An innovative Braille alphabet teaching tool for visually impaired individuals based on advanced tactile embossed 3D graphics

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Abstract

In this paper, tactile tiles for teaching Braille alphabet were created using three different 3D printing techniques. This research was conducted in relation to the target population and their specific need, with expert co-operation, as well regarding the possibilities of devices that may be used for creation of 3D plates for achieving optimal results. Recent developments in 3D printing technology enable researchers to experiment with new approaches towards the creation of new tools for teaching the Braille alphabet. It is important to examine the Braille lettering standards, capabilities of 3D printers and, in cooperation with experts who work with the visually impaired, discuss the design and functionality of the created tiles. In this research, a set of 3D printed tiles has been created, each divided into three main parts. The first part of the tile shows a basic Braille letter. This is followed by a corresponding embossed model of an object that correlates to the first letter of the word. The third section consists of the entire word corresponding to the embossed model at the bottom of the tile in Braille writing. Tiles are standardized by size and part position for corresponding letters of the alphabet and words describing the embossed model. It has been proven that the developed tiles are an appreciable additional tool for visually impaired individuals, as was affirmed through surveys. Several iterations of tiles have been printed with multiple 3D printers, with the purpose of determining optimal settings required for producing the best possible product prototype.

Keywords: Braille, tiles, 3D printing, visual impairment, technology.

1. Introduction

Recent developments in the field of 3D printing technology provide researchers with an opportunity to combine their skillsets from different fields of graphic industry with the purpose of producing new and innovative solutions in the educational tools field. The solution proposed in this research is a teaching tool for Braille alphabet intended for use by teachers in schools for blind and visually impaired children and adults. Visually impaired people can enhance and broaden their experience of their surroundings by auditory, tactile and olfactory stimuli. Numerous researches have been conveyed toward providing a better experience while using graphics and tactile graphics by visually impaired students, as well as successful teaching of the Braille alphabet to sighted adults as shown in research made by Bola et al., [1,2]. One of the methods used in the development of Braille tiles is raised printing and approximating abstract forms of artwork adaptation, in order to provide an enriched experience of different types of two-dimensional artwork. Example of such a tactile adaptation is the painting *Portrait of Empress Elisabeth of Habsburg* [3].

In this presented paper, a process of creating 3D tactile tiles through a three-stage process involving a combination of education, art and technology is described. The chapters that follow provide a detailed insight into the development of these custom tiles, including the initial sketches, 3D modeling, 3D printing, prototyping and testing the user experience of the created tiles. The goal was to find the optimal printing system and filaments, improving the design, and producing the best possible prototype based on suggestions from educational experts. It is asserted that such approach is relevant and adaptable to a variety of regionally-specific requirements (adjusting the alphabet localization and tile images), and for different visually impaired student or other groups, while considering the factor of their prior familiarity with the Braille alphabet. In our research a decision was made to focus on a group of visually impaired children aged 8-10.

2. Methods

The process of designing Braille tiles started with simple sketches. When designing the first 3D prototype, an emphasis was made on determining the correct size of the tiles while keeping in mind the necessity for rational placement of the three aforementioned tile segments. In the first step, three proposed tile sizes were discussed among children and their teacher; large (10x10 cm), medium (8x8 cm) and small (6x6 cm). The large size was discarded because of the lack of necessity for its inherent portions of empty space, while the smaller tiles have been discarded due to the insufficient spacing between tile parts. This ultimately led to the decision of using 8 cm by 8 cm (3.14 in by 3.14 in) as shown in Figure 1. In the upper left corner of the tile a chamfer is positioned in order to provide an easier and faster way for the user to determine the correct tile orientation. The second aspect of the tile is the layout of its elements, which is divided into three sections. The first section consists of the main alphabet letter positioned in the top center of the tile. The letter in question is surrounded with a thin embossed border, with the purpose of easier tile orientation. Second section is an embossed image of a corresponding object (e.g.: b for balloon, c for car, etc.). The third section of the tile is located at its bottom-center and consists of to the entire word representing the above embossed image. The embossed models of the object take up different areas of the tile due to their varying sizes. Empty space is left between sections in order to prevent interferences between section surface locations, which in turn allows the user to correctly recognize and read the main letter and the corresponding word. In addition, Braille alphabet on the tiles is created in accordance with the international norm for embossed Braille on paper, which among other rules, states that height of a dot should be 0.48 mm, the nominal base diameter of the dot shall be 1.44 mm and cell spacing of adjacent dots in one cell shall be 2.340 mm, as well as the distance of corresponding dots in adjacent cells shall be 6.2 mm [4]. After the sketch had been made, the next step in the tile creation was using a computer application for three-dimensional modeling, in this case Autodesk Fusion 360.

