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Producing accessible intersection maps for people with visual impairments: an initial evaluation of a semi-automated approach

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Producing accessible intersection maps for people with visual impairments: an initial evaluation of a semi-automated approach

Street intersections are challenging for people with visual impairments. While tactile maps are an important support in both mobility training and independent journeys, the caseload of manual map production has made them less accessible. This paper explores the possibility of (semi-)automatically producing tactile maps for street intersections at large scales, with an initial evaluation focused on the graphic aspect of the produced maps. The automation attempts to identify acceptable default parameters and values and proposes an exploration of possible choices for potentially open decisions. It adapts the classic map production process with parameters to present the information tactilely at the intersection scale, and produces representation meaningful for PVI and realistic for an automatic procedure, resulting in ready-to-print maps in two scales of three sizes, with different levels of details and styles. The resulting maps are evaluated by professionals involved in tactile graphics through a questionnaire to evaluate the defaults and discuss the possibility of open choices. The professionals validated the maps, and their evaluation emphasized the need to have an acceptable default while keeping some options open to cater to the diversity in the visually impaired audience.

Keywords: tactile maps; visual impairment; accessibility; orientation and mobility; street intersections; map design; automated map production.

Introduction

Mobility is a challenge without vision. To travel safely with independence, people with visual impairments (PVI) take orientation and mobility (O&M) training to acquire conceptual knowledge and skills to explore and navigate the environment (Fazzi & Barlow, 2017). Crossing the street is essential in everyday journeys and an important O&M skill. A successful street-crossing requires understanding the layout and traffic flow of the street intersection (referred to as “intersection” in the paper) to start and finish at a safe location and time (Fazzi & Barlow, 2017). Without assistance, it is a

complex task that can hinder PVIs' confidence and independence (Gallagher et al., 2011).

To facilitate training and independent journeys, tactile, e.g., raised-line, maps are widely used for teaching and guidance. Tactile maps and models are important tools in O&M training, where maps and map-related activities are integrated at an early stage (Wiener et al., 2010), for mobility and general spatial knowledge and skills (Espinosa et al., 1998; Spencer et al., 1992). The maps are considered by some instructors as a vital orientation tool for teaching that would not be replaced by GPS applications (Baldwin & Higgins, 2022). Meanwhile, instructors and PVIs have talked about the unavailability of such maps despite their need (Baldwin & Higgins, 2022, Rowell & Ungar, 2005), and some recent developments in automated tactile mapping services have been appreciated: PVIs are actively requesting and using more maps from the service, and instructors can quickly make and customize maps for classes (Biggs et al., 2022).

For street intersections, tactile maps can facilitate journey preparation and provide guidance on-site. Simple make-shift maps are frequently used (Wiener et al., 2010), but often provide few details. On-demand tactile maps with more details would be very useful, but without automated services, the workload of manual mapping restricts their availability (Baldwin & Higgins, 2022). A few automated mapping services have been developed in recent years to provide city or neighborhood maps, but there is not yet one for intersections.

Despite existing guidelines on tactile graphics (e.g. Braille Authority of North America [BANA], 2010), there is not enough knowledge to fully constrain the automated production of tactile intersection maps. To produce usable tactile intersection maps, the classic automated map production pipeline needs to be adapted to balance the

amount of information needed to understand the area and the high requirements of the tactile graphic being simple and clutter-free (BANA, 2010).

This work presents an approach to semi-automatically produce tactile maps of urban street intersections and an initial evaluation with professionals working in tactile graphics. It aims to produce intersection maps with enough details to help navigate specific intersections while being easily readable and clutter-free. The decisions in the automated process are explored to identify both constraints and flexibilities. The produced intersection maps can be printed on microcapsule paper (swell paper) in two scales and three sizes (A3/A4/A5), incorporating various roadway and roadside objects to assist street-crossing. As an initial evaluation, the graphic aspects of maps were evaluated by professionals experienced in tactile graphics: the geometry, style, and map layouts, also exploring additional possibilities in the map design.

Related work

Assisting orientation and mobility around street intersections

Street-crossing is an important but difficult task for PVI. With limited visual information, PVI can experience great difficulties in understanding the layout of the street intersection and executing a safe crossing (Bentzen et al., 2004; Wiener et al., 2010). Several assistive technologies are being developed to assist it, such as smart canes that locate pedestrian crossings or phone applications to identify traffic lights status (Subbiah et al., 2019), or hand-held devices using beacons to help maintain a correct heading during the crossing (Shin et al., 2022). However, these devices are not widely used because they often require adaptation of the street infrastructure (e.g. installing beacons on street poles) or a much higher cost (a “smart” cane with obstacle detection functions can cost over €1000), and a vast majority of PVI still need

assistance crossing the street (Hoogsteen et al., 2022).

Tactile maps have always been an important support for PVI's mobility around street intersections for both teaching and specific guidance (Wiener et al., 2010). Together with make-shift models and tool kits (American Printing House for the Blind, 2010; Wiener et al., 2010), schematic diagrams (LightHouse for the Blind and Visually Impaired, 2021), and potentially 3D printed schematic models (Holloway et al., 2022), tactile maps are used to teach geometry and traffic concepts about the intersections, preparing PVI's for on-site O&M sessions.

However, the production of tactile maps is currently mainly a manual process restricted by its caseload (Baldwin & Higgins, 2022; Giudice & Long, 2010). With the development of automated mapping, some on-demand tactile mapping services have become available for public use (Červenka et al., 2016; Kärkkäinen, 2018; Miele et al., 2006; Watanabe et al., 2014). This increased availability is appreciated by both PVI's and instructors (Biggs et al., 2022).

The TMAP (Tactile Map Automated production) project (Miele et al., 2006) is one of the first initiatives to automatically generate tactile mobility maps with street lines and braille labels. Further, the TMACS (Tactile Map Automated Creation System) project (Watanabe et al., 2014) uses OpenStreetMap data to generate neighborhood-level maps of street lines and additional features such as stations and obstacles. Mapy.cz also uses OpenStreetMap data to generate maps at country, city, and neighborhood scales, with the neighborhood scale showing streets and building footprints, along with other features such as stairs, and water areas (Červenka et al., 2016). Similar maps are also produced using the data from the Czech's national mapping agency (Štampach & Muličková, 2016). BlindWeb provides neighborhood-level maps with a more accessible interface enabling visually impaired users to choose the desired zoom level, map

objects, and printing material (Götzelmann & Eichler, 2016). TouchMapper (Kärkkäinen, 2018) provides maps on various scales (9 scales from 1:1000 to 1:10000) based on OpenStreetMap data, with the most detailed level showing street and building footprints.

The automated services are supporting manual map production to some extent (Biggs et al., 2022), but not yet for street intersections. The maps they produce on the neighborhood scale do not represent street intersections with enough details: the intersections are represented by either two intersecting street lines or as blank areas, with little space to manually incorporate more details. To our knowledge, there is no automated service producing tactile maps with enough details that could be used for navigating street intersections.

The decision-making process in large-scale automated tactile mapping

Similar to visual mapping, automated tactile map production follows a pipeline involving choosing the size, scale, and content (objects), geometry processing (generalization), and symbolization. As tactile maps should adapt to PVI's haptic perception and mobility needs, it is not a "reproduction" process of the existing visual maps. The graphic elements should be (re-)designed to be meaningful to the haptic system to be readable and clutter-free, but still with sufficient details to support the mobility task.

This process involves many decisions. Among them, some are constrained by tactile graphic guidelines (e.g. BANA, 2010; The N.S.W. Tactile and Bold Print Mapping Committee [TABMAP], 2006) where geometry and symbolization are specified according to haptic perception limits to ensure the readability of the map. Other decisions are more driven by individual use cases: for example, choosing the

geographical objects to include. Finally, some decisions are inherently flexible, with no consensus to follow for automation.

Size, scale, and content

The first decisions are about the map size, scale, and content. Although scale and content generally depend on the intended usage of the map, they must also consider the intended print size and technology (Červenka et al., 2016). Current automated mapping services for mobility maps are mainly at a neighborhood scale of about 1:2000, to be printed on A3 or A4 swell paper (Červenka et al., 2016; Miele et al., 2006; Štampach & Muličková, 2016). The exact scale is often determined by the print size. For instance, once the target paper size is decided, the scale can be determined by making the minimum width of the street satisfy the minimum gap required between lines (Červenka et al., 2016).

The content of the map is driven by the intended usage of the map, and object selection is largely a flexible choice. For instance, PVIs would require different objects on maps for city centers or residential neighborhoods (Papadopoulos et al., 2020); and O&M instructors have different opinions about objects for a street intersection model (Holloway et al., 2022). For automated mapping, this is usually pre-defined based on the targeted scale and available data. Common objects for neighborhood maps are streets, buildings, vegetation blocks, water areas, tramways, and public transport stations (Červenka et al., 2016; Götzelmann & Eichler, 2016; Watanabe et al., 2014). Some services allow users to add objects according to their own needs (Götzelmann & Eichler, 2016).

In both manual and automated mapping, object selection is largely constrained by the limited space on the map to avoid cluttering and ensure readability (Rowell &

Ungar, 2005). In automation, object selection is also constrained by data quality. For example, sidewalks can be important for mobility maps (Cohen & Dalyot, 2021; Fazzi & Barlow, 2017), but they are often missing or only estimated because of the lack of quality data (Schmitz, 2015).

