# Specification of symbols used on Audio-Tactile Maps for individuals with blindness

| D2.3 | Production of AT-Maps |
|---|---|


| | |
|---|---|
| **Prepare by :** | Konstantinos Charitakis |
| **Contributors** | All partners |
| **Work Package :** | No 2 |
| **Email:** | kcharitakis@uom.edu.gr |
| **Form:** | Final |



Lifelong Learning Programme

*"This project (543316-LLP-1-2013-1-GR-KA3-KA3MP) has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein."*

## THE ATMAPS CONSORTIUM

| No. | Partner Name | Logo |
|---|---|---|
| 1 | University of Macedonia (UOM) – Project Coordinator | |
| 2 | Karlsruhe Institute of Technology (KIT) | |
| 3 | GeoImaging Ltd (GEO) | |
| 4 | National and Kapodistrian University of Athens (UOA) | |
| 5 | Mustafa Kemal University (MKU) | |
| 6 | Panhellenic Association for the Blind (PAB) | |
| 7 | Association of Barrier Free Access (ABFA) | |

## ABBREVIATIONS

| Term | Explanation |
| --- | --- |
| IVIs | Individuals with Visual Impairments |
| AT-MAPS | Audio-Tactile Maps |
| AT-Symbols | Audio-Tactile Symbols |
| WP | Work Package |

## COPYRIGHTS

# Contents

## 1. EXECUTIVE SUMMARY

Touch and hearing are the primary senses that Individuals with Visual Impairments (IVIs) use in order to access written and graphical information and to acquire knowledge about attributes of an environment and their surroundings.

Until now tactile maps included raised graphic patterns recognizable only by touch.

Nowadays, information technology offers the means to convert spatial information into audio, tactile or audio-tactile form.

Therefore the benefits of tactile graphics can be combined with audio information with the use of special devices. Audio-touchpad devices are touch-sensitive pads that can simultaneously provide users with tactile and audio information, while they explore tactile graphics with their fingers. In the case of audio-tactile maps, information is represented by audio symbols, tactile symbols, audio-tactile symbols (combined) and Braille labels.

What needs to be carefully examined is the basic query of which information should be presented in haptic mode by tactile symbols or with braille labels and which information should be presented in audio mode by audio symbols or delivered via audio-haptic mode by audio & tactile symbols combined.

Moreover, it should be specified what audio-tactile symbols (tactile, audio, audio & tactile) will represent specific information in audio-tactile maps.

The fundamental aim of the ATMAPS project is the specification of audio, tactile and audio-tactile symbols to be used in Audio-Tactile Maps (AT-Maps).

In practice this means that it needs to be defined what information should be included in the AT-Maps and in which format this information should be presented.

Additionally, the results of the user requirements elicitation process that took place in previous phase of the project as well as the categorization and definition of the symbols in the appropriate mode should be the fundamental material for the production of pilot AT-Maps in a format that it will be easy to monitor the way symbols are recognized when included in AT-Maps.

The third deliverable of WP2 is a report on the production of such pilot AT-Maps to be used within the project.

The present report is comprised of three sections. The first section refers to the theory of tactile map designing and construction. The second section describes in detail the procedure and the principles of designing and producing the AT-Maps. The third section concerns the delineation of AT-Maps as part of the Work Package 2 of the project.

## 2. Introduction

Vision plays an important role in comprehending the spatial structure of an environment (Thinus-Blanc & Gaunet, 1997) and as such, IVIs seem to face difficulties in the acquisition of concepts relevant to spatial relationships (Warren, 1994). Research data concerning the ways that IVIs perceive spatial information should be taken under serious consideration when it comes to designing and constructing tactile maps and AT-Maps.

Maps, in general, constitute a significant orientation and mobility aid supporting the absolute and relative localization for an abundance of reference points as well as the estimation of directions and distances between those points (Brock, Truillet, Oriola, Picard & Jouffrais, 2012). Moreover, maps are designed and constructed in a way that leads to the acquisition of survey knowledge; a knowledge than can be obtained more quickly and with less effort than direct experience either from sighted individuals (Thordyke & Hayes-Roth, 1982) or from IVIs (Caddeo, Fornara, Nenci & Piroddi, 2006). Especially in the case of IVIs, maps also contribute to the handling of daily living problems inducing autonomy, independence and a better quality of life (Espinosa, Ungar, Ochaita, Blades & Spencer, 1998; Jacobson, 1998).

Tactile maps and AT-Maps are passive mobility aids, according to the categorization of Lahav and Mioduser (2008), and as such they help IVIs explore and code spatial environment before they actually reach real environment. A fundamental way to deal with spatial coding is by using compensatory sensorial channels to collect information (Lahav & Mioduser, 2008). Receiving tactile and auditory information in combination with each other is suggested to provide a more complete concept in less time than each medium separately would require. That is because tactile graphics present the relationships among the elements, while auditory cues supply detailed information (Landau, Russell & Erin, 2006).

