

Possibilities of perceiving space and developing ideas about it through 3D audio-tactile models

(scientific paper)

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Abstract: *The following article aims to present partial outputs of the project TAČR (TL03000679) – Reduction of information deficit and development of the imagination of people with visual impairment through 3D models with auditory elements. The project is currently in the final part of its solution. This paper will not only present the project goals but mainly focus on the outputs and partial results achieved so far. The paper will focus not only on 3D printing but mainly on the outcomes aimed at developing the spatial imagination of people with severe visual impairment.*

Keywords: *people with visual impairment, 3D models, historical monuments, modelling*

1 Introduction

The following article summarizes the interim results of the TAČR project (TL03000679) – Reduction of information deficit and development of the imagination of people with visual impairment through 3D models with auditory elements. The project aims is 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 use of multisensory action. The goal is to be achieved through the creation and practical implementation of 3D audio-tactile models of historical and religious monuments. Based on educational and research work with them, it will be investigated how and whether information deficits in spatial imagination can be reduced in a wide range of respondents.

The implementation team consists of the members of the research team – members of the departments (Department of Geoinformatics at the Faculty of Science and the Department of Christian Education at the Sts Cyril and Methodius Faculty of Theology) and institutes (Institute of Special Education Studies at the Faculty of

Education) of Palacký University in Olomouc (Czech Republic) (and external experts from practice – historians, educators, and students. Such interconnection leads not only to an increase in the expertise of the whole team but above all to a broadening of the range of expertise, which is then promoted through workshops and online and face-to-face consultations into the key activities of the project.

The application partners of the project are the Grammar School for the Visually Impaired and the Secondary Vocational School for the Visually Impaired, the Kafira organization, and the Primary School for Pupils with Visual Impairment. All of the above-mentioned organizations have been providing their services – not only educational – to people with visual impairments for a long time. The facilities were selected with regard to the age group of their service users and pupils, but also, above all, with regard to the long-term quality of professional outputs towards the target group.

At the beginning of the project, extensive professional research was carried out in several areas – the RVP for primary and secondary schools and the curriculum for schools for pupils with visual impairment and architectural models of buildings in the Czech Republic and abroad. The first area of research provided us with answers to the questions which teaching subjects in primary and secondary schools our research can bring innovation to through haptic models, 3D haptic-acoustic models of historical and religious monuments. The second helped us to map the very low uptake of haptic models globally. At the moment, we can therefore conclude that due to the technology we intend to use and the complexity of the resources we are presenting, our outputs will be unique and, above all, comprehensive.

2 Site selection as part of the project solution

As part of the project, we have committed to creating at least 14 models of historical and religious monuments, in which locations a methodological investigation will be carried out to obtain information leading to further opportunities for the development of spatial imagination of people with severe visual impairment.

The sites were selected so that there would be at least one historical and religious monument in each region. The pre-selection was made by a historian based on the significance of the sites. The list was then passed on to the research team, who made a shortlist – taking into account the possibilities of modelling and 3D printing, and the whole implementation team made a final deliberate selection in an online workshop meeting. Representatives of all project partners commented on each monument and made a selection so that the monument and its historical, ecclesiastical, or cultural value could be further implemented in the pupils' learning.

The final list of monuments includes the following sites:

1. Moravian-Silesian Region – Church of the Assumption of the Virgin Mary in Opava
2. Olomouc Region – St. Morice Church (Olomouc), St. Wenceslas Hill (Olomouc)
3. Zlín Region – Buchlov Castle
4. South Moravian Region – Villa Tugendhat
5. Vysočina Region – Žďár nad Sázavou – Church of St. John of Nepomuk
6. Pardubice Region – Litomyšl Chateau
7. Hradec Králové Region – Kost Castle
8. Liberec Region – Trosky Castle
9. Ústí Region – Ploskovice Castle
10. Karlovy Vary Region – Chebská falc – fortified palace
11. Pilsen Region – Plzeň – St. Bartholomew's Cathedral
12. South Bohemia Region – Holašovice
13. Central Bohemia Region – Karlštejn Castle
14. Prague – Charles Bridge in detail + 3D map Klementinum, National Theatre

All these monuments were modelled and printed on both a P.I.A.F. thermal printer and a 3D printer and served as one of the main means of research.

