“Research, study, design and production of a tactile map, created by 3d printing technology, in order to cater the people with partial or total blindness in the interactive park and the citadel of Leivithra”

Mikrou Giorgos

SCHOOL OF ECONOMICS, BUSINESS ADMINISTRATION & LEGAL STUDIES

A thesis submitted for the degree of
MASTER OF SCIENCE (MSc) in
Strategic Product Design

May 2017, Thessaloniki - Greece
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March // 2017
Thessaloniki – Greece
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I hereby declare that the work submitted is mine and that where I have made use of another’s work, I have attributed the source(s) according to the Regulations set in the Student’s Handbook.

March//2017
Thessaloniki - Greece
Summary

This dissertation was written as part of the MSc in Strategic Product Design at the International Hellenic University.

The present study combines the research, study, design and manufacturing of a tactile map for the navigation of visually impaired people into archeological sites. 3d printing was chosen as the method of manufacturing due to its versatility and ease of production. The map design is modular to allow for future modification and the material was chosen based on a research conducted with a group of visually impaired people. Furthermore, the study focuses in pre-elementary children and was made in collaboration with the School for the Blind “KEAT” and its instructor Leia Avraam.

Resin was chosen as the optimum material for manufacturing, based on a survey that took place among the students of “KEAT”. The other suggested materials were PLA and PA and PP. The map was designed using Solidworks software and has as a primary goal to help the end-user orient himself within the archeological site. The modular design allows potential future users to print archeological site maps in their 3D printers at home. In order to minimize the haptic noise, further studies were made with the same group, involving different types of connections with the pieces. The type of connection that was chosen features a male to female connection among the different pieces.

Mikrou Giorgos

15/3/2017
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“It's a dangerous business, Frodo, going out your door. You step onto the road, and if you don't keep your feet, there's no knowing where you might be swept off to.”

— J.R.R. Tolkien, The Lord of the Rings
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1. Introduction

The purpose of this study is to design a tactile map to aid people with partial or total blindness navigate in archaeological sites. Namely this involved the research for the optimal method for manufacturing, the use of the best materials for haptic feedback and the most efficient map design for easy orientation within the site.

The current study involves the participation of a group from the “KEAT” School for the Blind. It is limited to the archaeological site of Leivithra with the prospect of further implementing it in other archaeological sites around Greece and the globe.

The first step of this project is to make a theoretical research about the visual impairment, the spatial cognition and the 3D printing methods. Next, there is a research of similar projects and a comparison of their features, in order to extract guidelines for the development of the project. What follows, is a research and experimentation on the 3D printing materials and the selection of the most suitable material for the materialisation of the tactile map. The final step is the design proposal that includes the design details and photorealistic representations of the final object. The report is completed with the conclusions and suggestions for further research.
2. Theoretical Background

In order to comprehend and develop the subject of this dissertation, there should be a theoretical foundation about the different aspects of the topic. First of all, there is some research about the visual impairment. What follows is a theoretical research about spatial cognition, which is directly related to mapping, and how it applied to visual-impaired people. Next, there is some information about the tactile maps. Finally, there is a research on the 3D printing methods and applications.

2.1 VISUAL IMPAIRMENT AND SPATIAL COGNITION

2.1.1 Visual impairment

According to the World Health Organization, 285 million people are visually impaired around the world (WHO, 2012) and 14% of them (39 millions) are blind. So, the attempt to improve the quality of life for this major part of the population is a quite significant as well as challenging mission.

The first step is to try and understand what the term "visually impaired" means. It includes a vast range of conditions, ranging from minor vision problems to severe impairments, such as total loss of vision. It could mean myopia, far-sightedness, extreme sensitivity of light, astigmatism, colour blindness, dimness, foggy vision, spots in the visual fields and many more.

Table 1 Classification of Visual Impairment based on visual acuity as defined by WHO (2010)

<table>
<thead>
<tr>
<th>Category Nr</th>
<th>Category Title</th>
<th>Visual acuity worse than</th>
<th>Visual acuity equal or better than</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Mild or no visual impairment</td>
<td>6/18, 3/10, 20/70</td>
<td>6/18, 3/10, 20/70</td>
</tr>
<tr>
<td>1</td>
<td>Moderate visual impairment</td>
<td>6/60, 1/10, 20/200</td>
<td>6/60, 1/10, 20/200</td>
</tr>
<tr>
<td>2</td>
<td>Severe visual impairment</td>
<td>3/60, 1/20, 20/400</td>
<td>3/60, 1/20, 20/400</td>
</tr>
<tr>
<td>3</td>
<td>Blindness</td>
<td>1/60, 1/50, 5/300</td>
<td>1/60, 1/50, 5/300</td>
</tr>
<tr>
<td>4</td>
<td>Blindness</td>
<td>No light perception</td>
<td>Light perception</td>
</tr>
<tr>
<td>5</td>
<td>Blindness</td>
<td>Undetermined</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This table presents the classification proposed by the World Health Organization (WHO, 2010) that aims at categorizing the visual impairment conditions, based on visual acuity. "Visual acuity is calculated as the quotient of the distance from which a specific person sees an object and the distance at which the same object is seen by a person without visual impairment." (Brock, 2013). That means that an acuity of 6/60 means that if a person with normal vision sees an object in a specific way at a distance of 60 meters, it needs a distance of 6 meters for a visually impaired person to perceive it the same way.