More specifically, for tactile maps, researchers have pointed out that raised-line graphics of the spatial environment prepare IVIs to travel an unfamiliar space more safely and efficiently than with a verbal description or a sighted guide (Espinosa et al., 1998). Additionally, Thinus-Blanc and Gaunet (1997) stated that when IVIs read a tactile map they perceive the ability to maintain a stable reference point.

Nevertheless, despite the advantages of tactile maps, a series of limitations have been pointed out by researchers and should also be taken under serious consideration when designing and constructing tactile maps and AT-Maps. Jacobson (1998) mentioned that fingertip resolution is lower than eye's resolution and hence cartographers face the problems of simplification, generalization, classification and symbolization of the information included into a visual map.

Furthermore, when extended Braille labelling is required, this leads to overload and is prohibitive for those who do not know Braille reading. The abundance of the information and the complex graphics cause greater memory load (Ungar, Blades & Spencer, 1993), while an increased amount of spatial information clearly influences spatial coding and representation (Papadopoulos, Koustriava & Kartasidou, 2012). Moreover, separate legends restrict immediacy and uninterrupted interaction with the map.

Many of these limitations have been counterbalanced by the introduction of auditory information in tactile maps resulting in AT-Maps (Brock et al., 2012). Verbal assistance can help IVIs to overcome many of the obstacles mentioned above by substituting Braille labels and legends, as well as by providing guiding information, such as spatial relations, descriptions of buildings (Habel, Kerzel & Lohmann, 2010) or other significant landmarks (Wang, Li, Hedgpeth & Haven, 2009). Information provided through speech in combination with touch can be quite helpful overcoming the restrictions of touch to serial information gathering (Wang et al., 2009).

AT-Maps form the context for these solutions while specific technological devices, such as touch tablets and touchpads represent the tools for using AT-Maps. Nowadays, assistive technology seems to play a fundamental role in education and everyday life of IVIs (Maor, Curie & Drewry, 2011; Brown, McHugh, Standen, Evett, Shopland & Battersby, 2011) as it has recently great progress in the field of non-visual access to information for IVIs ( Abu Doush, Pontelli, Simon, Son & Ma, 2009).

The combination of auditory and tactile information results in a more complete concept (Landau, Russell & Erin, 2006). Landau and his colleagues (2006) found that IVIs can enjoy control and independence coming from the ability to make choices between tactile and auditory information used through a touchpad. Moreover, touchpads give the ability to use environmental auditory cues, incorporating, in a way, the soundscape into the tactile map. Including auditory cues in a map may promote an individual's orientation, since IVIs are proved to use auditory cues to determine and maintain orientation within an environment (Jansson, 2000), to associate the soundscape with the structural and spatial configuration of the landscape and create cognitive maps (Papadopoulos, Papadimitriou & Koutsoklenis, 2012).

Another significant parameter which is linked to the production of tactile maps and AT-Maps is the way such mobility aids deliver spatial information and if this way is in line with the strategies IVIs use.

However, the study of spatial knowledge seems to be a complex process, especially considering that cognitive maps IVIs create are dynamic entities which continuously change and evolve (Kitchin, 1994). The evaluation of spatial knowledge for IVIs uses techniques divided into route-based techniques and configurational techniques (Kitchin & Jacobson, 1997). The former examine parameters of spatial knowledge with respect to the relation between two different points of reference and how these two are connected, while the latter investigate parameters with respect to the relative location of all elements in a specific space.

Consequently, configurational techniques constitute the highest level of evaluation for spatial knowledge, since the connections between the relative location for points of reference require coding, processing and recalling multiple parameters consisting of position, distance, direction, orientation, and angle as well as their composition into a single entity (Kitchin, Blades & Golledge, 1997).

All issues and research data mentioned above constitute that production of tactile maps and AT-Maps is a multidimensional procedure where an abundance of designing and constructing principles must be taken under serious consideration.

# 3. METHOD

The researchers decided that within this task of the project should include the following:

- Development of pilot tactile maps that will be used as testing instruments in later tasks of the project during the evaluation of the tactile symbols created
- Development of pilot AT-Maps.

In this way it would be easy to continuously monitor the way the symbols are recognized when included in maps.

The optimal case for ATMAPS project would be that symbols produced in a previous task (Task 2.2) are included in a different pilot map for each one of the eight map types (i.e. indoors, campus, city center etc.), in order to allow the evaluation of the symbols and the correlations between them.

However, such a large number of pilot maps during the tactile symbols' evaluation procedure would cause fatigue to the IVIs which in turn may affect the quality of the results.

Therefore, in order to overcome those issues, a small number of different maps were produced.

## 3.1 Aims

The pilot maps created included the symbols created in the Task 2.2. In this way it was easy to continuously monitor the way the symbols are recognized when included in AT-Maps. This is considered necessary since many created symbols will be combined and used on the surface of AT-Maps and not individually.

