Mapping Indoor Spaces to Support Blind and Visually Impaired People

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Abstract: - The present study focuses on methods for supporting the orientation of blind and visually impaired people within public buildings. Various innovative navigation solutions are reviewed, including principal mapping approaches and systems based on artificial intelligence. Based on the identified challenges and the specific needs of visually impaired users, the authors propose the development of tactile maps incorporating Braille labels in accordance with an established standard. A tactile floor plan of a building was developed using Fused Deposition Modelling (FDM), 3D-printing technology featuring marked locations and dimensions that comply with standard requirements. The selected method offers rapid production at relatively low cost, thereby facilitating the mapping of a larger number of public buildings. Future work will include an analysis and evaluation of the map's tactile usability and suitability for practical application.

Key-Words: - Tactile mapping, Indoor space, Orientation, 3D printing, Blind and Visually impaired people

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1 Introduction

Vision is one of the primary sensory modalities through which humans perceive and interpret their surroundings. Sighted individuals obtain immediate information about the shape, orientation, and appearance of objects, whereas blind and visually impaired individuals rely on non-visual sensory channels to construct spatial representations. Consequently, the development of assistive solutions that facilitate access to buildings, institutions, public spaces, and other environments is of particular importance. In [1], experiments were conducted with sighted and congenitally blind participants, who were presented with visual or auditory objects in order to examine how object characteristics are mapped within peripersonal space. The results revealed no significant differences between the participant groups, indicating that the absence of visual experience does not substantially impair spatial representation.

Blind and visually impaired people face persistent challenges when navigating unfamiliar environments, where undetected obstacles may compromise their safety and independence. Assistive technologies can help users locate objects and navigate during everyday activities. Numerous navigation systems based on electronic travel aids have been developed; however, many are bulky or expensive and require external data processing, which limits their practicality for everyday use. The device proposed in [2] simultaneously localizes the user and maps the spatial geometry while detecting obstacles along the user's path. In [3], blind participants were evaluated using several prototypes for object search and orientation in simulated living-room and office environments. The study reported positive results regarding their effectiveness, with ObjectFinder being the preferred prototype because of its more efficient hardware implementation.

The objective of this study is to identify an appropriate approach for indoor mapping and orientation that supports blind and visually impaired people. Following the selection of a suitable approach, a map of an existing building area is developed to facilitate user orientation within the environment.

2 Main Approaches to Mapping and Navigation

Accessible mapping is essential for supporting the orientation of blind and visually impaired people in buildings, university campuses, shopping centers, hospitals, railway stations, and urban environments. The principal mapping and navigation approaches intended to support these users are discussed below.

2.1 Tactile Maps

Tactile maps are raised representations that are read through touch. They commonly incorporate Braille, raised lines, differentiated textures, and embossed symbols and may also include audio components. Typical applications include schools, universities,

metro stations, public buildings, and museums. Research indicates that tactile maps are particularly useful for familiarization with an environment, understanding complex buildings, and orientation and mobility training. The main types include:

1. Orientation maps - used for orientation in schools, universities, and public buildings;
2. Route maps - present a specific route, for example from an entrance to an office, from a transport stop to a lift, or along an evacuation route;
3. Geographical tactile maps - represent cities, countries, transport networks, and metro systems;
4. Interactive tactile maps - combine a raised map with a touchscreen, audio output, and artificial intelligence.

2.2 Indoor Navigation

Indoor navigation is used to support blind and visually impaired users in public buildings and cultural institutions. Because Global Positioning System (GPS) signals are generally unreliable indoors, alternative technologies are employed, including:

- Bluetooth beacons;
- Wi-Fi positioning;
- radio-frequency identification (RFID);
- computer vision;
- simultaneous localization and mapping (SLAM) systems;
- light detection and ranging (LiDAR), as used, for example, by Good Maps.

Applications based on these technologies can provide spoken instructions, vibration cues, descriptions of the surrounding environment, and obstacle warnings through the user's mobile device. Review studies identify reliable indoor navigation as one of the most important mobility needs of blind and visually impaired people.

2.3 Beacon-Based Systems

Beacon-based systems employ compact Bluetooth transmitters installed at selected locations within a building. When a blind or visually impaired person enters the building, a mobile device detects the beacon, determines the user's approximate location, and provides navigation instructions. Guide Beacon is an example of a system designed for wayfinding in large buildings. Bluetooth beacons are relatively inexpensive and can support point-to-point navigation towards destinations such as lifts and staircases [4].