2.1.2 Spatial cognition and cognitive map

What is more, it is important to clarify some terms and notions that are crucial for the aim of this thesis. A map is related to spatial knowledge, which is needed and utilized both by sighted and non-sighted people. Spatial knowledge is obtained and treated via perception and sensation, memory, language, thinking, imagery and problem-solving mechanisms. It exploits the whole range of the senses and it can also be acquired through the use of media like 3D models and verbal descriptions. Also, it is dynamic and it can be changed over time via learning and development.

Spatial knowledge can be divided into three large categories: landmarks, routes and survey (Siegel and White, 1975). Landmarks are distinctive spatial features that play a significant role for orientation, navigation and also map reading. Routes are defined as the way the landmarks connect with each other so they represent travelling lines. Survey knowledge consists of the combined information about landmarks and routes that allows a user to have an overall knowledge of the topographical properties of an environment. This can be obtained from direct navigation and experience of a place or via map. What is more, there is also a distinction between allocentric and egocentric reference frame. Allocentric information is relative to an external framework and it can be obtained through the "bird's eye view". On the other hand, egocentric knowledge is relative to one's body and it is perceived from the observer's perspective. These two frameworks coexist and collaborate to form one's spatial behaviour. This knowledge leads to the creation of a cognitive map.
'Cognitive map', also known as imaginary map, mental map, environmental image, spatial image, spatial schema and spatial representation, is the aggregated knowledge and data that create a perceptual image of the environment. Cognitive maps are used for all our spatial behaviour, orientation navigation and existence in the space. They are not precise representations but a combination of transformed, augmented, distorted information that lead to a kind of spatial perception through scale change, rotation, abstraction and symbolization. The necessary information for the construction of the mental map is the location information (where something is) and qualitative information, which is the spatial properties of something, like the shape, pattern, movement, size, distance, direction, separation, connection (Montello, 2001).

What is more, some definitions related to this matter that need to be defined and discerned are the orientation, way finding, locomotion and navigation. Orientation is the perception and knowledge of where you are. Way finding is the ability to find and reach a destination that is out of the close sensorial field. Locomotion is the skill to guide oneself in the immediate sensorial field. Finally, navigation is the combination of all the above mentioned skills that lead to the positioning and movement in an environment and the ability to reorganize the path to a destination in case of becoming lost. Clearly, the abilities defined by these terms presuppose the existence of a cognitive map and the manipulation of spatial knowledge (Loomis, Gollende, & Klatzky, 1998).

2.1.3 Spatial cognition without sight

Spatial cognition of sighted people significantly depends on the visual input. Consequently, this raises the question how spatial cognition is developed when vision is minimum or absent, like in the case of visually impaired people. There are three contradicting theories concerning the spatial cognition of visually impaired people: deficiency, inefficiency and difference theory (Fletcher, 1980). The deficiency theory was the first to be developed and it suggests that in case of total absence of visual ability, there is no spatial understanding. The inefficiency theory argues that there is some spatial cognition developed, but it is significantly less efficient than this of the
sighted people. The difference theory, on the other hand, advocated the ability of the visually impaired people to develop an equally efficient spatial cognition, that may be qualitatively different from the one of the sighted people, but functionally equal. Research and experiments have shown that the truth most probably lies on the third theory, whereas the first one is totally rejected. So, there is indeed a way for non-sighted people to perceive their environment and build a respective cognitive map, but with different processes and parameters in contrast to sighted people.

Moreover, sighted people mostly rely on vision to obtain spatial knowledge, whereas visually impaired people utilize the haptic reference system. So, it may need similar effort for the perception of a small scale environment, but in case of a large scale environment, vision gives a significant advantage, because it does not require direct contact. This can be addressed by the use of a symbolic representation in smaller scale that can be handled with touch.

2.1.4 Tactile maps _ Design and production_

In order to build a cognitive map, without the use of vision, there are some tools that have been developed and can help visually impaired people navigate and travel independently, safely and efficiently. Such tools are 3D models, maps and images, verbal descriptions and electronic travel aids. These tools can be categorized into two types: the dynamic devices that can be used during the journey and the passive devices that are used before the journey in order to develop a cognitive map (Lahav and Mioduser 2008). The tool that is going to be researched in this thesis is the tactile maps.

A map is a two-dimensional projective representation of an environment in a smaller scale and from an allocentric survey perspective. The information that is presented depends on the purpose of the map, which can be geographical, topological, touristic, thematic etc (Lloyd, 2000).

Apart from the conventional maps, there are also maps that address the visually-impaired people and they are based on the haptic sense. They are actually
raised-line drawings that represent contours. The reading of these tactile maps has proven to be really challenging, so there are suggestions about adding 3D information to the maps, like texture, convex and concave surfaces or small symbolic volumes, to enhance the spatial representation.

**Design of tactile maps**

A tactile map provides information through the haptic sense, using different lines, symbols and textures and textual information written with Braille script. One of the most crucial guidelines, when designing a tactile map, is to keep it as simple as possible. Additional information and decorations may be interesting when placed in a map for sighted people. However, in the case of the visually-impaired people, it only makes the map more confusing and disorienting. Also, it should present high tactile contrast, using textures, shapes, sizes, orientations and spacing (Tatham, 1991). What is more, there are constraints regarding the haptic perception. That means that there are recommended guidelines about the distance between two lines, the number of symbols and textures and other parameters about the haptic capability.

