International Cartographic Association
Association Cartographique Internationale

# Tailoring Tactile Maps Based on Blind Users' Needs

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**Abstract**: The Sustainable Development Goals aim to "leave no one behind," including visually impaired individuals who should have equal access to information. However, the production of tactile maps for the visually impaired has been inhibited by factors such as a lack of data and technology, cartographical challenges, and high production costs. To address this issue, two research projects developed prototype tactile maps for visually impaired users and evaluated their usability through a focus group discussion and hands-on experience. In the first project, the maps were appreciated for their continuous style, thematic versatility, and proportional information density. Suggestions for improvement included the addition of a clear map title, an overview map, a mandatory legend, and distinguishable icons. Tactile maps were seen as supplementary to mobile navigation by providing a geographical overview, information about locations of interest, creating and correcting cognitive pictures of the living environment, and sharpening geographical and common knowledge. The second project focused on refining the results in multiple iterations, and for this purpose a multidisciplinary consortium was formed that, in collaboration with a test panel of visually impaired users, contributed to the aim of making tactile topography on-demand, fit-for-purpose and globally available.

**Keywords:** inclusiveness, tactile mapping, topography, products on demand, user participatory design

## 1. Introduction

The Sustainable Development Goals – which were adopted by the General Assembly of the United Nations in September 2015 – are built on the principle of "leaving no one behind." (Department of Economic and Social Affairs 2019, 244) Each individual (despite physical or cognitive challenges) should be able to navigate one's own life and should have equal access to information. However, how does that function for visually impaired people who literally try to find their way in our societies? This question has occupied several people throughout history and led to numerous efforts to produce tangible media to accommodate this need.

Several factors, however, seem to have inhibited the realisation of these maps into products, such as lack of fitting geographical data, appropriate technology, cartographical challenges, and high production costs. These factors become especially apparent since for most people a blind's real-life challenges are not first-hand experiences and therefore it is difficult to create solutions that properly address that user's needs. On top of that, there is a small group of users and both factors influence the willingness to allocate budget and to invest in knowledge acquisition.

Other factors related to the sensory-cognitive processing of information also influence the development of an accessible, user-friendly tactile map. Unlike sighted people, blind and visually impaired people process spatial information bottom-up rather than top-down: they start with the details and construct their overall picture from them. They obtain this detailed information sensorially, by touch, which places restrictions on the amount of data a tactile map can contain. Simply reusing traditional maps is not possible because information density and detail in symbology are indistinguishable by touch.

For that reason, it is of the utmost importance to take the user's perspective on tactile information into full account and to evaluate the requirements of topographic maps for the visually challenged.

### 1.1 Aim and Contribution of the Study

The remainder of this article provides an overview of a Dutch collaboration on the production of tactile maps which takes blind users' needs into account. The tactile map thereby serves as a complement to navigation apps and serves for orientation in the living environment. The project explicitly strives for an inclusive product that provides the end user with the tools and resources that maximize their independence and autonomy.

Proceedings of the International Cartographic Association, 5, 22, 2023.
31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-5-22-2023

## 2. Background

Before discussing previous research and experiments, the technological potential of mapping, the necessity of user research as well as the printing material we first briefly explore the concept of blind- and visual impairment.

### 2.1 Visual Impairment, Blindness and Cognitive Spatial Maps

Some real-life statistics help to better understand the extent of blindness and low vision: out of 17.6 million Dutch people (Statistics Netherlands (CBS) 2022), 300,000 are blind or visually impaired and an even smaller minority (6,000 people) are blind *and* capable of reading braille. But what exactly is being talked about when the terms blindness and visual impairment are used?

People become blind or visually impaired at all ages, regardless of gender, social class, or intellect. The causes of visual impairment or blindness are not unambiguous: parts of the retina or optic nerve can be damaged by a disease, but sometimes the problem lies in the optic nerve or the brain. Disorders that are classified under visual impairment are also diverse: a limited or incomplete field of vision, reduced visual acuity, impaired cognitive image processing, or reduced colour and contrast perception.

Despite this diversity of causes and types of indications, two main classes are distinguished in practice: visual impairment and blindness. The World Health Organization (WHO) considers a person to have poor vision when the visual acuity is between 10 and 30 per cent. When the visual acuity is between 5 and 10 per cent, this is considered low vision (Ackland, Resnikoff, and Bourne 2017). According to the WHO, three levels of blindness are distinguished: complete blindness (total absence of light perception), blindness (visual acuity of less than 2%) and legal blindness (visual acuity of 2-5%) (Ackland, Resnikoff, and Bourne 2017).