Geometry processing

Once the size, scale, and content are decided, the geometry processing often follows the classical cartographic generalization pipeline, integrating the constraints dictated by tactile graphic guidelines as parameters (Wabinski & Moscicka, 2019). For large-scale neighborhood maps, using state-of-the-art generalization algorithms, the process typically involves: reclassification, displacement, and simplification of the road network; reclassification, simplification, and squaring/smoothing of area features; displacement of point and area features along the road network (Červenka et al., 2016; Touya et al., 2019; Wabinski & Moscicka, 2019). Along the process, many decisions are constrained by tactile graphics guidelines. But some decisions have more flexibility. For example, there is no guideline about the preferred level of details, and different levels of details are observed from the existing examples. For instance, regarding the generalization level of building patches, Mapy preserves the building footprint with detailed geometries (Červenka et al., 2016), while some others make significant generalizations only showing highly simplified patches (Štampach & Mulíčková, 2016; Touya et al., 2019). Similar situations occur when solving conflicts caused by overlay or clutter: features might be removed, clipped, or displaced (Barvir et al., 2021), or dynamically decided through an optimization process based on the user-preferred importance of these features (Hofmann et al., 2022).

Since it is not realistic to ask for human input at every decision point during the

automation, such geometric choices would likely be default and implicit in an automated procedure. But they would directly influence the appearance of the map and the information presented.

Symbolization and styling

The symbolizations for tactile maps can be very flexible. There is some consensus about symbolization for some objects, e.g. rendering major line objects with a thick solid line (TABMAP, 2006), and a few proposals of symbol sets for specific scenarios (3D printed maps in Barvir et al., 2021; urban maps in Lobben & Lawrence, 2012 and The Australian Division of National Mapping [ADON], 1986; generic symbol sets in Prescher et al., 2017); but there are no (working) standards. The symbolization choices are diverse in both manual and automated mapping (Engel & Weber, 2022), as personal preferences also play a role (Prescher et al., 2017). However, for automation, while the symbol choice could be left open for the users, there needs to be a set of default symbols that can be consistently used in a specific context.

Summary and objective of the paper

To sum up, while guidelines already cover many aspects involved in the automated tactile mapping process, they do not dictate every decision in automation. Especially, for detailed tactile maps at the street intersection level, there are not enough established constraints to drive the automation. There could be implicit considerations in manual work, and there will always be some flexible decisions depending on individual preferences that should be left open. Because automation aims to provide consistent and usable tactile maps, these implicit and flexible choices should be identified first, to support the automation to provide acceptable defaults together with open choices.

In this paper, we explore the decision process for automated tactile mapping of street intersections. The constraints, potential defaults, and flexibilities are identified, to produce maps of several sizes, with different levels of detail.

A semi-automated procedure for tactile street intersection maps

To adapt a classic map production pipeline for tactile street intersection maps, we identify the parameters or choices involved in the process and their possible values. For the parameters whose values are dictated by the guidelines, they are used as default. The potentially flexible decisions will be explored with multiple proposals, to be evaluated by professionals in tactile graphics later. The following sections will discuss the design consideration and parameters of the automation process. The process has been implemented with a Python workflow based on OpenStreetMap data (OpenStreetMap contributors, 2015), where the data is prepared and processed into relevant geometries, and the styles and layouts are applied, to export the maps ready to be printed on swell paper. Most steps in the procedure can be automated, with manual inspection and curation between major geometry processing steps. A detailed description of the implementation can be found in (Jiang et.al, 2023).

The various parameters and choices involved are:

- Basic geometry-related parameters recommended by tactile graphic guidelines;
- Size and scale that depends on different usages of the map (i.e., classroom exploration of a large and more detailed map, and on-site exploration of a small and portable map);
- Geometry processing choices regarding specific objects;
- Symbolization choices;
- Design of the map layout.

Basic parameters for geometries

The geometries on tactile maps have to be large and separated enough to be properly perceived, and the related parameters regarding the size and distances have been studied through empirical research (e.g. Nolan & Morris, 1971) and recommended by tactile graphic guidelines (e.g., BANA, 2010). They constrain the automated procedure.

Various guidelines have been proposed by regional or national organizations (North American: BANA, 2010; Australian: TABMAP, 2006; Round Table on Information Access for People with Print Disabilities, 2022a; Swedish: Eriksson et al., 2003).

Compared to findings from empirical research, these guidelines are more generic and standardized as they “evolved from information gathered in surveys and research investigations into methods and current practices in use” (BANA, 2010).

Not every guideline specifies the exact value of each item. While the proposed values generally agree across them, there might still be some small disagreements about the exact value. This issue has also been discussed (Štampach & Mulíčková, 2016; Wabiński et al., 2022). When multiple values are suggested by different guidelines, we choose the smallest value to fit more graphical information on the map. The following values we used are synthesized from various guidelines around the world:

- Points (to recognize its shape): minimal size of 4mm (TABMAP, 2006);
- Lines: 1mm width for main lines, 0.5mm width for secondary lines (TABMAP, 2006);
- Areas (to recognize as different textures): minimal dimension of 6mm (BANA, 2010);
- Gaps: minimum 3mm around points (TABMAP, 2006); 3mm between parallel lines (Bris, 2001); 4mm between lines and areas (Bris, 2001), 5mm between area

features (Bris, 2001), with an exception that no gap is needed between two area features with contrasting textures (BANA, 2010).

Size and scale

To accommodate the potentially different use cases, maps are generated in three sizes: A3, A4, and A5. Among them, A3 and A4 are commonly used for maps in manual mapping (Rowell & Ungar, 2003) and automated services (e.g., Miele et al., 2006), but A5 is rarely used for tactile maps (Rowell & Ungar, 2003). However, A5 maps can be very portable, and with recent developments in audio-tactile interactive graphics on small tablets (e.g. Barvir et al., 2021), they can potentially facilitate mobile usage.

The scale of a tactile map is often derived from fitting the street to the required minimal size (Štampach & Mulíčková, 2016). In our work, the scale is derived from the width of the streets with boundaries (curb line). A street with one traffic lane (approx. 3.5 meters wide) should be at least 3mm wide on the map to ensure the gap distance between them. Also considering the extent of the map, the scale is set to 1:1000 for A4 and A5 maps, 1:500 for A3 maps.

Objects and geometry processing choices

The object selection and processing choices are based on the O&M instructions regarding street-crossing (Wiener et al., 2010). This work is limited to an urban context, as the crossing techniques and data availability could differ in suburban or rural contexts. The objects include both roadway (streets, pedestrian crossings, and traffic islands) and roadside features (buildings, vegetation areas, large parking areas, sidewalks, cycleways, and bus stops). Some other objects that might be considered important by O&M instructors (e.g. traffic signals, tactile paving, Holloway et al., 2022) are currently not included because high-accuracy data is rarely available, and assuming

the existence or location of such features can be dangerous if the reality turns out to be otherwise. An illustration of the basic geometry process is shown in Figure 1.

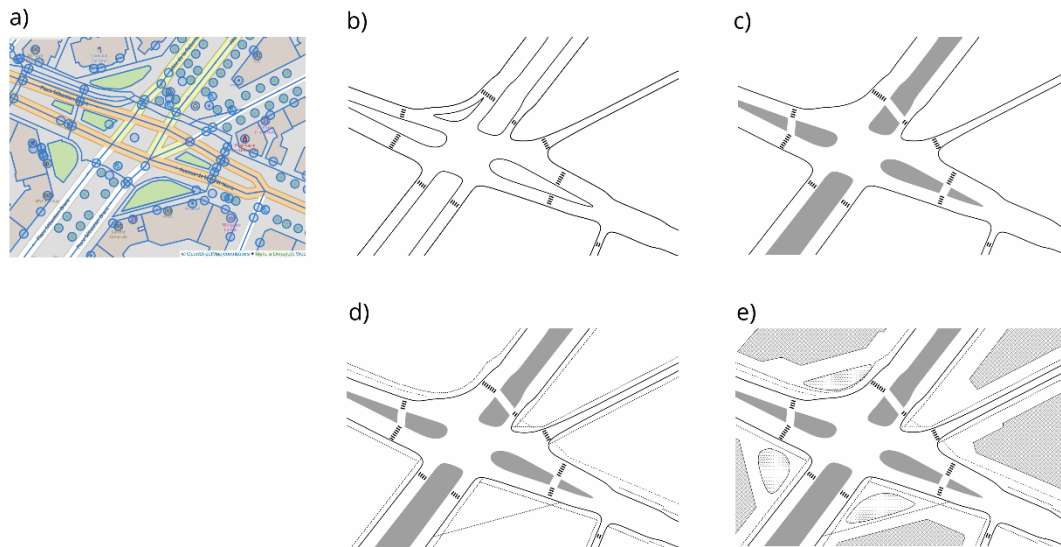


Figure 1. Illustration of the geometry process. (a) data from OpenStreetMap; (b) street and pedestrian crossing transformation; (c) traffic island estimation; (d) sidewalk and cycleway integration; (e) generalization of roadside patches.

The roadway objects represent the basic intersection layout. The streets are represented by their boundary lines, with the distance between the two boundaries proportional to the width of the street, to facilitate street detection and crossing time estimation (Fazzi & Barlow, 2017) (Figure 1b). Pedestrian crossings (normally tagged as points in OSM) are transformed into line features (Figure 1b). Because traffic islands are hard to detect by PVI (Fazzi & Barlow, 2017), they are estimated using the processed street boundary data and displayed with the island configuration manually informed (whether the island has a cut-through design, see Federal Highway Administration, 2017, for traffic island designs) (Figure 1c).

The roadside objects could indicate walkable and dangerous areas near the intersection and provide cues for orientation (e.g., trailing the grassline to align with the

street; Fazzi & Barlow, 2017). During the processing, the roadside objects are displaced and generalized, under the constraints that they are large and separated enough to be recognized. Sidewalks and cycleways are displaced along the streets with the required gaps. Buildings, grass areas, and large parking areas are simplified and displaced accordingly.

