Co-designing a 3D-Printed Tactile Campus Map With Blind and Low-Vision University Students

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Abstract

Blind and low-vision (BLV) university students often encounter campus accessibility challenges that impede their ability to navigate campus environments effectively. The lack of customization offered by some navigational-focused assistive technologies (ATs) often falls short in addressing their diverse and specific navigational needs. 3D printing, a promising tool for creating affordable and personalized aids, has been explored as a method to create customized tactile maps to aid BLV individuals with general navigation. However, the use of 3D-printed tactile maps by BLV university students and the impact of their direct involvement in the design process remain largely unexplored. We employed a participatory design (PD) approach to engage BLV students from a university in the United States (U.S.) through semi-structured interviews and a co-design session to create a prototype 3D-printed tactile map. Additionally, we consulted with a blind rehabilitation and independence expert for insight into their perspective on AT and, more specifically, tactile maps and showed the prototype to a group of visually impaired youth and instructors visiting our university for feedback. We present and discuss our findings, provide an overview of the prototype design process, and outline future work.

CCS Concepts

• **Social and professional topics → People with disabilities**; • **Human-centered computing → Accessibility technologies**.

Keywords

3D printing, assistive technology, participatory design, higher education

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1 Introduction and Motivation

University and college students who are blind or have low vision (BLV) often face accessibility barriers when accessing academic resources and campus accommodations [18, 33]. Further, while many university and college campuses in the United States (U.S.) offer some form of disability services and resources to address these barriers, differing campus policies, internal politics, program availability, and the sometimes prohibitive cost of assistive technology (AT) [42] can challenge their ability to support the needs of these students [6]. These hurdles pose a formidable challenge for BLV individuals who rely on learned orientation and mobility skills to navigate their environments independently and with others [41] in less-familiar environments [43].

While existing navigational-focused ATs have empowered BLV individuals with greater levels of independence and access [26], they do not always cater to their varied and specific navigational needs [27, 32, 36]. Consequently, maker approaches, particularly Do-It-Yourself Assistive Technology (DIY-AT) [10, 16, 25] and 3D printing, a promising enabler for DIY-AT [21, 23] have opened up new possibilities for creating affordable and personalized navigational tools, such as 3D-printed tactile maps. The use of tactile maps to support wayfinding and orientation by BLV individuals [7, 17], and the benefits and drawbacks of 3D-printed tactile maps have been studied extensively [24, 30, 38, 39].

Previous work has also highlighted the uses and benefits of participatory design (PD) [5, 22, 34, 40], as a means for engaging marginalized communities in co-design [4, 8, 12] and highlighted the challenges of engaging non-expert individuals with disabilities on novel systems [9, 15, 20, 46]. These studies have shown that involving marginalized communities in design directly not only makes accessible and usable designs possible [28], but importantly, in the case of co-designing tactile media, directly reframes and repositions the process of making, empowering BLV individuals as "creators, designers, and producers of their own media" [37]. However, the extent to which 3D-printed tactile maps are designed and used by BLV university students on a university campus and the potential impact of their direct involvement in the design process remains largely unexplored. To address this research gap, we employed a PD approach to engage BLV students from a university in the U.S. through semi-structured interviews and a co-design session to answer the following research question:

How could collaborating with BLV students in a design session for a 3D-printed tactile map prototype inform the development of future tactile maps for campus navigation?

2 Related Work: Engaging Vulnerable Groups in PD

While the uses and benefits of PD have been widely discussed and debated [5, 14, 22, 34, 40], several bodies of work have highlighted the challenges and struggles of including vulnerable and marginalized groups in the co-design process. Such works include Brulé and Spiel, which highlighted how gender and disability identities are continuously negotiated during the design process, advocating for researchers to reflect on their own identities when working with these communities [4]. Hardy et al. and Haimson et al. expanded on these concepts by conducting future workshops with LGBTQ individuals [8, 12]. They collectively emphasized the efficacy of using this format and PD, in general, as effective means for engaging with marginalized communities [ibid].