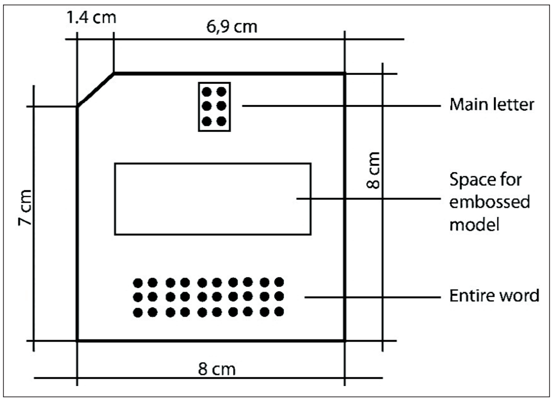

Figure 1. Tile layout

When all characters were included (the Croatian alphabet consists of 30 characters), compatible embossed models representing each letter were modeled in aforementioned program. One of the main issues faced in determining which object would be convenient and appropriate for the word was picking objects that are relatively small, familiar, often found in households, not abstract and not too detailed. Some objects/images used when learning the alphabet among children which are not visually impaired could not be used as examples to be embossed on tiles (e.g. an owl and a parrot are birds, but it is more convenient for visually impaired children not to differentiate types of birds). To determine which objects would be appropriate for visually impaired children, an educational expert was consulted. In Figure 2 a rendered preview of a tile modeled in Autodesk Fusion 360 is presented. This preview shows a tile corresponding to the letter "A", with an embossed model of a tool as well as the word "ALAT" (Croatian word for "tool") written in Braille.

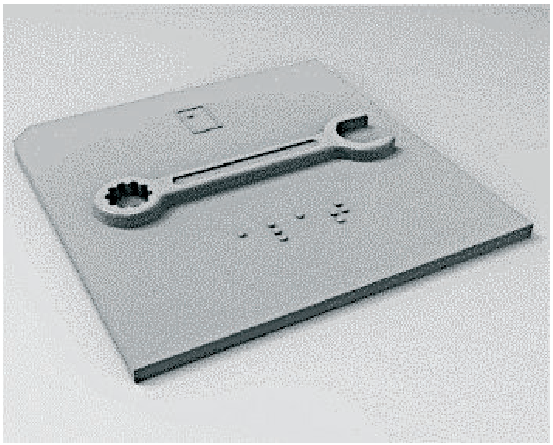

Figure 2. Render of the tile "A" for "ALAT" (Croatian word for tool)

2.1 Printing the prototypes

Three different printers were used for creating the tiles, each of them described in this paper. After the entire alphabet was modeled, a test print was performed on the FDM (fused deposition modeling) 3D printer. Even though this type of printing was invented by a company named Stratasys more than 20 years ago, this printing technology is quite common nowadays and may be utilized mostly for personal and not overly complex projects [5]. It is important to understand how each type of 3D printer used in this research works, in order for the shortcomings of produced tiles to be more understandable and, possibly, for it to be easier to fix possible oversights afterwards. Table with all three 3D printers specifications is shown in Table 1 below.