Moreover, the Braille script is a raised dot embossed alphabet that was invented by Louis Braille in 1824 and it is the international standard writing system for blind people. Each letter consists of a number of dots placed in a rectangular grid of 6 to 8 places and its size corresponds to the average size of a fingerprint (Cattaneo & Vecchi, 2011). When included in a map, it has to be considered the fact that unlike the normal fonts, this script has a standard size, spacing and orientation.

**Production of tactile maps**

The most common techniques for the creation of a tactile image in swell-paper and vacuum-forming. Swell-paper, or microcapsule paper or heat sensitive paper, requires a conventional printer, a heater and a certain kind of paper. In this procedure, the map is printed in a special paper that has microcapsules of alcohol in its coating. The black ink absorbs more heat, so when the paper is passed through the heater, the printed capsules of alcohol expand, creating a tactile image (Edman, 1992). The advantages are the relatively low cost of production, since only the heater has a higher
cost and the ability to present information not only for the visually-impaired people, but also for the sighted ones. The disadvantages are the low capability of presenting information, since there can only be two levels of height, printed and not printed, and its low durability, because the images can lose their readability after repeated uses.

Vacuum-forming, also called thermoforming is a method that allows the production of multiple copies of a tactile image. A master matrix is created that represents the desired tactile information. This matrix is placed with a sheet of plastic on top of it, in a certain equipment that uses high temperature and vacuum. The result is a permanently deformed sheet that can represent raised lines and different layers of height to improve readability. The disadvantage of this process is the high cost and the specialized equipment that is needed (Edman, 1992).
2.2 3D printing

Nowadays, 3D printing has gained more and more popularity in our everyday life and it has changed the conventional way that things are implemented. Houses are being built through this method, bridges are being constructed and this is only few of the various applications of 3D printing.

3D printing is an additive manufacturing method, through which a three dimensional object is being synthesized by deposit of successive layers of materials. The whole process is being monitored by a computer. The wide popularity of this method is completely understood, if we consider its advantages. Among the main merits of 3D printing is the ability to create an object no matter how complex it may be. In comparison with the existing additive manufacturing methods, the complexity of the object’s geometry doesn’t make its creation more difficult.

Another element that characterizes this method is the ability to rapidly produce prototypes. Consequently, a large number of prototypes or small-scale versions of the real object can be produced in less time than using the conventional methods. By this way, designers and engineers can examine potential flaws of their model and improve it in a previous stage, as the change the characteristics that affect the functionality and quality of the prototype.

Taking these into account, customized products can be easily and quickly produced. As a result, storage cost is eliminated to zero, as manufactures don’t have to keep inventory of their products. On the contrary, they can manufacture an object, when it is needed (Forster, 2014). The low productivity cost cannot also be overlooked. Although the initial cost of setting up a 3D printing facility is relatively high, it is counterbalanced by the lack of other costs, like labour and manufacturing costs.

Moreover, as it happens with every new technology, 3D printing will create new job opportunities, as more engineers and technicians will be needed to operate 3D printers and create blueprints for products. Apart from the above, a major contribution of 3D printing in health. Customizable human body parts and organs will be able to be manufactured in the near future through Bioprinting. With this
revolutionary technique, not only the shortage of organ donors, but also the organ rejection will be handled, since the organs that are built will consist of the patient’s unique characters and DNA (3D Hubs, 2017).

On the other hand, 3D printing has also disadvantages. Limitation of size as well as of raw materials are the main ones. In contrast to the conventional methods, the materials that are compatible with 3D printers are limited. Also, the common 3D printers are limited by size constraints. Furthermore, the strength and endurance of the occurring parts are limited due to the layer by layer creation of the object, resulting to the creation of weaker parts than their traditional counterparts (3D Hubs, 2017).

Although 3D printing has been recently widely used, this technology had been developed in the early 1980s. As it is described further on, there are various additive manufacturing methods.

- Fused Deposition Modelling (FDM)
- Stereolithography (SLA)
- Selective Laser Sintering (SLS)
- Direct Metal Laser Sintering (DMLS)
- Inkjet Printing
- Jetted PhotopolymerLaminated Object Manufacturing (LOM)

In Fused Deposition Modelling, the plastic filament is pushed through the extrusion nozzle. The nozzle moves over the build platform along X and Y axis, creating a cross section of the object onto the platform. Consequently, this thin layer of plastic cools and hardens, immediately binding to the previously deposited layer. After the completion of each layer, the base is lowered, so that the next plastic layer can be added.

The same procedure applies also to Stereolithography (SLA). SLA uses a liquid photopolymer resin and converts it into solid cross-sections with the help of an ultraviolet laser (3dsystems.com, 2017). On the other hand, solid powder materials are
being used in Selective Laser Sintering (SLS). This method uses a laser beam controlled by a computer, through which the particles in the powder bed are being bonded together. Consequently, the powder temperature rises above the glass transition point, evoking adjacent particles to flow together (Materials, 2017).

Direct Metal Laser Sintering (DMLS) also uses materials in powder form and, with the help of a laser, it converts them into a 3D object (Protolabs.com, 2017). Moreover, Inkjet Printing uses thermoplastic and wax materials in liquid form in order to create the 3D object. The liquid drops of these materials instantly cool and solidify to form a layer of the part, offering excellent accuracy and surface finishes. Inkjet Printing combined with Stereolithography comprise Jetted Photopolymer, through which smooth, accurate parts, prototypes and tooling are being produced (Tzetzis, 2016). Finally, Laminated Object Manufacturing (LOM) uses adhesive-coated paper, plastic or metal laminates, which are being glued together.

In the table below (Table 2) the materials used in every method are presented.