However, previous work has highlighted the challenges of engaging non-expert individuals with disabilities on novel systems. For example, Holone and Herstad, examined the tensions between the ideals of PD and the practical realities of engaging with participants, noting the unavoidable compromises between time, level of skill required, and facilitating good communication between stakeholders [15]. Works by Hamidi et al., Korte et al., and Yip et al., among others, have offered promising solutions to these challenges, exploring the use of low and medium-fidelity prototypes and the involvement of multiple stakeholders in discussion as a means to engage non-expert individuals with disabilities in PD [9, 20, 46]. Despite the challenges in engaging individuals with disabilities in PD, involving them directly not only makes accessible and usable designs possible [28], but importantly, in the case of co-designing tactile media, directly reframes and repositions the process of making, empowering BLV individuals as "creators, designers, and producers of their own media" [37].

3 Research Methods

In the spring of 2023, the university's Office of Student Disability Services (SDS) approached our research lab to discuss the possibility of collaborating to create a 3D-printed tactile map of their campus. SDS proposed using tactile maps as a tool to help new students orient themselves to the campus layout and aid in general navigation. They envisioned collaborating with our lab to assist students in customizing tactile maps to meet their individual needs.

We subsequently recruited three students from the university to take part in semi-structured interviews. Notably, despite the support we received from several university organizations, it was difficult to recruit additional BLV students, a challenge that has been well-documented by Becker et al. [1]. However, we recruited students with varying demographics, including two blind male students, aged twenty-three and forty-five, and a twenty-two-year-old non-binary student with low vision. All students had an opportunity to interact with the initial prototype and provide feedback. Their input was subsequently used to develop a second iteration of the map, as described in Figure 1.

Semi-structured interviews were followed by a co-design session with one blind student and utilized the second iteration of the prototype as a starting point. The co-design workshop aimed to enable collaborative, iterative updates to the second prototype iteration.

Additionally, we conducted an unstructured interview with a blind rehabilitation and independence expert to learn more about their experience working with and supporting BLV individuals, their organization, and their perspective on AT and tactile maps. Finally, we showed the tactile map prototypes to a group of youth and instructors visiting our university from a local workforce development organization. The group included four youth and young adults with visual impairments (three female) and one male instructor with visual impairment. In the short focus group that took place in our lab and took approximately 20 minutes, we talked about 3D printing and prototypes and asked participants about their previous experiences and feedback on the prototypes.

Following data collection, we thematically analyzed all audio transcripts and field notes collected from the research sessions [3]. This study and all materials were reviewed and approved by the university's Institutional Review Board (IRB).

4 Findings: Co-Design Challenges

Following initial discussions with SDS, we used Touchmapper [1] and Tinkercad [2] to design the initial prototype 3D-printed tactile map. The prototype featured a top-down view of a frequently visited section of the university campus, including raised representations of buildings, text labels to identify them, a star to aid with orientation, and raised representations of pathways. We refined the prototype with a second iteration by replacing text labels with braille and introducing cone shapes to signify accessible entrances.

However, iterating further on the tactile map through co-design posed a challenge. Specifically, the participant's screen reader was unable to interpret the TinkerCAD interface or its design tools. This limitation made it impractical for them to manipulate the design independently, resulting in their frustration that the interface was inaccessible and would not be adequate for the co-design activity:

> "[TinkerCAD's] canvas is not accessible in this virtual document [and] in no way will this work [for me]. The [inaccessibility of the tool] is definitely something to consider." (Co-Design Participant)

Consequently, two sighted researchers acted as a form of AT, encouraging the student to vocalize their thoughts and preferences while using TinkerCAD on their behalf to update the design. Their

[1] https://touch-mapper.org/en/
[2] https://www.tinkercad.com/

design preferences were incorporated into the third iteration of the prototype.

Design changes for the third iteration included increasing the size and scaling of both English and Braille labels, adding a more detailed compass marked with cardinal directions, and using cylinders instead of cones to represent accessible entrances, as they were less abrasive to touch. Figure 1 shows our iterative design process.

While our workaround of having two sighted researchers act as a form of AT, loosely translating their verbal design directions into adjustments to the 3D model, partially addressed the immediate inaccessibility of TinkerCAD, this challenge highlighted the well-known limitations of these tools in supporting the engagement of BLV individuals in the design process. This experience reflects a broader challenge of finding free design tools that are universally accessible and supportive of collaborative design projects with non-experts. For instance, the student had limited experience with 3D printing and expressed discomfort with both troubleshooting 3D printers and navigating 3D modeling software.

Promisingly, we discovered that the rehabilitation and independence expert used non-3D-printed tactile learning tools to train orientation and mobility skills at their rehabilitation school. Despite being familiar with 3D printing, their students preferred alternative methods and materials, such as yarn and common tactile office supplies, to create 3D maps. These maps, designed to assist in navigating the school's indoor layout and for guiding others, were not only effective but also enjoyable for the students to create and easy to learn.