Table 1. specifications of 3D printers

Type of printer	RapMan 3.1 FDM	Spectrum Z 510	Ultimaker 2+ FDM
Weight	17 kg	204 kg	11.3 kg
Dimensions	650 x 570 x 820 mm	1070 x 790 x 1280 mm	342 x 493 x 588 mm
Print Area	270 x 205 x 210 mm	254 x 356 x 203 mm	223 x 223 x 205 mm
Print speed	15 mm^3/s	2-4 layers/min	30 to 300 mm/s
Layer resolution	0.125 mm	0.089-0.203 mm	0.125 mm
Materials	ABS, PLA	powder	PLA, ABS, CPE, CPE+, PC, Nylon, TPU 95A, and PP
Nozzle temperature	280 °C	/	180 – 260 °C

Working principals of FDM printers are as follows - the printer produces a previously prepared 3D model by extrusion of heated plastic (usually ABS plastic) through a nozzle that deposits the plastic layer by layer onto the surface [6]. The quality that printer system offers, depends on the maximum resolution of the printer measured in microns, which are used to define thickness of one 3D printed layer of plastic (i.e. 20 microns equals 0.02 mm equals 0.0007874016 inches). This implies that printers capable of printing thinner layers of plastic can produce higher quality plastic models, in this case the proposed tile prototypes. For tiles in this research, RapMan 3.1 FDM printer was used for the first test print. Printing the tiles using an FDM printer unfortunately did not provide satisfying results, as several technical issues were faced due to the specific quality requirements of the product design. Main issue was due to roughness and asperity of plastic filament material, which resulted in unintelligible Braille lettering and indistinguishable embossed models. Furthermore, the 280°C (536 F) heat produced by the nozzle for raw plastic melting had an unfortunate side effect of proximity burning the plastic itself while printing details in high resolution. Lastly, the issue of plastic flexure while cooling was encountered, due to some parts of the printout being hotter than others, resulting in plastic curving. A theoretical solution for his issue was proposed which involved installing a heated bed as a surface for printouts yet, unfortunately it was not possible to test it in practice at the time. Figure 3 shows tiles "A" for "ALAT" and "C" for "CVIJET" (Croatian words for "tool" and "flower") printed on RapMan 3.1. In conclusion, the described printing method was deemed not suitable due to the fact that it did not meet the required standard of quality. A Braille letter should always be perfectly printed in order to be unambiguously readable, therefore it was concluded that low-cost printing systems are not suitable for tile production purposes.

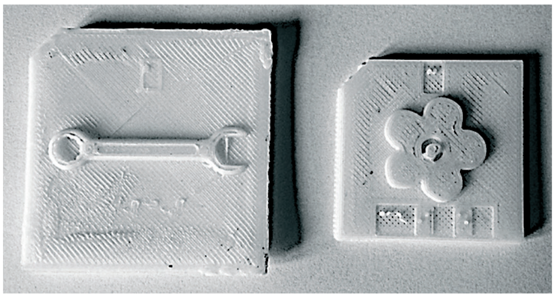

Figure 3: Tiles printed on RapMan 3.1

The second 3D printer tested while assessing higher quality options was Spectrum Z 510. This 3D printer is a different type of machine for the creation of 3D products, known as "binder jetting" or "drop-on-powder". It consists of several main parts including a roller, print assembly, build piston and powder bed. The process of printing starts with geometry of the model being sliced using a software platform into layered cross-sections, followed by mechanical deposition and binding of printing material. The roller collects powder from the powder bed and spreads the first layer of powder, which is of the same thickness as one layer of cross-sectioned 3D model, across the build area. This is followed by printer head applying binder solution which binds particles of the powder, creating a solid layer. After finishing one layer, the build piston moves one level down and the roller applies a new layer of powder, repeating this operation until the whole model is finished. Any extra powder left over from printing can be saved and reused for subsequent printing tasks [7]. Figure 4 presents an image of tiles printed on Spectrum Z 510 3D. Printouts made using this technology were of surpassingly better quality than the ones printed on RapMan 3.1. Tile surface was much smoother, Braille alphabet was printed in accordance with international standards and embossed models are of much higher tactile fidelity, while keeping the tile from deforming in any way.