<table>
<thead>
<tr>
<th>AM Method</th>
<th>Used Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fused Deposition Modelling (FDM)</td>
<td>thermoplastics</td>
</tr>
<tr>
<td>Stereolitography (SLA)</td>
<td>ABS, polycarbonate and polypropylene</td>
</tr>
<tr>
<td>Selective Laser Sintering (SLS)</td>
<td>plastic, ceramic, glass and nylon</td>
</tr>
<tr>
<td>Direct Metal Laser Sintering (DMLS)</td>
<td>ferrous metals (Stainless Steel, Steel alloy, etc) and non-ferrous (Aluminium, Titanium, Ceramics)</td>
</tr>
<tr>
<td>Jetted Photopolymer</td>
<td>thermoplastics and acrylic</td>
</tr>
<tr>
<td>Laminated Object Manufacturing (LOM)</td>
<td>thermoplastics, paper, ferrous and non-ferrous metals as well as ceramics</td>
</tr>
</tbody>
</table>
Although 3D printing is more and more used in our everyday life, the materials that are compatible with 3D printers are still limited. The most widely used are Acrylonitrile Butadiene Styrene (ABS), nylon and Polylactic Acid (PLA), as well as their blends (Torrado Perez, Roberson and Wicker, 2014). However, lately more unusual materials are being used, such as fabric, wood, metals, composites, ceramics, and even chocolate (3D Hubs, 2017). 3D Printing finds usage in many applications, such as in chemical and food industry, in mechanics, in education, in aeronautics, in automotive, in textile as well as in robotics and in electronics (Sculpteo.com, 2017).
3. Benchmarking

The next step after the theoretical research was to explore the current examples of how visual impairment and 3D printing are combined so far. There are various examples that use this technique in order to help the visually impaired gain spatial knowledge. Some of them are presented in this chapter.

3.1 Related applications

3.1.1 Tactile map of Alvar Aalto library in Vyborg

![Tactile map of Alvar Aalto library in Vyborg](source: Proarte.ru, 2014)

The Alvar Aalto library was built by the famous architect in 1933-35 in the city of Vyborg and it was renovated in 2013. Although it is not specifically function as a venue for the visually impaired, it does include books printed in Braille script and special devices for the visually impaired readers. So it was considered as a necessity to
facilitate the navigation and wayfinding in the building for those specific users (Proarte.ru, 2014).

For this reason a tactile map was designed that presents the multilevel space of the library. The map is made from birch veneered plywood and it has text written both in regular alphabet and in Braille. It is actually a 3D model of the building that is enhanced with tactile symbols, to enable the non-sighted understand the spatial properties.

3.1.2 Tactile map of Wilmington Public Library

Figure 2_ A 3D prototype of Wilmington Public Library (source: http://technical.ly)

The Division for the Visually Impaired (DVI) and the Wilmington Public Library are collaborating in order to develop a project that would help the visually impaired members of the community. Their aim was to create a tactile map of the inside of the library's buildin, in order to help the users walk around the place (Podraza, 2017).
The design of the map was a simplified version of the actual plan of the library. The basic shapes and spatial features were traced and then enhanced with the addition of some text written in braille. The whole layout was then 3D printed. The project is still under development, but the prototype demonstrates the usability of the final upcoming map. The intention is to improve the quality of the 3D printing, in order to have better finishing and more legible braille texts.

3.1.3 Touch Mapper

Touch Mapper is an organisation that provides tactile mapping services. They create custom outdoor maps for any address in order to help blind and partially sighted people orient themselves and plan routes. It can be also used by non-sighted users for public areas, outdoor tourist attractions and orientation and mobility.
specialist to help clients build a mental map of an area more easily (Touch-mapper.org, 2017).

The map is printed using an embosser, a swell paper printer or a 3D printer. It represents roads, buildings, railways, waterbodies, the symbol of orientation and the name of the addresses. It is a quick and affordable way to make a spatial cognition tool for the visually-impaired.

### 3.2 Benchmarking

Table 3 _ Benchmarking table of 3D printed applications on mapping

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing/Material</td>
<td>birch veneered plywood</td>
<td>3D printed</td>
<td>Embosser, swell paper, 3D printed</td>
</tr>
<tr>
<td>3D representations</td>
<td>3D accurate model</td>
<td>Symbolic 3D volumes</td>
<td>Symbolic 3D volumes</td>
</tr>
<tr>
<td>Size</td>
<td>50 x 70 cm</td>
<td>10 x 16 cm</td>
<td>17 x 17 cm</td>
</tr>
<tr>
<td>Color</td>
<td>2 (white &amp; black)</td>
<td>1 (white)</td>
<td>1 (white)</td>
</tr>
<tr>
<td>Text</td>
<td>Braille &amp; regular</td>
<td>Braille</td>
<td>Braille</td>
</tr>
<tr>
<td>Use</td>
<td>public</td>
<td>public</td>
<td>Private</td>
</tr>
<tr>
<td>Users</td>
<td>Visually impaired &amp; sighted</td>
<td>Visually impaired</td>
<td>Visually impaired</td>
</tr>
</tbody>
</table>

As seen in the table (Table 3) above, there are various attempts to make tactile maps. The common characteristic is the intention to improve the representation and manufacturing format and to use a new way of materialization, instead of the conventional methods, like swell paper. More particularly, the [1] is made like an architectural 3D model, with birch veneered plywood, representing the actual
geometry in a minimalised way. The [2] is 3D printed, whereas the [3] uses both the conventional and the new methods. The last two are presenting a symbolic view of the area, more like an extruded projection plan.

