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Internship Report

From January 18th to June 29th

Co-design of low-cost 3D interactive model for visually impaired people

Case Study

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Contents

Abstract

Spatial knowledge acquisition and comprehension is one of the key factors in the independent mobility of a visually impaired person. The tools currently used for teaching spatial knowledge have many limitations. They are cumbersome, long to create and do not allow information updating.

The extremely fast evolution of information technologies and more particularly of rapid and low-cost prototyping technologies offers the possibility to improve the spatial knowledge teaching conditions and therefore, to improve the spatial skills of visually impaired people while providing a good user experience.

In this study, we present an interactive and innovative 3D printed mock-up of a building for the introduction of the vertical organization concept. We have carried out a co-design process in order to meet the needs of visually impaired people and their specialized teachers.

The aim of our work was to create a proof of concept and the early outcomes are promising. They confirm that the device is useful, acceptable and provides high user satisfaction. Moreover, mobility and orientation specialists are already noticing spatial orientation improvement over visually impaired students after the 3D mock-up exploration.

Keywords: Visually impaired, Spatial knowledge, Co-design, Low-cost prototyping, 3D printing

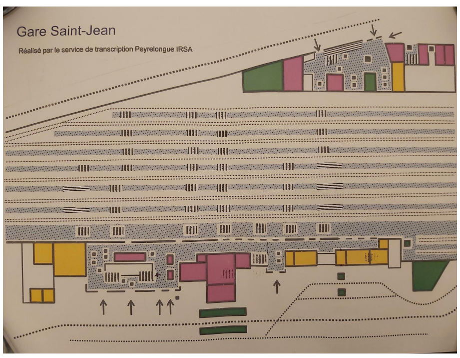
Introduction

Visual impairment is a term used to describe any kind of vision loss, but a person is stated as visually impaired (VI) when she/he presents a very low visual acuity after correction (worse than 1/10 in severe vision impairment and worse than 1/20 in blindness)[1]. According to the World Health Organization, there are 285 million VI people in the world, including 19 million children under 15 years old. Visual impairment requires specific adaptations in the environment as well as in the education (instructional or material adaptations). Independent mobility is one of the major factors for a VI person's autonomy [1]. Thus, one of the main concerns for VI people is spatial knowledge.

Spatial Knowledge Acquisition

Contrary to sighted people, VI people acquire spatial knowledge through tactile, proprioceptive and auditory modalities. Therefore, spatial knowledge is constructed and integrated through sequential exploration [2]. Auditory information supports mobility and orientation and allows the formation of a mental picture of the environment that facilitates movement [3] [4]. Haptic perception replaces vision to elaborate mental representations of space, but also involves a high cognitive cost [5]. Haptic perception is sequential and covers a small perceptual field, which leads to a strong mobilization of cognitive resources for the information to be kept in memory [6]. Currently, in special education centers, spatial knowledge is mainly taught with raised-line maps (Figure 1), which enable a VI person to explore with their fingers the areas raised above a paper (lines, symbols, textures, etc.).

a)



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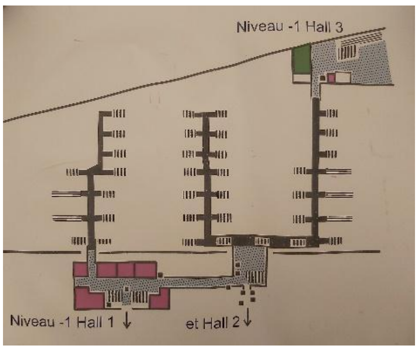


Figure 1: Raised-line maps of the St-Jean railway station of Bordeaux; a) Ground Floor, b) Hallway

[1] https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

Tactile maps are useful tools as a support for the introduction to a particular space, and spatial cognition improvement in the long term [7]. Although the benefits of these maps have been proven, they are still expensive (especially in manufacturing time), cumbersome (text written in braille is about 30 to 50 times larger than an "ordinary" text[2]) and cannot be updated. Moreover, with these maps, the information is provided from two different sources (map and legend) which lead to 2 issues. First, the continuous back and forth movement, to match textual and symbolic elements, disrupts exploration and divides attention, thereby overloading the working memory [6]. Second, they are not accessible to all VI people, since the legend is in the braille alphabet and only between 10 and 15% of VI are braille readers[3]. Furthermore, map representations are not perfect representations of the environment [8]. There can be some deformations due to spatial data transformation by the cartographer and also due to spatial information transformation into spatial knowledge by the reader [9].

In addition to raised-line maps, specialized teachers also use wooden mock-ups, cardboard models as well as maps with magnets. They also use the technique of collage of textures with various materials on cardboard for example. These techniques do not benefit from the extremely fast evolution of information technologies. This is due to a lack of simplified methods for professionals but also the lack of skills and knowledge in new technologies among specialized teachers. The maker culture can overcome this issue. Indeed, the culture of makers is a subculture of DIY (do-it-yourself) culture that emphasizes shared and open-source learning, co-working and the use of new technologies for low-cost and rapid prototyping. The interest of the maker culture in the world of visual impairment is growing, as 3D printers and laser cuttings are becoming more accessible and are allowing rapid and low-cost prototyping. Moreover, 3D printing offers opportunities for DIY and rapid prototyping solutions and enables high-level customization capabilities that enhance the user experience and satisfaction [10] [11].

In this study, we rely on a makers' culture in order to create a low-cost, innovative and updatable 3D mock-up that will meet real needs. Our study aims to prove that DIY and makers' cultures are an opportunity to improve the learning conditions of spatial notions over VI people, and more especially the introduction to verticality concept.

[2] https://www.ribambel.com/article/decouvrir-l-alphabet-braille-et-son-histoire/4707
[3] https://informations.handicap.fr/a--2732.php

State of the Art

3D Marketed Educative Mock-ups.