3 Editing, modelling and printing of 3D models

A variety of materials were used to prepare virtual 3D models of historical and religious monuments, which were subsequently used in the creation of interactive physical aids for people with visual impairments. Since many of these monuments are not accurately spatially documented or their plans are difficult or impossible to access, publicly available data sources, floor plans, maps, photographs or other visualizations were used. The usefulness of primary GIS data in the form of digital elevation and surface models was also assessed. In the case of the land surface, these datasets were used, but for the representation of buildings and man-made objects, their detail was found to be a problem with respect to haptic response and model size. The order in which the 3D models were created was determined based on the availability of the underlying data, which was collected sequentially. The models were created in the modelling software SketchUp. 8. At the same time, the modelling had to take into account the specifics that are typical for individual buildings from different periods. For those buildings that allowed it in terms of scale, more emphasis was placed on capturing the characteristic elements of architectural styles. For larger complexes, on the other hand, it was crucial to convey an idea of their size through models. The modelling also took into account non-technological aspects in the form of specificities that are crucial for the target user group of blind and visually impaired people.

These include the absence of sharp edges that could potentially cause injury to users when handling the physical model. Thus, various open-source Blender tools were also used to smooth the Earth's surface. Furthermore, it was necessary to ensure that the models created were resistant to re-touching. Detailed or thin structures were therefore thickened or omitted. The specifics of 3D printing as a subsequent production method also had to be taken into account during modelling. When using a dual-extrusion printer, one of the nozzles is dedicated to a conductive material allowing the subsequent use of TouchIt3D technology to complement the audio-tactile interaction, while the other nozzle is dedicated to a non-conductive plastic string. There is no free nozzle left for any support material, so they must be designed to be completely self-supporting during the manufacturing process. At the same time, considerable effort had to be devoted to topological cleanliness and correction of geometric continuities on the model so that the model could subsequently be divided into conductive and non-conductive TouchIt3D elements. From the perspective of special education for people with visual impairment, the appropriate abstraction rates and levels of rendering (modelling) detail on the presented models were subsequently investigated with respect to the capabilities and needs of the target user group.

Printing of the models within the project was carried out on several printers. The printers were Ultimaker 3, Stratasys F170, CraftBot IDEX XL and Prusa MK3S. The individual printers were always chosen with regard to the detail required and the resulting size of the model. A very important parameter to keep track of was the resulting interactivity of the model. Testing of the different types of materials was carried out during the implementation. A number of parameters were considered with regard to the intended use of the models:

- the relationship between materials and the quality of the resulting 3D model,
- details at specific layer heights,
- material compatibility with conductive PLA material (Proto-pasta),
- construction of large models,
- mechanical durability,
- drop resistance,
- susceptibility to breakage of fine details.

After tests with PETG, ABS, ASA, PLA, Polymaker PolyMax PLA was chosen as the starting material. It is a material with improved mechanical properties thanks to Polymaker Nano Reinforcement technology.

Different possibilities of realization of multimedia content of 3D models were tested to best meet the needs of the target group of users (viewing model, tutorial mode, working with the model in the field). The TouchIt3D technology, developed at Palacký University in Olomouc, applies to all 3D printing processes where it is

possible to 3D print by combining two or more materials, at least one of which is a conductive material, or where it is possible to create two independently printed models that are subsequently combined into one functional unit. The resulting models can be primarily thermoplastics (e.g., ABS, PLA, PETG), but other materials can also be used. The use of the created objects is very wide, they can serve for example to control smartphones, tablets, electronic book readers, navigation, remote controls, automotive displays or to control displays in industrial deployment. Primarily, it is the creation of spatial 3D models used for presentation and navigation, for example in shopping malls, hospitals, administrative buildings, which can become interactive when placed on a capacitive display. The technology is particularly suitable for teaching children and adults, games, conveying information and knowledge to the visually impaired, blind, or otherwise disabled, space presentation, and navigation. A crucial application is the use of the technology in the creation of interactive tactile maps. 3D audio-tactile maps represent an important facilitating element in the development of spatial imagination and the consolidation of spatial orientation skills of people with visual impairments. Its development is a key prerequisite for promoting the independence and personal self-sufficiency of 3D audio-tactile map users. For the successful implementation of this modern technological phenomenon, it is essential to follow a basic methodological hierarchy of the procedure. In order to implement a set of educational materials, a special technological procedure for the use of TouchIt3D technology for 3D models of monuments had to be developed. The technology uses a specially developed software tool TactileMapTalk, which was functionally extended and adapted to the required aspects of use in the presentation of 3D models of monuments for the needs of this project and the set of educational materials.