Both sighted and people with visual impairment (PVI) create cognitive representations of the world at large but also of areas incorporating locations, directions, and distances between locations (Papadopoulos, Barouti, and Koustriava 2018; Ottink et al. 2022). A key difference between the sighted and PVI, however, is the representations these cognitive maps are based upon. Whereas sighted people tend to take an allocentric (birds-eye) of reality, PVI normally take an egocentric approach to form a cognitive map as they acquire spatial information sequentially (bottom-up) instead of concurrently (top-down) (Gual, Puyuelo, and Lloveras 2015; Quiñones et al. 2011). Though an egocentric representation suffices for navigation, it is always unsuited for inference of Euclidean distances, detours, and shortcuts. Hence, PVI can often construct a route in, but not an overview of their environment (Ottink et al. 2022).

### 2.2 Previous Research and Experiments

To meet this need for an overview, cartographers and educators have sought to create maps tailored towards the need of the blind and PVI. Experiments on palpable topography for visually impaired people have a long history and at least predate 1780 (Levy 1872, 138). Illustrative is a Flickr image collection (Perkins School for the Blind Archives n.d.) which shows a diversity of 19th and 20th-century examples of tactile maps using, for instance, embossed characters and raised lines (figure 1), but also woodcuts and wooden 3D globes, all purposed for use in geography education.

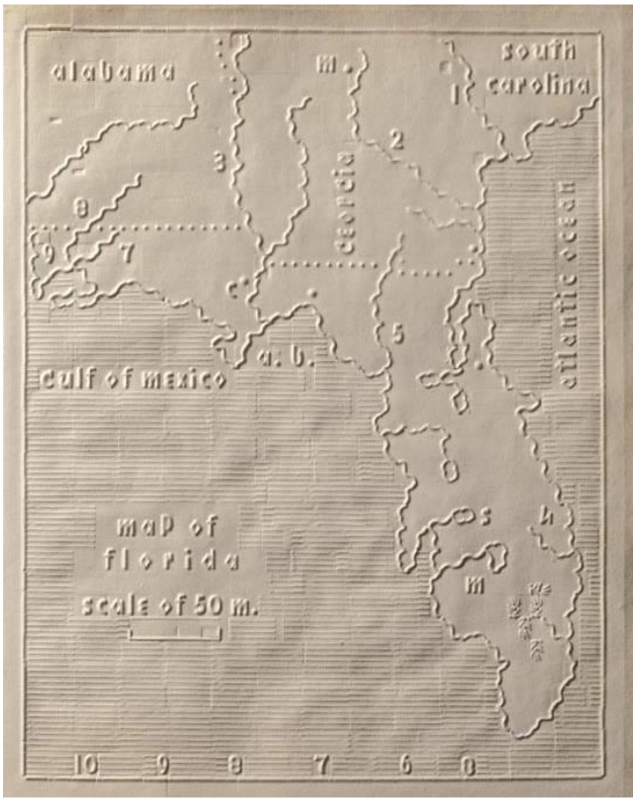

Figure 1. Map of Florida (Howe, Cray, and Ruggles 1837).

Tactile maps have since been the object of scientific and applied research of which only a few initiatives can be highlighted here. Wiedel (1966) already noted that while Braille has advanced, tactile graphics for the blind, like maps, remain limited despite efforts to improve the graphics and significant demand. In his view, this was due to challenges posed by symbolization and reproduction. However, these challenges did not hinder other researchers and practitioners to continue experimentation and production of customized tactile maps.

In the last decennium, developments seem to speed up. In 2016 a Czech collaboration between the ELSA Center, Teiresias Center, and Seznam.cz started, which aims to improve accessibility and provide updated tactile maps quickly and easily. On the web portal Mapy.cz users can select areas within the Czech Republic for map production (Červenka et al. 2016). In Switzerland, in 2017, a psychologist commissioned a special atlas for a blind friend who loves maps. This tactile atlas was created by an intern at Esri CH at that time. Additional copies have been distributed to the national library and the Swiss Institute for the Blind. (Miller 2017) In the same year, the ICA Commission on Maps and Graphics for Blind and Partially Sighted People published a methodological guidance for education about geographic space through touch (Coll Escanilla, Barrientos Guzmán, and Huentelemu Ramírez 2017).

