Thematic Tactile Maps for Blind and Visually-Impaired People: A Conceptual Cartographic Framework for Map Creation using Open-Source Data and LCD Printing Technology

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Introduction

Medical screening technology and treatment efficiency have been constantly improving over the decades but despite such advances the majority of people with vision impairment still have no access to treatment although their condition could likely be cured or at least be improved so that they could partake in everyday activities without facing obstacles or even exclusion (Pascolini & Mariotti, 2011**)**. Better medical possibilities, however, do not always include improved opportunities, and the increase of the world's population and the number of people that can actually be treated is not balanced. As a consequence, the number of people living with vision impairment has been continuously growing at an almost constant rate (WHO, 2019). In countries with a super- or hyper-ageing population, such as Japan, Germany, Italy, the US, or Taiwan, the number of people with severe vision impairments increases even faster due to ageing effects, with blind people representing 82% in the group of people aged 50 years or above (Pascolini et al., 2002 Pascolini & Mariotti, 2011). Today, 295 million (285 million in 2011) people live with vision impairment, 43 million (39 million in 2011) of them are blind and need to rely on other sensory input (IAPB, 2021).

When it comes to visual communication, cartography has always been providing a foundation for optimizing visual perception and comprehension of complex spatial topics, and such visual tools have been a matter of extensive research over the decades with pivotal work published by, e.g., Bertin (1983), and with new trends targeting richer experiences relying mainly on visual communication (e.g., Peterson, 1994; Taylor, 1994; Kraak, 1999; Konecny, 2011). And while visual communication is a key in conventional cartography, it excludes people suffering from severe vision impairment or blindness, who instead have to substitute visual input for gathering spatial contextual information. As a response to this limitation, tactile maps have been created and used in education and for orientation purposes since the 19th century. Furthermore, 3D maps have been important assets in architecture and building design, city planning or historical city views. While the possibilities have become richer after the popularization of computer technology, 3D printing has remained expensive for non-professional businesses until the early 2000s. Among those technologies, Fused Deposition

Modelling (FDM) and more recently polymerization through stereolithography (SLA) have become attractive alternatives (ISO, 2021) and are also in reach for the blind and vision impaired (BVI) community.

For modern 3D printed maps, the underlying cartographic concept is often highly reduced as the focus was often put on the reproduction of map geometry for orientation, rather than map semantics and added complexity (see, e.g., Goetzelmann & Pavkovich, 2014). With the availability of higher-quality and lower-cost printing, the potential for producing usable and semantically richer tactile maps has increased considerably. Tactile maps benefit from their three-dimensional representation and an increased level of model freedom with respect to variables such as shape and texture. The approach reported here focuses on developing such an underlying cartographic concept with feedback from the community, which aims at implementing a prototype that allows to create more complex, multi-thematic maps focusing on education as assistive technology.

Methods and Approaches

The development approach for this research comprises (1) the creation of a conceptual cartographic model for tactile thematic maps using published foundations and standards and specifically targeted at the BVI community; (2) the implementation of a map-making framework using open-source resources, for both geometry and semantics, and free and open-source software (FOSS); and (3) the validation of concepts and implementations with iterative feedback from the BVI community.

The conceptual component focuses on the overall approach and communication design and includes both boundary conditions and limitations as extracted from published work, from iterative discussions as well as technical limitations. The view here is not centered at the technology as this has been a major point of criticism found in the literature (e.g., Perkins, 2002). We have tried to avoid this matter by not only making use of and integrating published guidelines and standards, but also by establishing communication with users from the vision-impaired community and by creating an initial participatory process that builds on comments and feedback.

The main aim in conventional visual cartography is to communicate a complex, often multi-thematic, topic by means of visual map variables and aesthetically pleasing and well-balanced organization of supporting information, including a legend and metadata. In tactile cartography, topic density, i.e. simplification and generalization, map scale and variables become even more important as the freedom to experiment with ranges or even unconventional aspects is limited as it would otherwise put considerable pressure on the map reader and turn the experience into a confusing or even stressful one at worst. Of these driving factors, the translation of visual variables are considered to be of major importance as their design will allow people to grasp the map contents without having to interpret each tactile feature in detail at the beginning. This immediate perception of contents is commonly facilitated by colors and sizes (as selective variables). While the degree of freedom is reduced due to the lack of color perception, the tactile component allows for height variation which allows for another layer of attribute information instead of geometry.