Within the scope of the project the most important information that should be included in AT-Maps was defined based on the following types of AT-Maps.

1. AT-Maps of the indoors/inner space of buildings,

2. AT-Maps of neighbourhoods/residential areas,
3. AT-Maps of campuses,
4. AT-Maps of city centres,
5. AT political, physical, historic, and thematic maps

The initial aim of Task 2.3 of Work Package 2 (WP2), according to the project proposal, was the production of pilot AT-Maps in order to test the audio-tactile symbols created in previous task of the project.

However, during the project implementation the research team decided that the tactile symbols created in Task 2.2 (Creation of tactile symbols) should be first evaluated by IVIs in regard to their ease of identification and readability and then the audio-tactile symbols would be created.

Therefore, at the initial stage of Task 2.3 the pilot maps created consisted only of tactile maps. The pilot tactile maps created were fictional, meaning that they represent a fictional area so that there was no need to create many maps. Additionally the same maps could be used in all partner countries by all IVIs participating during tests. Therefore the same instruments were used in all partner countries.

For this part of the project it was decided that the creation of all five different types of maps created for the testing of the tactile symbols would be too much work and very time demanding procedure for the IVIS and researchers. Too much work and too much time needed to conduct the tests for the evaluation of the tactile symbols will cause fatigue of the participants and hence this could affect the tactile symbols' evaluation results. Therefore it was decided that only the following three different types of pilot AT-Maps should be produced:

1. Pilot tactile map for indoors,
2. Pilot tactile map for outdoors (neighbourhood, campus, city, etc.),
3. Pilot physical tactile map.

Each map included all the symbols created in the Task 2.2. In this way it was easy to monitor the way the symbols are recognized when included in AT-Maps.

The pilot tactile maps as output of the third task (Task 2.3) of WP2 would then be used as input for the following tasks of the particular WP and the creation of audio-tactile symbols.

As a next stage of Task 2.3 the pilot AT-Maps were created. The pilot AT-Maps developed as output of the third task (Task 2.3) of WP2, consist a sample of AT-Symbols.

## 3.2 Procedure and principles

The production (designing and constructing) of pilot AT-Maps is based on a specific procedure followed by principles appropriate for the ATMAPS project.

### 3.2.1 Tactile graphics, tactile maps and AT-Maps

Tactile graphics, including tactile pictures, tactile diagrams, tactile maps, and tactile graphs, are images that use raised surfaces so that IVIs can feel them through touch. They are used to convey non-textual information such as maps, paintings, graphs and diagrams. Tactile graphics can be seen as a subset of accessible images. Images can be made accessible to IVIs in various ways, such as verbal description, sound, or haptic (tactual) feedback, or even all together integrated on AT-Maps. However, one of the most common uses for tactile graphics is the production of tactile maps.

The types and forms of tactile maps began with the oldest and most basic or a mixed media format. This tactile map is produced by simply attaching objects to a substrate to represent different items or symbols. More recent tactile maps are produced by computers through different means.

Nowadays, two widely used means are thermoform and microcapsule paper (also called swell paper).

Thermoform is one of the methods of producing tactile maps. This process is also known as vacuum forming. Thermoform maps or plans are created from a process where a sheet of plastic is heated and vacuumed on top of a model or master. The master can be made from many substances, although certain materials are more durable than others. Since this process involves creating a mold, it is somewhat time consuming.

Microcapsule paper is the most common method of producing tactile maps. Microcapsule paper is a technique where the map is printed on special microcapsule paper. The microcapsule paper has a special coating of microcapsules of heat-reactive chemicals. Placing black ink on the paper prior to a heat process provides control over the raised surface areas. When the microcapsule paper is heated using a special device the black ink absorbs heat and the capsules on the surface of the paper expand providing the raised graphics. This type of map is not as robust as the Thermoform map, but can be produced with less effort and it is less expensive.

The advantages of this technique are the low cost of production (cost of microcapsule paper and special heating device), the ease of reproduction, and the fact that the tactile image is perceivable both by tactile and visual senses. However, the disadvantage is the fixed height of the raised graphics that cannot be changed and the fact that they might wear off after long time of extensive use of the material.

Effort and expense as well as easy reproduction were the fundamental reasons that made microcapsule paper the appropriate mean chosen for AT-Maps project and the production of pilot tactile maps.

Nowadays, the benefits of tactile maps can be combined with those of the verbal aids with the use of computer peripheral devices, such as audio-touchpads and touch tablets (e.g. IVEO, T3). Such devices are touch-sensitive pads that offer IVIs access to the benefits of tactile maps and verbal aids simultaneously while they explore tactile graphics with their fingers.

As far as maps are concerned, for AT-Maps, information can be represented by tactile symbols, audio symbols and audio-tactile symbols. That allows a vast amount of information to be simultaneously presented.

### 3.2.2 Procedure

The procedure of the pilot map production included the following main steps.

#### *3.2.2.1 Pilot tactile maps production*

The procedure of tactile maps production includes the following main steps.