The geometry processing is largely constrained by tactile graphic parameters regarding sizes and distances. For some decisions, there is little flexibility due to the nature of the large-scale intersection maps (e.g., there are no different levels of generalization possible for parking areas at this scale), but some other decisions involve more flexibility and need further consideration.

Buildings - level of generalization

Different generalization levels of buildings are observed from existing examples, from detailed footprints to highly generalized patches (Červenka et al., 2016; Touya et al., 2019). Detailed buildings might provide cues approaching the intersection because some PVIs prefer to walk on the inner side of the sidewalk (Bentzen et al., 2017) trailing the building line. But very detailed building footprints might cause clutter and distraction on a map about the intersection. Therefore, two levels of generalization are proposed based on the original building footprints (Figure 2a): the detailed footprint (Figure 2b) that keeps individual buildings separated (similar to Červenka et al., 2016), and the rough footprint (Figure 2c) that merges the buildings in a block and only retains a simplified outline.

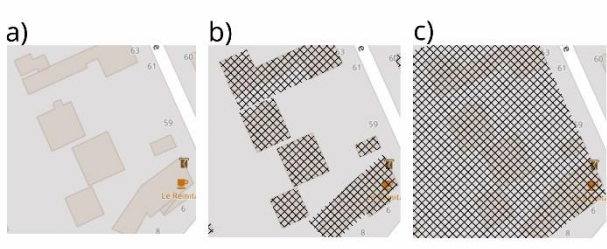


Figure 2. Buildings in two generalization levels. (a) The original building footprint; (b) the detailed building generalization; (c) the rough building generalization. Base map from OpenStreetMap.

Bus stops – solving point-line conflict

As bus stops are often close to the curb, to satisfy the tactile graphics requirements regarding the minimal size and gap for point symbols, the resulting bus stop symbol often overlaps the street boundary line on the tactile map, causing a point-line conflict that breaks the continuity of the line. We explore two options (Figure 3): displacing the bus stop away from the street boundary line to prioritize the continuity of the main line feature; and retaining the point on the line with the gap to preserve its original location.

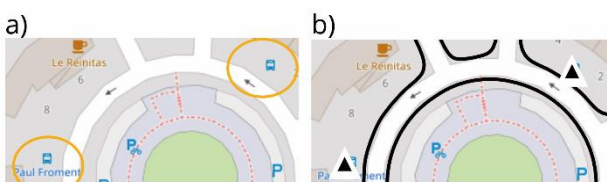


Figure 3. Bus stops. (a) the data from OpenStreetMap, two bus stops circled in orange; (b) The bus stop to the west is slightly displaced from the street, and the bus stop to the north remains in its original position, the required gap around the point symbol intersects the street boundary line.

Sidewalks -geometry type

Sidewalks can be represented as a line or an area. It is partly dependent on data

availability, but also partly constrained by the scale and size of the map as sidewalks cannot be presented as an area feature on the 1:1000 (A4/A5) maps without major distortion. Now, the sidewalk is processed as a line feature, as sidewalk tags and line geometries are more available than polygons in OSM. An additional map with sidewalks as areas is manually made for evaluation later.

Styling and layout

Without standards in tactile map styling, the automation will need to have a set of default symbols, while supporting other choices. The default set of symbols and textures (Figure 4) is chosen based on guidelines, empirical research, and manual practice (e.g. Prescher et al., 2017, and the BANA pallet). Alternative stylings can also be supported (as .sld/qml files).

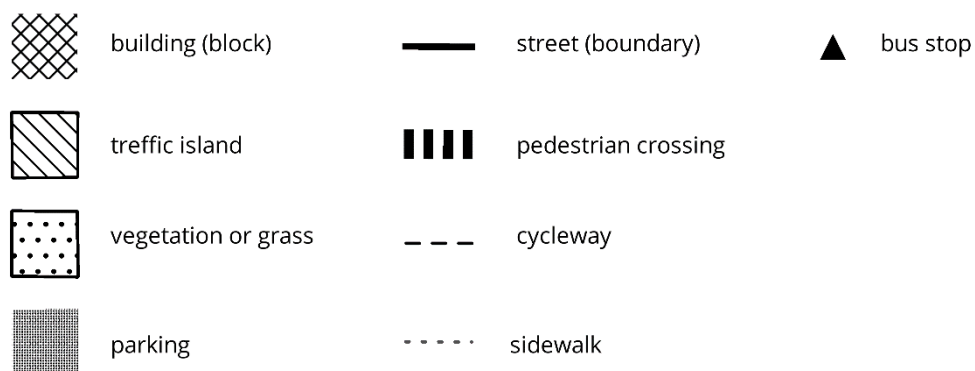


Figure 4. The default set of symbols. Textures, line, and point symbols are based on the palette of BANA (2010) and TABMAP (2006), the zebra symbol for pedestrian crossing is inspired by Martin (2018).

The map page layout (margins, distances between layout items, etc.) is based on existing guidelines (BANA, 2010; Bris, 2001). All three sizes have the title and the north arrow on top of the page, the legend on the left, the graphic on the right, with required margins. Print text is added over braille in green so it is only visible to sighted

users (e.g. instructors; Štampach & Mulíčková, 2016). An example of the A5 map layout is shown in Figure 5. More example maps can be found in the evaluation section.

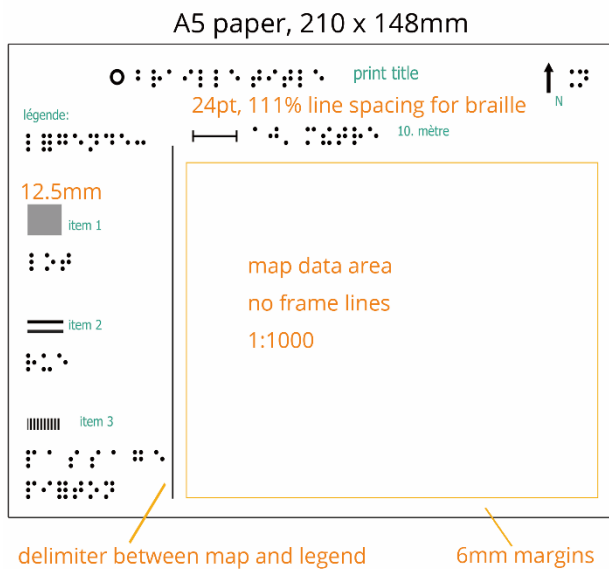


Figure 5. Page layout example for A5 maps. Black and gray traces will produce relief; green text labels are only for sighted users; orange text is only for annotation.

Figure 6 shows an example of an intersection map (A4, 1:1000) produced by the described procedure c), along with maps from existing services (d) TMAP, e) TouchMapper, f) Mapy) at a similar scale. The map produced with the described procedure contains more details on intersection-specific features for PVIIs (more precise street shapes, pedestrian crossing, and traffic islands) and significant generalization of the buildings to reduce clutter, with the legend and the map frame on the same page. More examples can be found in the next section.

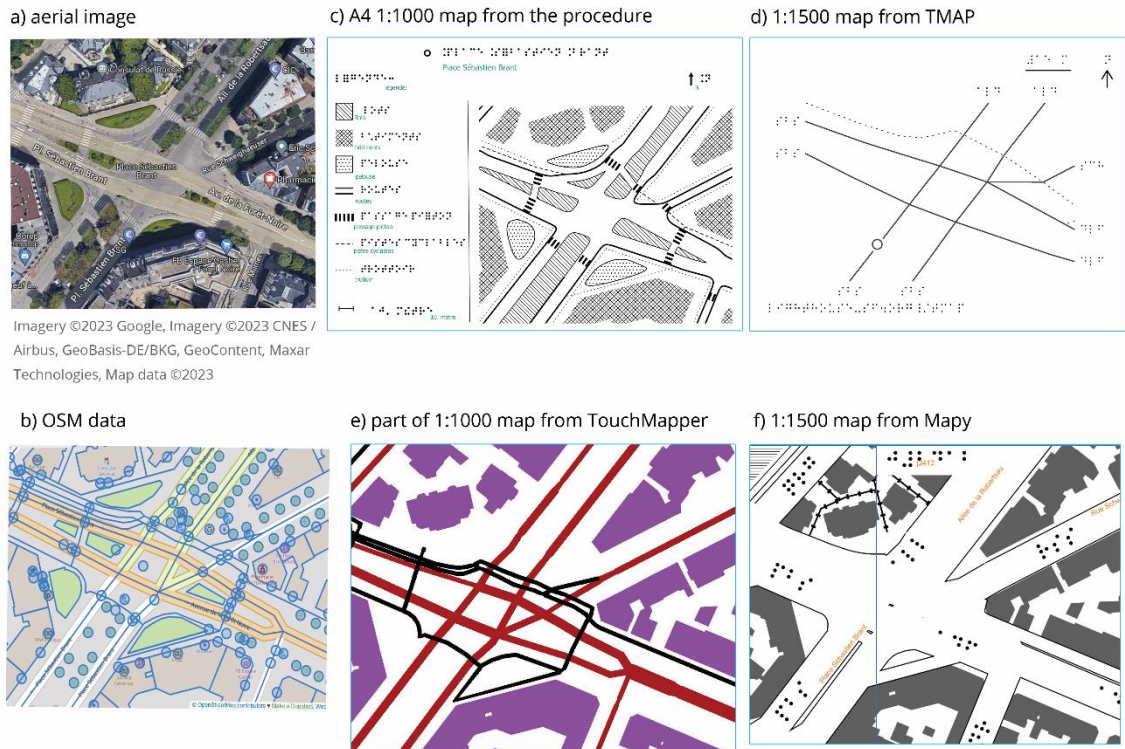


Figure 6. (a) aerial image of the location; (b) OpenStreetMap of the location; (c) A4 1:1000 map of the intersection with the described procedure; (d) 11 x 8.5 inch (similar to A4) 1:1500 map from TMAP, labels on a separate page; (e) 1:1000 map from TouchMapper (original size 27.9 x 27.9 cm, the image is cropped to show the center of the intersection); (f) 1:1500 map from Mapy.cz. (This map is provided in two tiles, they are stitched and cropped to the center of the intersection, the blue line in the middle is where the original tiles are separated.)