In addition, when implementing labels and annotations, the use of Braille symbols faces the challenge that non-Western characters require transliteration that is actually understood by the community. While this is straightforward for Hanyu Pinyin (simplified Chinese), it becomes challenging for traditional Chinese characters that are represented by phonetic symbols called Zhuyin (37 characters and five tone marks).

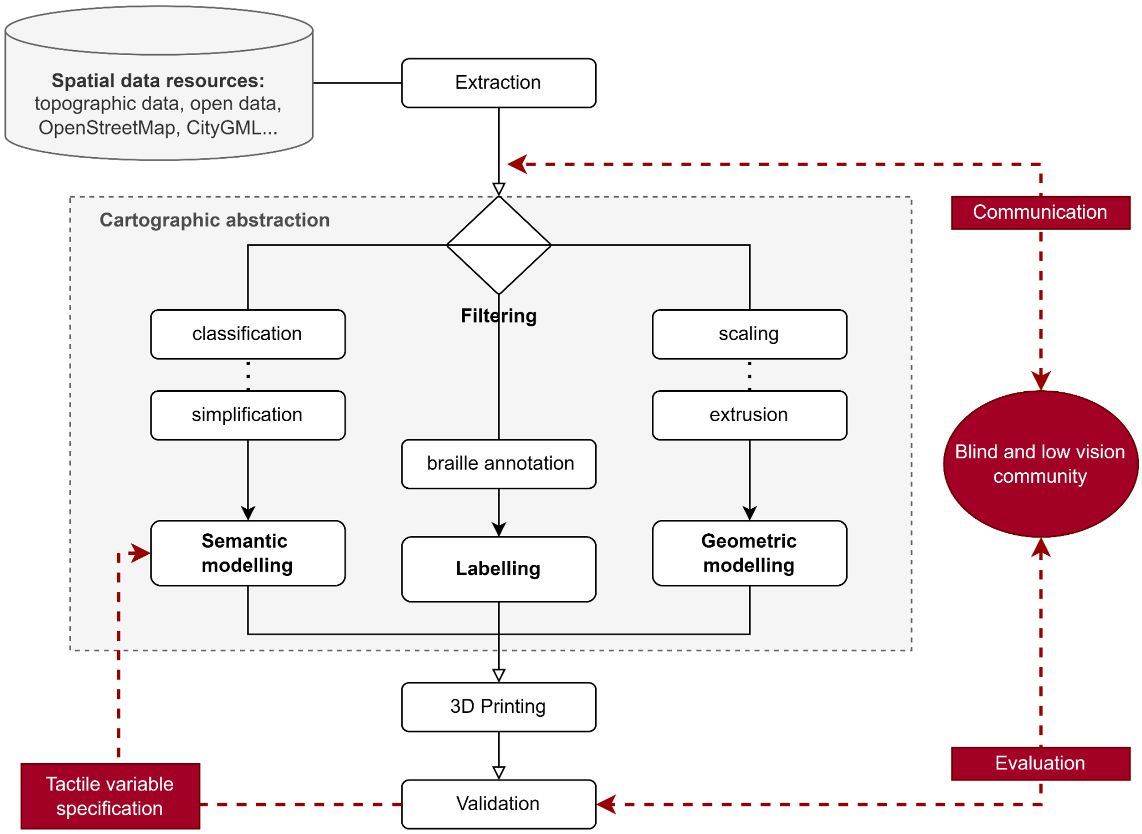

Figure 1. Workflow for establishing the conceptual model and prototype using OpenStreetMap data and OpenSCAD modelling.

