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3D audio maps and models for people with severe visual impairment

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3D printing is a modern approach to aids that can make spatial representations more accessible to people with severe visual impairments, refine their perceptions of the space around them, create an idea of things that are difficult to palpate, etc. At Palacký University in Olomouc we started research on this topic in 2008 and we are still not finished. This article summarizes more than fifteen years of work in this area and presents the results of each research period. The largest part of the article is then devoted to the possibilities of linking 3D models, maps and plans with the audio output provided by an application on a tablet or mobile phone.

Schlagworte: 3D Printing; TouchIt3D technology; tactile map; people with visual impairment; audio tactile output; 3D maps; 3D plans
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Introduction

3D printing is currently experiencing great development in the Czech Republic. The purchase costs of printers are not high and the investment in 3D models is worthwhile about durability, health safety and slipperiness of the model surface. This meets the requirements for aids that can be used both in education and in leisure activities of people with severe visual impairment.

The history of 3D models and objects that can be perceived by touch can be traced back to antiquity, even though they were not originally intended for people with severe visual impairment. At that time, statues were carved in wood, carved in stone, and later made of iron or ceramics. The same was true for font, which always worked with what was available to the company – e. g. knotted font, carving letters in wood, or later extruding them with metal dies etc. 3D models have been around for a relatively long time, the first ones being carved in wood, carved in stone, cast in iron or bronze, or glued together in paper for the home environment. All the options were primarily used (also due to the cost and time required to produce them) for mainstream society. The production of models and plans that were intended for people with severe visual impairment was concentrated in schools and very often in the field of geography and spatial orientation and independent movement. It is only with the advent of the capability of current 3D printers and large format 3D printers that models are being prepared specifically for the needs of people with severe visual impairment and this is being reflected in the teaching of more subjects or even leisure activities.

At Palacký University in Olomouc, the Department of Special Education (now the Insti tute of Special Pedagogical Studies) and the Department of Geoinformatics began their research in the field of 3D models and maps as early as 2008 (Project of the Grant Agency of the Czech Republic 406/08/1031 for 2008–2010 – Perception of geospatial space through modern tactile maps). At that time, it was about the creation of 3D maps created with the help of a 3D printer, which used a printer (at that time one of two existing in the Czech Republic) of the Danish company Contex. The printer created a 3D object print from a computer three-dimensional model (processed in GIS) not by "turning", but by printing in 0.1 mm layers based on gypsum powder and binder, which can also be differenti ated in colour by the technology of traditional inkjet printers. The maps thus produced were the beginning of our research, but also the beginning of 3D maps that were to be made available to institutions.

From 2018 to 2023, two projects supported by the Czech Technology Agency (TL01000507 – Development of independent movement through tactile-assistive devices were carried out by slightly modified teams of researchers at the above-mentioned workplaces, TL030000679 – Reduction of information deficit and development of imagination of people with visual impairment through 3D models with auditory elements), which focused on linking 3D plans of selected sites

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and models of historical and religious monuments in the Czech Republic with sound via tablet and mobile phone. The aim of both projects was to motivate people with visual impairments to explore the space, repeat the route, familiarise themselves with their surroundings etc.

Technology

To sound the plans that were created first, the TouchIt3D technology was used, which was developed at the Faculty of Science of Palacký University and consists in printing a map, plan or model with conductive and non-conductive material on 3D printers (in this project Ultimaker 3). The sounding of the resulting plan was then provided by means of a tablet and the newly developed TactileMapTalk application.

In the second project, which was developed based on the experience with the plans and their testing, we already focused on the sounding of individual, interesting parts of the 3D models. The technology was the same, but a new application was developed – Tactile Explore Talk, which, compared to a tablet, sounded a mobile phone. The mobile phone was chosen to make the model portable and easier to handle.

Both applications then work thanks to the fact that each raised point on the plan or model corresponds to a point at the bottom of the plan and model, which presses on the tablet or mobile phone and pressing its top part activates the device screen and thus activates the audio track assigned to that point.