Evaluation with professionals in tactile graphics

The main goal of the evaluation was to gather feedback from professionals using or making tactile graphics (maps). We aimed to know whether the decisions about geometry, styles, and layouts are acceptable to them and if they can convey the intended information. It also aimed to get comments on the decisions that have not been dictated in the guidelines and might be flexible.

Participants

The evaluation is aimed at professionals who frequently work with tactile graphics and have specialized knowledge about their design, production, and use. This includes tactile transcribers, special education teachers (school subject teachers and O&M instructors), or ergonomists working with tactile graphics. While tactile transcribers specialize in producing tactile material (both braille text and graphics) and take commissions from individual clients or special education professionals, the latter (including O&M instructors) also make tactile maps and graphics in their work. They are not excluded from participating because their practice would enable them to judge the graphical quality of the maps, and their understanding of the cognitive process of the PVI during a street-crossing scenario (Arsal et al., 2022) can also give insights regarding the use of such maps.

Sixteen professionals participated in the questionnaire, including 10 tactile transcribers, 5 specialized teachers, and 1 engineer involved in tactile graphics. Most of them have a long experience working with children and adults with varied tactile reading skills (8 have over 10 years of experience). In their work, they use a variety of production techniques & materials (swell paper, 3D printing, embossing), with swell paper being the most often used. The professional details of the participants can be found in the supplementary material.

Material and methods

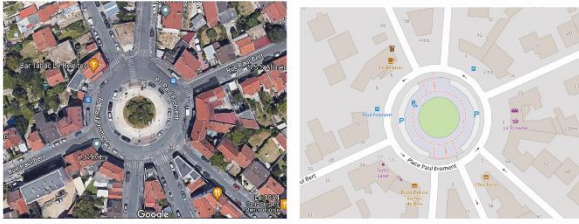
The evaluation is conducted through an online questionnaire where the maps (with ready-to-print files) are provided. The participants rated if the maps were acceptable, and provided further feedback. The main consideration to use an online questionnaire instead of mailing the printed maps is that an online procedure would be easier to

engage more participants and retrieve feedback. It was also considered that viewing and editing the graphics on screen before printing them is part of practice for the professionals, and with their training and experience, they would be able to judge the quality of the graphics. The participants are also explicitly informed that they should examine the image in the original format and can print the map.

Street intersections and the maps

Because roundabouts and intersections with traffic islands are particularly difficult for PVIIs (Fazzi & Barlow, 2017), two intersections are chosen to represent these two scenarios (Figure 7). Location 1 (L1) is a 7-way roundabout in a residential area. Location 2 (L2) is a 5-way intersection with traffic islands from a mixed commercial-residential area. They are located where PVIIs may encounter in their daily life, with many common objects found at urban intersections: streets, pedestrian crossings, traffic islands, buildings, green areas, parking areas, and bus stops. They are both far from special education facilities (where the O&M lessons often take place). Although there is no reason to believe that previous knowledge of the location might change the results (as most of the questions are about graphic representations less relevant to local knowledge), it is unlikely that the participants are familiar with these locations.

L1, roudabout in residential area



Imagery ©2023 Google, Imagery ©2023 Aerodata International Surveys, CNES / Airbus, Maxar Technologies, The GeoInformation Group | InterAtlas, Map data ©2023

L2, 5-way intersection in mixed commercial-residential area



Imagery ©2023 Google, Imagery ©2023 CNES / Airbus, GeoBasis-DE/BKG, Maxar Technologies, Map data ©2023

Figure 7. The two locations for the evaluation, aerial image from Google Maps (Google, 2023), data view from OpenStreetMap.

The maps of the two locations are produced in A5, A4, and A3 sizes (full-size maps can be found in supplementary materials):

- One A5 map each for L1 and L2 (L1-A5, L2-A5) that contains the roadway objects (Figure 8)
- Two A4 maps for L1 (L1-A4-1, L1-A4-2): Apart from the roadway objects, L1-A4-1 has two bus stops and rough building footprints, L1-A4-2 has detailed building footprints, parking, and vegetation areas. (Figure 9)
- Two A4 maps for L2 (L2-A4-1, L2-A4-2). Apart from the roadway objects, L2-A4-1 contains sidewalks and cycleway lines, L2-A4-2 additionally has detailed building footprint and grass areas. (Figure 9)

- One A3 map for L1 (L1-A3) and two A3 maps for L2 (L2-A3-1, L2-A3-2) contain all the available objects from the intersection. L1-A3-1 and L2-A3-1 have sidewalks as lines, L2-A3-2 has sidewalks as an area. (Figure 10)
- Four maps with “alternative” styles are also produced with other symbols present in guidelines or practice. The alternative maps are one A3 map of L1 (ALT-L1-A3), two A4 and one A3 map of L2 (ALT-L2-A4-1, ALT-L2-A4-2, ALT-L2-A3). (Figure 11)

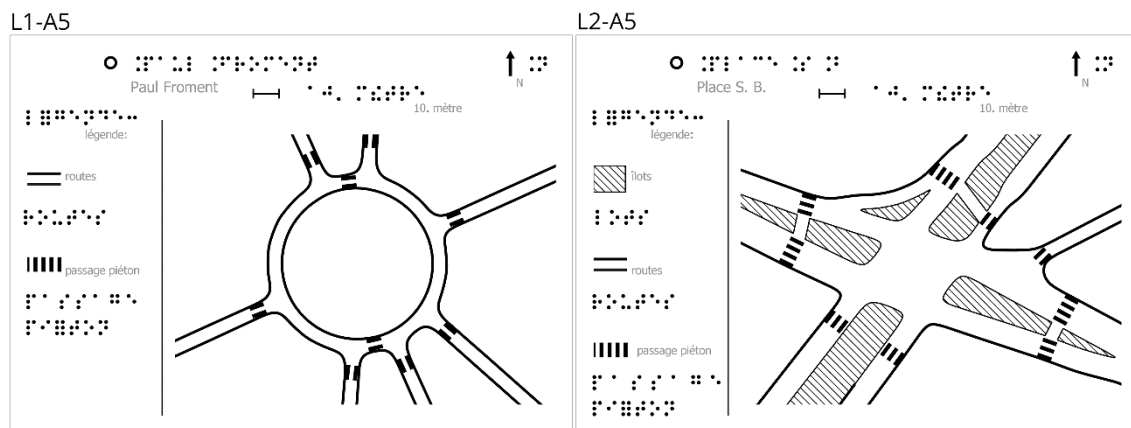
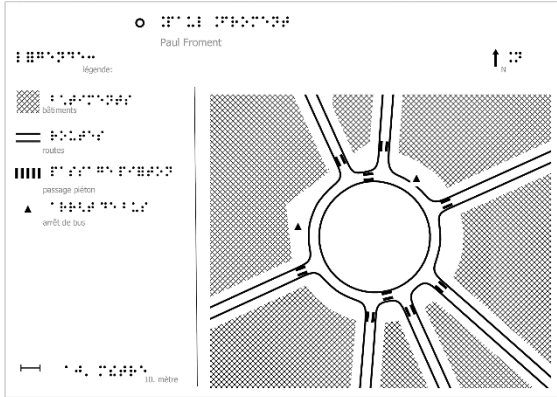
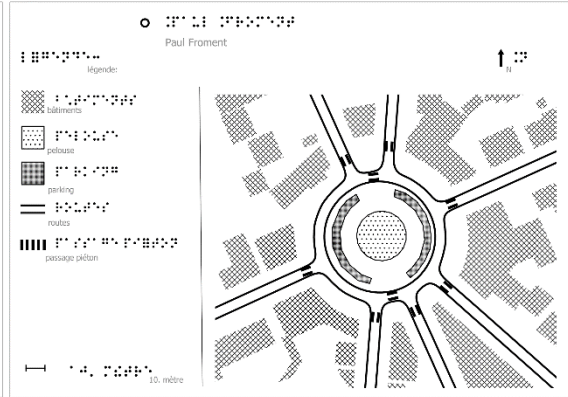


Figure 8. Two A5 maps of Location 1(L1) and Location 2 (L2)

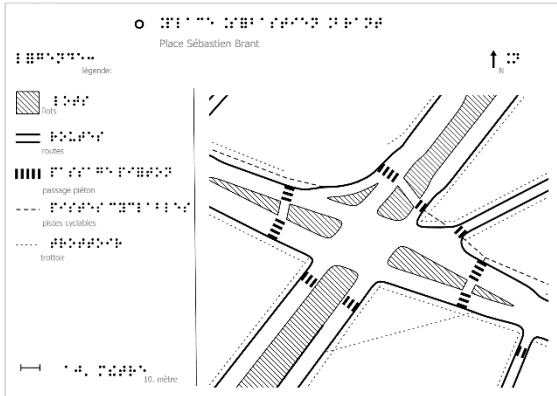
L1-A4-1



L1-A4-2



L2-A4-1

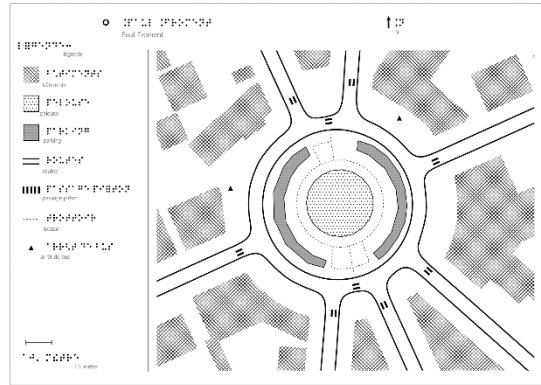


L2-A4-2

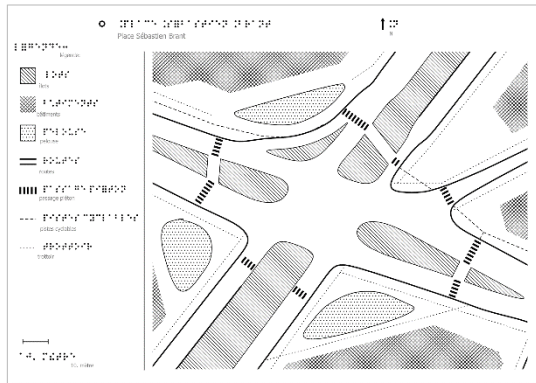


Figure 9. Four A4 maps: top: two A4 for Location 1 (L1), with different objects and two levels of detail for the buildings; bottom: A4 for Location 2 (L2), with and without buildings and grass areas along the sidewalks and cycleways.