2.4 Artificial Intelligence, Computer Vision, and SLAM

More recent systems combine cameras, artificial intelligence-based recognition, three-dimensional mapping, and simultaneous localization and mapping (SLAM). Such systems can generate a real-time representation of the environment, localize the user, and detect obstacles that may pose a safety risk [5].

2.5 Audio and Haptic Navigation

Audio and haptic navigation systems are intended to provide more intuitive guidance. They may combine spoken commands with vibration cues for turns, differentiated vibration patterns, audio directions, and three-dimensional spatial audio [6].

2.6 Main Problems and Challenges

Several major challenges arise in the development of maps and navigation systems for blind users:

- lack of harmonized standards;
- high infrastructure costs;
- insufficient localization accuracy;
- dynamically changing environments;
- complex user interfaces;
- different requirements among individual users [7].

Studies involving blind users [8] indicate a preference for:

- a combination of tactile and audio systems;
- clearly marked spaces;
- simple instructions instead of excessively complex high-technology solutions [9].

3 Tactile Maps

Following a review of available navigation methods for blind and visually impaired people, tactile orientation maps were selected as a comparatively simple and accessible solution for navigation within public buildings. Such maps can represent the spatial organization of a university floor, metro station, or shopping center and provide information about the user's current location and the arrangement of the surrounding environment.

Because tactile perception has a substantially lower spatial resolution than vision, tactile maps must be considerably simplified. They are specifically designed to communicate spatial information through touch rather than sight. The design process usually begins with a conventional visual map, which is simplified while important features are enlarged. Different textures may be used to distinguish

environmental categories, and all symbols must be readily identifiable by touch.

A tactile map is explored sequentially with the fingers by identifying textures and tracing raised lines. In contrast to a sighted user, who can perceive the overall map almost instantaneously, a blind user constructs a mental representation progressively by exploring individual areas. Therefore, tactile maps require simplified content, enlarged symbols, and careful selection of the information presented.

3.1 Design Requirements for Tactile Orientation Maps

Designing tactile orientation maps requires the careful presentation of information, proper layout, and tactile legibility so that users can familiarize themselves with the depicted features and orient themselves within the space. Certain symbols and textures vary by country, which can create difficulties for international users. To standardize tactile legibility, the ISO 19028:2016 [10] standard is used; it defines requirements regarding information content, symbols, Braille, mounting, and the accessibility of tactile orientation maps. The most critical task in designing tactile maps is simplifying spatial information by depicting only the building's most essential features—such as entrances, corridors, room access points, stairs, elevators, and restrooms. Despite this simplification, it is crucial to maintain the environment's connectivity by indicating the links between individual rooms. For tactile maps, the general spatial layout is more important than precise geometric proportions. Raised lines are used to indicate corridors and streets, while Braille is used for names, room numbers, and legends. Special symbols can denote buildings, elevators, and other key landmarks. Symbols must be recognizable by their overall shape rather than by fine details. The amount of information should be kept to a minimum. Recommended limits involve approximately 10–15 symbols and 3–6 textures, ensuring sufficient spacing between adjacent elements to prevent them from merging into an indistinct tactile pattern. Symbol dimensions are also significant; as a rule, they should be no smaller than 5 mm [11].

Finally, the inclusion of a map legend is of particular importance. If names must be abbreviated, they are explained in the legend in the simplest possible way, avoiding the creation of a complex coding system. The legend allows users to familiarize themselves with the symbols and terminology before proceeding to the actual exploration of the map.

The map is mounted on stands or attached to a wall at body height to ensure it is convenient and accessible for exploration and orientation.

4 Materials and Technologies

One widely used technique for producing tactile maps is swell paper, also known as microcapsule paper. The map is printed using dedicated ink and subsequently passed through a heating unit, causing the printed dark areas to expand and form a raised surface.

But three-dimensional printing currently provides a rapid, precise, and cost-effective alternative. It enables the manufacture of complex geometries, supports rapid prototyping, and allows designs to be readily customized or modified. The map is developed using computer-aided design (CAD) software and exported as an STL file. This workflow permits fabrication using different additive manufacturing technologies and materials.