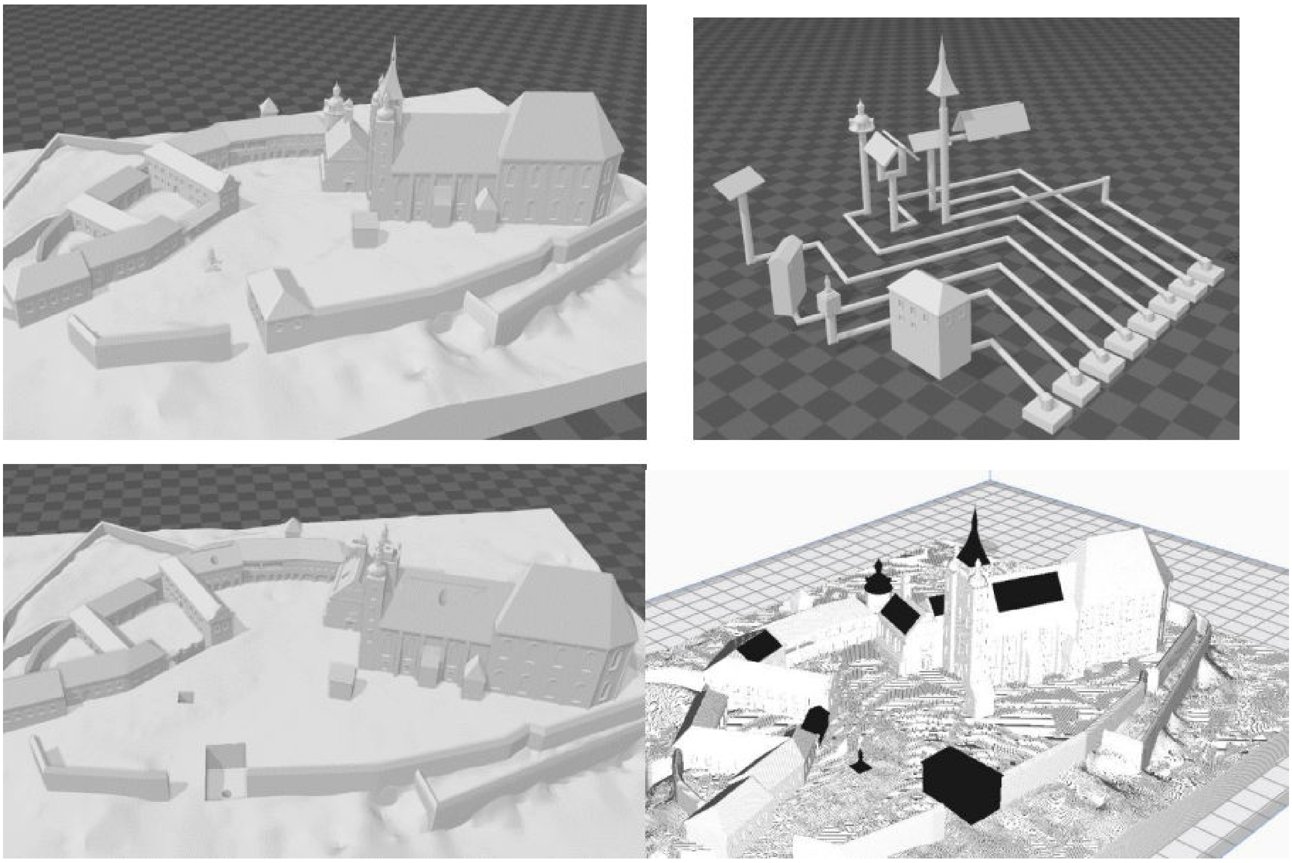

Figure 1: Example of programming a track for the model sound system (authors' archive)
(Beschreibung siehe Abbildungs- und Tabellenverzeichnis mit Alternativtexten)

Tactile Explore Talk (also the original TactileMap Talk) is a mobile application for the Android operating system primarily designed for mobile phones and tablets with capacitive touchscreens as a platform implementing the interactivity of TouchIt3D 3D printed models for people with severe visual impairments and the blind. However, its applicability is much broader, and it can be used simultaneously as a platform for any interactive aids with electrically conductive segments. Thanks to its modern architecture and configurability, it allows efficient preparation of the bases, called schematics, for a wide range of models and easy operation by a wide range of users. Innovative features include an integrated schematic editor with the ability to define and modify soft buttons that function in a view mode for activation by conductive model elements and presentation of content.

