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UV printed tactile maps of historic parks

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Abstract. Tactile maps are complex to develop because people with visual impairments (PVI) have perception limitations that require the maps to be highly simplified. However, tactile maps also need to meet other criteria, such as being user-friendly, cost-effective, and fast to produce. Current production methods for tactile maps are not satisfactory. Fortunately, we observe a rapid development of novel production techniques, e.g. additive manufacturing. One of them is UV printing, which has not been applied to tactile graphics yet. Our preliminary research indicates that this technique fulfils all the criteria for making tactile maps. A case study map of a historic park UV printed on a foamed PVC that consists of both: highly-contrasting graphic content and height-differentiated tactile content, has been positively evaluated in a controlled study session by 15 PVI. This technique could enable easy and cheap production of high-quality tactile maps, improving the availability of cartographic materials for PVI worldwide.

Keywords. tactile maps, barrier-free cartography, UV printing, people with visual impairments, cultural heritage

1 Introduction

Tactile maps are maps for people with visual impairments (PVI) that have both contrasted graphics and raised tactile features. Tactile maps need to be strongly generalized, because PVI have lower touch and sight perception than normal vision (Klatzky and Lederman, 2003; Yanoff and Duker, 2009). Therefore, traditional maps cannot be simply extruded and coloured – tactile maps have to be either transcribed from existing visual maps or translated from raw spatial data (Cole, 2021), following the existing guidelines and best practices (Wabiński et al., 2022).

According to these guidelines, tactile maps must be, above all, legible – not only by legally blind users but also people with residual and normal vision. This can be mainly achieved through appropriate design of symbols as well as edition and generalization of tactile maps. But there are several other aspects of tactile maps development that depend mainly on the production method used. Their production must be cheap (even in small batches), simple (adapted for use by PVI), fast (for both prototyping and final products) with the final maps being durable (resistant to touch and weather conditions) and comfortable to use (without causing quick fatigue of fingers or eyes). Moreover, it should allow the use of any symbolization, including varied heights of tactile symbols and highly-saturated colours for visual content.

All this makes the development of tactile maps a complicated and time-consuming process that requires involvement of many specialists. If we add to this the fact that currently either manual (handcrafted) method and/or large-volume methods (e.g. thermoforming) are the most commonly used for production of tactile maps (Wabiński et al., 2022), it will become understandable that in many parts of the world (including highly developed countries), we experience a shortage of tactile cartographic materials.

In our previous research, we experimented with various production techniques, including TIGER embossers, swell-paper, TactPlus, CNC milling, resin and silicone molds, as well as 3D printing methods like FDM, SLA, SLS and PolyJet. None of them fulfilled all the criteria we mentioned earlier.

This research is part of bigger project, that aims to develop technology for production of tactile maps of historic parks in different garden design styles. When seeking for an optimal production technique for our final maps, we learned about UV printing technique, which is widely used in food and advertising industries. To the best of our knowledge, it has not been used in tactile cartography before. Therefore, we ask the following research question: Can UV printing be used for cheap and simple production of legible, durable and highly informative tactile maps?

2 Methods

Within our project, the goal is to prepare maps that show the garden compositions as a whole by highlighting the main features for each garden style, rather than focusing on orientation and mobility like the most existing tactile maps do. The next section explains the pipeline for developing tactile maps of historic gardens using UV printing technology, where we focus on the printing process itself: preparation and production.

2.1 Case study

We demonstrate our methodology (Fig. 1) on a case study – the map of Romantic Park in Arkadia, Poland, at the first level of detail, i.e. the entire garden composition (Zwirowicz-Rutkowska et al., 2023). This park is an example of landscape parks with naturalistic plant formations. These asymmetrical parks have curved paths and many small architectural elements that create a sense of spontaneity and disorder.