The tactile map was prepared using a CAD program. A Bambu Lab P1S printer, operating according to the widely available Fused Deposition Modeling (FDM) process, was used in the present study to realize the project [12], shown in Figure 1, with an automatic material system (AMS) that allows printing contrast details for visually impaired people for example. FDM is an additive manufacturing process in which a thermoplastic filament is heated, extruded through a nozzle, and deposited layer by layer according to a predefined digital model [13].

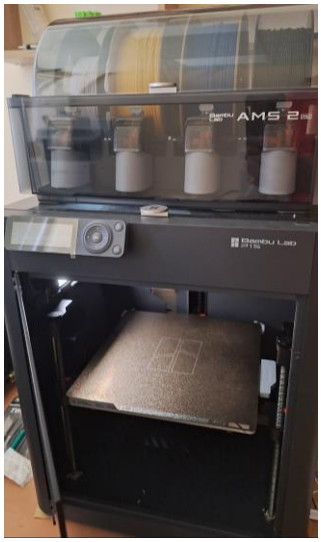


Fig. 1: Used 3D printer Bambu Lab P1S
Source: created by the authors.

The dimensional accuracy and surface quality of the manufactured components depend on several process parameters, including layer height, nozzle diameter, printing speed, build orientation, and material properties [14], [15]. Because of its relatively low production cost and its capacity to manufacture customized relief geometries, FDM has been successfully applied to the production of tactile maps and navigation aids for blind and visually impaired

users. Recent studies have also demonstrated the feasibility of manufacturing legible Braille dots from PLA using FDM technology [16]. These findings support the application of extrusion-based additive manufacturing to customized tactile evacuation plans containing raised spatial outlines and Braille room labels.

The maximum build volume of the printer is 256 x 256 x 256 mm. PLA Basic was selected for manufacturing the tactile map and was supplied automatically through an Automatic Material System (AMS). An extrusion nozzle with a diameter of 0.4 mm and filament with a diameter of 1.75 mm were used. The principal printing parameters are presented in Table 1.

Table 1. Parameters of the 3D printing process

Parameter	Value
Nozzle temperature	220 °C
Build plate temperature	55 °C
Layer height	0.2 mm

Source: created by the authors.

5 Design and Preparation of the Tactile Map

Developing the tactile map involved a series of operations that transformed an existing visual evacuation plan into a three-dimensional relief model suitable for additive manufacturing. The workflow encompassed: obtaining the reference image; reconstructing and simplifying the floor plan geometry; adapting the design to the available print area; modeling relief boundaries and Braille lettering; verifying the digital geometry; and preparing the print paths. The primary objective was to preserve the spatial relationships essential for orientation while creating a compact layout that could subsequently be interpreted through touch.

An existing evacuation plan for one wing of a building was used as the source of geometric information. The plan was documented on site using a mobile device, and the resulting image is shown in Figure 2. The raster image was imported into a CAD environment and was used as a reference for reconstructing the principal geometric features of the selected floor area. The original plan was used as a reference for spatial layout rather than as a precise measurement of the building. Consequently, the resulting model represents the general arrangement of the selected space.

The boundaries of the rooms, corridors, and principal circulation areas were reconstructed by systematically tracing the contours visible in the reference image. The resulting two-dimensional geometry forms the primary spatial framework of the tactile map. Particular attention was paid to the connections between adjacent rooms and the continuity of circulation areas, as these features serve as the basis for perceiving the floor layout. The model focuses on the primary spatial outlines and room designations. The geometry was scaled and adapted to the maximum build area of the 3D printer. This enabled the plan to be manufactured as a single component without segmentation and subsequent assembly. The entire design avoids seams between the individual parts of the map, allowing the spatial image to be explored on a continuous supporting surface.

A three-dimensional CAD model was generated from the reconstructed two-dimensional geometry, as shown in Figure 3. The model combines a supporting base, raised room boundaries, and integrated Braille lettering into a single digital component. The supporting base was designed with a thickness of 2 mm to provide adequate geometric stability during manufacturing and use. The room boundaries were represented as raised elements extending 0.6 mm above the base surface. This relief enables users to trace the spatial arrangement of individual rooms and circulation routes through touch.



Fig. 2: Original evacuation plan used as the source of geometric information

Source: created by the authors.