The map contents itself builds upon openly accessible data from OpenStreetMap (OSM) and openly accessible governmental data, which can be extracted and processed further. The extracted information contains geometric (2D) data, including partially semantic data. Information querying and extraction for OSM can be accomplished using the Overpass API and Query Language, where geometric and semantic information can be filtered according to user criteria, and finally stored in a readable Extensible Markup Language (XML) format (cf. Götzelmann & Pavkovic, 2014) as well as other formats that can be exchanged in CAD software (here: OpenSCAD) such as the Drawing Exchange Format (DXF). This flexibility will be of advantage for (1) selecting only required information and for (2) transferring semantic information into symbology and braille labels (see Figure 1).

The overall development was designed with iteration in mind, i.e. feedback from the BVI community was important right from the start either as derived from published research literature, recommendations and standards, and, in the second phase, through interviews with the community. These interviews have been conducted with various prototypes and with focus on detectability of line features, perception of height variation as cartographic variable, ease of perception of topic, as well as map scale limitations. Interviews were conducted with blind as well as severely visually impaired community members with varying degrees of knowledge and experience about Braille and about tactile maps.

Results and Discussion

The proposed requirement provides a general framework in whose boundaries we were able to develop an approach that is taking into account individual experiences as well as technical boundary conditions that should be met in order to provide a workable solution at low costs.

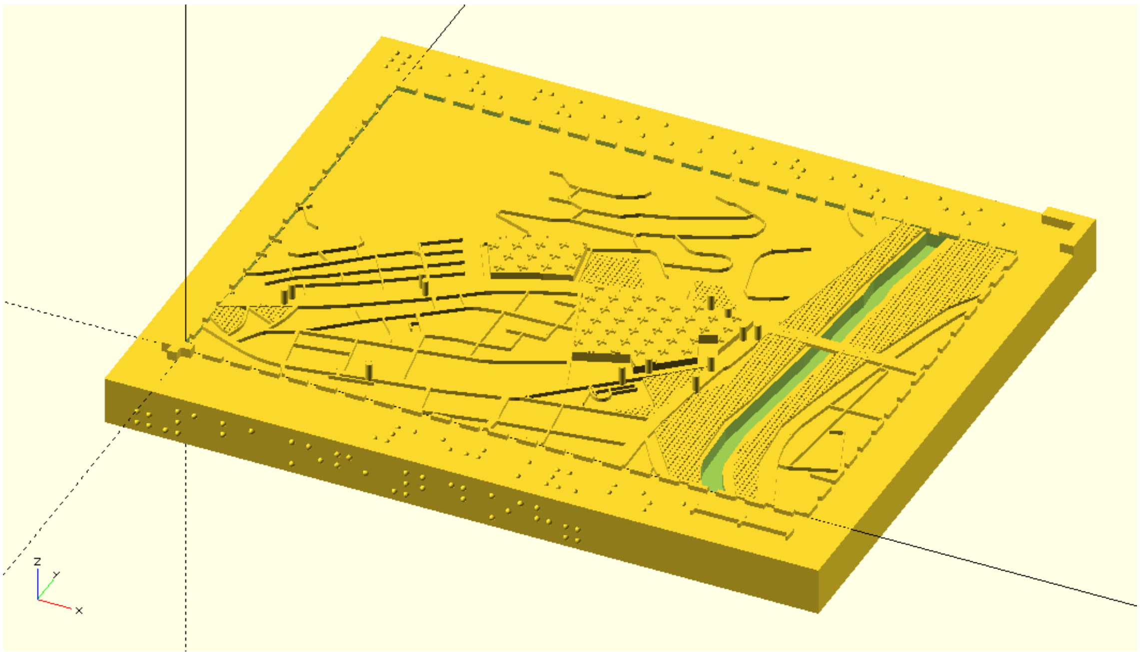

Figure 2. OpenSCAD model and rendering of map area before printing.

The presented workflow can be considered complete when it comes to the extraction of information, and implementation of the cartographic concept, i.e., the simplification and transfer of visual variables into the tactile domain, as well as the preparation and transfer for 3D printing, including printing itself (see Figures 2 and 3). While automatic extraction of spatial data as well as semantic information, including Braille translation, works well despite challenges in some areas depending on local characteristics, there is still work to do when it comes to the actual modelling of 2D map information to 3D objects with textures that are clearly separable despite thematic overlap.