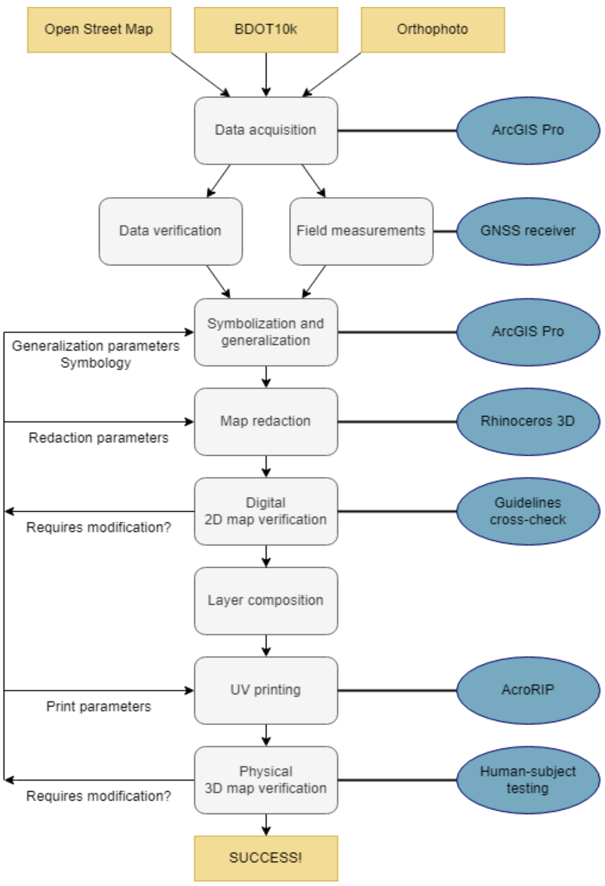

Figure 1. The methodology applied on a case study map.

The first step is to collect the data for map development. We searched the open spatial databases for vector features that represent the romantic style, in four categories: arrangement, vegetation, water, small architecture, based on our previous methodology (Zwirowicz-Rutkowska et al., 2023). We used open sources of spatial data that fit our criteria. Since we had visited each park before making the maps, we could identify the missing features in these sources. We then added them by vectorizing orthophotomaps and conducting field measurements using the GNSS receiver.

We first merged the raw vector data and symbolized them, using the symbols accepted by PVI in iterative sessions (Mościcka et al., 2024). Then, we generalized these data so that the maps would be legible by touch and sight, following the existing guidelines (e.g. Wabiński et al., 2022; BANA and the CBA, 2010; Edman, 1992).

Until this point, most of the work was automatic, but the map redaction process required some manual editing, such as creating map miscellanea, trimming texture elements, and applying colours. All these tasks are carried out in accordance with our, yet unpublished, redaction rules, of which the most important are:

- The minimum horizontal distance between two symbols should be 2 mm, or 4 mm if they are extruded to the same height.
- Texture elements (also the trimmed ones) smaller than 1mm^2 are removed.
- Point symbols should not be placed in a way:
  - causing area symbols to be divided into patches smaller than 3.2 cm^2;
  - intersecting with line symbols, unless this reflects a characteristic topological relationship.
- The minimum width of area symbol is 10 mm.

Next, we cross-check the 2D vector drawings with the generalization, redaction and generalization guidelines. In case of any non-compliances, we apply modifications and carry out another iteration of verification. When approved, we move to the layer composition phase.

The UV printing technology requires a series of vector or raster graphics, each with a different height for the elements to be raised above the map sheet. In our methodology, we define heights of each symbol type as follows:

- Area symbols: 0.5 mm
- Braille characters: 0.8 mm
- Line symbols: 1 mm
- Double lines: 1.5 mm
- Point symbols: 2 mm
- Internal parts of point symbols: 2.2 mm

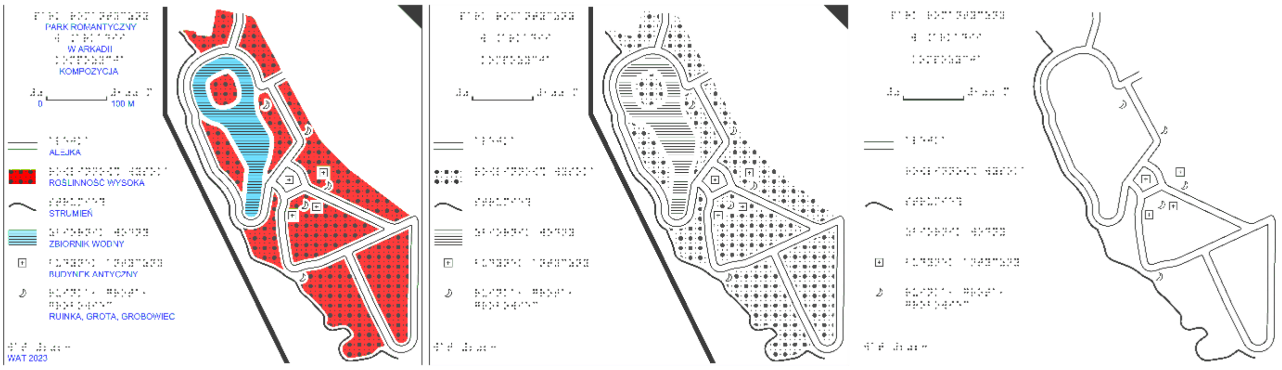

Figure 2. Three layer files for UV printing. From left: colour underprint, elements extruded by 0.5 mm, elements extruded by 0.8 mm.