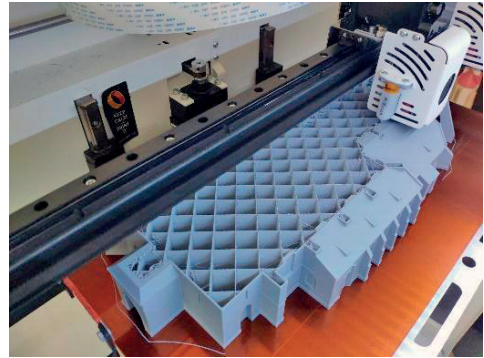
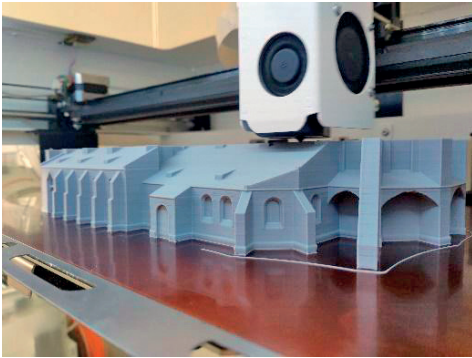
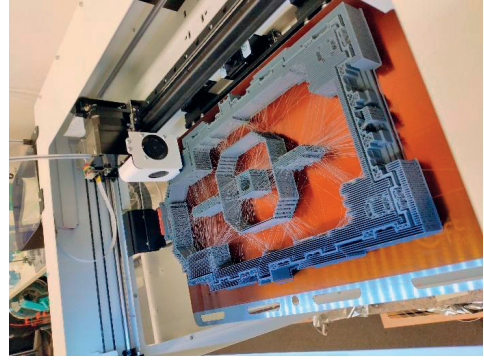
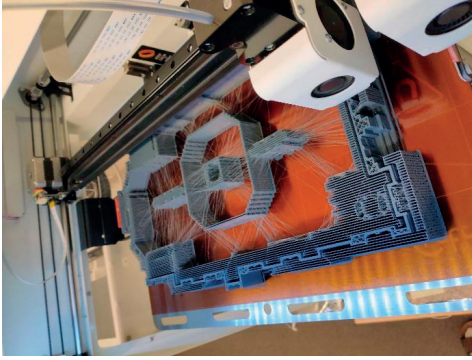