During the focus group with youth and instructors with visual impairments, we found that the group had experience with 3D printing identifying tactile tags for their white canes previously. When they saw and touched the tactile map, one of the female youth mentioned that it would be helpful for the map to include features that point out emergency call stations, especially for people new to campus. The instructor accompanying the group was interested in what feedback we received on the map previously and how we incorporated it into the design.

5 Discussion: Implications for Co-Designing 3D-Printed Tactile Maps with University Students

Collaborating with BLV students on designing and customizing 3D-printed tactile maps has highlighted the potential for these tools to empower students to customize tactile maps to their individual navigational needs. However, we recognize that feelings of discomfort with technical tasks, especially for those who are non-experts [15], pose a barrier to active participation in co-design activities. These feelings of discomfort can extend beyond technical hurdles, intersecting with issues of identity and the particular challenges faced by individuals from historically underrepresented groups who might feel intimidated by the prospect of engaging with others in making [19]. Therefore, we propose that designers and campuses should ensure that co-design processes are not only technically accessible but also culturally sensitive and inclusive. As a starting point, we suggest creating pre-designed digital map templates to establish a technical baseline and streamline the initial stages of the design process. With guidance and support throughout the design process, these digital templates would reduce the need for advanced technical skills, allowing students to customize tactile maps to meet their specific needs. For example, in a university setting, a digital template of the campus featuring essential elements such as buildings and pathways could be downloaded and further personalized using a 3D design tool. Students could then add specific details, such as bus stop locations, to suit their individual preferences and navigational requirements. Students' ability to customize and adapt tactile maps based on evolving navigational needs is not just beneficial; it is instrumental in fostering their independence and helping them navigate campus throughout their time at the university.

Furthermore, the process of customizing tactile maps faces limitations specific to the detail and granularity achievable in a 3D print, constraints based on the designer's modeling and design skills, the printer's technical specifications, and the time required for printing. The availability and ability to use materials that provide greater tactile feedback also pose challenges [11], particularly for accurately representing braille lettering [44]. Consequently, we recommend tactile map designers use design approaches explored during our design iterations, such as employing recognizable shapes to denote important features such as accessible entrances, as a method to convey necessary navigational information. We contend that such opportunities can considerably lessen the cognitive load associated with remembering complex environmental layouts, such as stair locations, thus simplifying navigation [2]. Furthermore, new research into optimizing 3D printing for braille [29] is promising for further mitigating material constraints and facilitating new design possibilities.

Yet, the ongoing barrier to this progress is the inaccessibility of current 3D design tools, a problem noted in prior research [31]. Our decision to use TinkerCAD was influenced by its relative ease of use and ability to allow multiple users to collaborate on a single 3D file in real-time. However, other available tools such as ShapeCAD [3] and OpenSCAD [4], which offer alternatives to traditional graphical interfaces through the use of scripting languages and specialized hardware [35], can be complex and challenging for users to learn, which rendered them impractical for our co-design with non-expert students. This limitation hinders effective collaboration between BLV students and 3D printing professionals, underutilizing their potential as designers [45] and foreclosing opportunities for mutual learning. Following the strategies suggested by Higgins et al., we advocate for a concerted effort to refine these tools and foster productive partnerships between BLV students and accessibility experts [13].

6 Conclusion and Future Work

We engaged BLV students from a university in the U.S. through semi-structured interviews and a co-design session to explore how collaborating with these students in the design of a 3D-printed tactile map prototype can inform the development of future tactile maps for campus navigation. Additionally, we consulted with an orientation and rehabilitation expert to gain their perspective on AT and tactile maps. Our iterative co-design process produced three versions of the prototype tactile map, each refined through