Furthermore, a significant scientific impetus has been given by the doctoral research of Jakub Wabiński. He reviewed the information value of tactile maps (Wabiński, Mościcka, and Kuźma 2020; 2021), evaluated guidelines for standardizing the design of tactile maps (Wabiński, Mościcka, and Touya 2022), tested the application of height differentiated tactile symbols (Wabiński, Śmiechowska-Petrovskij, and Mościcka 2022), and researched the semi-automatic development of thematic tactile maps (Wabiński, Touya, and Mościcka 2022).

## 2.3 Methods of Printing

Tactile maps come in diverse types. One type is thermoform, a production method where a plastic sheet is heated, vacuum formed onto a mould, and trimmed to create a tactile product. It is fast and inexpensive for making multiple copies, but drawbacks include mould costs, minimum shape sizes, and limited colour options for inclusive use.

A second type is braille embossing, which uses the braille system of dots but aligns them in lines and shapes thus creating an image. The technique uses the same paper used for braille text and some braille printers support making images. However, the 'resolution' is low which prohibits the creation of fine shapes.

A third type is created utilising UV printing, a new method where special thick ink is put down and instantly dried by printhead to create raised shapes on paper. The final layer can use full-colour ink to create a true 'twin vision' product which can be utilized by both sighted, PVI and blind users. However, the inflated costs, slower production times, and specialized equipment associated with UV printing are some of the limitations to consider.

The most usual form, however, is swell paper: a heat-sensitive paper which has a chemical substance on one side that reacts with black ink, causing it to swell when heated. The design is printed using laser or inkjet printers, but the printer must run cold, and the ink must adhere to the coated paper. After printing, the paper is run through a swell oven (see Figure 2) for a tactile effect. It is easy to work with and does not require special facilities. Furthermore, costs are low (Lobben and Lawrence 2012; Wabiński, Touya, and Mościcka 2022).

Figure 2. Swell Paper Machine

## 2.4 Advances in Technology

Up till recently, the creation of maps in general, and tactile maps in particular was the domain of experts. Especially in the case of tactile maps, specialist knowledge is required to produce a readable map from not always up-to-date geographic information. As a result, customization is almost always required.

Fortunately, there are developments today that mitigate these challenges. By national open data policies geographic information is increasingly becoming available which can be appended with Volunteered Geographic Information like Open Street Maps, and industry-based solutions like Esri's Living Atlas.

Another positive development is the increasing number of applicable algorithms and sophisticated tools which are becoming available to process and tailor data for specific applications. State-of-the-art solutions include various automated mapping implemented by NMAs in recent years (Duchêne et al. 2014; Stoter et al. 2016), while there is also a growing diversity of internet applications with maps on demand, e.g. the USGS' Topobuilder (U.S. Geological Survey, n.d.).

## 2.5 User Research

Given the state of affairs in research and technology, one might wonder what has been hindering the implementation of production systems that make usable tactile maps available to blind people. Systems and tools do exist but seem not to suffice the needs of their prospected users for a variety of reasons. One cause for these shortcomings is that these tools often lack feedback from the end user (Elli, Benetti, and Collignon 2014). In this respect, not much seems to have changed over time: "This want of success, however, has not been caused by any inherent difficulty in the case, but has proceeded simply, as it would appear, from the caterers not sufficiently understanding the wants of the blind in connection with tangible maps, and the means best adapted to meet those wants" (Levy 1872, 138).

https://doi.org/10.5194/ica-proc-5-22-2023 |

## 3. User-centred Research

To accommodate this concern, the project decided to place blind and PVI at the heart of the project. Therefore, user-centred research was conducted over two different projects. In 2020, an intern created tactile topographic maps for the blind and visually impaired. and developed prototype maps, which were evaluated by prospected end-users, revealing the potential benefits of tactile maps. Due to the success of this internship, a follow-up project was initiated in 2022 to further develop the prototypes. To this end, a week was organized to conduct more user testing and gather elaborate feedback.

### 3.1 Internship with Two Focus Groups

The intern created tactile topographic maps for the Netherlands and Europe by building upon the symbology used for the Tactile Atlas of Switzerland catered to the needs of the blind and PVI, see figure 4.