Figure 1a–1f: 3D Printing of the Monument

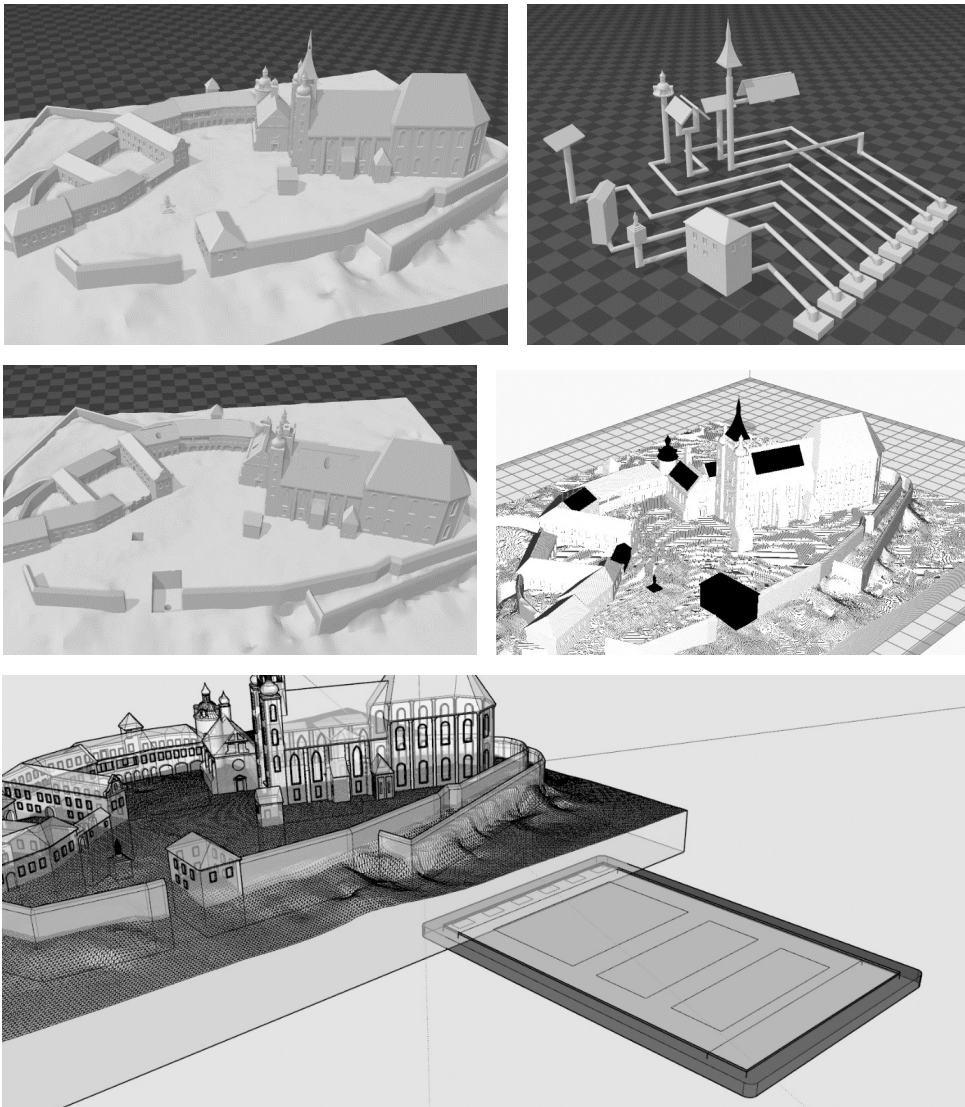


Figure 2a–2e: *Demonstration of modelling a 3D object and adapting it to a mobile phone application*

The course of the research and partial conclusions of the investigation

Different options for the multimedia content of the 3D models were tested to best suit the needs of the target user group (viewing the model, tutorial mode and working with the model in the field). The field testing is being carried out by all application partners of the project in proven successive stages, which are concluded with

a questionnaire for respondents and observers at the beginning and end, the final evaluation of which will be completed in September 2023, but we can already specify partial results.

Stages of the survey: work with 2D materials (this is the stable name for materials printed on ZyFuser thermal paper, which then include a map of the Czech Republic showing the location of the monument, the location of the monument in the surrounding terrain, a 2D plan of the object) → 3D model → verbal presentation of the monument (historical and geographical information about the object) → 3D multimedia model → visit the object (2D and 3D models still available) → 3D model and 3D multimedia model.

Partial conclusions of the investigation

1. Our set stages of investigation are valid and welcomed by the respondents.
2. The models and plans must be kept with us during the testing at the monument located in order to anchor ideas about space and spatial relationships, or to re-establish them.
3. People with disabilities need to be influenced not only tactilely, but also aurally and “locally” at the same time – describing and letting them feel in the moment.
4. People who are later blinded have a poorer orientation to plans and need models to create even basic ideas.
5. Primary school pupils with visual impairment appreciate the opportunity to link the idea of space to the plan and 3D multimedia aid – it is something new for them.
6. The 3D multimedia model needs to be set up to complement the information that has already been communicated, otherwise, it needs to be used as a 3D model first.
7. In testing, it became apparent that if the term is not known, there is no linking of the idea of the overall space, even if it is only a partial naming of a part of the object – especially for pupils there is the need to avoid verbalism and to give space for learning a new “concept” by explaining verbal explanation, as well as by demonstration on the model and then in the site (e.g. vestry, courtyard, “three-aisle church”, etc.).
8. Well-guided excursion with the possibility of supplementing the verbal information with the tactile, olfactory, and locomotor effect of the monument leads to a quicker creation of an idea of the object, and its location in the terrain and also faster orientation afterward on the plan or model.
9. 3D multimedia model and its use in the conclusion – i.e. anchoring information about the object leads to a quicker internalisation of the idea of the object and its quicker equipping (both of the object itself, its parts, and the location where it is located).



Figure 3a–3b: Photos from on-site testing of 3D models

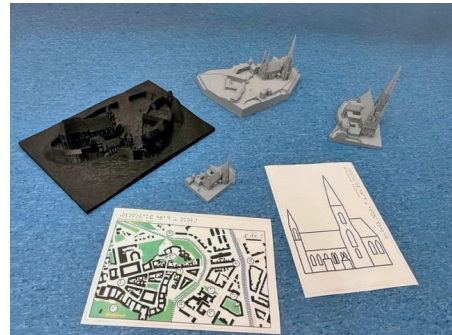


Figure 4a–4b: Sample test set of some monuments

4 Conclusion

The final stage of the project is currently underway, with models being printed according to the requirements resulting from testing with users with visual impairment. However, our project has already fulfilled several key activities (organizing a workshop, publishing a functional sample), and even surpassed some of them (publishing a guide to the monuments), while there are still more to come, among which are

mainly those resulting from the requests of the application partners themselves – adding a glossary of terms to the functional samples, publishing a monograph, organizing a conference, etc.

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