Several cultural sites and companies offer 3D mock-ups for VI people. For example, "Accès Culture"[4] conceives 3D tactile models for VI people. They have notably designed the buildings of the National Dance Theater of Paris, Opéra-Comique of Paris, the Opera of Dijon, etc. The Saint-André abbey has also been printed in 3D, representing the whole site, buildings and gardens. Contrary to minimalist models, the designers made sure that visually impaired people could get to know the abbey in detail. Archi-Tact[5] offers a range of tactile 3D models of architecture, urbanism and pedagogy, made on a small scale with materials with multiple touches so that they can be understood by a visually impaired public. A braille legend allows discovering the model in an autonomous way.

3D printing technology is also used to create building floorplans. For instance, "FeelObject"[6] is a French startup that creates tactile interactive floorplans for establishments, such as universities, big companies, but also a mini version of the product is offered for sale that people can carry with them and have access to several plans (several floors of the same building or different buildings). The company adds specific 3D printed tactile signs on the plans.

Yet, there are no scientific evaluations that would measure the efficiency of these devices, regarding both spatial skills and user experience. Moreover, the conception techniques of these models do not benefit from several benefits of makers' culture, and more especially rapid and low-cost prototyping, updatability and adaptability possibilities.

Benefits of interactive maps and mock-ups

Very often, 3D models of scientific publications are the result of co-design with the participation of VI persons, specialists and researchers. Recent scientific literature put forward several approaches for audio-tactile, interactive 3D printed models. To make these models

[4] "Maquettes Tatiles". https://accesculture.org/maquettes-tactiles/
[5] "Archi-Tact, Maquettes tactiles pour aveugles et mal voyants." http://www.archi-tact.com/
[6] "Feelobject - Et la matière devient sens." https://www.feelobject.fr/

more accessible for VI persons, their caregivers and teachers, these models should be easy to create, use and update (add, change and remove some information easily).

Holloway and collaborators showed that interactive 3D printed models are preferred over traditional tactile materials [12]. Giraud and collaborators created a 3D printed interactive small-scale model, which is composed of 3D pieces and provides geographical and historical audio descriptions. Better memorization of spatial and textual information was reported after the use of a 3D printed interactive small-scale model [10]. Furthermore, Brock and collaborators showed that interactive audio-tactile maps are more usable than regular raised-line maps with the braille legend [13]. Picard and Pry have demonstrated the efficiency of small-scale models of a familiar urban area, in spatial cognition improvement and more especially in survey knowledge, independently of the level of visual impairment [14]. Spatial tactile feedback is a contributing factor for a successfully mental map (relationships between places) building and maintaining [15].

Rossetti and collaborators developed low-cost interactive 3D models that allow a VI person to discover a cultural site (Pisa, Italy) with tactile information and audio descriptions. Since this model detects the user and activates an audio user guide, a VI person can explore it autonomously [16]. Even though the results are subjective, it is important to highlight that six out of eight users perceived an improvement in the interaction while exploring the models and all participants found the audio support useful for the interaction.

Halloway and collaborators developed a map with 3D icons [17]. They find out that many representational 3D icons could be recognized by touch without the need for a key and that such a map could help for mental models of the event space. The maps were found to support the orientation and mobility process, and importantly to also promote a positive message about inclusion and accessibility. Götzelmann developed 3D printed maps for small devices (phones) [18]. He developed a mobile application that recognizes the map by an ID and provides audio descriptions when specific locations are touched during the exploration. This research provided a higher satisfaction over VI participants and highlighted the possibility to make maps for small mobile devices.

To sum up, there is a number of evidences that 3D printed interactive and innovative models could improve spatial knowledge acquisition and improvement in long-term over VI people. Moreover, Picinali and collaborators showed that interactive exploration of virtual acoustic room simulations can provide sufficient information for the construction of coherent spatial mental maps and that the mental representation of the virtually navigated environments preserves topological and metric properties [19]. It means that innovative and interactive tools can be used for Orientation and Mobility (O&M) sessions in classrooms. O&M sessions consist of numerous repetitions of paths, identification of points of interest and training, and to date, sessions are often performed on-site.

To our knowledge, despite the amount of research on accessible tools for VI, there are no interactive 3D mock-ups that can introduce the concepts of vertical organization of buildings (floors, stairs, elevators) to a VI person.

However, In 2017, researchers from INLB (Institut Nazareth et Louis-Braille, Quebec)[7] introduced a 3D model of a three-storey subway station (Figure 2). The model is used by specialists in O&M, as it represents the station very effectively (corridors, stairs, doors are represented very clearly and there is also a braille legend for important locations); and provides better visualization of the environment. This model is promising because it would be easier for a VI person to explore a new environment after having explored it with the 3D model.

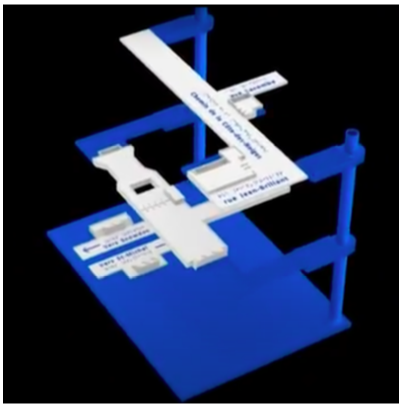


Figure 2: A 3D model developed in INLB

In this paper, we introduce a 3D printed innovative device for such spatial knowledge acquisition and comprehension.

Maker movement and low-cost prototyping

As mentioned before, typical interests enjoyed by the maker culture include engineering-oriented pursuits such as electronics, 3D printing, laser cuttings and the use of computer numeric control tools. The movement supports open sourcing and co-working, thus leading to low-cost and rapid prototyping. These techniques have the potential to make specialized teachers autonomous in the creation of the adapted materials and to make the O&M sessions more motivating.

[7] https://www.youtube.com/watch?v=BpXFPCqPyaY

Research questions

From the overall data, three related research questions have been addressed:

- How to design the 3D mock-up? (Which pieces should be mobile, interactive, etc.)
- What is the usability of the model and the 3D model-related user experience?
- What are the cognitive outcomes when using the model (spatial learning and transfer to on-site navigation)?