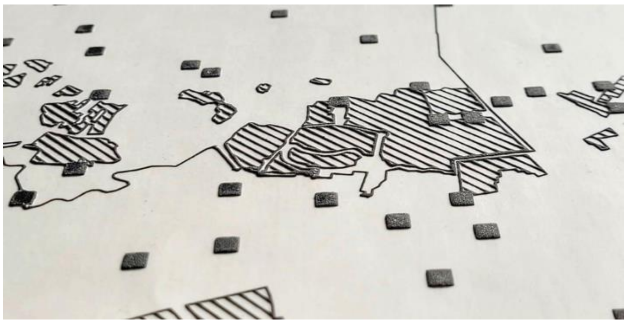

Figure 4. Detail of a Tactile Map on Swell Paper

### 3.1.1 *Approach*

In addition to the creation of new maps, focus groups were organized to evaluate the results. In these focus groups the following questions were addressed: What expectations do blind or PVI have concerning topography and its usage? Subsequently, in which way could a national mapping agency improve the accessibility of its maps? To answer these questions, several prototype tactile maps were developed for evaluation and assessment in a two-hour face-to-face meeting, which combined a focused group discussion (O.Nyumba et al. 2018) with usability research (Welbergen 2021). The outcomes provided insight into shared general needs regarding the use of maps and focused on individual detailed preferences regarding the usability of topographic maps. The session, which due to COVID-19 had to be held twice, was divided into three parts: a group discussion, hands-on experience with maps, and a group evaluation of the prototypes. We evaluated the prototype with people who can read Braille (blind/very visually impaired) and people who could not (visually impaired), to see if we could design a fully inclusive product (see Figure 5).

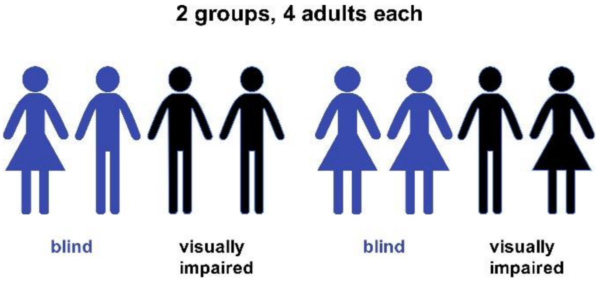

Figure 5. Composition of Focus Groups during the Internship

### 3.1.2 *Discussion*

Although it appeared from the group discussions that users doubted whether the maps will be used much ‘on the road’ since mobile devices nowadays provide the blind with navigation facilities, it was concluded that tactile maps could supplement mobile navigation in four ways: 1) by provisioning a geographical overview which helps to orient in an area; 2) by providing information about locations of interest to a tourist or first-time visitor; 3) by creating and correcting the cognitive picture of one’s living environment; and 4) by enlivening one’s geographical and common knowledge and thereby sharpening one’s understanding of the world at large.

Figure 6. User Tests

In the second part of the session, individual participants gained hands-on experience with the prototypes. These prototypes covered topography on several levels: maps of neighbourhoods, provinces, the Netherlands, as well as of Europe. On the one hand, the example maps were appreciated for their continuous style and thematic versatility. Furthermore, the information density was proportional and different topographic objects could be distinguished. On the other hand, the broader context of the map was missing. Therefore, the addition of a clear map title and, if applicable, an overview map were suggested. Also, the placement of a (mandatory!) legend and usage of clearly distinguishable icons appeared to be critical to discriminate geographic features.

### 3.1.3 *Conclusion*

The session concluded with a discussion on tactile maps which was based on the assessment of the provided prototypes. This also took into account a broader perspective of the benefits of tactile maps and their integration with existing solutions. Furthermore, the current state of geospatial technology to produce maps on demand has the potential to provide more up-to-date information and could also accommodate the need for continuity between tactile maps in different scales.

## 3.2 The Sequel

To further develop the prototypes created by the intern and to extend the usability research a follow-up project was initiated. This project identified two focal areas that are critical to the success of the medium to be developed. On the one hand, aspects such as data, GIS, printing, and swelling have their influence on the production of a tactile map; on the other hand, research on user requirements, cognitive processing, practice, and explicit user feedback promotes the usability of these maps, see Figure 6. To do justice to these two foci, different disciplines and areas of expertise are necessary.

Figure 6. Two Foci for Successful Tactile Map Production

For this reason, the project began by bringing together a collaborative group in a start-up meeting, during which the representatives from four organisations (Dedicon, Accessibility, Esri Nederland and Kadaster) became acquainted. These organisations cover diverse disciplines: accessibility research with a specific focus on user needs, mapping and visualization, geographic data acquisition, geo-information technology, map fabrication and tactile media production.

Next, a meeting was organised with blind and visually impaired users, in which topics like visual impairment, orientation and digital skills were discussed. The purpose of this session was to gather information about how people with visual impairments orient and navigate in our societies.