What is more, the [1] is a large map that is installated in a standard place, whereas the [2] and [3] are smaller and possibly portable. All three tend to use one color or a second one for the information that addresses the sighted. Also, they all include information written in Braille script and the [1] has also text for the sighted users. That can be justified by its use. It is meant to have a public use and to be used both by sighted and non-sighted, since it is located in a library. The [3] is intended for private use, like a personal map to one's home. The [2] for the time being is small and can be portable, but the intention is to make a larger map to install it in the entrance of the library. The [2] and [3] are mainly for the visually-impaired users.

3.3 Conclusions of the Benchmarking

The benchmarking research revealed that there are indeed some attempts to update the making of tactile maps, but they are fragmentary. 3D printing has been introduced in this area, but the ordinary methods are still in use and 3D printing is still under research. So there is room and an opportunity for more experimentation on how to use 3D printing in order to produce tactile maps.

What is more, it seems that there is no pre-defined decision of whether to make a tactile map also legible for the sighted. This contains parameters like the way or representation, the colors and the text. The ideal would be to enable both groups of users to gain spatial cognition through a single tactile map.

In conclusion, there is an opportunity to study how 3D printing could be applied in a tactile map. So, the next chapter is a research on 3D printed tactile materials, that could enable and guide the next step towards an actual application.
4. Research on 3d printed tactile materials

4.1 Introduction

Continues to the benchmarking research, the idea was to print a single specimen in a variety of 3d printed materials in order to understand the functionality of each one. Key elements of the final selection are the direct and correct information of the user during its interaction with the map. During our research in the area of Thessaloniki, we came across with 5 3d printing stores. The final selection was made due to the given price, the friendly environment and the customer service.

4.2 Material selection

At first we collected 5 different small samples of the same print in order to understand and clarify each type of print. The initial printed samples were selected according to their printing time, price per m3 and final printed result (tactility). On the picture below (Figure 4) you can see our primarily material selection. From left to right we have High detail resin (ABS like), Clear resin (ABS like), Polylactic acid (PLA), Nylon powder(PA) and Plaster powder (PP) print.

Figure 4 _ Primary material selection samples
After our first look of each material, we had to create a basic sample that would combine all the benefits of the 3d printed model in order to achieve best user’s experience.

4.3 Specifications of the 3d printed specimens

The final model is a small plate 100 X 60 mm and tries to integrate the most basic and essential elements that a visually impaired will face during its experience (Figure 6). As we see in the following picture (Figure 5), our sample includes a variety of different lines with different thickness and width, two basic geometrical shapes, both in different sizes, a sample text in Braille system in order to get feedback regarding the tactility of the dots and points and finally a house alike and compass shape. All the elements that have been included in the sample plate were previously discussed with the supervisors of KEAT Thessaloniki in order to understand better the needs and how information can be translated into shapes.

Figure 6 _ General view of the sample plate

Figure 5 _ Elements of the sample plate
The next step was to prepare the sample plates for print! As we previously mentioned the price/m3, the printing time and the final tactility of the model would be crucial. The final sample plates, as shown below (Figure 7) were printed in 4 different materials. 1. Clear Resin (ABS-like), 2. White Resin (ABS-like), 3. Polylactic Acid (PLA), 4. Plaster Powder (PP). Very important aspect of the final selection was the durability of its material, the brittleness and the longevity in time.

4.4 Data collection and data analysis

Before selecting the final material, we gathered a small group of actual users, both partial and in total blindness to interact with the sample module and give us their feedback. Also the age factor was taken into account since KEAT Thessaloniki includes pre-elementary children and adults. The evidence taken from our study is presented to the following table.
The benchmarking criteria that were defined in order to compare the material are the following

- **Transparency**

  Transparency may not be the first thing that comes in mind when talking about blindness but for the partial blind is a key element to understand the overall shape. Besides sharp contrasts, transparent objects, won’t allow a partial blind to have a clear view of the surface of an object.

- **Brittleness**

  In order for a blind person to collect all the information given by an object, the surface needs to be clean and clear. Brittle surfaces are can be really disturbing on long continues usage. For the best users experience the surfaces has to be smooth.

- **Durability**

  By the continues use of a 3d printed object, distortion may emerger and the information on it be lost. A durable material is important in order to maintain the information intact in the period of time.

- **Noise**

  In experimental sciences, noise can refer to any random fluctuations of data that hinders perception of an expected signal. Continues noise may lead the user to misinterpret the actual information.

- **Legibility**

  Not all the visually impaired are familiar with Braille system but since that can be a great source of information for someone that can read, the words should be legit enough to understand.

- **Price**

  Last, but not least, the price is also a comparing factor.
All previous criteria are been placed in the following table and rated from a scale of 1-5 with 1 be the least good and 5 be the best rating.

### Table 4 - Benchmarking table of 3D printed materials

<table>
<thead>
<tr>
<th></th>
<th>Clear Resin ABS-like</th>
<th>White Resin ABS-like</th>
<th>Polylactic Acid (PLA)</th>
<th>Plaster Powder (PP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparency</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>(partial blind)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brittleness</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>(less is better)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Noise</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>(less noise is better)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legibility</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>(Braille)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price/m3</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>SUM</td>
<td>19</td>
<td>22</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Ranking</td>
<td>****</td>
<td>*****</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

Following the table above, we understand that all materials are really close on ranking. The selection of the final material will be made according to the best users experience and not based on pricing.
4.5 3d printer and material final selection

4.5.1 3d printer specifications

Every sample that needed to be print during the research as well as the final product/map were printed by Form2 (Formlabs). More details about the specifications of the printer you can see on the table below.