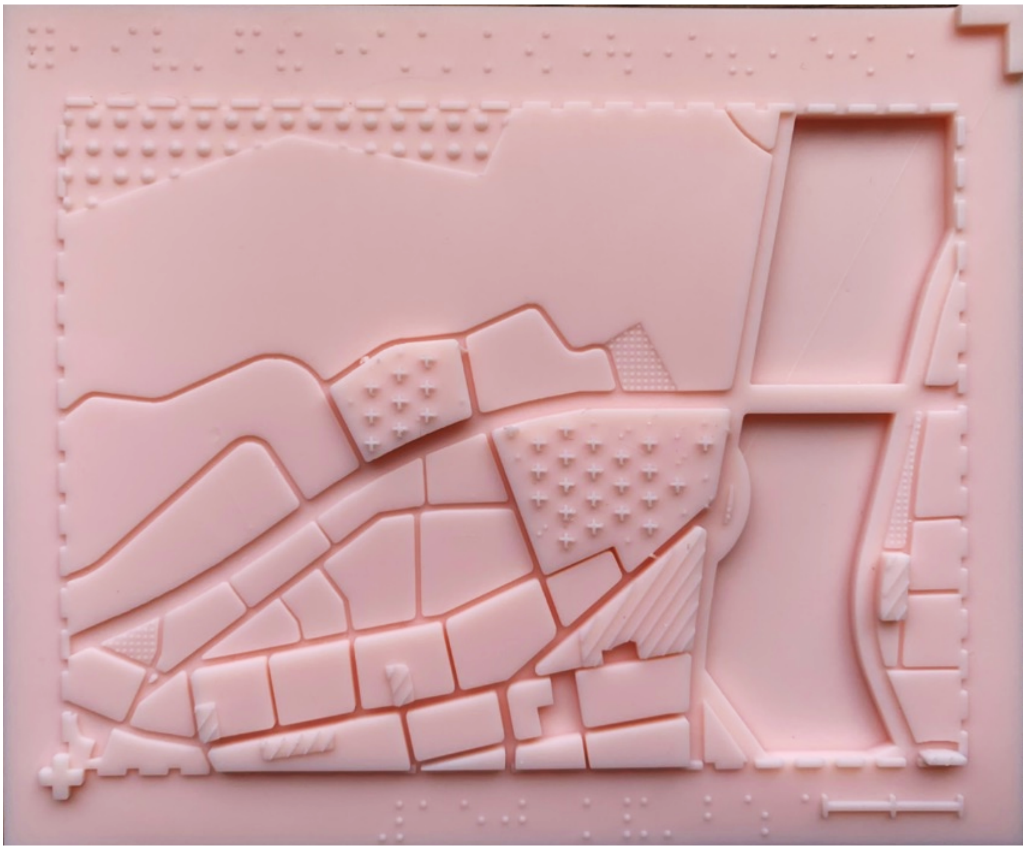

Figure 3. 3D printed land-use map as early prototype for BIV community iteration (scale 1:7,000, legend on separate print model).

The current development represents a basic functional prototype rather than a final operational framework ready for production at educational facilities at this stage. The reasons for that lay in the fact that further iterations with BVI community members are needed to identify limitations of complexity. While published guidelines very much focus on the geometry of objects and their separability when it comes to texture, size and spacing, the level of complexity – or density of information – is something that needs to be investigated further. Also, map reading approaches (the initial 'overview') are not well understood and size limitations play an important role here.

Also, while 3D LCD resin printing is attractive in terms of costs and detail, it might not be the best option when it comes to material and effects caused by photochemical reactions. Studies are warning that during polymerization of printing material toxic fumes may develop and proper ventilation and handling with gloves are required (MEF, 2017; Davis et al., 2019; Kress et al., 2020). After all, thermal degradation continues even after printing and the effects of volatiles and their biocompatibility are not completely understood thus far.

Additionally, in our cases LCD printed maps have shown differential contraction and bending which could not be completely eliminated despite tests using support structures and material thicknesses. This effect does not impact the tactile quality of map contents and was largely ignored by the community, but for larger area-printing which should be accomplished using tiling, this effect would severely impact the overall model quality.

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