Materials and Methods

Participatory Design

In order to transmit spatial information to VI people and to improve their comprehension of the vertical organization of buildings (floors, stairs, elevators) we opted for a participatory design (PD) method [11]. The PD or co-design (Figure 3) is a collaboration between researchers, professionals and end-users of the final conception. The PD methods help to define the problem and to focus ideas for a solution; it also helps to assess proposed solutions during the experimentation [20]. The professionals are invited to share experiences and issues around the subject. Thus, allowing reliable detection of real needs (objective and subjective measurements). It is noteworthy that PD methods are demonstrated as leading to more innovative concepts and ideas while increasing the technology acceptance by the targeted end-users as well as the technology uses and long-term adoption [21][22].

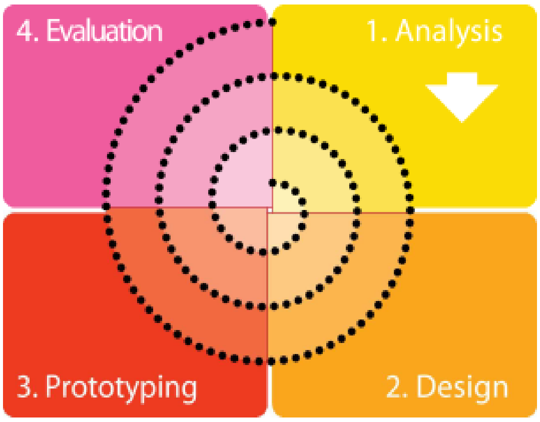


Figure 3: Process of Participatory Design

Participants

In this framework, we collaborated with the *Centre de Soin et d'Éducation Spécialisé (CSES)* Alfred Peyrelongue[8] situated at Carbon Blanc, near Bordeaux. The CSES is specialized in the accompaniment of children, adolescents and young adults with visual impairments (including blindness), with or without associated disorders. Specialized teachers of the center assist

[8] http://www.irsa.fr/cses-alfred-peyrelongue

students in order to encourage their development and the progressive acquisition of independence.

Orientation and mobility specialists are special educators, teaching individuals with visual impairments to travel safely, confidently and independently. We prepared this study in collaboration with 2 O&M specialists of the CSES. One of specialists is a psychometrician, specialized in orientation and mobility since 12 years. The second specialist is an ergotherapist, specialized in orientation and mobility since 6 years. They are both working individually with VI children and young adults of the CSES.

Co-design Process

Method

Throughout the co-design process, we were in contact with O&M teachers via email and phone. In total, we have organized 7 meetings, each lasting between 1 hour and 2 hours. The meetings took place either at the Peyrolongue center or by videoconference.

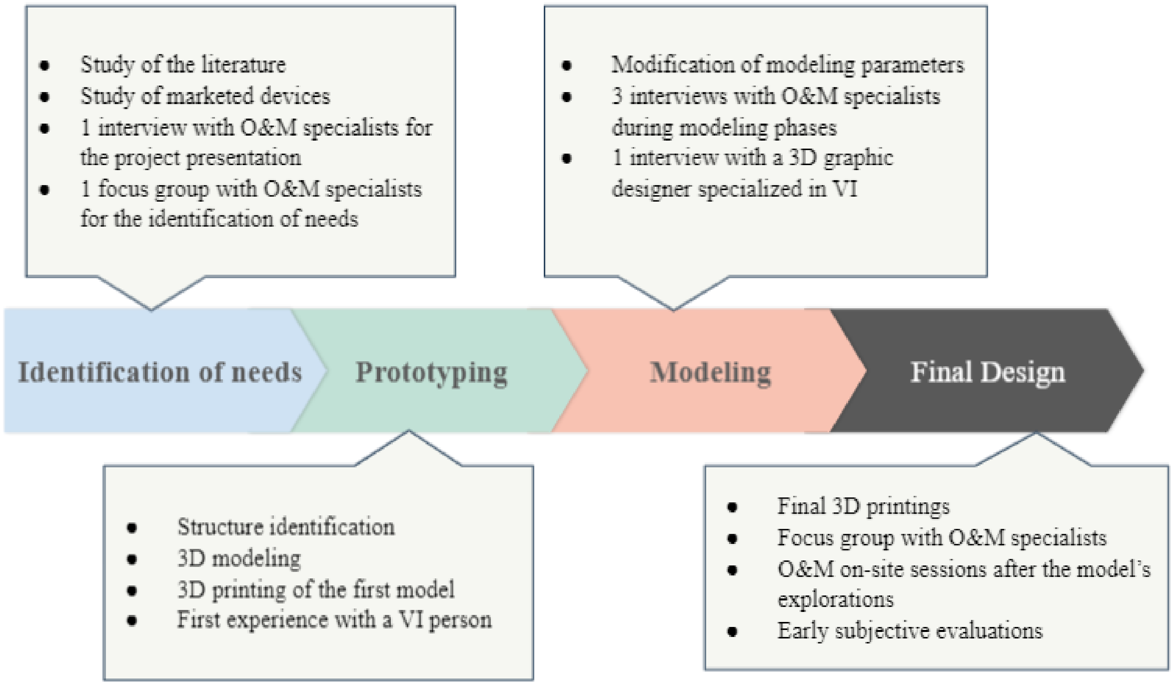


Figure 4: Co-design process

As a first phase of a participatory design, we analyzed the needs in terms of innovative tools for spatial knowledge teaching. O&M specialists confirmed the need for a tool allowing a better learning of the vertical organization of the buildings. After preliminary discussions, O&M specialists asked us for a 3D interactive model of a railway station of Bordeaux. As it is a huge and complex structure, we had to identify a strategical way for the model and information optimization.

Figure 4 illustrates the main phases of the participatory design. In the following sections, we describe in detail each of the steps, issues and overcoming methods.