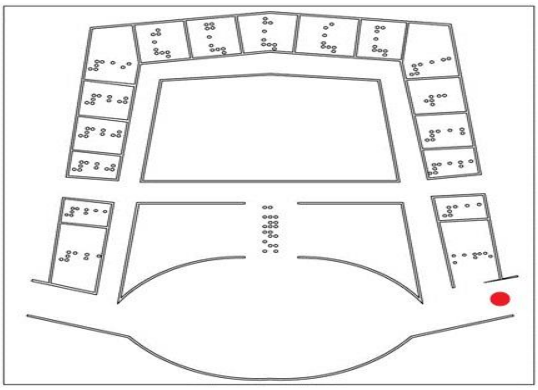


Fig. 3: CAD model of the tactile map with Braille labels

Source: created by the authors.

The room numbers were converted into the corresponding Braille dot patterns and positioned within the boundaries of the respective rooms and the map user's position with a red dot. Placing the labels inside the rooms establishes a direct link between each identifier and the corresponding space. The available space for the text depends on the size and shape of the room's representation after scaling. Consequently, the relationship between the label's placement and the surrounding raised boundaries is a crucial factor, particularly in the case of smaller or closely spaced areas. The individual dots of the Braille alphabet must remain clearly distinguishable, and their arrangement must accurately reproduce the corresponding identifier. Consequently, the legibility of the markings will depend on both the CAD geometry and the physical quality achieved during printing. The Braille labels were modelled as raised geometric features integrated into the overall three-dimensional model [17], [18]. In this manner, the visual information contained in the original evacuation plan was transformed into a relief representation suitable for actile perception by blind and visually impaired users.

After completion of the modelling process, the geometry was examined for open contours, intersecting features, and disconnected elements. The finalized model was exported from the CAD software in STL format, which is widely used for transferring geometric data in additive manufacturing workflows.

The STL model was imported into Bambu Studio, where it was positioned on the build platform and the printing toolpaths were generated. According to the preliminary software simulation, the required filament length was approximately 38.14 m, corresponding to a mass of 115.58 g. The estimated printing time was 2 h 10 min, while the total time, including preparatory operations, was approximately 2 h 16 min. The software setup and sliced model are presented in Figure 4.

The preview of the generated layers was used to evaluate contour continuity, the expected formation of the Braille labels, and the correspondence between the developed CAD model and the anticipated additive manufacturing result.

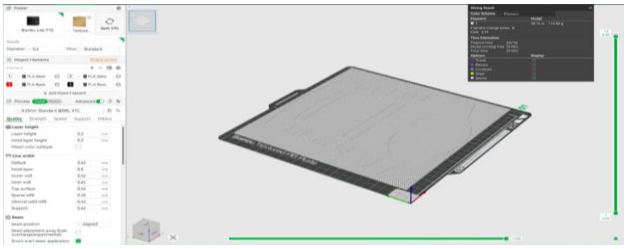


Fig. 4: Preparation and preliminary simulation of the printing process in Bambu Studio
Source: created by the authors.

6 Conclusion

This study reviewed several approaches to mapping indoor spaces for blind and visually impaired people. Although a range of innovative technologies is available, previous user studies indicate that comparatively simple mapping solutions are often preferred. A tactile mapping approach based on FDM additive manufacturing was therefore selected. The proposed workflow enables tactile maps to be customized for different public buildings and prepared for manufacturing within a short time and at comparatively low cost. The resulting approach has the potential to improve access to spatial information and support independent orientation by visually impaired users.

7 Future Work

Future work will focus on the physical implementation of the proposed design through FDM printing of the tactile map. Additional legends will be added for map location, emergency exits, and nearby adjacent streets and buildings. Its tactile usability will subsequently be evaluated with blind and visually impaired participants, as is made in another work [19]. The evaluation will examine users' ability to interpret the map, orient themselves within the building, and benefit from the introduction of tactile orientation aids.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Miglena Paneva carried out the research of the types of orientation in indoor space for blind people.
Nikolay Stoimenov and Miglena Paneva analyzed the data and chose the Tactile map for orientation in indoor space.
Peter Panev and Nikolay Stoimenov organized and executed the reproduction of CAD models and simulation of the printing process.
Miglena Paneva carried out the raster images.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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