Projects Presentation

The project *Developing independent movement through tactile-auditive means* focused on the creation of tactile plans/maps. The first tactile maps were created for three expertly determined locations in 4 cities in the Czech Republic. The tactile maps were produced in dimensions corresponding to mobile devices (tablets), i. e. in the size of 208 × 130 mm with a scale as detailed as possible to capture the desired area. The map modelling process was carried out in SketchUp 8. The maps were continuously tested, and new prototypes of the tactile maps were continuously created based on the acquired knowledge, which were used for user testing and are used for working with the target group during the training of movement in space. In the second generation of tactile maps, for example, the signs for sidewalks and streets were extended to a minimum width of 5 mm, and instead of different layouts of interactive signs, the categories of marked points of interest were differentiated by the style of the surface shape of these signs (tip, inclined, flat).

Figure 2: Detail of interactive (left) and non-interactive tactile map (authors' archive)
(Beschreibung siehe Abbildungs- und Tabellenverzeichnis mit Alternativtexten)

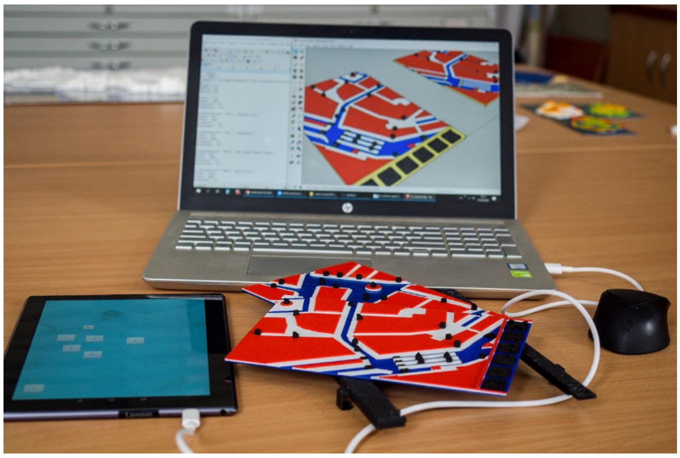

Figure 3: Tactile map modelling and compilation of the mobile application (authors' archive)
(Beschreibung siehe Abbildungs- und Tabellenverzeichnis mit Alternativtexten)

User testing with representatives of the target group is necessary for the verification of any proposed procedures. The aim of the testing throughout the project was to gain insights into the proposed didactic practices and the design of appropriate teaching materials, as well as insights into the proposed technologies and the associated templates, layers and appearance of maps and plans. The user testing was divided into several logical successive stages. User testing was conducted with both primary school pu-

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pils and adults. In the first phase, only templates and maps representing the different thematic layers were tested, the aim being to adapt to the needs of the users without having to work with a completely new concept of audio-tactile maps. The results of the user testing were favourable, and all the findings were incorporated into the map creation process. For example, the colour scheme was adjusted, the appearance of the characters was otherwise satisfactory to most respondents with individual reservations. Immediately after this testing phase, the TouchIt3D map testing phase followed with the incorporation of minor adjustments. For each of the selected test sites, interactive map features were modelled in the map. These include a graphic scale indicating a length of 50 m (height 4.5 mm from the base, line width 5 mm), pedestrian crossings (at a height corresponding to the base layer of pavements and streets, i. e. 2 mm or 1 mm high), start and end points of the crossing (circle 10 mm diameter, height 5.5 mm) and public transport stops (square with edge length 8 mm, height 5.5 mm). The findings from the second phase of testing were evaluated and incorporated into the design of the final tactile maps. After considering the results from the first phase of testing, the colour scheme was changed to blue-white-red to suit more respondents. Different features were also tested in terms of their vertical shape design (tip, sloping surface, horizontal surface), correct conductivity (touch point actuation), user friendliness and user evaluation within the Map Use concept. Testing results included, for example, defining a new parameter setting for the width of the pavements to a minimum of 5 mm for proper tangibility and understanding of the presented layer. The app can be installed on any Android device, but the size of the maps should be adapted to the size of the display. This proved to be crucial, although a minority of respondents commented on this issue in the first phase of testing. As testing progressed, the final designs were then tested with comments incorporated. Here it was confirmed that the changes made led to better working of the respondents with the tested maps. During the testing, it was very useful to gradually introduce the user to the concept of the map, to the individual "layer maps" and only afterwards to the TouchIt3D map, where the user already knew which points would be touched and that he should expect an audio response. From an educational perspective, multiple modes for a single map were a proven concept proposed in the second half of 2019 and this functionality was fully implemented and tested in 2020. In terms of using audio-tactile map content, the plan for multiple ways to trigger the audio track (tapping, long hold etc.) was dropped based on user testing. Only one long hold uniformly for the whole map proved to be more appropriate, which was easily understood by users.