Subsequently, the team brainstormed in a poster session about activities they would like to collectively undertake in a so-called sprint week and formulated preconditions such as end-user feedback These activities included conducting research with end users, assessing the map in different environments, and gathering immediate feedback.

## 3.3 Sprint Innovation Week

All these preparations culminated in a so-called innovation sprint that focused on developing a tactile map using GIS and was improved with direct feedback from users.

### 3.3.1 *Approach*

In April 2023, the usability of tactile maps was assessed during a sprint week organized by the collaboration group. Over the course of the week, the group engaged a total of nine participants with diverse backgrounds. Among the participants, six were completely blind, one was still able to distinguish light and dark (legally blind) and the remaining two were visually impaired. While the blind participants had varying levels of proficiency in braille, the visually impaired participants did not master braille, see Figure 7.

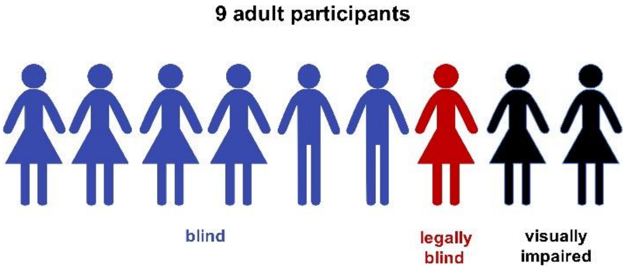

Figure 7. Composition of Participant Group in the Sprint

Several prototype maps were presented to the participants. On the primary testing day, the seven participants were divided into three subgroups, and each subgroup evaluated three different maps, the first of which contained an overview of a residential area (without Buildings) at a scale of 1:1500. The second map portrayed a detailed view of the same residential area (with Buildings) at scale 1:750 and the third map portrayed a nearby shopping centre (with buildings and symbols) at scale 1:750.

The tests aimed to evaluate the participants' ability to navigate and understand the tactile maps, and therefore they were asked to locate and interpret different areas on the maps and provide feedback on their experiences.

### 3.3.2 *Discussion*

Due to a lack of contextual information, the participants encountered difficulties in interpreting the maps. They provided recommendations to address this issue, such as including street names and landmarks as orientation points. Other recommendations were simplifying icons and legends, incorporating more white space to differentiate between roads and the surrounding texture, and providing reference points for orientation. Navigational challenges were particularly prominent with the second and third maps, primarily due to the absence of essential landmarks and an abundance of irrelevant details. Participants also struggled to distinguish between different surfaces (e.g., grass and pavement), and small symbols and encountered problems with the legend. They expressed a preference for more tangible representations of characters and symbols. Furthermore, the participants emphasized the need for additional information such as orientation arrows and expressed a desire for thematic maps. Lastly, they recommended including building entrances and numbers on the maps.

During these testing sessions, proficiency in reading braille was found to be an important aspect of map-reading skills. Blind users highly skilled in braille performed better with tactile maps, indicating the importance of braille proficiency. However, further investigation is needed to determine the direct correlation between braille proficiency and map-reading abilities.

#### 3.3.3 *Conclusion*

The study revealed the importance of designing maps that are easy to understand and interpret for visually impaired individuals. This includes providing sufficient contextual information and orientation points, utilizing sufficient white space, and simplifying icons and legends.

## 4. Overall Conclusion

In conclusion, both two studies provide valuable insights into the usability of tactile maps for visually impaired individuals. The recommendations made by the participants highlight the need for more accessible and user-friendly maps and provide important guidance for designers in this field. With continued research and development, it is hoped that tactile maps will become an increasingly effective tool for helping visually impaired individuals to navigate their surroundings and participate more fully in their communities.

Therefore, in follow-up research, the obtained results will be refined in multiple iterations by a multidisciplinary consortium in conjunction with a test panel of visually impaired users to a least viable product of a vicinity map. These efforts will further enhance the accessibility and usability of tactile maps, expanding their reach and impact. Initially, the focus will be on Braille maps, but the ultimate goal is to make these maps truly inclusive to serve sighted, visually impaired, and blind users, thus making tactile topography available: on-demand, fit-for-purpose, and globally.

### 4.1 Acknowledgements

The authors would like to thank the participants of the focus groups for their input, enthusiasm, and insights; Accessibility, a division of Bartiméus for organizing and guiding the focus groups; Dedicon for printing the tactile map prototypes; Esri Nederland for supplying software and Kadaster for the providing means, budget, and time to research this topic.

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31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-5-22-2023