Figure 4: Tiles printed with Spectrum Z 510 3D printer

Initial printing included six prototype tiles; "A" for "ALAT", "Đ" for "ĐON", "DŽ" for "DŽEP", "N" for "NOŽ", "P" for "PAHULJICA", "Z" for "ZVIJEZDA" (translations to English are in order: tool, sole, pocket, knife, snowflake and star). This was followed by a user experience survey held in "Vinko Bek", an educational institution for the blind and visually impaired children. Participants and teachers gave consent to their inclusion in the research. Survey participants were 10 visually impaired children (8 to 10 years of age) who already had experience with reading Braille alphabet, while their teachers helped in coordinating the study, which was held in their classroom. The user experience survey consisted of four questions with an emphasis on Braille readability, print quality and object recognizability. The survey questions were presented in a simple "yes or no" format which was deemed appropriate to participants' age, while capable of providing useful information necessary for design adjustments.

Survey questions were as follows:

1. Can you read the top letter?
2. Do you know what the object in the middle is?
3. Do you like the way it is modeled?
4. Can you read the word at the bottom?

Survey results are presented in Figure 5.

3. Results and Discussion

In this section survey results are shown in Figure 5 where the number of positive answers are presented for selected tiles tool, star, sole, knife, snowflake and pocket.

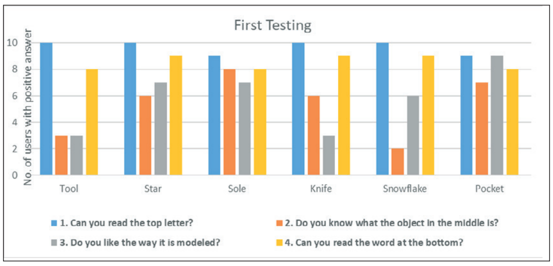

Figure 5: First user experience survey results

The results of the survey indicated some imperfections in the tiles. Some of the embossed models were deemed too complicated and difficult to recognize.

Model "A" for "ALAT" (tool) is one such example. It was concluded that children who had never been in contact or touched a similar object in real life would have difficulties recognizing it as an embossed model, so, therefore, it had to be replaced with a different model. Model for letter "N" for "NOŽ" (knife) was also replaced with simplified embossed model. The snowflake tile is especially interesting because children assumed that it was a flower, even though it is an enlarged version of an actual snowflake. After a discussion with group leaders we had concluded that the snowflake tile should remain as it is, because it could familiarize children with some abstract terms while learning in school. The basic set is made according to the Croatian alphabet, but it can be rearranged or redesigned into any language, for any target group requirements. The downsides of this solution were brittleness and price of tiles made using this 3D printing technique. Tiles tend to fall from tables in educational institutions which would pose a risk of breaking due to the brittle nature of material used. A third prototype had to have been made.

The third and final iteration of the tiles was produced using a combination of Ultimaker 2+ 3D printer and Roland UV LEC 330.

The design approach that was applied in planning for this iteration was based on both positive and negative experiences with previous attempts. Major drawbacks of RapMan 3.1 were roughness, bending and Braille unreadability, while Spectrum Z 510 was deemed unsatisfactory due to brittleness of tiles. The solution for the third version differed from the previous two in that the tile was to be assembled from two different parts. In preparation, the tile with the embossed model was printed on the Ultimaker 2+ FDM printer, the specifications of which can be found in its accompanying instruction manual [8]. What distinguished this printer from its previous FDM counterpart RapMan 3.1, is its significantly higher printing resolution. It is also important to mention that this type of 3D printer supports different types of plastics filament materials, while the RapMan 3.1 supports only one type. Filament used for this printer was nGen co-polyester from ColorFabb - a high quality, high durability, low odor material, with a smooth surface finish. The Braille letters were printed on an inkjet printer Roland UV LEC 330, which is unique in its use of UV light [9]. The printer uses UV light to cure a special varnish deposited on a sticker paper turning it, layer by layer, into a raised relief surface. The number of layers for Braille was 6 (high quality with double layer thickness setting), which had been determined according to research made earlier by Golob et al., 2014. [10]. The sticker sheet with Braille lettering was cut and applied onto corresponding tiles.