The testing clearly showed that a slight difference in surface texture is not enough and, with respect to the printing technology, the texture of the individual layers is not very desirable. It was also found that all conductive parts of the map must be raised and ideally with their own characteristic features (shape of the character), otherwise the user finds them very clumsily on the map and the audio tracks are triggered by touch when viewing the map without the user wanting them to be. Whether users have previous experience with (tactile) maps or with modern technology proved to be a very important aspect. It is therefore best to introduce users to these modern methods already during their training.

The aim of the project *Reduction of information deficit and development of imagination of people with visual impairment through 3D models with auditory elements* was to reduce the information deficit caused by the loss or limitation of visual perception in people with visual impairment and at the same time to develop their spatial imagination through the creation and practical implementation of 3D audio-tactile models of selected historical and religious monuments. The results of the project published here have been published in Tactile Maps – Tactile Models – Aids for people with visual impairment: developing the imagination of people with visual impairment through 3D models with auditory elements. (Kolektiv autorů 2023)

One of the aims of the project was to capture the most important architectural and religious monuments in the Czech Republic. To achieve the most even distribution, one monument was selected from each region of the Czech Republic and the capital city of Prague. The uniqueness of a given monument, its historical significance, the possibility of its modelling and 3D printing were then considered in the selection process. At the same time, the aim was to maintain diversity across the entire sample in all respects so that no two very similar monuments, albeit from different locations, were selected. This resulted in the following list of monuments. The selection of the monuments involved the project researchers, the historian and then the application guarantors themselves (a primary and secondary school for pupils and students with visual impairments and Kafira – an organisation providing its services to people with visual impairments up to the age of 8).

From the special education point of view, the main objective of the research was to find out the extent of information deficit in people with visual impairment in the context of the problem addressed and how to create the best possible teaching kit for multisensory exposure using modern available technologies. The research was carried out in the framework of several user trials, where the content was mainly aimed at verifying the findings from previous research and, of course, at further evaluating the effectiveness of information deficit reduction using the different levels of the presented models. From a methodological point of view, the final part of the research dealt with the design of the project results to make the most of the potential of the knowledge gained during the project implementation. The user testing included intensive use of the Tactile–graphic set of educational materials for selected monuments of the Czech Republic (hereinafter referred to as the "set of educational materials"). The set of educational materials includes the Guide for the Blind to selected monuments of the Czech Republic, which includes maps printed tactilely using the thermal printing method (the so-called "guide for the blind"), 2D materials and 3D spatial plastic models printed with 3D printers using TouchIt3D technology, i. e. with the possibility of connecting selected 3D models to smart devices and a specialised software application. Based on user testing during 2023, the content of the Guide has been further adapted to the needs of the target group of users. Similarly, the audio-tactile models were finalised and the software that makes the models interactive in combination with smart devices was finalised. Based on user testing and consultation with experts from the application guarantors' offices, the set of educational materials was enriched with "non-conductive" models, which are much simpler and more accessible in terms of production and use and were extremely helpful for the test subjects to recall memories and information about the project presented. Simply put, when the user worked with the interactive model for a period, the non-interactive model then helped them to recall the knowledge they had gained, while reinforcing the respondents' perception of the real spatial layout of the monument.