Mock-up

The O&M specialists considered it useful to design a mock-up of the Saint Jean railway station because it is a complex structure and the architecture is difficult to understand by VI people. They believed that a 3D model would illustrate well the whole station, as well as the vertical organization of the 2 stages.

We realized a focus group with a specialist in order to understand their expectations of the model. We highlight here the most important points we took into consideration during the prototyping and final modeling:

- The mock-up should contain only essential information (points of interests, entrances, number of tracks, means of access)
- The final model should not be very large but the items should respect the minimum size to be understandable to the touch
- An important space between items should be respected for the exploration (this distance was clarified after the first prototype)
- The model should be easy to use and all items should be buildable
- Color contrast should be considered during the printing phase, as it is an important interaction element for people with visual residues

Due to technical (3D printing dimensions) and practical reasons, we have decided to create a buildable model; the big 3D model is composed of 2 times 11 mini-models. This technical solution was accepted by the specialists. Moreover, the buildable character of the model would allow them to teach different parts of the railway station separately. We cut the model in several parts following a logic so that there is an interest to use each part separately.
At the request of O&M specialists, we made all the architectural structures (stairs, elevators, escalators, slopes) buildable. Indeed, we have modeled half of the items on the hallway, and the other half separately, so the users can assemble themselves (Figure 4).

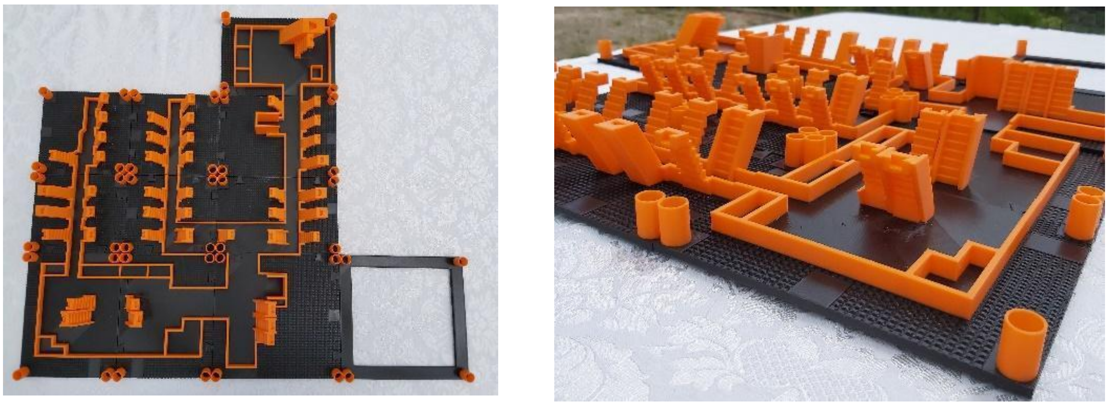
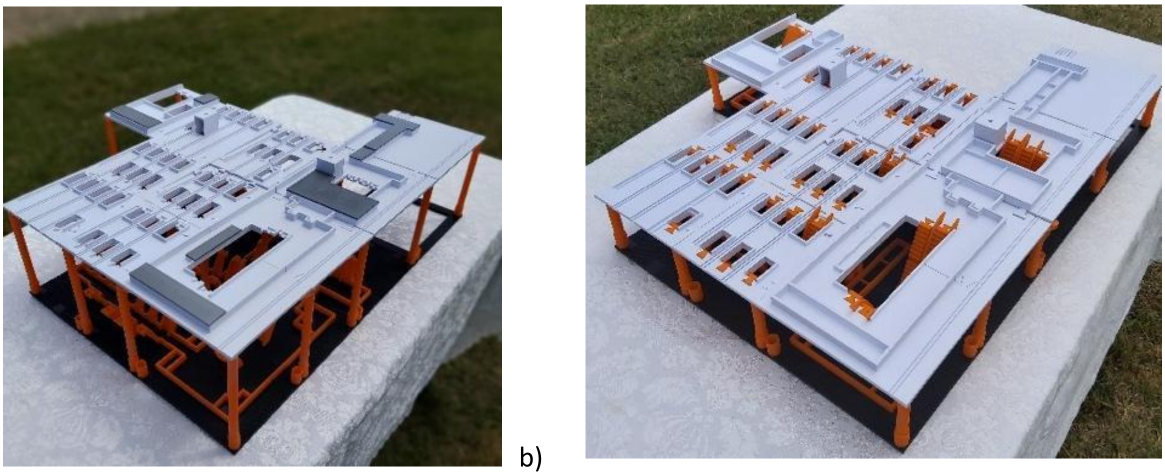


Figure 5: 3D model of the hallway

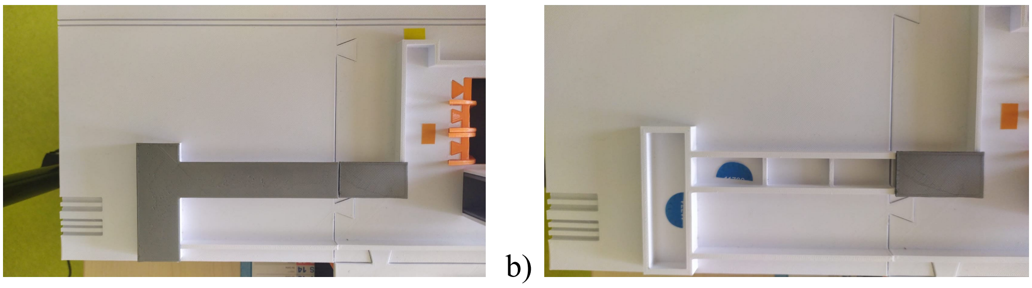
In order to improve the spatial exploration of the model and allow a better comprehension of the vertical organization between the 2 levels of the station, the hallway and ground floor are assemblable as well. Specialists have requested that the mock-up include 2 exploring modes. The first mode is 10 cm high (Figure 5b) and all the items can be assembled. The second mode is 20 cm (Figure 5a) high and allows a freer exploration as there is 15 cm of free space in height between the hallway and the ground floor. We have provided cylinders on each model, and pillars that will serve as support for the floor above.