1. Designing of maps (development of digital maps on computer),
2. Production of the tactile maps (printing maps on microcapsule paper),

During the first step of the procedure, digital maps were developed using the appropriate graphics design software. As mentioned above, three types of maps were produced:

1. Pilot tactile map for indoors,
2. Pilot tactile map for outdoors,
3. Physical pilot tactile map.

The optimal concept was that all symbols should be included in one A3 sized microcapsule paper for each type of map in order to allow the evaluation of the interactions between them.

However, a large number of symbols included in one A3 sized map could cause problems in their representation. It was soon proved that this was practically impossible since the large number of symbols did not allow enough space between them causing problems to the identification of the symbols.

In order to overcome this issue it was decided that each map should consist of two parts (a left part and a right part for each map) where it was then feasible to include all symbols in each type of map with enough free space around each symbol. Therefore each map was designed to fit in two A3 size microcapsule papers with portrait orientation where the two parts (left-right part) would be placed side by side.

The first part of each pilot map consisted of the left part of the map and was named left map and the second part of each pilot map consisted of the right part of the map and was named right map.

The second step of the procedure included the printing of the tactile maps. This step was implemented with the use of microcapsule paper. Consequently, the left part and right part of pilot maps for indoors, outdoors and physical map were produced on microcapsule paper.

#### *3.2.2.2 Pilot AT-Maps production*

The procedure of AT-Maps production includes the following main steps.

1. The procedure of tactile map production includes the following main steps.Designing of maps (development of digital maps on computer),
2. Production of the tactile maps (printing maps on microcapsule paper),
3. Setting of tactile maps on touch tablets and addition of audio/verbal information on predefined symbols.

During the first step of the procedure, digital maps were developed using the appropriate graphics design software. As mentioned above, three types of maps were produced:

4. Pilot tactile map for indoors,
5. Pilot tactile map for outdoors,
6. Physical pilot tactile map.

The optimal concept was that all symbols should be included in one A3 sized microcapsule paper for each type of map.

However, a large number of symbols included in one A3 sized map causes problems in their representation. It was soon proved that this was practically impossible since the large number of symbols did not allow enough space between them causing problems to the identification of the symbols.

However, in the case of AT-Maps the solution with a map consisted of two parts (left and right part placed side by side) is not feasible since this is not possible because of the restriction set by the size of the surface of the audio-touchpad devices that have a fixed size touch sensitive pad where the tactile graphics are placed on.

Therefore the pilot AT-Maps were designed on a 33,2cm x 26,2cm sized image in order to fit and comply with the dimensions of the touch sensitive pad of the audio-touchpad and hence included only a sample of tactile symbols.

The second step of the procedure included the printing of the tactile maps. This step was implemented with the use of microcapsule paper. Consequently, the pilot AT-Maps for indoors, outdoors and physical map were produced on a single 33,2cm x 26,2cm sized microcapsule paper.

Lastly, the third step of the procedure was the addition of audio/verbal information to the tactile maps. The IVEO Creator and IVEO Viewer software was used in order to create the digital Scalable Vector Graphics files (.SVG) and add audio information on the pilot maps elements leading to the final pilot AT-Maps.

### 3.2.3 Principles

The production of the pilot AT-Maps followed a number of principles that are associated to the construction of tactile maps, but always in conjunction with principles which are linked to the design of ATMAPS project.

According to the production of tactile maps, a tactile map is a representation of a printed map designed in a manner that is the most meaningful to the blind reader. It is not an exact reproduction of the actual map and the fact that pilot maps were fictional was quite helpful so as to stay in line with that principle.

All pilot maps where chosen to be fictional except of the pilot physical AT-Map that depicts a real map of the country of France. All other pilot maps were chosen to be fictional for one more reason. Since they were fictional, there was no need to create many different maps and additionally, the same maps could be used in all partner countries by all individuals with visual impairments during tests. Therefore the same instruments were used in all partner countries.

Each type of pilot tactile maps (indoors, outdoors, physical) included all symbols from all three categories (point, linear and areal symbols) created in previous task of the project. All symbols included were mixed in order to depict a fictional map:

1. **Point symbols**: A point symbol indicated a specific place within the map. It was usually placed alone, close to a line, or close to an area and represented specific data, such as a bus stop, a gas station, a city, etc.
2. **Linear symbols**: A linear symbol indicated linear information such as streets, rivers, important geographic boundaries, historical routes, pathways, etc. Lines represented either concrete or other imaginary information.
3. **Areal symbols**: An areal symbol indicated an area that has specific significance in the map, such as large areas, large buildings, states, different layers, different material, etc. Areas usually represented concrete portions of a map.

Moreover, in each type of pilot tactile map there was an attempt to include all symbols created in the Task 2.2. In this way it was easy to monitor the way symbols are recognized when included in maps and moreover this fundamental principle allows the evaluation of the interactions between all symbols.