L1-A3



L2-A3-1



L2-A3-2

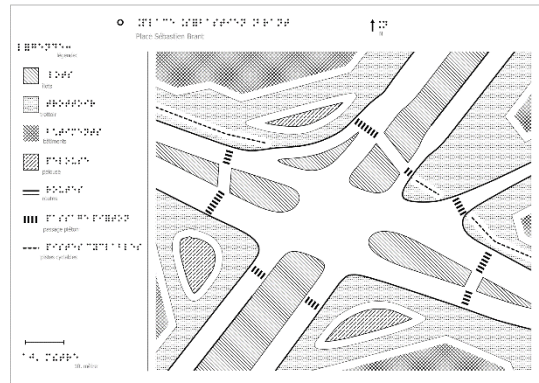
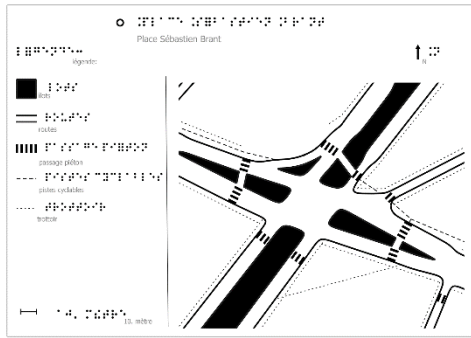
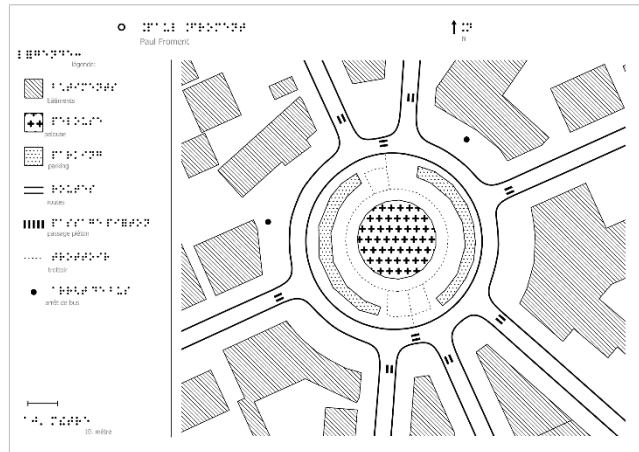


Figure 10. Three A3 maps: top: Location 1 (L1); bottom Location 2 (L2) with sidewalks represented as lines and areas.

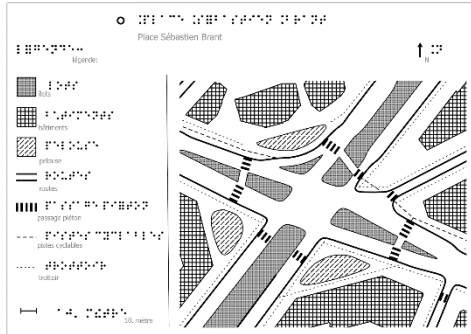
ALT-L2-A4-1



ALT-L1-A3



ALT-L2-A4-2



ALT-L2-A3

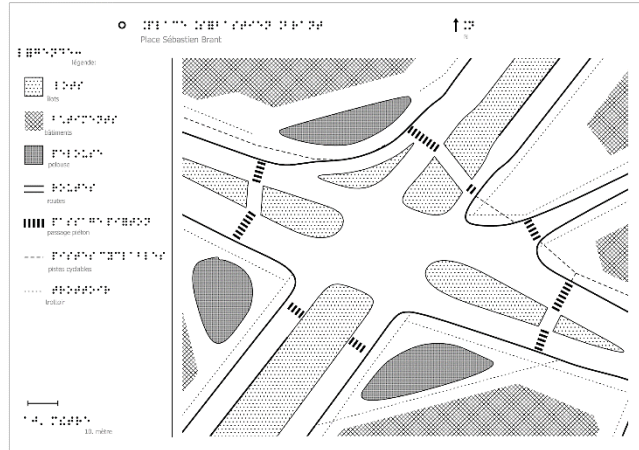


Figure 11. Four maps with "alternative" styles: on the left, A4 maps with “dense” textures from the BANA pallet; on the right: two A3 maps with a combination of default textures and “light” textures from the BANA pallet.

Questionnaire

The questionnaire contains three main sections with a total of 126 questions. The maps and questions were first pre-tested with tactile transcribers and modified based on their feedback. The questionnaire was later broadcasted on national mailing lists of the professionals as a Google Form with full-size images. The participants were recommended to examine the maps in full-size, they were also provided with PDF files to print the maps. The full questionnaire translated in English is provided in the

supplementary materials.

Procedure

After reading the introduction, the participants gave informed consent and professional details. Then they answered two blocks of geometry questions about locations 1 and 2. The questions mostly consist of 7-point Likert questions, some multiple-choice questions, and open comments.

After the geometry questions, with access to all the maps they'd seen before, participants would answer about the layout and default styles in these maps and their usage for the three map sizes. They were then asked about the styling of the four maps with alternative styles.

At the end of the questionnaire, they would give general comments regarding the questionnaire and the maps before submitting the form.

Professional details. Participants were asked about their profession (e.g. transcriber, special education teacher), the type of organization they work in, experience in making tactile maps, and how many they make weekly. They also indicated all the production techniques they use, and the most frequent one.

Geometry questions. For each map, participants rated the effectiveness of individual geometry representation (street border, street width, etc.). They also indicated if they agree with the geometry processing choice: building generalization levels, representations of overlapping objects, and sidewalk representations. They also assessed potentially confusing empty areas (areas not occupied by a symbol or texture other than

the required gap) and rated the understandability and clutter of the map. Then they could share their comments and feedback.

Layout, styles, and usage questions. Participants were asked to rate the overall effectiveness of the three map layouts and the default styles on the maps they have just seen. They could then give comments and suggest changes.

For each map size, participants were asked about the frequency they produce or use maps of this size, and to explain the cases or reasons for using or not using this size. They then envisioned, regardless of their practice, the purpose and audience this map size could be useful for.

Then, the participants were asked to rate the effectiveness of the alternative styles and give feedback.

Results

The results from the evaluation are presented below in the order of geometry - layout and styling - usage of the three sizes. All ratings are shown in the figures, but for the length of the paper, only important items are discussed in the text. Full results descriptions can be found in the supplements.

Geometry

Basic geometries: effectiveness of street, pedestrian crossing, and traffic island representations. The effectiveness rating of the street, pedestrian crossing, and traffic island representations is shown in Figure 12.

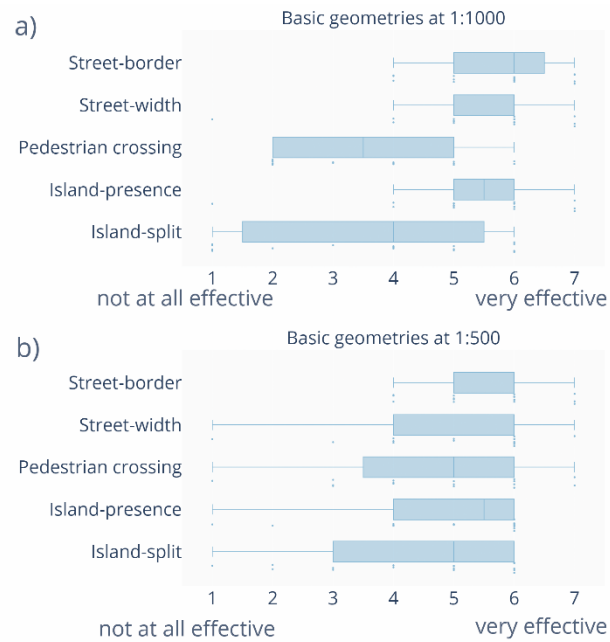


Figure 12. Effectiveness rating for basic geometry representations

The representations of streets, pedestrian crossings, and traffic islands for both scales were generally accepted. One major issue is the pedestrian crossing on the 1:1000 map (L1-A4-1): participants were concerned about it touching the edge of the street. The pedestrian crossing on the 1:500 map was better accepted. The island representation was generally accepted, but some doubted the necessity of showing the split (curb configuration) saying it could already be indicated by the tactile warning (P14).

Buildings: the level of generalization. The votes for the generalization of building footprints are shown in Figure 13.