a) b)

Figure 6: a) 3D Model 20cm height mode; b) 3D model 10cm height mode

With O&M specialists, we decided to create 2 levels of difficulties on the model. The first level of difficulty represents all the roads/routes and all points of interest (Figure 6a). The second level allows exploring the model in more details, i.e. the covers over the buildings can be removed and the user can discover the inside of the buildings (Figure 6b). The interior walls are lower than the exterior walls.



a) b)

Figure 7: a) First mode of exploration b) Second mode (more detailed) of exploration

First of all, we realized and printed the first prototype of the model. A blind user explored this prototype, whereupon we modified some configurations, such as the length and thickness of the walls, the number of steps on the stairs, the depth of the escalator railings. All the modifications were made in agreement with the O&M specialists. We decided to add a texture, unpleasant to the touch, for the non-accessible areas.

In the framework of this co-design, we discussed with a 3D graphic designer, specialized in visual impairment, from *Institut National des Jeunes Aveugles* in Paris. Inspired by his realizations, we decided to make a color contrast on our models, as visual interaction is very important for people who still have visual residue.

Interactions

Regarding the audio interactions, O&M specialists decided to use the PenFriend label reader. PenFriend is an easy-to-use, low-cost audio labeler that offers a convenient record/re-record labeling system. Audio recording is saved on the PenFriend and the detection of the label launches the audio recording. The labels are self-adhesive, colorful and easily identifiable by touch. As these labels are very easily handled, the specialists consider adding interactions regarding the VI user's needs and spatial skills. In view of the number of entrances to the station and their width, the specialists decided to add interaction in front of the entrances and not to model them directly on the mock-up. They consider also asking to VI users to add interactions themselves. We realized several tests to make sure that the spacing was correct and that the PenFriend would work without problems.

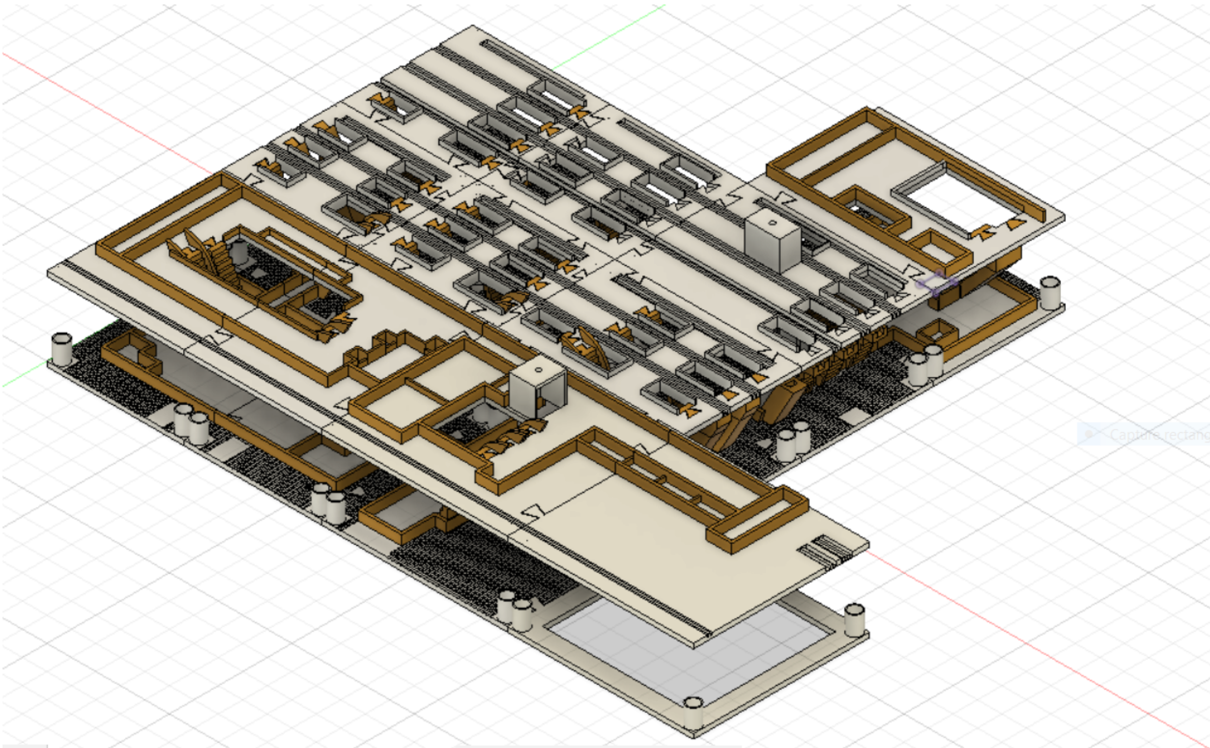


Figure 8: Capture of the complete model in Fusion 360

All 3D models were designed and modeled with the Fusion 360 Autodesk software. Models were printed in PLA using a Creality CR10-v2 3D printer.

Focus group

After the printing of all models, we carried out a focus group with the O&M specialists. The main goals of this focus group were to understand the utility, usability, acceptance and user satisfaction provided by the 3D mock-up of a railway station of Bordeaux. We conducted a semi-directed interview. The questionnaire for the interview should include questions about utility, usability, acceptance and user satisfaction. Thus, the questionnaire (Appendix 1) was prepared and adapted from a questionnaire of Venkatesh and a MeCue user experience questionnaire [23] [24]. The questionnaire was sent to the professionals by email in advance so that they could reflect on the questions, since none of the questions required a spontaneous response. The focus group lasted almost 2 hours during which we were allowed to record the answers.

The semi-conducted interview we conducted during this focus group led to interesting and constructive conclusions.