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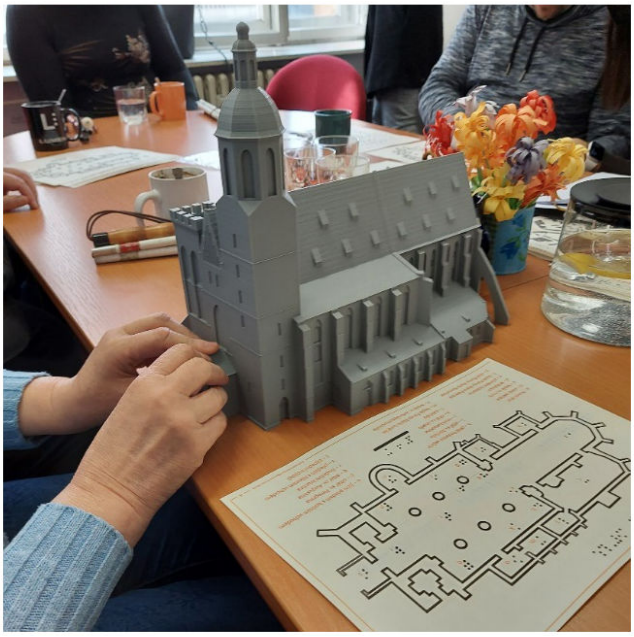

Figure 4: Sample of testing (authors' archive)
(Beschreibung siehe Abbildungs- und Tabellenverzeichnis mit Alternativtexten)

All outputs from the projects can be found on the website: https://hmatovemapy.upol.cz/en/homepage/.

Results of testing in both projects are summarised

The first project focused on spatial orientation through pre-selected locations that were designed primarily for adults. In the course of the testing, which took a year and a half and during which changes were made to both the maps and especially to the software, approximately 20 adults with visual impairment from the Czech Republic and subsequently about 6 from Slovakia participated in the testing. This number might seem low in the context of the number of people with severe visual impairment in the Czech Republic, but it was necessary to test the functionality of the maps, their connection to the tablet and especially their effectiveness in achieving the goal. The aim was mainly to display the route, practice it and then possibly repeat the route in a specific location. And in the context of the fact that each route implied the need for just that particular practice, fixation and eventual repetition of the route, this number is sufficient, therefore, to be able to pronounce valid conclusions below. In addition to the respondents with severe visual impairment themselves, their trainers in spatial orientation and independent movement, as well as experts in cartography for people with visual impairment (15 people) also took part in the comments. During the testing it was proven that the standards for graphic representation valid in the Czech Republic so far cannot be used for the representation of maps and plans printed on 3D printers. For these it is important first of all the scale allowed by the printer itself, then the simplification of the map to leave important landmarks and areas to be touched at a given scale. Although initially the colours seemed important only to us instructors and researchers, this premise proved wrong – people with residual vision demanded the contrasts and our colours changed (red for buildings, blue for roads and yellow for sidewalks).

Testing in the second project has already involved a larger number of respondents, especially in terms of breadth of age – 22 pupils and students took part in testing the models in their primary form and then voiced over two years, and these were joined by 10 adults. In addition to the people with severe visual impairment themselves, teachers of the pupils and spatial orientation instructors of adults with visual impairment were again involved in the development. There were 12 of these persons in the project. User testing then took place over two years, through service users and student application sponsors. During this period, respondents ranging from third grade elementary school to seniors of varying ages participated in the testing. Testing for both pupils, students and adults with visual impairment followed the same pattern. The testing of the models and the subsequent changes in the perceptions of people with visual impairments took place in certain stages, which gradually built on each other and were directed towards the goal, which was not only the creation of a 3D audio-tactile model, but also a change in the creation of the perception of space and spatial relationships within the monument. The testing also included the possibility of visiting the monument directly in the given location. The sites were selected according to several criteria, the most important of which were the accessibility of the monument for one of the groups of respondents, the accessibility of the monument, the interest of the monument or the site, and the interest of the respondents. We then visited one of the monuments repeatedly, as the approach of its administrators was exemplary, and it was important for us that all groups of respondents visited the monument. Ideas about the monument and its location in space were what we tried to influence with our models. Whether and how a given idea was influ enced by the model, or by visiting the site in combination with the 3D model and the 3D audio-tactile model, was explored in the way outlined above. The set of 3D models, and later the 3D audio-tactile models, were used in two modes, without visiting the monument and with visiting the monument, each of which was therefore influenced by different variables.