We need a number of files (layers) for each map, depending on the map's content. If a map sheet has all types of geometry, we need 7 files – 1 for each element type listed above and 1 for the colour underprint that forms the graphic map content for visual perception.

Graphics must consist only of elements that will be printed – the background should be transparent. Each subsequent, higher layer of content has fewer elements. In Fig. 2, the layer marked as 0.8 mm contains only the features raised above the map sheet by 0.8 mm or more.

We then import the layer files into the printer's software and adjust the printing parameters in an iterative process, depending on the printing equipment, ink used, substrate material and expected characteristics of the final map. The main parameters of UV printing are:

- Layer saturation – affects the colour intensity and layer height. More saturation means more extrusion. Material absorbency and ink hardening speed must be considered.
- Planar printing resolution – affects the printing time and accuracy. Higher resolution requires longer printing time but is more precise.
- Printing direction – left to right, right to left or bidirectional. This affects the map finish (matte or gloss).
- Ink drops size – affects the minimum element size and curing time.
- Colour profile settings – allows colour correction for non-standard substrates.

Regardless of the print parameters, the substrate material must be firmly fixed to the printer bed, either by glueing it or using a dedicated vacuum overlay. We use special UV inks in the printing process. The device used – Aquila UV LED v2 allows installation of 6 inks. For our purposes, we installed 4 ITink Co. UE5C inks from the CMYK system and an additional white ink to optimize printing cost and time (Fig. 3).

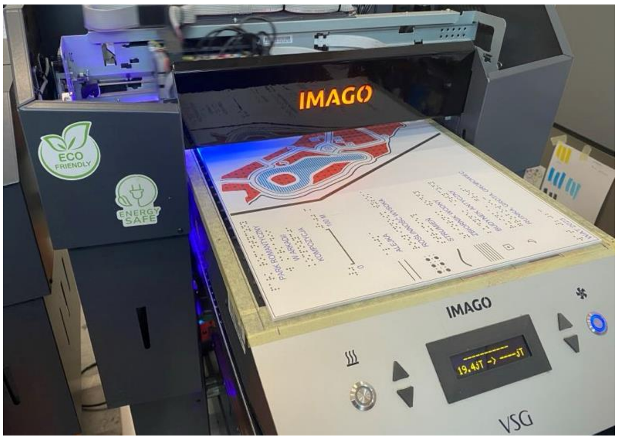

Figure 3. The UV printing process.

It is possible to print on many substrates with UV printers. For tactile maps, we need smooth, rigid and cheap substrates. We used white foamed PVC that has a smooth surface and durable symbols, thanks to the ink penetration. It is also cheap, lightweight and rigid (Fig. 4). The maps are ready to use after printing – no postprocessing is required. However, we recommend covering them with transparent acrylic varnish to protect them from sunlight and discolouration.

Figure 4. Case study tactile map UV printed on a foamed PVC substrate - height differences of particular symbol geometries are visible.

2.2 Data and Software Availability Section

We used the following data sources for our project: BDOT10k (Topographic Objects Database (BDOT10k), 2024), OpenStreetMap (OpenStreetMap, 2024), local geoportals (if available, e.g. Geographic Information System, 2024). If these were insufficient to cover all the object from our features catalogue, the datasets were later enhanced by manual vectorization from orthophotomaps (Orthophotomap (ORTO), 2024), and/or field measurements using the GNSS receiver.

We used ArcGIS Pro 3.1 to combine the vector data from different sources, vectorize additional features from orthophotomaps and to perform map generalization and symbolization. Next, we exported the cartographically sound drawings to a vector format and carried out the redaction process in Rhinoceros 3D 7 software. Finally, we exported the raster layers files in PDF format to AcroRIP software that had been previously configured to work with the UV printer we used – Aquila UV LED v2.

3 Results

The UV printed map of Romantic Park in Arkadia was 344 x 296 mm in size and printed on a 2 mm thick A3 sheet of foamed PVC. The printing took about one hour and the cost of substrate, ink and electricity did not exceed 5 euro.

The resulting map (and 12 other maps produced using different techniques) were evaluated in a controlled study session with 15 PVI (Fig. 5). They had to solve location tasks that involved reading the legend and finding symbols, , e.g. “please find all the antique buildings on the map” (in Polish: “budynek antyczny” – cf. Fig. 2). Each participant solved 5 to 6 such tasks. In case of UV printed map they made no errors for point and area symbols and 2 errors for line symbols, because of a complex composition of alley and stream in the north-west part of the map.