Results

Utility

O&M specialists confirmed that the model is going to be very useful for spatial knowledge teaching. The model, through its interactive and assemblable modalities, can be adapted to the user's needs, for example, according to the age of users, associated disorders and needs in terms of spatial knowledge.

Here we present a non-exhaustive list of tasks O&M specialists consider to carry out with the 3D model according to age and cognitive skills of users:

- The whole model exploration over VI young adults without associated disorders and good cognitive skills. They will not only discover the organization of the station and the location of points of interest but also anticipate future on-site visits.
- Introduction of separate parts of the model for other VI children for spatial notions introduction and improvement such as differences between architectural structures.
- Introduction to the mechanism of the elevator that opens from two different sides on the two floors.
- Verticality concept introduction.

- Orientation lessons will be done with the model. The user will be asked to locate the East, West, North and South regarding his position on the model. Specialists confirm that there will be no possibility of confusion contrary to a 2D map.

It is important to highlight that some activities were planned from the beginning but most of the ideas occurred during the process of conception. Even tough, the main purpose of the mock-up was the verticality concepts' introduction; specialists consider introducing the horizontality notions too. In fact, the three corridors are vertically parallel while the train tracks are horizontally parallel. The model allows a comparative approach and could facilitate the comprehension of these notions.

Usability

O&M instructors consider the model as easy to use:

- The assembly is easy and quick, visually and with the short manual, we prepared.
- Considering the size of the real railway station of Bordeaux, the size of the model is very good since it allows exploring it properly.
- We respected the initial request regarding the size of the mock-up. Smaller, it would not have enough details needed for good comprehension and bigger it would not allow to "see" the whole environment.

Acceptance

According to the Technology Acceptance Model [25], acceptance is based on two factors: perceived usefulness and ease of use. The perceived usefulness refers to "the degree to which a person believes that using the device would improve their performance". The perceived ease of use refers to "the degree to which a person believes that using the device would be free from effort".

Based on the interview and the conversations throughout the co-design process, we are convinced that this device is acceptable to the O&M professionals.

Moreover, contrary to the raise-line maps, the 3D model allows a complete exploration without back and forth movements for the legend, neither between two separate maps for each floor.

User Experience early evaluations

The device provided a high user satisfaction over O&M professionals. They were satisfied by the result and happy that “finally someone created a 3D model of the railway station”.

As mentioned before, we included a blind person in the co-design process and were guided by his advice all along. He was satisfied by the final device and could understand the architectural organization of the railway station of Bordeaux despite the fact that he never visited it.

In addition, 2 young VI children participated to “train discovery” sessions. The younger participant is 15 years old and is studying in a high school. She has albinism and no associated disorders. Her visual acuity is between 1/10 and 3/10 and her visual field is at least 20 degrees. She has difficulties regarding spatial representation. She also has difficulty in moving from an egocentric to an allocentric frame of reference. The older participant is 16 years old boy and is studying in a technical high school. He has associated unlabeled psychological disorder. His visual acuity is between 1/20 and 1/10 excluded and his visual field is at least 10 degrees.

During the first session, O&M specialists introduced the model for 20 min and then asked them for some tasks. They were able to easily find a route from point A to point B using the audio descriptions. Moreover, they were pleasantly surprised and expressed their admiration and interest in the 3D interactive model.

The second session was an on-site O&M session after 15 minutes of model exploration. According to O&M specialists, the model exploration before the visit was more than relevant, such as one of the participants with associated disorders and orientation difficulties navigated significantly better than usual. Both of them have memorized important information from the model that allowed them to better localize themselves in the station. O&M specialists affirm that the outcomes would be even better if they had done longer sessions of exploration.

Perspectives and possible improvements for the model

The O&M specialists are considering the addition of a visual contrast on the train tracks. They also reflect the color of the pillars. They may paint them in a different color than the items. However, they consider the model as perfectly adapted for their needs, and that we totally meet their needs.

Discussion and Perspectives

This study aimed to create an innovative, interactive, acceptable device for VI people and their specialized teachers. The device we created is the first proof of concept. Throughout the process of conception, we focused on the real needs of specialized teachers. The biggest challenge of the conception was the lack of recommendations on the creation of such a device, and more precisely, the spacing, sizes, colors, textures to be respected for the 3D items. Nevertheless, through low-cost prototyping, we could easily and quickly provide solutions and improve the model's quality.

Our conception method has some limitations. First, there is a risk of an overly socio-determined approach. Indeed, it seems clear that O&M specialists participated with a lot of interest and the biggest wish to get an original device, which would correspond, to the technological innovations, but there is a risk that their needs were unconsciously ego-centred and would tend to improve their performances while teaching spatial notions rather than VI user's performances. Further research should consider more assessments with VI people during the prototyping phase.

Second, the structure we were asked to conceive was huge and therefore the conception period was long. The design of a set of small structures would allow us to derive more conclusions and be more flexible in terms of spatial knowledge evaluations.

The other limitation to our study is the particular circumstances levied by Covid-19, which made the organization even more complicated with O&M specialists and VI students. Further research should carry out comparative experiments in order to confirm or reject the following research topics:

- The 3D model of the railway station allow a good comprehension of spatial notions.
- The 3D interactive model of the railway station allows a better understanding of the organization of the railway station compared to an interactive 2D map.
- The 3D model provides a good user experience over VI people and their specialized teachers.
- The 3D model allows a transfer of spatial learning on a real navigation site.

If there are enough participants, a comparative experiment with a control group could be conducted. If not, a Single Case Experimental Design [26] can be set up to confirm or refute the hypotheses. In order to assess the physicalization of the model as an added value and not the interaction, a raised-line interactive map (DERi[9]) should be taken as a baseline. The spatial knowledge questionnaire should include questions on route recognition, wayfinding, orientation and survey (Appendix 2).

The user experience questionnaire should be inspired by a MeCue questionnaire (Appendix 3) as it includes all the required components such as a usability, utility, induced emotions, usage consequences, etc.

