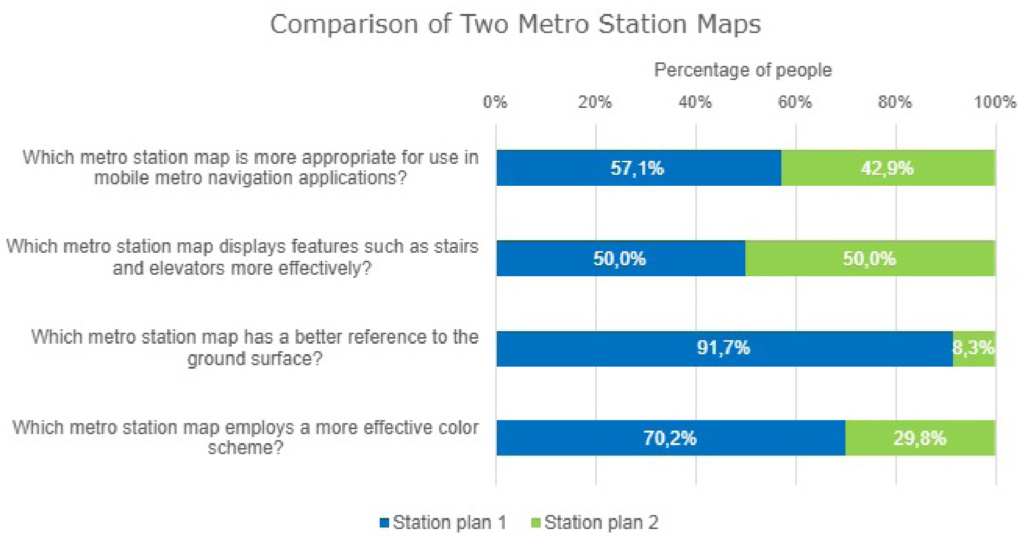


Figure 15. Bar chart comparing the two presented station maps evaluated by all respondents

interview was held separately to minimize the impact on the interviewee's responses. Respondents were presented with printouts of the designed geovisualization, which was the same as station map 1 from the quantitative study, and its digital version displayed on a phone screen. Unlike the quantitative study, no respondent in the qualitative study is professionally involved in cartography or geoinformation, nor are they studying related fields.

As for the use of Warsaw Metro, three people use it less than once a month, two once a month, two once a week, and five several times a week. Field orientation ratings were as follows: two rated poorly, three moderately, six well, and one very well. All respondents reported no difficulty reading indoor maps or schemes. Most respondents had no difficulty identifying key objects at the station, such as the stairs and their entrance side, elevators, entrances, ticket machines and ATMs. Despite the general approval of the signs, some respondents, particularly those in older age groups (45–53 and 54+), encountered difficulties in recognizing specific objects, primarily ticket machines and information boards with station maps. Additionally, one respondent, who is a wheelchair user, misinterpreted the icon depicting a person in a wheelchair near the ticketing area as an indication of a restroom for persons with disabilities. However, all respondents were able to identify the direction of routes around the station without difficulty.

Respondents also agreed on the aesthetics of the geovisualization, attributing this to the appropriate choice of colours, which effectively convey the purpose of various objects, as well as to the overall legibility of the geovisualization. Most of the respondents noted that the color-coding for different types of station objects was helpful, enabling them to clearly distinguish categories.

As noted previously, most respondents had no difficulty identifying ticket machines, though some suggested that the icon used to represent them could be improved. Additional recommendations included clearly marking the beginning and end of routes to enhance navigational clarity. Based on the study results, changes were made to the geovisualization including the improvement of symbols of selected objects, such as ticket machines.

6. Discussion and conclusions

As part of this article, a detailed cartographic visualization of the Świętokrzyska metro station has been prepared with the intention of placing it in a mobile navigation application. The methodology was developed based on the principles of cartographic presentation and accessibility guidelines, taking into account the needs of users with special needs including persons with mobility disabilities, persons with colour vision deficiency, and persons, who often travel with baby strollers. An evaluation addressing various aspects of the designed cartographic visualization was also conducted.

The visualization of the metro station was generally evaluated positively by both those with and without experience in geoinformation or cartography. Similarly, despite the diversity of needs and perspectives of persons with different limitations, the visualization of metro station maps showed some positive features. At the same time, there is potential for further enhancing the visual appeal and readability of the geovisualization, which may contribute to better usability of this project for both a wide range of users. It is worth continuing research to develop visualizations to provide more comprehensive and customized solutions for persons with different needs and limitations.

Some limitations of the studies should be noted. First, the sample was not representative of the entire population of metro users. Second, the qualitative study was a non-systematic evaluation. Extensive quantitative and qualitative research related to the effectiveness of the cartographic visualisation will be carried out during the final testing of the geo-information application using the metro station map proposed in this article.

The proposed geovisualization can be applicable not only at metro stations but also, after careful adaptation, at train stations, airports, or cultural and educational facilities. This possibility of diversified use creates a potential for further development of applications that use it.

When creating a product accessible to the general public, it is crucial to gather their opinions and insights. The completed surveys provided valuable knowledge. Persons with disabilities, geoinformation professionals, as well as ordinary users of public transportation, participated in the surveys. Nonetheless, to best tailor the mobile app and station visualization to user needs, more tests are required on a diverse audience, including tourists unfamiliar with Warsaw's metro network.

It is inherently challenging to adjust the map symbols to suit every user, as it is an individual issue, and some users may not understand even widely used symbols. Therefore, while prioritizing the majority's opinion is crucial, insights from individuals should not be disregarded. This challenge is ubiquitous in product design, as no "one-size-fits-all" solution exists. However, striving for the most user-friendly solution that meets the needs of a wide range of users remains essential.

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