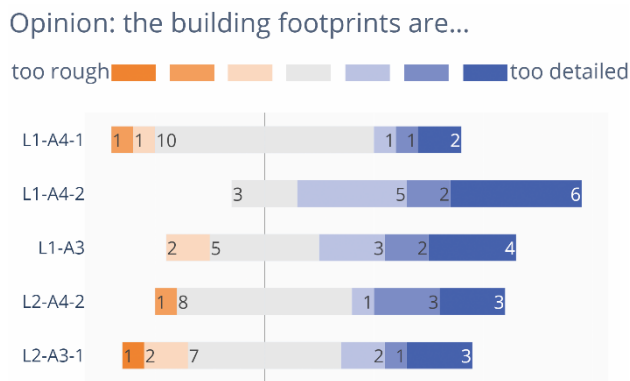


Figure 13. Votes for building generalization level.

Generally, the “detailed” building footprints (L1-A4-2, L1-A3) were judged as too detailed. The “rough” generalization (L1-A4-1, L2-A3-1) was better accepted. Despite having different generalization levels, L2-A4-2 was judged similarly to L2-A4-1, potentially because they both don’t have many footprints involved. Still, some people preferred the detailed building footprint, saying this could depend on the intended usage of the map (P12), the task, or the ability of the reader (P8) and that it might be useful to have more building information regardless (P5).

Bus stops: solving point-line conflict. Participants’ opinions about the different strategies for the potential conflict between bus stops and street boundary lines are shown in Figure 14.

Opinion: the statements on the positioning of the bus stops

Q1: It is acceptable for bus stops to overlap street boundary lines, provided there is sufficient white space around the point.

Q2: It's better to move bus stops away from street boundary lines, as long as they remain relatively close to the street and their actual position.

Q3: When the bus stop overlaps the street boundary line, it appears to be more salient than when it is away from the street.

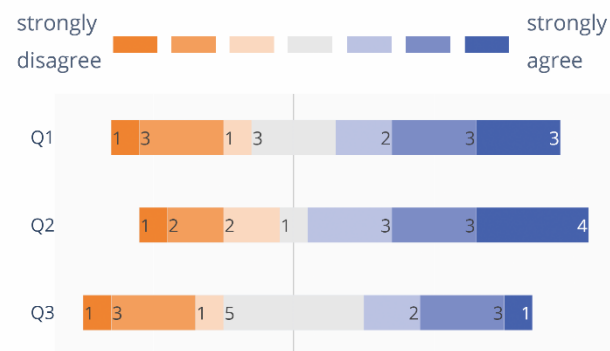


Figure 14. Opinions about the positioning of the bus stops

There was a mixed view over all three questions. Although Q1 and Q2 are very different and use almost opposite strategies, both were accepted to some extent, and the amount of “agree” votes for Q3 might indicate that “making the bus stop more prominent” could be an incentive for such a direct overlay strategy. The comments indicated that this might not be a “standalone” choice but related to other elements on the map: it could depend on the number of elements on the map (P8) and whether “the street is long enough to overlay” (P3).

Sidewalks. The votes for the effectiveness of the sidewalk representations are shown in Figure 15.

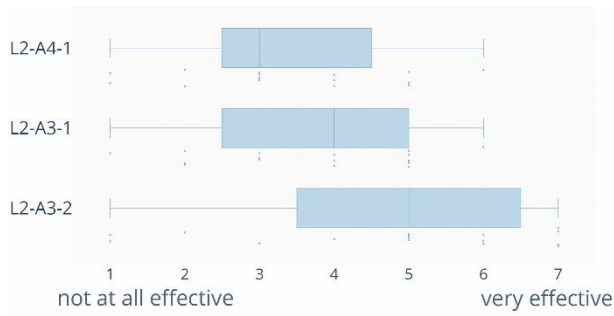


Figure 15. Effectiveness rating for sidewalk representations.

Many showed a strong preference towards the area sidewalk (L2-A3-2) for both sizes. This is a notable preference, especially for L2-A3-2 with building and grass patches that already make the roadside more cluttered.

The participants then rated their agreement on the detailed aspects of the sidewalks (Figure 16.)

Opinion: regarding the sidewalks...

- Q1: Area sidewalks are better than lines
- Q2: It's not necessary to have sidewalks when they are directly next to the street
- Q3: It's confusing to have sidewalk when they are directly next to / parallel to the street.
- Q4: It's confusing when both sidewalk and cycleways in the map

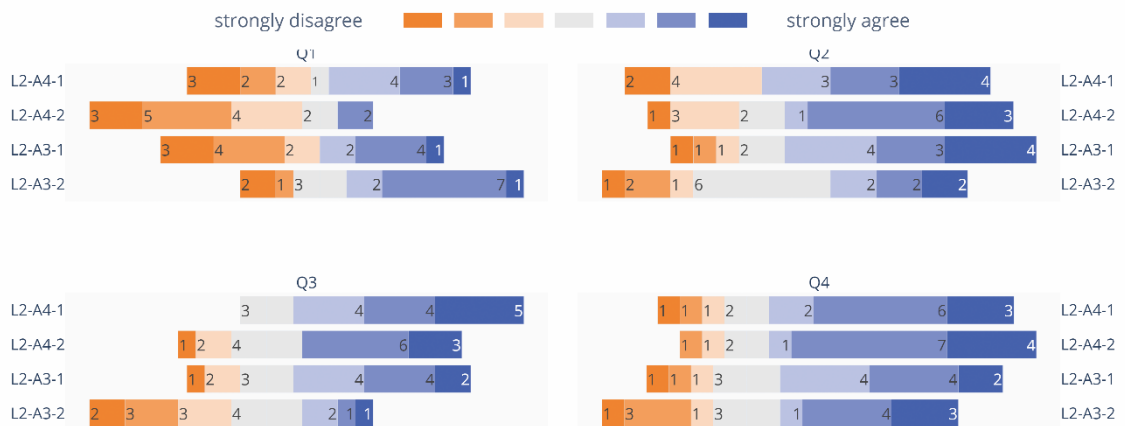


Figure 16. Opinions regarding the detailed sidewalk options

Between the area and line representations (Q1), some participants preferred the area representation of the sidewalk, especially for the L2-A3-2 map. But not for L2-A4-2, probably because there are already many textures on this relatively small A4 map. Some explained the preference saying sidewalks are not a linear feature in reality (“larger than a line”, P5).

Participants tended to agree that it’s not necessary and it is confusing for the line sidewalks to be placed next to the streets (Q2/Q3), but it was not a problem for the area sidewalk as the discrimination between the sidewalk texture and the street was clear (P5). Participants explained that explicitly displaying sidewalks could help discover shortcuts or other walkable places not directly next to the street (P5).

For the cycleways (Q4), it’s judged less confusing to overlay them with the area sidewalk than the line sidewalks, making it a potential option to have both sidewalks and cycleways on the map.

Empty areas on the map. The votes for “if the map has confusing empty areas” is shown in Figure 17.

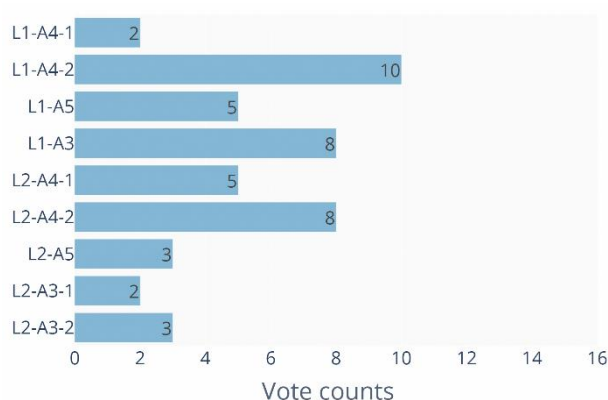


Figure 17. Votes for "if the map has confusing empty areas"

Overall, there were mixed views regarding empty areas, with three participants saying none of the maps have confusing empty areas. Participants voting for L1-A4-2 and L1-A3 mentioned the emptiness between the “detailed” building footprint. P8 also noticed that such emptiness, as a result of the building generalization, is essentially “wrong” information that “gives the impression that there is a street or an accessible passage whereas it is a fenced garden”. L2-A4-2 also received eight votes, with empty areas between and “around” the buildings (the “sidewalk” areas between the street and the buildings are empty).

Despite having large unoccupied areas, the two A5 maps were not confusingly empty. Some participants mentioned the lack of roadside objects and would like to fill it with a texture (x3). P5 explicitly mentioned some roadside objects like grass may be important to be included because they are harder to notice by PVIs.

Overall geometry: easy to understand and clutter. The ratings for the understandability and clutter of the maps are shown in Figure 18.

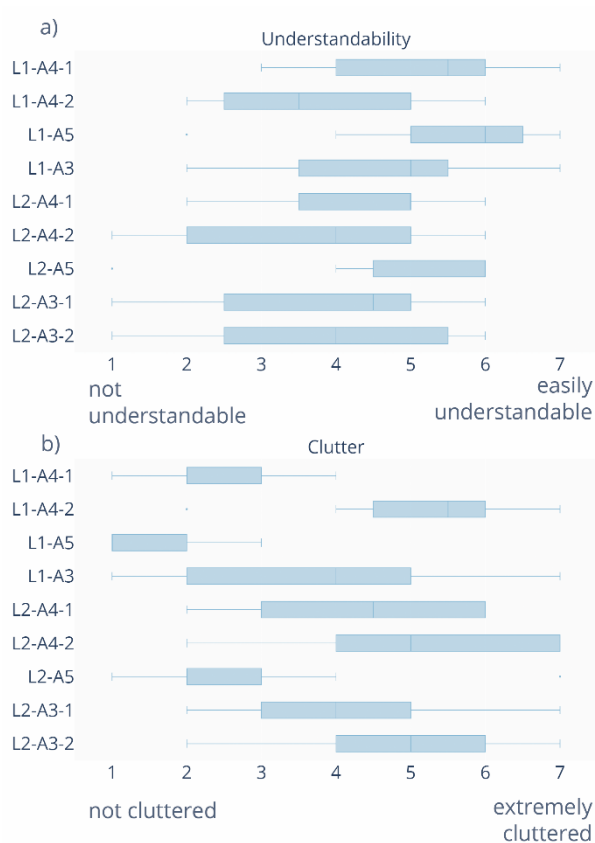


Figure 18. Ratings for the understandability and clutter.