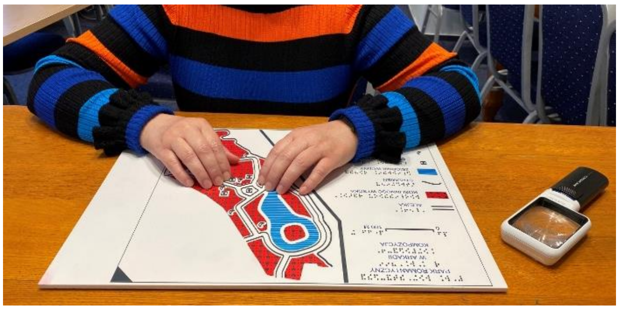

Figure 5. One of the study participants during session.

Human-subject testing also involved haptic, pragmatic and emotional evaluation of the resulting map (and other production techniques) by the study participants, using the semantic differential method. Profound analysis of the human-subject testing methodology is not within the scope of this paper - we will describe only the results of emotional evaluation. We asked the study participants to respond with a number from 1 to 5 (where 3 meant no clear opinion in the given topic) on the questions from a researcher (Table 1).

Table 1 Case study map evaluation - questions asked, the scale applied and average scores.

Question	Response		Average score
	1	5	
Is it pleasant or unpleasant?	Unpleasant	Pleasant	4.38
Do you like it?	Don’t like it	Like it	4.50
Does the map stand out from other tactile maps you know?	Nothing special	Extraordi-nary	3.94
Would you recommend it?	Wouldn’t recommend	Would rec-ommend	4.44

Since the final maps might be installed outdoors, we exposed the case study maps to extreme weather conditions for 2 months – freezing, thawing, rain and sun, to verify its durability. We have noticed small defects of substrate material on the map’s corners. This suggests the need to use a less porous substrate material if maps are to be used outdoors. We did not notice other changes, except some dirt that was easily washable (Fig. 6).

Figure 6. Case study map after being exposed to weather conditions.

4 Discussion and conclusion

Using the proposed methodology we developed a UV printed tactile map that most study participants liked and found innovative. Considering the low error rate in location tasks, we can conclude that the resulting map is legible, which is the most important feature of a tactile map. It also meets all our requirements for tactile maps production technique: it must be cheap, relatively fast and uncomplicated. Besides, it must allow height differentiation of tactile symbols and full-colour printing, which allows conveying larger amount of information without loosing its legibility (Wabiński et al., 2020). Finally, the physical products must be durable and weather-resistant. All this translates into a positive answer to the research question posed.

The PolyJet (one of the other verified techniques) also had similar characteristics and received positive feedback from PVI, but the printing costs are incomparable with the

UV printing. The remaining tested techniques had different drawbacks that limit their use, e.g. swell-paper technique does not allow height differentiation of symbols, SLA 3D allows preparation of transparent tactile overlays with graphic underprints but is a very complicated and time-consuming technique.

However, at this stage, our methodology has some limitations, e.g. it requires manual editing of the maps. We want to automate some processes, such as making legends, miscellanea, and layer files. Currently, we need many software programs, which may have compatibility issues. We plan to script the software transitions, aiming at fully automatic pipeline in the future. Moreover, reliable UV printers are costly and need supervision when operating, but since additive manufacturing is a rapidly developing industry, we believe that these issues will be mitigated soon.

UV printed tactile maps can be further enhanced with multimedia, such as audiodescriptions providing additional details about the mapped places. So far, we verified the utility of NFC tags placed underneath the case study map – smartphone sensors easily read such tags through the 2 mm thick PVC layer. We want to experiment with other visual and sound tags in the future (e.g. NaviLens, 2024).

To conclude, transcription of the existing visual maps and/or translation of the raw geospatial data into a form legible by PVI remain laborious and, at least partially, manual tasks, thus affecting their price. But new technologies, like UV printing, can reduce the costs and meet the tactile maps design guidelines. Considering the rapid development of machine learning that already facilitates generalization of traditional maps (e.g. Karsznia et al., 2023; Touya et al., 2019), we may soon be able to make tactile maps fast, cheap and accessible to everyone, leading to a true inclusiveness of, not only PVI, but people with special needs in general.

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Author contributions

Conceptualization, Jakub Wabiński, Albina Mościcka; Data curation, Andrzej Araszkiewicz, Damian Kiliszek; Investigation, Jakub Wabiński, Emilia Śmiechowska-Petrovskij, Damian Kiliszek; Methodology, Jakub Wabiński, Andrzej Araszkiewicz, Albina Mościcka, Emilia Śmiechowska-Petrovskij, Damian Kiliszek; Project administration, Albina Mościcka; Validation, Jakub Wabiński, Andrzej Araszkiewicz; Writing – original draft, Jakub Wabiński; Writing – review & editing, Albina Mościcka, Emilia Śmiechowska-Petrovskij, Andrzej Araszkiewicz, Damian Kiliszek.

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