Our study is a proof of concept with early promising results that should be considered in the future. Further research should focus more on the tangible interactions, by including more VI people in the conception process. It would allow to choose the more adapted and innovative tangible interaction techniques for spatial knowledge acquisition. The inclusion of end-users (O&M specialists and VI people) would enable to improve the user experience and device acceptance as well.

Finally, as a result of these numerous interviews with the professionals, we identified a real need for adapted and innovative tools for people with visual impairments. Thus, we think that it would be important and interesting to create and make available to specialized teachers a library with constitutive objects as well as simplified methods of creation of this type of devices so that teachers can become autonomous in their work. The specialized teachers confirmed our conclusions when they shared with us their wish to have a kit with small 3D printed objects that can be carried on-site and explored within an on-site navigation session.

[9] https://cherchonspourvoir.org/deri-la-surface-interactive/

Conclusion

Throughout this research, we showed that spatial knowledge teaching can benefit from DIY and maker movements for VI people. Our study is a proof of concept of an interactive and low-cost 3D mock-up for the introduction of the verticality concept. The co-design we carried out with O&M specialists, led to promising conclusions. In particular, we have shown that such a device has the potential to improve the quality and conditions of teaching.

Indeed, through numerous exchanges and interviews with mobility and orientation specialists, we were able to confirm the utility, usability and acceptance of the 3D interactive model. We found out that the real need for innovative models is associated with a lack of skills and knowledge among specialists in computer tools to meet their own needs.

This study highlights the lack of adapted and innovative tools but also the possibility to easily overcome this issue. The early evaluations of the 3D mock-up show high end-user satisfaction and even improvements in spatial orientation and localization. Further research should focus on the scientific assessment of cognitive outcomes when using the 3D mock-up, especially the spatial learning and the transfer of the learning to on-site navigation.

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Appendix 1

Entretien semi-dirigé du focus groupe final

Utilité

- Pensez-vous que la maquette 3D interactive de la gare Saint Jean vous sera utile pour votre pratique professionnelle ?

    - Pour quels types de tâches ? (Pouvez-vous nous décrire une tâche (ou plusieurs) que vous comptez réaliser avec la maquette ?)
    - Pour quels profils d'élèves ?
    - Pensez-vous pouvoir réaliser toutes les tâches que vous aviez imaginées avec la maquette au début de la co-conception ?

- Pensez-vous que la maquette vous simplifiera la/les tâche(s) ?
- Pensez-vous que la maquette est plus facile à utiliser que les cartes 2D en relief de la gare ? Pourquoi ?
- Pensez-vous que vous utiliseriez ce type de maquette avant chaque séance de locomotion ?

Utilisabilité

- Est-ce que la maquette est facile à utiliser (assembler, manipuler, explorer) ?
    - Quelles sont les choses que vous avez trouvées difficiles lors de l'utilisation de la maquette ?
- Est-ce que la taille et les détails de la maquette vous semblent adaptés pour l'exploration ?

Interactions

- A quel endroit est-ce que vous allez ajouter des interactions ? Est-ce qu'il y en aura beaucoup ?

Discussion / Transfert

- Qu'est-ce que vous changeriez si vous aviez la possibilité ?
- Est-ce que vous êtes contentes du résultat ? Est-ce que la maquette correspond à vos attentes ?
- Souhaiteriez-vous continuer à utiliser des maquettes 3D interactives pour d'autres bâtiments ? Si oui, lesquels ? Si non, pourquoi ?
- Est-ce que vous voudriez créer vos propres maquettes selon vos besoins si vous aviez des outils adaptés (modélisation simplifiée ou bibliothèque d'objets constitutifs) ?
- Est-ce que vous aimeriez remplacer les cartes 2D par des maquettes 3D ? Si oui, pourquoi ? Si non, pourquoi ?
- Quelle est la valeur ajoutée de la maquette par rapport à la 2D (physicalisation (3D), interactions ou les 2) ?

Appendix 2

Spatial knowledge questionnaire

- Points d'intérêt : Mémorisation des noms des points d'intérêt : les participants doivent se rappeler les noms des points d'intérêt présents sur sur la maquette 3D

- Routes : Mémorisation des routes (Nous allons ajouter 3 repères (A,B,C) sur les quais.)

    - EDI - Estimation de la distance d'un itinéraire : deux itinéraires différents (A-B et A-C) sont décrits et les participants doivent décider quel est l'itinéraire le plus long. [max : 4 points]

    - RI - Reconnaissance de l'itinéraire : un itinéraire est décrit, et les participants doivent décider si l'itinéraire est correct ou non. [max : 4 points]

- Survey knowledge :

    - ED - Estimation de la direction : un point de départ et un objectif sont donnés et les participants doivent indiquer la direction vers l'objectif en utilisant un système d'horloge (par exemple, à 10 heures, à 3 heures).[max : 4 points]

    - ED - Estimation de la distance : deux ensembles de POI sont proposés (POI1-POI2 et POI1-POI3) et les participants doivent décider quelle est la distance la plus longue à vol d'oiseau.

1) L-POI : Quels étaient les noms des 6 points d'intérêt (cela inclut les lieux remarquables, les rues, etc.) sur la maquette ?

Points d'intérêts sur la maquette de la Gare Saint Jean :

- Accès Plus
- Arrêt de tram
- Accueil Point Info
- Dépôt Taxi
- Rue Charles Domercq
- Parking Hall 1 et Hall 2 (dépôt minute sous-sol)
- Belcier

2.1) R-RDE : lequel de ces 3 trajets est le plus long ?

a)

Trajet 1 : Du Hall 1 Niveau -1 au quai 1B.