For all pilot tactile maps map generalization was implemented in order the produced tactile maps to be readable by active touch.

1. Sometimes, many print illustrations are too complex (i.e., they contain too much information) to show tactually without simplification. Consideration was given so as not to over-simplify because that could detract from or interfere with the comprehension and intended purpose of each map.
2. Print information was eliminated only if it would not hinder the purpose of the map. Moreover, frames or borders around the map were eliminated as well.
3. Small areas were combined and shown as a larger area or linear features if they were important but too small to depict accurately. Additionally, a very small or narrow area or linear feature was proportionally distorted if this could assist in detection or labeling.
4. When a map was separated into sections (left part and right part of map), a transcriber's note indicated what type of division was made and the number of parts into which the illustration was divided. At the same time, when the map was separated into sections, a few points of reference would allow the reader to understand how the separate parts fit back together.

Additionally, there was an extra effort while designing the digital maps on the computer in order to avoid overlapping between symbols. Overlapping could create confusion at the task of evaluating symbols and that could lead to conflicting results.

Lastly, all pilot maps were designed and constructed in such a way so as to facilitate future evaluation of all symbols that carry specific information in the following tasks of the particular WP.

In the case of AT-Maps each type of pilot tactile maps (indoors, outdoors, physical), due to the restriction set by the size of the surface of the audio-touchpad devices, they only included a sample of symbols from all three categories (point, linear and areal symbols) created in previous task of the project. All symbols included were mixed in order to depict a fictional map except the physical map that represents France.

# 4. PILOT MAPS

Three types of pilot tactile maps and AT-maps were produced:

1. Pilot map for indoors
2. Pilot map for outdoors
3. Physical pilot map

Each type of pilot tactile map consisted of two parts (a left part and a right part) as an attempt to include all symbols in each pilot map type. As mentioned above, this decision offered the opportunity for the evaluation of the interactions between all symbols and simultaneously it was also necessary in order to overcome issues concerning their representation, due to the large number of symbols.

Symbols in each type of pilot map (indoors, outdoors, physical) were mixed, but in every single map produced there were symbols from all three categories (points, linear and aerial).

As a result and taking under consideration the fact that maps were fictional, a series of questions for each single symbol was answered before being added on each map. Based on the categorization of the symbols, questions were:

1. **Point symbols**:
    a. Are symbols far enough from a line to distinguish?
    b. Are symbols distinguishable from a close area?
2. **Linear symbols**:
    a. What does the line represent…???
        i. An imaginary boundary
        ii. Something to follow (river route, street, etc.)
        iii. A lead line to a label placed somewhere else?
    b. How can IVIs understand the line?
3. **Aerial symbols**:
    a. Is the area distinguishable from surrounding areas?
    b. How many distinct areas will be portrayed in the map?
    c. Are all areas significantly different?

d. How are the different areas defined…???
   i. Defined by a line (imaginary boundary)?
   ii. Defined by an abrupt change in textures?

Consequently, and by following all the principles mentioned above, six pilot tactile maps were produced (two for each pilot map type) and they were finally named as shown in the list below:

1. **Test_indoor_map_Final_LEFT**
2. **Test _indoor_map_Final_RIGHT**
3. **Test _outdoor_map_Final_LEFT**
4. **Test _outdoor_map_Final_RIGHT**
5. **Test _physical_map_Final_LEFT**
6. **Test _physical_map_Final_RIGHT**

The images of the six pilot tactile maps are presented in **Appendix I: Pilot maps**.

The same principles were applied for the production of the pilot AT-Maps. The images of the three pilot AT-Maps are presented in **Appendix II: Pilot Audio-Tactile maps**

## REFERENCES

Abu Doush, I., Pontelli, E., Simon, D., Son, T.C., Ma, O. (2009). Making Microsoft Excel™: multimodal presentation of charts. *Proceedings of the 11th international ACM SIGACCESS conference on Computers and accessibility, pp.*147-154.

Brock, A., Truillet, P., Oriola, B., Picard, D. & Jouffrais, C. (2012). Design and user satisfaction of interaction maps for visually impaired people. In: Miesenberger K, Karshmer A, Penaz P, Zagler W, editors. *ICCHP*, 7383:544-551.

Brown, D.J., McHugh, D., Standen, P., Evett, L., Shopland, N. & Battersby, S. (2011). Designing location-based learning experiences for people with intellectual disabilities and additional sensory impairments. *Comput Educ,* pp.11-20.

Caddeo, P., Fornara, F., Nenci, A. & Piroddi A. (2006). Wayfinding tasks in visually impaired people: the role of tactile maps, *Cognitive Processing*, 7(1), pp.168-169.

Espinosa, M. A., Ungar, S., Ochaita, E., Blades, M. & Spencer, C. (1998). Comparing Methods for Introducing Blind and Visually Impaired People to Unfamiliar Urban Environments, *J Environmental Psychology,* 18(3), pp.277-287.