### Hardware

<table>
<thead>
<tr>
<th><strong>Dimensions</strong></th>
<th>35 X 33 X 52 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight</strong></td>
<td>13 kg</td>
</tr>
<tr>
<td><strong>Operating Temperature</strong></td>
<td>Auto Heats to 35oC</td>
</tr>
<tr>
<td><strong>Temperature Control</strong></td>
<td>Self-Heating Resin Tank</td>
</tr>
<tr>
<td><strong>Power Requirements</strong></td>
<td>100-240 V</td>
</tr>
<tr>
<td></td>
<td>1.5 A50/60 Hz</td>
</tr>
<tr>
<td></td>
<td>65 W</td>
</tr>
<tr>
<td><strong>Laser Specifications</strong></td>
<td>EN 60825-1:2007 certified</td>
</tr>
<tr>
<td></td>
<td>Class 1 Laser Product</td>
</tr>
<tr>
<td></td>
<td>405nm Violet Laser</td>
</tr>
<tr>
<td></td>
<td>250mW laser</td>
</tr>
<tr>
<td><strong>Connectivity/Optical Path/Printer control</strong></td>
<td>Wifi Ethernet and USB/Protected/Interactive touch screen</td>
</tr>
</tbody>
</table>
### Printing Properties

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>Stereolithography (SLA)</td>
</tr>
<tr>
<td><strong>Peel Mechanism</strong></td>
<td>Sliding Peel Process with wiper</td>
</tr>
<tr>
<td><strong>Resin Fill System</strong></td>
<td>Automated</td>
</tr>
<tr>
<td><strong>Build Volume</strong></td>
<td>145 X 145 X 175 mm</td>
</tr>
<tr>
<td><strong>Layer Thickness</strong></td>
<td>25, 50, 100 microns</td>
</tr>
<tr>
<td><strong>Layer Spot Size (FWHM)</strong></td>
<td>140 microns</td>
</tr>
<tr>
<td><strong>Supports</strong></td>
<td>Auto Generated / Easily removable</td>
</tr>
</tbody>
</table>
### 4.5.2 Material properties

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Green (2)</th>
<th>Postcured (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Photopolymer Resin for Form 1+ and Form 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tensile Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile Strength at yield</td>
<td>38 MPa</td>
<td>64 MPa</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>1.6 MPa</td>
<td>2.8 MPa</td>
</tr>
<tr>
<td>Elongation at Failure</td>
<td>12%</td>
<td>6.2%</td>
</tr>
<tr>
<td><strong>Flexural Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>1.25 GPa</td>
<td>2.2 GPa</td>
</tr>
<tr>
<td><strong>Impact Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notched IZOD</td>
<td>16 J/m</td>
<td>25 J/m</td>
</tr>
<tr>
<td><strong>Temperature Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat Deflection temp. @264 psi</td>
<td>42.7 C</td>
<td>58.4 C</td>
</tr>
<tr>
<td>Heat Deflection temp. @66 psi</td>
<td>49.7 C</td>
<td>73.1 C</td>
</tr>
</tbody>
</table>

The material properties on the table are comparable for all Standard Resins, White, Grey, and Black of formlabs.

This material can be easily painted, and when the surface is finished or coated, produces a highly clear part. Upon post-cure, tensile strength and stiffness exceeds that of injection-molded or 3D-printed ABS.
4.6 Conclusions

White resin ABS-like was the material we finally selected. The reasons of selection were its low brittleness values and also the legibility and noise of the sample were low. We haven’t selected the Clear one because as we previously mentioned information were lost due to the transparency of the object.

Concerning the price parameter the selected material was the most expensive. There were thoughts about the tradeoffs concerning price and quality. However in this specific occasion the quality is more significant than the price because a crucial parameter of its functionality. So we choose not to compromise the quality because of the price.
5. Design brief

Product description

A tactile map, created by 3d printing technology, in order to cater the people with partial or total blindness in the interactive park and the citadel of Leivithra

Targeted market

Visually impaired visitors of the park of Leivithra

Especially children

Assumptions and constrains

Tactile map

Legible both from partially sighted and non-sighted users

3D printed

Modular form
6. Design Proposal

6.1 Introduction

The chosen area to implement the whole idea of the 3D printed tactile mapping system was the archaeological site of Leivithra. In order to design the map, the parameters that taken into account were the specifications about the design for the visually impaired along with some ergonomic guidelines. Also, the manufacturing of the map had to be studied, not only for the process and material, but also for the practical making and assembling.

6.2 The site

The archaeological site of Leivithra was selected because of various reasons. First of all, the proximity of the site to the city of Thessaloniki was an advantage, since it enabled the frequent visiting of the site that was necessary in order to obtain all the needed information and feedback. What is more, the site is organized with specific routes and it has multiple activities, in the frame of being an interactive park. Also, they already receive visits from visually impaired people, so they have modulated the place and activities in such a way to enable the non-sighted navigation and interaction. So, there was already a promising foundation and a need for improvement and development.

Most importantly, the School for the Blind “KEAT”, that was a crucial factor for feedback and consultation during the development of this process, had already been to the archaeological site of Leivithra, so they could help using their actual experience.