Trajet 2 : Du Hall 1 Niveau -1 au quai 1A

Trajet 3 : Du Hall 1 Niveau -1 au quai A

Trajet 4 : Du Hall 1 Niveau -1 au quai 1C

b)

Trajet 1 : De l'Accès Plus au quai 4A

Trajet 2 : De l'Accès Plus au quai 4C

Trajet 3 : De l'Accès Plus au quai 4B

Trajet 4 : De l'Accès Plus au quai B

c)

Trajet 1 : De l’arrêt de tram au quai A

Trajet 2 : De l’arrêt de tram au quai 5A

Trajet 3 : De l’arrêt de tram au quai 2A

Trajet 4 : De l’arrêt de tram au quai 3A

d)

Trajet 1 : De l’Accueil à Hall 2

Trajet 2 : De l’Accueil au quai 2C

Trajet 3 : De l’Accueil à Hall 1

Trajet 4 : De l’Accueil au quai 3C

2.2) R - RI : Ce trajet est-il correct ? (structure = ensemble des escaliers, escalators, ascenseurs, pentes)

a) Pour aller (par le chemin le plus court) du Hall 1 Niveau -1 au quai 2A, j'emprunte une structure pour descendre d'un étage, je traverse le couloir et j'emprunte une autre structure pour monter jusqu'au quai 2A. Incorrect

b) Pour aller (par le chemin le plus court) de l'Accès Plus au Quai numéro 4, j'emprunte une structure pour descendre au sous-sol, je traverse le couloir et j'emprunte une structure pour monter jusqu'au quai 4. Correct

c) Pour aller (par le chemin le plus court) du quai 3 jusqu'à l'Accueil, j'emprunte successivement une structure pour descendre, je traverse le couloir et une structure pour monter jusqu'au quai 4. Correct

d) Pour aller (par le chemin le plus court) de la voie A à l'Arrêt de Tram, je n'emprunte aucune structure. Correct

3.1) S-ED : Pour répondre, utilisez le système de l'horloge pour indiquer la direction à partir de votre position (à midi, à 6h, à 3h, à 9h, à 10h, etc.)

a) Imaginez-vous dans le Hall 1 Niveau 0 et vous regardez vers NN. Dans quelle direction se trouve le Hall 2 Niveau 0 par rapport au Hall 1 Niveau 0 ?

b) Imaginez-vous à l'Acces Plus et vous regardez vers NN. Dans quelle direction se trouvent les quais A, B et C par rapport à l'Acces Plus ?

c) Imaginez-vous à l'Arrêt de Tram et vous regardez vers NN. Dans quelle direction se trouve le dépôt Taxi par rapport à l'Arrêt de Tram ?

d) Imaginez-vous à l'Accueil et vous regardez vers NN. Dans quelle direction se trouve le tram par rapport à l'Accueil ?

3.2) S-ED : A vol d'oiseau (c'est-à-dire sans marcher, mais en faisant comme si vous pouviez aller en ligne droite par les airs comme un oiseau), lequel de ces deux trajets est le plus long ?

a) Arrêt de tram - Hall 1 Niveau 0 ou Arrêt de Tram Belcier

b) Dépôt Taxi - Quai A ou Dépôt Taxi - Quai 5

c) Accueil - WC ou Accueil - Accès plus

d) Parking Hall 1 Niveau 0 - Quai 2A ou Parking Hall 1 Niveau 0 - Quai 4A

Appendix 3

MeCue : entretien semi-dirigé avec les élèves déficients visuels

Module	Dimension	Question
Perception du produit	utilité	• Est-ce que la maquette a été utile pour comprendre l'organisation de la gare Saint Jean / l'architecture de la gare ? (Pourquoi ?) • Est-ce que le fait que la maquette puisse faire des sons est utile ? (Pourquoi ?) • Pour quelle(s) autres(s) activité(s)/ structure(s) penses-tu qu'une maquette interactive serait plus utile qu'une carte 2D à relief (ou une DERi si l'élève en a déjà utilisé) ? (jeux, travail scolaire, à la maison, en centre…) • Question inverse : Dans quels moments/situations penses-tu qu'une carte 2D à relief (sans les sons) serait plus utile qu'une maquette 3D ?
	utilisabilité	• Est-ce que la maquette a été facile à utiliser ? Dès le début ? • Quelles sont les choses que tu as trouvées difficiles lors de l'utilisation de la maquette ?

	esthétisme	• Est-ce que la maquette a été agréable au toucher ? • Est-ce que tu as aimé le fait que la maquette soit en plusieurs couleur ?
	<u>Statut</u>	• Est-ce que tu serais plutôt content ou plutôt gêné d'utiliser la maquette 3D interactive avec tes copains ou tes camarades de classe ? A ton avis, que pensent-ils de la maquette ?
II émotions	Emotions positives	• Est-ce que tu t'es senti content d'utiliser la maquette 3D ?
	Emotions négatives	• Est-ce que tu t'es senti énervé, agacé, ennuyé ou fatigué d'utiliser la maquette 3D ?
III conséquences sur l'usage	<u>Fidélité</u>	• Est-ce que si tu avais la possibilité d'utiliser d'autres outils (une carte 2D, une maquette 3D non interactive, etc..) pour apprendre la structure de la gare tu choisirais une maquette 3D interactive ? • Si tu avais la possibilité de choisir l'outil pour apprendre la structure de la gare, tu choisirais quoi ?
	Intention d'usage	• Est-ce que si c'était possible, tu aimerais avoir des maquettes 3D interactive d'autres bâtiments ? Si oui, lesquels et pourquoi ? Si non, pourquoi ? • Est-ce qu'il y a des cas où la maquette 3D te paraît vraiment intéressante et Pourquoi ? Et des cas où elle ne te parait pas du tout nécessaire et pourquoi ?

IV Evaluation globale		• Est-ce qu'il y a des choses qui t'ont gêné pendant que tu utilisais la maquette ? Lesquelles et pourquoi ? • Est-ce qu'il y a des choses que tu aimerais changer sur la maquette ? Lesquelles et pourquoi ? • Est-ce que la maquette t'a permis de mieux comprendre l'organisation des bâtiments à étage ? • As-tu trouvé la maquette plutôt bonne ou mauvaise ? Globalement, quelle note lui donnerais-tu sur 10 ?