Habel, C., Kerzel, M. & Lohmann, K. (2010). Verbal Assistance in Tactile-Map Explorations: A Case for Visual Representations and Reasoning, *in Proc. of Visual Representations and Reasoning*.

Jacobson, R. D. (1998). Navigating maps with little or no sight: An audio-tactile approach. In: *Proc. of the workshop on Content Visualization and Intermedia Representations* (CVIR), pp.95-102.

Jansson, G. (2000). Spatial orientation and mobility of people with visual impairment, in B. Silverstone, M. A. Lang, B. Rosenthal, and E. E. Faye (Eds.), *The Lighthouse handbook on visual impairment and rehabilitation* (pp.379–397). New York: Oxford University Press, 2000.

Kitchin, R.M. (1994). Cognitive maps: What are they and why study them? *J Environ Psychol*, 14:pp.1-19.

Kitchin, R.M., Blades, M. & Golledge, R.G. (1997). Understanding spatial concepts at geographic scale without the use of vision. *Prog Hum Geog*, 21:pp.225-242.

Kitchin, R.M. & Jacobson, R.D. (1997). Techniques to Collect and Analyze the Cognitive Map Knowledge of Persons with Visual Impairment or Blindness: Issues of Validity. *J Visual Impair Blin,* 91:pp.360-376.

Lahav, O. & Mioduser, D. (2008) Haptic-feedback support for cognitive mapping of unknown spaces by people who are blind, *Int J Hum-Comput St*, 66(1), pp.23-35.

Landau, S., Russell, M. & Erin J.N. (2006). Using the Talking Tactile Tablet as a Testing Accommodation, *RE:view,* 38(1), pp.7-21.

Maor, D., Currie, J. & Drewry, R. (2011). The effectiveness of assistive technologies for children with special needs: a review of research-based studies. *European Journal of Special Needs Education,* 26(3), pp.283-298.

Papadopoulos, K., Koustriava, E. & Kartasidou, L. (2012). Spatial Coding of Individuals With Visual Impairments, *Journal of Special Education*, 46(3), pp.180-190.

Papadopoulos, K., Papadimitriou, K. & Koutsoklenis, A. (2012). The role of auditory cues in the spatial knowledge of blind individuals, *Int J Special Education,* 27(2), pp.169-180.

Thinus-Blanc, C. & Gaunet, F. (1997). Representation of space in blind persons: Vision as a spatial sense?, *Psychol Bull* , 121(1):20-42.

Thorndyke, P. W. & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation, *Cognitive Psychology*, 14(4), pp.560–589.

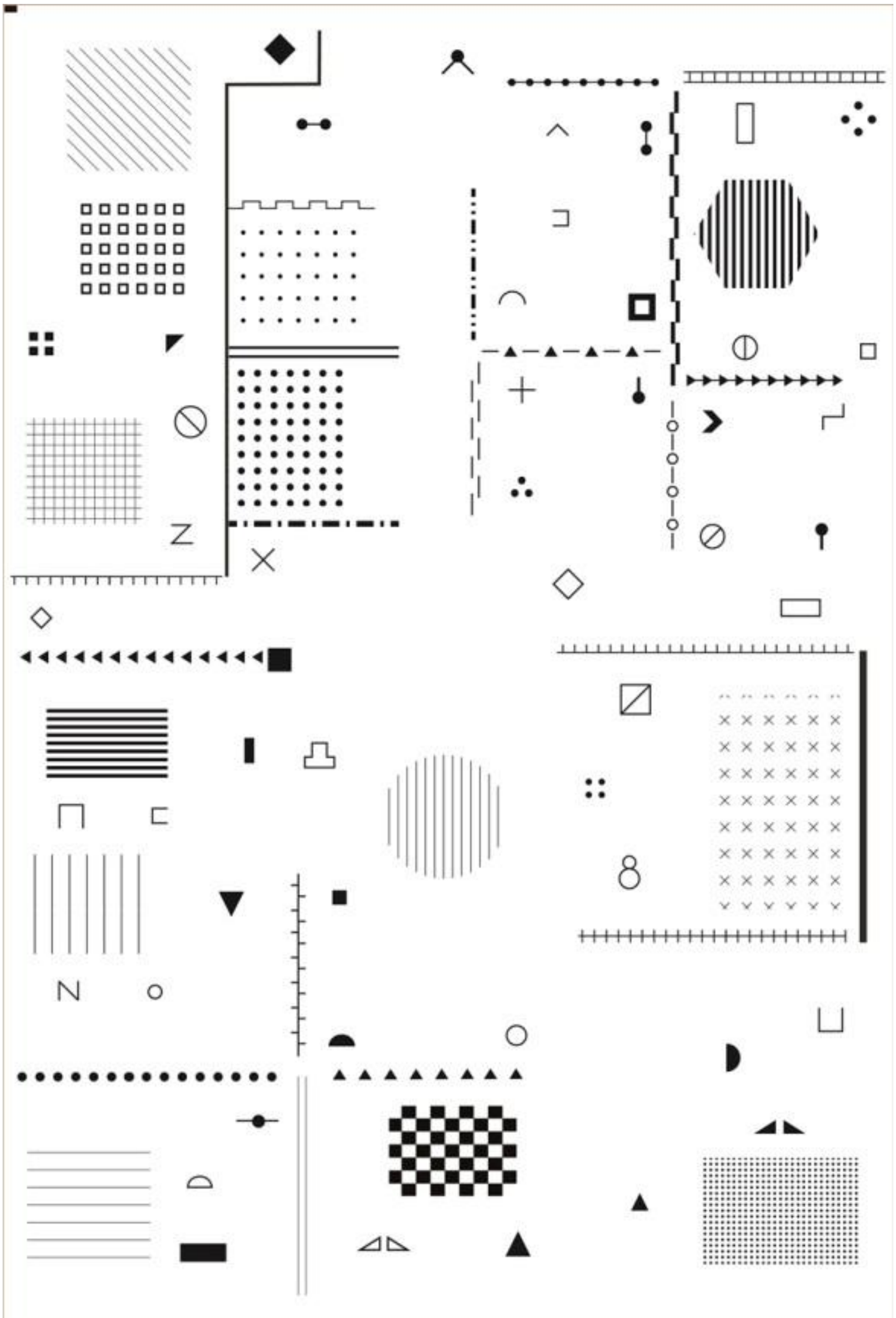
Ungar, S., Blades, M. & Spencer, C. (1993). The role of tactile maps in mobility training, *British Journal of Visual Impairment,* 11(2), pp.59-62.