Testing a set of 3D models and 3D audio-tactile models without visiting the monument.

- The models were created to meet the needs of schools and social service settings for adults with visual impairments, as was the 3D school toolkit discussed below.
- For both pupils and adults with visual impairments, it was the models and plans on thermoactivated paper that were used to create ideas. However, their combination was necessary; it turned out that it was relatively unimportant in which order the two sets of materials were given to the respondents, but they had to be given together. In some of the testing, it occurred that before we presented the 3D model, it had already been requested (similarly, if the respondent got hold of the model first, maps or plans were requested).
- Some participants came to testing well prepared with knowledge of a particular monument and even its historical context. However, their idea of the space around this unknown monument was very limited in terms of scale and location. However, after working with the test set, significant changes occurred. Persons with visual impairments, regardless of age range, became able to navigate well on a map of the country and the city’s locations. Likewise, they were able to identify the described monument among other monuments based on the characteristics discussed and provided.
- Pupils and students usually discussed the monument with teachers first, which was the opposite situation for adults, who had to show interest on their own. This led to a marked change in how quickly participants were able to orient themselves when they first encountered the monument. Here it happened that the students were faster than the adults, who needed time to orient themselves both to the information and to become familiar with the models. – It turned out that, even though the respondents had not visited the monument, they were able to visualize the monument thanks to the chosen combination of verbal description, the respondents’ experience and the 3D audio-tactile models and materials from the Guidebook, to the extent that they were able not only to describe it verbally,

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but above all to show it on the map after wards and to show the desired places (tower, stairs, courtyard etc.) on the model.

Testing a set of 3D models and 3D audio-tactile models with a visit to the monument.

- We had the opportunity to visit some of the monuments. The selection of these monuments was based on location, suitability, but also substitutability with other monuments. The selection at these sites was purposely chosen to have an even greater impact on the imagination and fantasy of people with visual impairments.
- It was the visit to the monument that showed us that even if the process of familiarisation with the monument remains the same, visiting the monument with a model or plan in hand will refine the idea and move it more quickly in the desired direction.
- By visiting the sites in person, it was noted that respondents were better able to imagine the surroundings and the setting of the monuments in space. This, together with the 3D models and the interpretation of the guides, greatly helped to improve spatial imagination.
- Last but not least, we have to highlight the fact that the familiarisation of the monument also through the 3D audio-tactile model was not only motivating, but above all more appealing, so much so that the model continued to serve both in refining the monument and in repeating the familiarity of the space after leaving the monument.

In the research carried out, it was found that working with modern educational materials, which was the focus of the project, reduced the information deficit both in the creation of spatial imagery and in their equipment and involvement in the practical life of people with severe visual impairment of a wide age spectrum.

Although both projects have been successfully completed, the maps, plans, models and applications are continuously tested and subsequently updated thanks to opportunities for presentations at conferences and exhibitions. In this way, we have increased the number of respondents for children by about 25 (as expressed by schools) and about 35 adults (as estimated by visually impaired people at conferences).

Conclusion

3D printing is now widespread. 3D printing is now relatively inexpensive. 3D printing is breaking boundaries. 3D printing has a future in the education of the visually impaired. 3D printing brings modern compensatory aids. 3D printing is interesting. If we let these few statements die down, we can see that 3D printing for people with visual impairments will not only be used in the areas of spatial orientation or geography. 3D printing, as similar projects in Germany also show, is applicable in every school environment. An interesting and certainly also one of the possibilities is to use it also in the context of teaching style/creative writing in the mother tongue. Here, the models can be used to do exactly what we mentioned in the introduction – to create one's own ideas, to consolidate them and thus to develop the imagination of people with severe visual impairment. This imagination, which is not influenced by the emotional colouring of the communicator/guide, can then be passed on in the person's own words, and this brings us to the goal of any action – the independence of the visually impaired person. If the 3D printing is then accompanied by sound, or for the visually impaired by colour, we get to increase the motivation to touch, or possibly even the motivation to explore or create such an aid.

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