What follows is a presentation of the Park of Leivithra, as seen in their official site (www.leivithrapark.gr)
The park of Leivithra (Figure 8) was subsumed in the Code ‘Development of cultural infrastructure / Modern cultural infrastructure’ of NSRF 2007-2013. It was initially implemented by the 27th Ephorate of Prehistoric and Classical Antiquities under the direction of E. Poulaki – Pantermali, who has inspired the project, and was accomplished by the Ephorate of Antiquities of Pieria, under the direction of E. Papastavrou.

It is located at the SE border of the archaeological site of Leivithra next to Mount Olympus. It extends on an area of 67 acres ceded by the Ministry of Rural Development to the Ministry of Culture. The thematic park aims to a cognitive and experiential contact of the visitor with ancient Leivithra and the wider area of Olympus, as well as with everyday life in antiquity. It has a pedagogical – ‘recreational’ purpose, achieved through educational programs, workshops and cultural events, utilizing the natural and cultural heritage of the Olympus area (Leivithrapark.gr, 2017).
It consists of three thematic areas:

- Educational – ‘Recreational’ area
- Flora and myths
- Forest improvement

The last topic is developed in the peripheral region and the first two in the central area of the park, where the ground plan of footpaths is in shape of lyre (bird eye view), noting the relevant myth of Orpheus and Muses.

A. Educational – ‘Recreational’ area

After the main SE entrance and the guardhouse for initial information, an apsidal building with rectangular shaped outbuilding dates to the late Bronze Age, is located. It was excavated in Platamonas area during National New Road’s construction and was transferred to the Leivithra Park.

Nearby there is a small oval building with natural construction techniques (building B). It has been built according to the dimensions and hypothetical form of an oval residence of the 8th century B.C., which was excavated and then covered at Krania site, on the foothills of Platamonas Castle. It hosts educational workshops for ancient handicraft, diet and pottery.

Figure 9 _ Photo of Building B (source: www.leivithrapark.gr)
In the central area of the park a rectangular complex can be found, which is the core of the educational programs and workshops. Its size and ground plan was inspired by a large wine-making complex of the late Classical – early Hellenistic period, excavated in the plain of Leivithra. At the east side a roofed building is located, where the visitor is informed about the archaeological sites from the broader Macedonian Olympus area (building A).

![Figure 10](source: www.leivithrapark.gr)

In the eastern and northern extensions of the building, stone foundations have been built, aiming to educational workshop on wall construction with mud bricks in a traditional way. At the west side of the complex a rectangular structure with stone foundations and a central paved yard can be found. It is to be used for agricultural workshops mostly related to the process of wine making, in connection with an adjacent small vineyard. Further north there are also small fields for workshops on traditional agriculture.
The path leads to four kiosks with educational material for Orpheus and Muses and to a small theater.
B. Flora and myths area & C. ‘Forest improvement’ area

The conservation, improvement and reinforcement of existing flora occurs in these areas, mainly through the planting of local varieties. Signs with mythological and historical information of the plants are also posted here. Moreover, visitors can wander in the natural, unstructured area of the park and in the adjacent, age-old plane-tree forest of Leivithra, and even further on, to the mount Olympus.

The next step was to determine the most important spatial elements of the site that need to be presented in a map, as shown in the figure below (Figure 13). The routes are marked with a red line and the stations of interest are numbered and explained accordingly.

Figure 13 _ Topographical map of the site with the important elements marked

1. Start of route
2. Guardhouse
3. Foundation of apsidal Mycenaean building
4. Small oval building with natural construction techniques
5. Archaeological information building
6. Kiosks for Orpheus – Muses
7. Theater
8. Fields for natural agriculture
9. Watchtower
10. To acropolis of Leivithra
6.3 Ergonomics and anthropometrics

Before starting to design the map, the dimension's layout needed to be determined. This includes the overall dimensions of the map and the physical base on which the map will be located.

The main targeted users are children visiting the site. So, information was gathered for the respective ergonomic and anthropometric measurements. This research led to the decision of making the map format 45x60 cm. The 60cm correspond to the front side of the map. The memorandum is also included in these dimensions. These dimensions correspond to the hands' span of a standing person, so the user can read the map without having to move around it.

The height of the map is defines at 90cm, which is ideal for children to read. This dimension considers all the possible users with a priority to the small ones, as the taller user can also read at that height.

Figure 14 - Anthropometric measurements of standing posture (www.researchgate.net)
6.4 Dimensions and design details

In previous phase it was determine that the dimensions of the map would be 600X450 mm including the memo on the bottom. This selected dimensions both serves children and adults in order to understand best the area that been Illustrated. The scale of the map is 1/500. The reason of selecting the specific scale and model size was that a single user can understand at once all the information on the map by standing in front of it and can easily navigate to it, without any further movement around. All the dimensions of each key element that assembles the final map are mentioned in detail below. Also, the total thickness of the map is 4mm, in order to prevent the wearing of the material due to the exposure to the sun and the ensure the durability of it.

6.4.1 Routes

The route of the archeological site is been divided to the main route and the suggested route, as this pointed by the supervisor architect. Suggested route is the route that mostly used from visual and non visual users. It covers all the important and marked places. Since we mentioned there are 2 routes (main and suggested), 2 different lines were created. A continues line for the main route and a dashed line for the suggested route. Both lines have 2 mm line thickness and 1mm height, with 0.50mm spacing for the dashed one. The route itself creates a lyre around the archeological site.
6.4.2 Points of Interest

Points of interest was the second most important thing to be displayed on the map. There are 9 points of interest. All points have a common base in order to be general recognized by the user. Each base has 10mm diameter and 3mm height. On top of each base there are 9 different symbols that indicate the 9 different points. Sketches of each point are inspired by the area that they represent.