[3] https://shape.stanford.edu/research/shapeCAD/
[4] https://openscad.org/

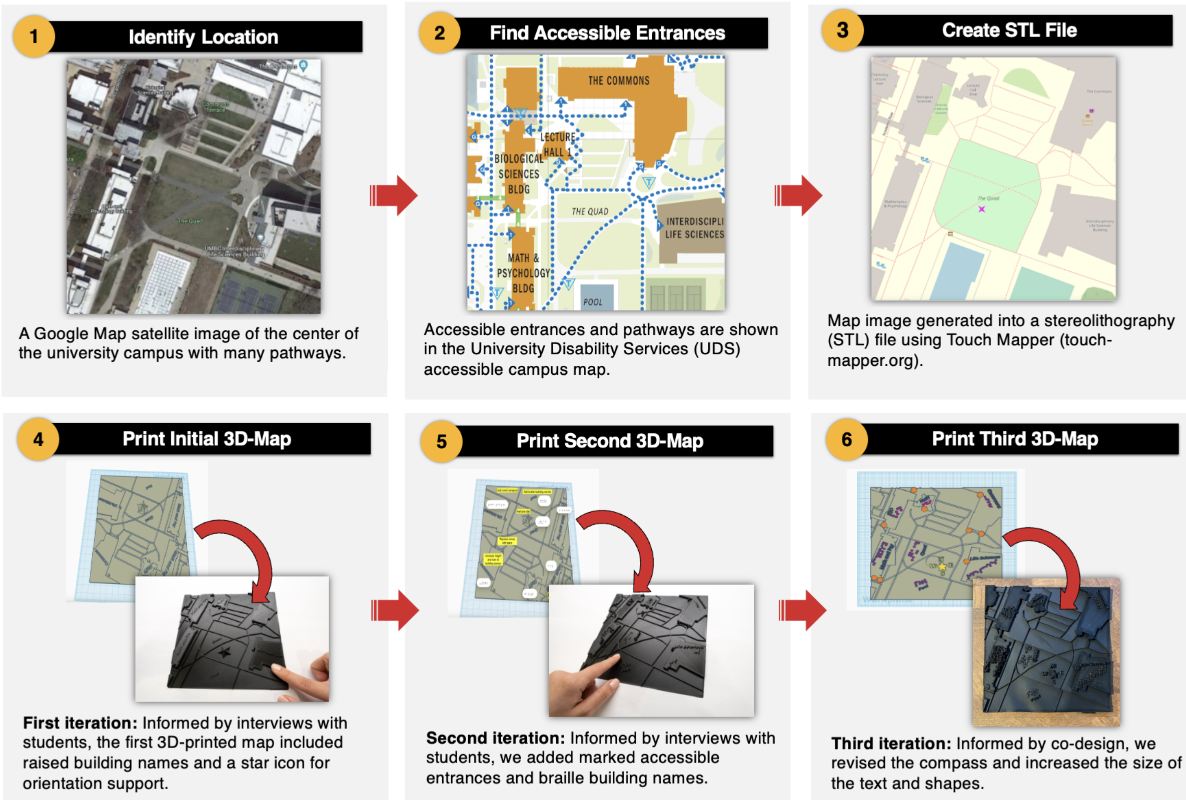

Figure 1: This figure depicts our design process for the first, second, and third iteration of the prototype 3D-printed campus map. Steps 1 through 4 describe the initial steps taken, which involved reviewing and selecting an initial location on campus, using the campus' accessible entrances map to identify accessible building entrances, and creating a .STL file. Steps 4 through 6 show the digital version (top-left) and physical version (bottom-right) for each of the three prototypes, respectively. Prototype 1 (step 4) included raised building names and a tactile star for orientation support. Prototype 2 (step 5) included additional marked accessible entrances and braille building names. Prototype 3 (step 6) included a revised compass and text and shapes with increased size.

student feedback to better meet their specific needs. These design evolutions highlighted students' preferences for customizable maps and underscored the importance of making co-design processes technically accessible for BLV students.

Future work will seek to incorporate accessible design and 3D modeling tools that allow participants to be more hands-on in the design process. This may also include conducting observational studies to evaluate the improved maps' practical use and gain insight into their efficacy in real-world navigation. Additionally, we plan to expand the scope of our research to include additional design iterations, potentially encompassing indoor areas of the campus. We also aim to strengthen our partnership further with the campus SDS to explore broader applications of tactile maps on campus. One potential opportunity could involve designing and printing a comprehensive campus map that serves as an orientation aid for new and prospective students. Furthermore, we will also seek to continue working closely with SDS to increase the availability of 3D-printed tactile maps to a wider student population and to refine our design and printing techniques.

Ultimately, we posit that co-design within the context of a university campus increases awareness of the priorities of students with different visual and navigational needs. It also highlights the importance of university support spaces and organizations being able to balance and align with each other to create a space for addressing issues from technical, social, and organizational perspectives.

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