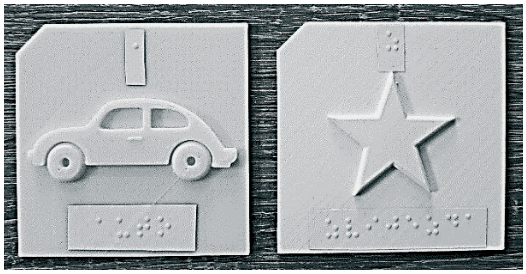

Figure 6: Tiles printed with Ultimaker 2+

Figure 5 shows tiles "A" for "AUTO" and "Z" for "ZVIJEZDA" (Croatian words for car and star) assembled from the plastic part printed with Ultimaker 2+ and Braille letter stickers printed on the Roland UV LEC 330 inkjet printer. The tactile transition between sticker and tile is seamless and barely noticeable. Creation of the third prototype was followed by a second user experience survey, also conducted in same conditions and same number of test subjects as first one, and the results of which are shown in Figure 6.

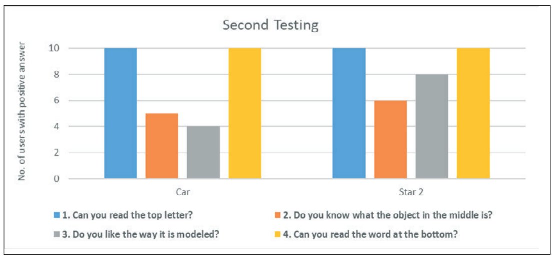

Figure 7: Second user experience survey results

These results confirm Braille readability on tiles printed with Ultimaker 2+, as well as an improvement in recognizability of the "Car" model in contrast to the previous "Tool" model which it replaced. The tiles printed in this manner were much less brittle, and the resident faculty at Vinko Bek agreed that the third prototype would be much better suited to their work environment.

4. Conclusion

Rapid development of 3D printing technology and new teaching methods have made paths for numerous new and exciting opportunities in enhancing tactile experience for visually impaired people. These tiles have been created as an example of an innovative Braille alphabet teaching tool using cutting-edge technology in conjunction with experience derived from traditional teaching methods. Additionally, it was tactile tool for visualization of selected objects for blind and visually impaired target groups, which can encompass both children and adults. Due to the fact that prototyping and production methods used in the development of the final product have only recently been made available to a broader spectrum of specialized researchers, there have been little to no previous examples of creating a similar educational tool, and mainly no information about the product and user's interaction. In our research, we went through several stages of prototyping and testing of product design, and described the advantages and issues that arose with each new method. The final method we used, a hybrid system created using both a 3D printer and a UV inkjet printer, provided very good results, considering both Braille readability which was the primary concern, and the overall printout quality of the embossed model and the tile itself. The final tiles have recognizable embossed models, easy to read Braille letters and low chances of shattering upon accidental impact, which, in combination, provided the best results in the tests we preformed according to performed surveys. It is also possible to further improve upon the design of the tiles, which would entail some additional or special information (numbers, special characters etc.) of the embossed model, as suggested by the experts of the institution for visually impaired children. This kind of an upgrade would be possible by using differently colored plastic or specially processed surface, for people with low vision. The conducted survey shows that the tiles are an appreciable additional learning tool for visually impaired individuals. Also, the ability to recognize the embossed model greatly depends on one's individual visual impairment, because a person who has seen before or has some partial ability to see would more easily recognize the embossed model, and person who has been blind since birth needs some time and help to recognize the models. The design of tiles is tested, appropriate printing system and filament are appointed for designed purposes, and shape of embossed images can be altered or redesigned for some other target group. The language used on presented tiles was Croatian, but it can be easily changed to any other language.

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