Overall, there was more agreement on some maps than others. The participants mostly agreed that both the A5 maps and L1-A4-1 are reasonably understandable and not too cluttered and that L1-A4-2 is too cluttered. The views were mixed for the others.

L1-A4-2 got a particularly low understandability rating and a high clutter rating probably because of the fragmented building footprints on a smaller map causing distraction and confusion. Participants mentioned the multiple textures on L2 maps could “overload” (P14, P8). Although the participants earlier preferred the area sidewalk in L2-A3-2, the understandability and clutter ratings for this map are rather similar to the ratings for the line sidewalk map L2-A3-1.

Many votes are scattered. These mixed views are partly because the perception of whether a map is understandable or too cluttered is subjective by nature as they

depend on many factors, including the reader's ability: "[they] depend on whether the user can recognize many elements on the same map." (P8).

Layout and styles

Default layout and styles. The effectiveness rating of the default layout and styles is shown in Figure 19.

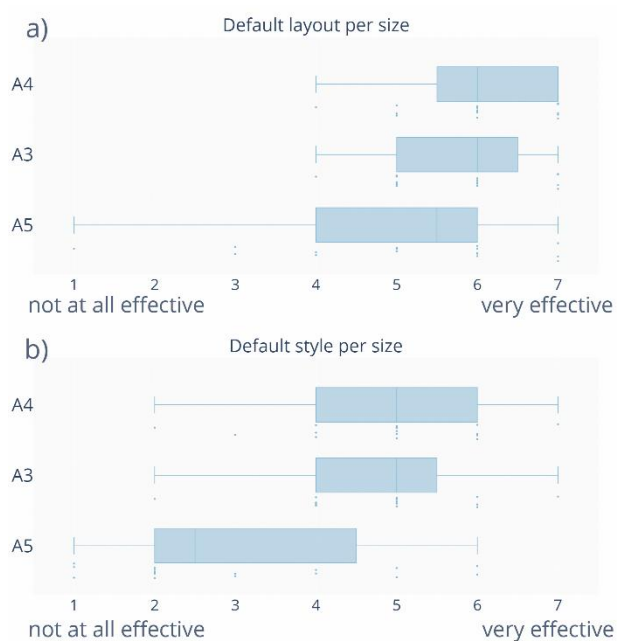


Figure 19. Effectiveness rating for the default layout and styles.

The map layout for all three sizes was accepted by the participants. Some minor problems such as braille misspelling were raised.

As A5 is a less used, very small size, and cannot have many objects, we further asked if having three objects on the A5 is enough for an overview of the intersection and if they want more objects on the A5 (Figure 20).

Participants agreed that having only three objects on A5 maps is enough for a basic overview of the intersection, while still wanting more objects to be included. This

is in line with the clutter and understandability ratings, also their earlier comments about wanting to texture the surrounding areas on the A5 maps.

Opinion: regarding the layout of the A5 maps...

Q1: having 3 objects is enough to show the overview of an intersection

Q2: it would be nice to rearrange the map layout so that the A5 map can have more than 3 objects (e.g., to include buildings or green areas).

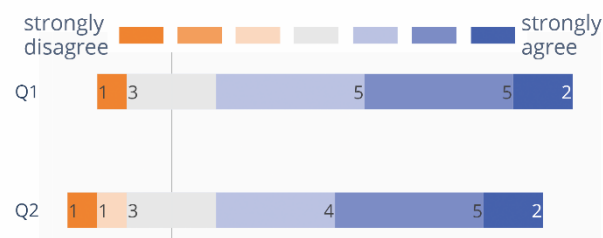


Figure 20. Opinions about the layout of the A5 maps.

The default styles were accepted on A4 and A3. But a major issue appeared on A5, which might relate to the “pedestrian crossing touching the street” problem raised earlier. The votes for the “style” ratings were overall more scattered than for the “layout” ratings, with participants giving opposite suggestions in the comments (P1 asked for sharper textures, P9 wanted lighter ones), reflecting the personal opinions in styling choices (Prescher et al., 2017).

Although not explicitly mentioned in the guidelines, multiple participants mentioned the need of balancing “strong” and “weak” textures and assigning them to “suitable” objects for contrast and emphasis. P8 asked for a “softer” gray fill for building or grass patches; P12 asked for an “alternation of strong and weak textures”; P5 recommended a “more impacting texture” for the grass to “improve the tactile comprehension.”

Alternative styles. The effectiveness ratings of the alternative styles are shown in Figure

21.

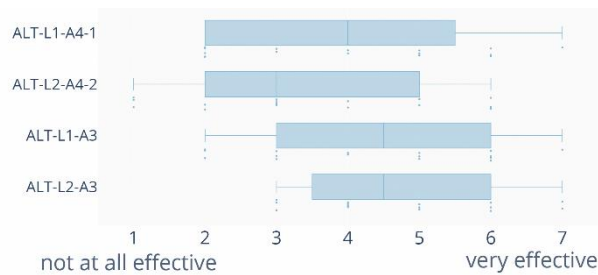


Figure 21. Effectiveness rating for the alternative styles.

The alternative styles were rated slightly less than the default styles (Figure 19) with more scattered ratings. The comments on these styles were also very mixed.

ALT-L2-A4-1 features the controversial solid black filling texture found in examples (Červenka et al., 2016; Martin, 2018) but is not recommended by the guidelines (TABMAP, 2006), and received scattered ratings: some were very in favor while many participants agreed with the guidelines that the black filling will damage the paper (“make it blister”, P7) during the heating process, resulting in an uneven surface.

ALT-L2-A4-2 features a combination of “dense” textures from the BANA texture palette. The participants generally did not find this style very effective but the opinion was disputed: 3 participants said the island texture (gray dense dots) is too similar to the building texture (thick black grid) while another (P7) explicitly said the textures in this map go well together. ALT-L1-A3 and ALT-L2-A3 feature a combination of the default styling but with some substitutions of “lighter” textures from the BANA palette. The participants rated them rather similarly to the default style.

Similar to the comments for the default styles, the “prominence” of the textures and aligning them to objects were also mentioned. P16 commented that the black filling on ALTER-A4-1 is “too prominent for an object [islands] of little interest.” P7 commented on the thick star pattern texture on ALTER-A3-1 that “puts the grass very

tactilely forward”, and for such (less important) objects, the texture “could be more discreet.”

Usage of the three sizes. The responses on how often they produce maps of each size and their envisioned usefulness (Figure 22).

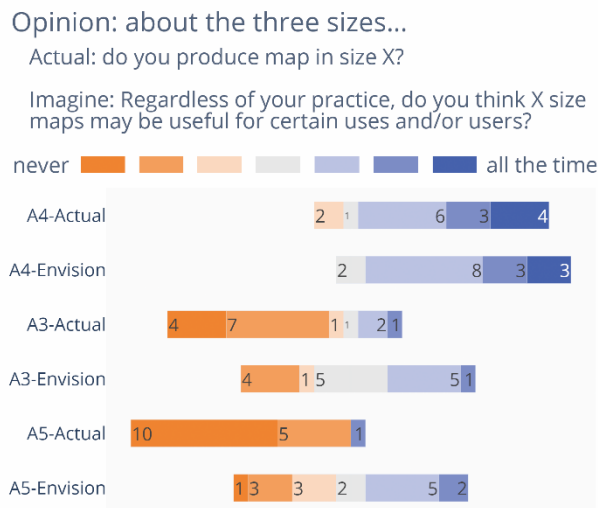


Figure 22. Opinion on the usage of the three sizes.

Overall, A4 is the most often produced (used) size. A3 is produced and envisioned for occasional usage. A5 is rarely produced but is envisioned to be useful in certain conditions.

A4 is seen as the “all-around” size that is used for various purposes, including school curriculum (x6) and locomotion training (x5), as it is small enough to be portable while still containing details (“transportable format and tactically realistic for analysis purposes and the discovery of the environment,” P5) Street intersections are also mentioned (x2) as potential usage of A4.

Contrary to the recommendations (BANA, 2010) or some previous questionnaire results (Rowell & Ungar, 2003), A3 maps are not made as often among

our participants. One major reason for not producing A3 maps is the difficulty in tactile exploration (x5) as it “can take a long time to explore” (P4). Additionally, its size makes it inconvenient to carry and store (x2).

Despite these problems, A3 maps are produced and used in textbook diagrams (x2) and mobility maps for complex places requiring extensive details (x4), e.g., large buildings and subways. Some participants commented that A3 maps may only be used while sitting and with informed users, such as in science or engineering lessons (P5, P13). Potential usages for A3 are large, complex areas, including complex routes (P8) and detailed neighborhood maps (P7).

A5 is rarely produced by the participants, mostly because it is too small. Some make A5 maps to be used in combination with screen-readers on portable tablets (x2). The one participant that uses A5 maps rather frequently (P16) said A5 can be used “for a specific intersection or a room in a house”. However, they can imagine cases where A5 maps can be useful for their portability, “as a quick reminder of a path they know but want to confirm” (P8). P6 and P14 never made A5 maps but said A5 could “be more convenient in everyday life.”

Discussion

Producing acceptable tactile maps for street intersections

The maps were generally accepted by the professionals participating in the study. In addition to the default decisions, there is a need for some decisions to be open; and the feedback provides some hints regarding the potential options. Many points for improvement and requests for new features are raised.