Figure 16 _ Indication of the points of interest

6.4.3 Navigation

It was important to include some navigation marks in order to locate the archaeological site in the wide area. So, three important symbols were designed, the mount Olympos, the sea and the acropolis of Leivithra. Also, an orientation symbol is included. These symbols were designed in a similar way. That is an extruded rectangular and on top of each specific raised lines that correspond to each symbol.

Figure 17 _ Navigation symbol

6.4.4 Texture and Surfaces

An important auxiliary element on tactile maps is the use of different textures in order to indicate the different areas. In this case, the a wide area that needed to be indicated was the fields of the natural agriculture. The selected texture was undulated raised lines. Also, apart from the different texture, another way to indicate the characteristics of an area is the alteration of the height. The theatre of the site has an amphitheatrical inclination. So, an inclined surface is inserted in the theatre area to represent the gradient height.

Figure 18 _ Texture differentiation

6.4.5 Workshops
As mentioned before, one of the reasons for selecting this site was the interactivity of the uses. There is a number of workshops taking place along the archaeological site. In order to indicate and locate these activities in the area, a symbol is designed that correspond to the workshops at each point of interest. The symbol is an extruded arrow.

6.4.6 Buildings and masonry

All major buildings in the area were represented by their original shape in a minimalised way (for instance small oval building) and the masonry, like the winery, are also represented by their original shape.

6.4.7 Textual information

Even though only a small percentage of the visually impaired people can read Braille, it was considered necessary to include textual information in Braille as a complementary way of providing information. The dimensions of the dotting system were according the regulations regarding this script, in order to be legible.
6.5 Tactile mapping for visually impaired and regular vision users

The map is addressing the visually impaired visitors. However, the information should be also understandable from the guides that accompany them. So, the textual information is also written with regular script. What is more, the main routes and points of interest are differentiated by a color that creates contrast. As seen in the picture below, when the elements are black, they are more distinctive. This, of course, is mainly aiming at enabling the partially sighted.

Figure 22 _ Contrast parameter and color differentiation
6.6 Assembling methods

6.6.1 General assembly methods

In order to determine the optimal way to assemble our modular map we designed a 100x100 sample plate with the best connection options.

As shown in the models shown next there are 4 type of connections on each side. The primarily reason to select the best connection was to interfere less on the total tactile feeling and smoothness of the map.

The drawer like style (4) was rejected because of its lack of durability during the connection of the pieces. Both (2) and (3) were similar in case of connectivity.

Number (3) was rejected due to the holes which would interfere a lot on the overall tactility of the map. Number (2) even if didn’t have the holes, the rectangular shape on top of each piece, may confuse the user.

Number (1) was the best possible way to connect all the pieces of the map. Due to its hidden connection in the middle of each piece the only notch to be noticed would be the actual pieces next to each other.

On the picture below (Figure 23) you have clear view of the actual printed connection sample plates

Figure 23 _ Sample of assembling methods

Figure 24 _ assembling methods
6.6.2 Map assembly

After concluding on the 4th connection that will be applied on the map, the individual pieces had to be properly cut. Not all the piece has the same dimensions because the details and crucial lines on the map had to stay intact. Information like main buildings, route intersections, points of interest were one piece and the same cut. You can see all the pieces in the following exploded view photo.

![Figure 25 _ Puzzle-like division of the map layout](image)

The connections of each piece has the same clearance for the best fit of all 18 individual parts. On the following picture you can see a draft drawing of the connections and continues to that the actual model.

![Figure 26 _ draft drawing of the connections](image)
Figure 28 _ Final connectivity pattern

Figure 27 _ Connectivity pattern of the memo
6.7 Presentation of the final product

In this chapter, there are the final photorealistic representations of the proposed object.

Figure 29  _Perspective view of the map

Figure 30 _ Top view of the map
Figure 32. Memorandum of the map

Figure 31. Proposal for a stand for the map
7. Conclusions

The aim of this project was to design a tactile map, created by 3d printing technology, in order to cater the people with partial or total blindness in the interactive park and the citadel of Leivithra. The first step was to gather the necessary information for the target users, that is the visually impaired, and the 3D printing technology. Afterwards, a research on the 3D printed materials was made, in order to specify the one that would best embody the whole idea of the tactile map.

In collaboration with the Blind “KEAT”, the specifications and requirements of the map were defined and in combinations with the information gathered by the Park of Leivithra, the design phase initiated. All the data collected were incorporated in the final design proposal that is a 3D printed tactile map of the archaeological park.

The contribution of this dissertations is reflected on the final object that attempts to cover a need that society seems to neglect. The visually impaired people should also have access to the cultural and historical sites and the navigation and wayfinding tools are crucial for this. Also, this dissertations shows the extent to which the 3D printing technology can facilitate our lives.

What is more, the whole project was developed having in mind the modularity parameter and the creation of a matrix that could generate similar maps for other sites, too. So, ideally, this project could give the initiative to other relative sites to make such tools, to enable this group of people.

Finally, the subject could be further investigated for different applications, like university campuses, city navigation, public buildings, libraries, city halls etc. There could also be a further investigation and experimentation about the 3D printing process and materials. What is more, since there are some various categories of visual impairment, there could be a research on the colour application for the partially sighted.
8. Bibliography


**Websites**