Wang, B., Li, B., Hedgpeth, T. & Haven, T. (2009). Instant Tactile-audio Map: Enabling Access to Digital Maps for People with Visual Impairment, *in Proc. of the 11th international ACM SIGACCESS conference on computers and accessibility*, pp.43–50.

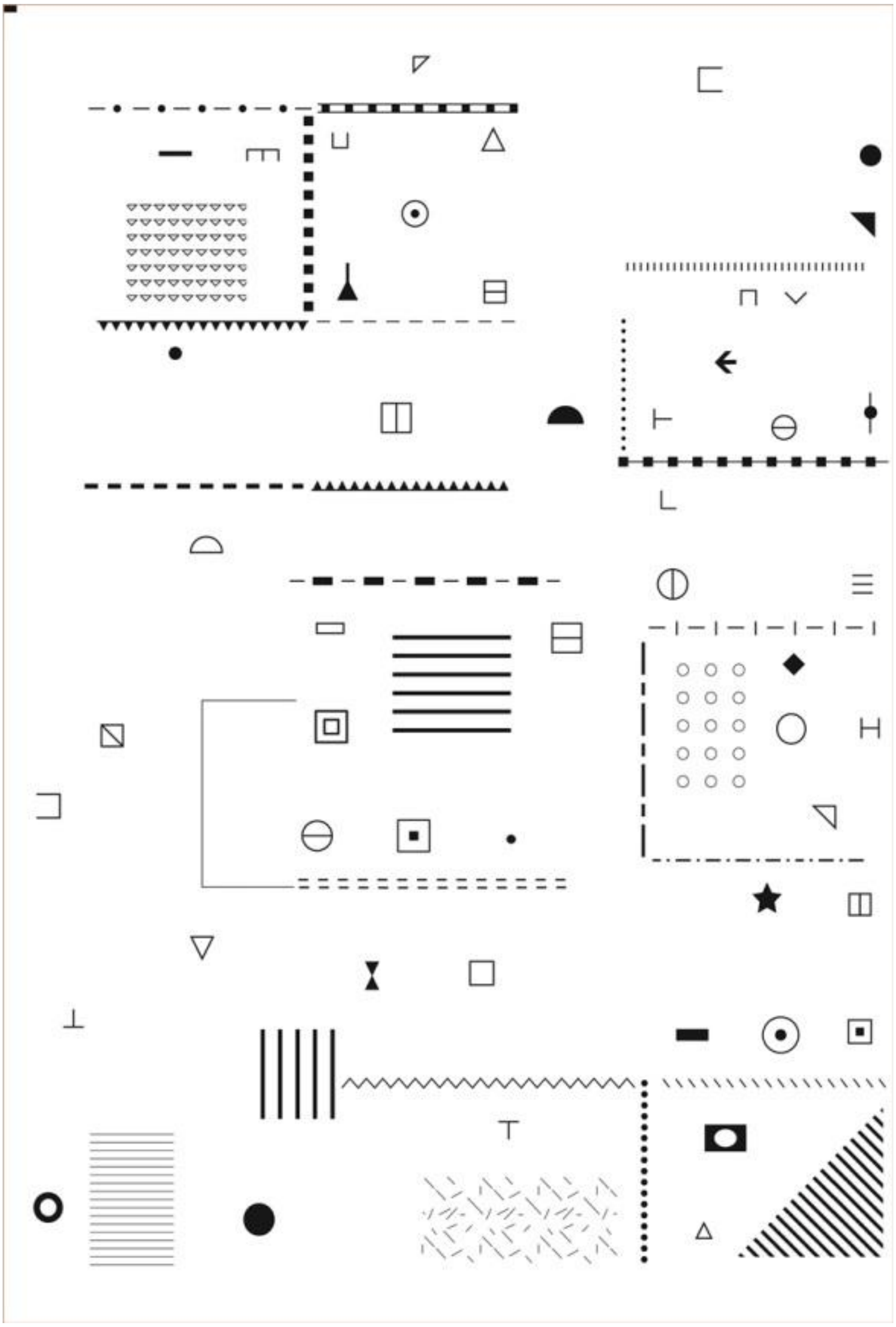
Warren, D.H. (1994). Blindness and Children: An individual Differences Approach. Cambridge: Cambridge University Press.