The geometries are generally deemed effective to represent the configuration and some surroundings of the street intersection. One particular problem is about the pedestrian crossing on narrow streets (1:1000 maps) when the end of the zebra symbol touches the street boundary line (Figure 23-a). This problem is not raised for the A3 map (L1-A3; 1:500), where the gap between the zebra symbol and the street line is also very small (about 1mm, Figure 23-b). One speculation is that, for a short pedestrian crossing with two bars (L1-A4-1), when both ends touch the street, the zebra symbol becomes less recognizable. And when the pedestrian crossing is longer (with more bars in the zebra symbol), touching the street boundary line doesn't hurt its recognizability (Figure 23-c). In the next implementation, this could be improved by e.g., slightly expanding the width of the narrow streets (a 1 mm expansion would make the zebra symbol fit in), and by having a white gap around the zebra symbol (see e.g. the bus stop intersection with the street line in Figure 3.)

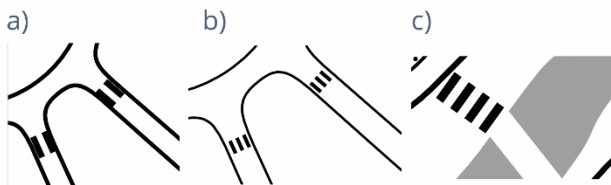


Figure 23. Issues with the pedestrian crossings. (a) in 1:1000 maps of L1, two-bar zebra symbols on narrow streets touch the street boundary on both sides; (b) the two-bar zebra symbol in the 1:500 map of L1; (c) in 1:1000 maps of L2, the zebra symbol with more bars touches the street boundary on one side.

The questionnaire results also suggest keeping some other decisions open and hint for potential options. The mixed views on how to position the bus stop along the street boundary line is an example of different preferences over conflict-solving strategies, due to the diversity in the PVI and the nature of the map-reading task itself.

Although it's not clear from literature how these different strategies would impact map reading, we believe they should still be provided as different options and further investigated.

Another open choice is the styling. The default styles used in our maps were generally accepted. However, the selection of symbols is a flexible choice that can be related to many factors (Engel & Weber, 2022; Prescher et al., 2017). There are also many other “acceptable” default combinations, and there should always be some freedom in the options, probably even with the options not recommended by the guidelines (e.g. the black filling texture.)

The results also raised further requests, such as having sidewalks as areas on A3 maps. Although often stored as linear features for visual mapping, the width and shape of the sidewalk can be useful for PVI's mobility (Wiener et al., 2010). Often, high-precision sidewalk data required for this usage is not available in OSM (Mobasheri et al., 2017) but this issue has been noticed, and recent sidewalk mapping initiatives (Vestena et al., 2022) can help to improve the data quality.

The three map sizes (A3, A4, A5) were generally accepted by the participants for different contexts. A4 could be the “all-around” size balancing portability and details. A3 maps are not often used by our participants due to reading and portability difficulties. But because of the large available space, it can still be useful to explore complex intersections with many details. In such cases, it should be designed to suit the usage where the user has a desk and more time to process all the details. Although the A5 is not commonly used now, it would be useful for the onsite scenario as it can provide a basic overview or reminder of the intersection. Its potential to be used over an interactive audio-tactile device (Barvir et al., 2021; Brock et al., 2015) provides further

arguments for this size. In future editions of the procedure, A5 maps could be explored further, considering different map designs to be used with an interactive audio-tactile device.

Implicit considerations

The questionnaire results also raise issues that are not dictated in the guidelines and reveal implicit considerations of the professionals. The notable ones are about empty areas and saliency.

Participants raise the issue of managing empty areas on the map, as some empty areas might be confusing. This is generally not a concern in the guidelines as long as the maps are not so empty that the user needs to search for features (BANA, 2010), but our results suggest that the small empty areas appearing at the “wrong” places can also be confusing. The participants are mainly concerned about the empty areas in between the buildings and between the street and the buildings. The problem is not necessarily about the size of the emptiness, but also about it appearing in “unexpected” locations. It might be understandable that a map only showing the street is omitting the surroundings (as these simple maps are also made in manual work like in Wiener et al., 2010), but it might be more challenging to infer large empty areas next to the street as sidewalks.

Managing empty areas on the map would involve multiple aspects. Generally, emptiness appears for two reasons: “missingness” caused by the absence of map features; and “artificial” emptiness introduced in the geometry processing process (in our case, this specifically refers to the emptiness between the buildings due to the building generalization algorithm). For the former case, unlike “no data” that can be addressed with a special visual variable in visual maps (Robinson, 2019), it’s harder to do so tactilely. For the latter case, it’s a matter of improving the algorithm. To minimize

confusion, manual inspection is needed on the empty areas, and potentially explanation of the nature of the emptiness.

The responses also indicate the saliency considerations regarding location and texture, which are rather implicit to the professionals and rarely mentioned in the guidelines. Many participants agree that overlaying the bus stop on the street line makes it more prominent, which might be related to the line-tracing strategy in tactile map reading (Perkins & Gardiner, 2003). Saliency is also mentioned for the textures, about balancing the “strong” and “weak” textures and emphasizing important objects with more “prominent” textures. The haptic saliency is being explored (Metzger et al., 2018), and in recent work, similar notions are also mentioned such as a “planar” texture makes a large area “dominant” (Engel and Weber, 2022). But how to achieve the intended salience with a balanced set of “strong” and “weak” textures, and even the adjectives to describe them, are rather implicit to the professionals. Such considerations need to be further explored to be adopted for automation.

Limitations

The semi-automated procedure is still under development and will be furthered to support more objects (e.g., potential landmarks) and street configurations (e.g. multi-level junctions) to better represent the urban environment near street intersections. Further work is needed to make it more consistent, generalizable, less dependent on high-quality data, and to provide an interface to make it an accessible service.

In this work, the maps are designed to be fully tactile. For partially sighted people, visual elements such as bold prints and contrasting colors could be very useful too (Round Table on Information Access for People with Print Disabilities, 2022b). For the street intersection scenario, designing colored visual maps is a more complicated

issue and not considered in the scope of this work, as it needs to consider what people can see (or not see) in the street to highlight features on the maps, which depends on the nature of their visual impairment. It is an open question for future research.

The questionnaire was limited to a national context and could result in some conclusions that result from country-specific guidelines or teaching practices, which might not be in line with previous survey results with a more international audience (Rowell & Ungar, 2003). In addition, with 16 participants, there is some diversity regarding e.g. the type of PVIs they primarily work with, which gives insights into the needs diversity but potentially results in variances in some results.

Furthermore, the online questionnaire adds uncertainty regarding how professionals inspect and evaluate the maps. The decision to evaluate the map with an online questionnaire was based on an assumption that their training and work experience would enable the professionals to judge the onscreen maps on their graphic aspect and spot issues. The comments indicated that they were able to spot some minor differences in distances and sizes. For example, P15 insisted that all the gaps (ranging from 3 to 5mm) should be 6mm wide (“It is always necessary to separate the objects from each other by 6mm”). And as printable files were provided, one participant (P12) explicitly said they printed the maps with a visually impaired youngster. We believe an online questionnaire is sufficient for an *initial* evaluation on the overall graphic aspects of the maps.

Evaluations in this paper relied on professionals that make and use tactile graphics. It was an insightful participatory study that helped us to validate the geometries, styles, and layouts, and hence make sure that the professionals agree with the produced maps and that they are inline with their own mapping practices. However, it is obvious that the maps that are made must be evaluated by tactile readers. Rapid

touch tests could have been added to this study, but then, they could have led to inconsistent and ultimately misleading results. A future work should systematically address many questions related to the perceptual and cognitive processes in reading the produced tactile maps.

The first questions are related to the tactile recognition and identification of the symbols and textures (perceptual processes), but should be completed by quantitative and qualitative data making sure that, beyond individual preferences, users can understand the represented intersection and eventually plan to cross it (cognitive processes). In addition, such a study should consider the tactile expertise of the readers that can have a strong impact on reading and comprehension (BANA, 2010; Rowell & Ungar, 2003). Finally, the perception or recognition of tactile elements, especially the textures, can be impacted by the printing process. For instance, swell paper overheating might cause textures to feel differently and cause dense textures to feel similar (TABMAP, 2006); and some textures can be distinguishable but feel “unpleasant” (Engel & Weber, 2022). Hence, future work should encompass both the perceptual and cognitive processes, the expertise of the reader, and the printing process. We are convinced that the pipeline should now encompass all these different variables to make maps that fit to many different use cases (e.g., an expert tactile reader using it to navigate a new intersection alone vs. O&M instructor making maps for a class with novice tactile readers).

Conclusions

This work presents an approach to semi-automatically produce tactile street intersection maps. It explores the decision process regarding choosing size, scale, map content, geometry processing, and styling. Tactile intersection maps were produced on two scales (1:1000 and 1:500) on three sizes (A3, A4, and A5) with different levels of detail.

The resulting maps were evaluated by professionals in tactile graphics through a questionnaire, regarding the geometries, styling, and the usage of the maps of different sizes. The professionals generally accepted the maps, while raising points for improvement and requesting to include other features in the maps. It emphasizes the importance of having an acceptable default while keeping options open to cater to the diversity in the visually impaired audience. The professionals also shared the implicit considerations during their mapping process that are not documented in the guidelines or literature, regarding managing empty areas and salience, which can be further explored to incorporate for automation.

Data availability statement

The data that support the findings of this study are available with the identifier(s) at <https://figshare.com/s/6277c49ff7b269d42adf>

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Disclosure statement

The authors report there are no competing interests to declare.

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