## Appendix I: Pilot Tactile maps

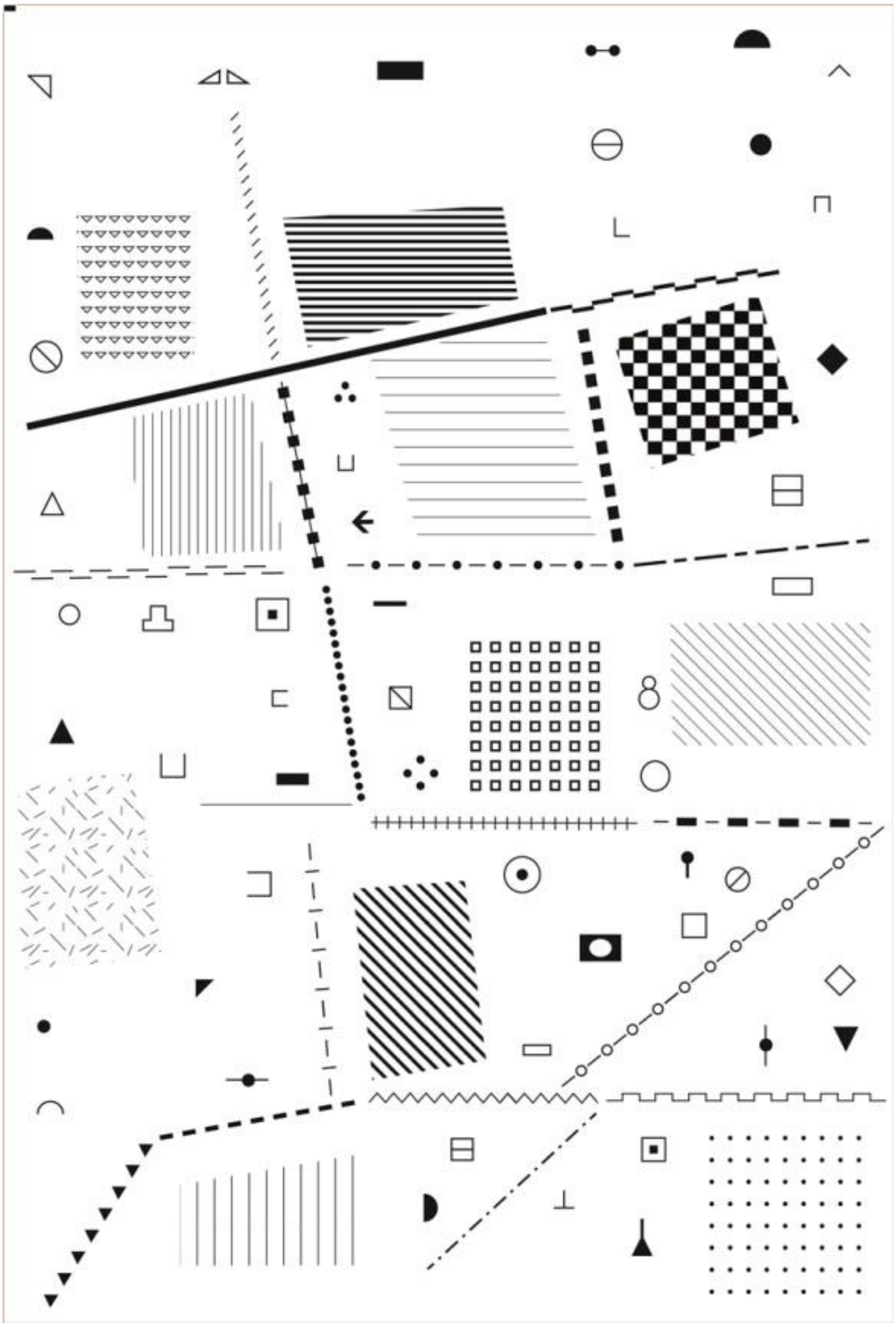
### Test_indoor_map_Final_LEFT



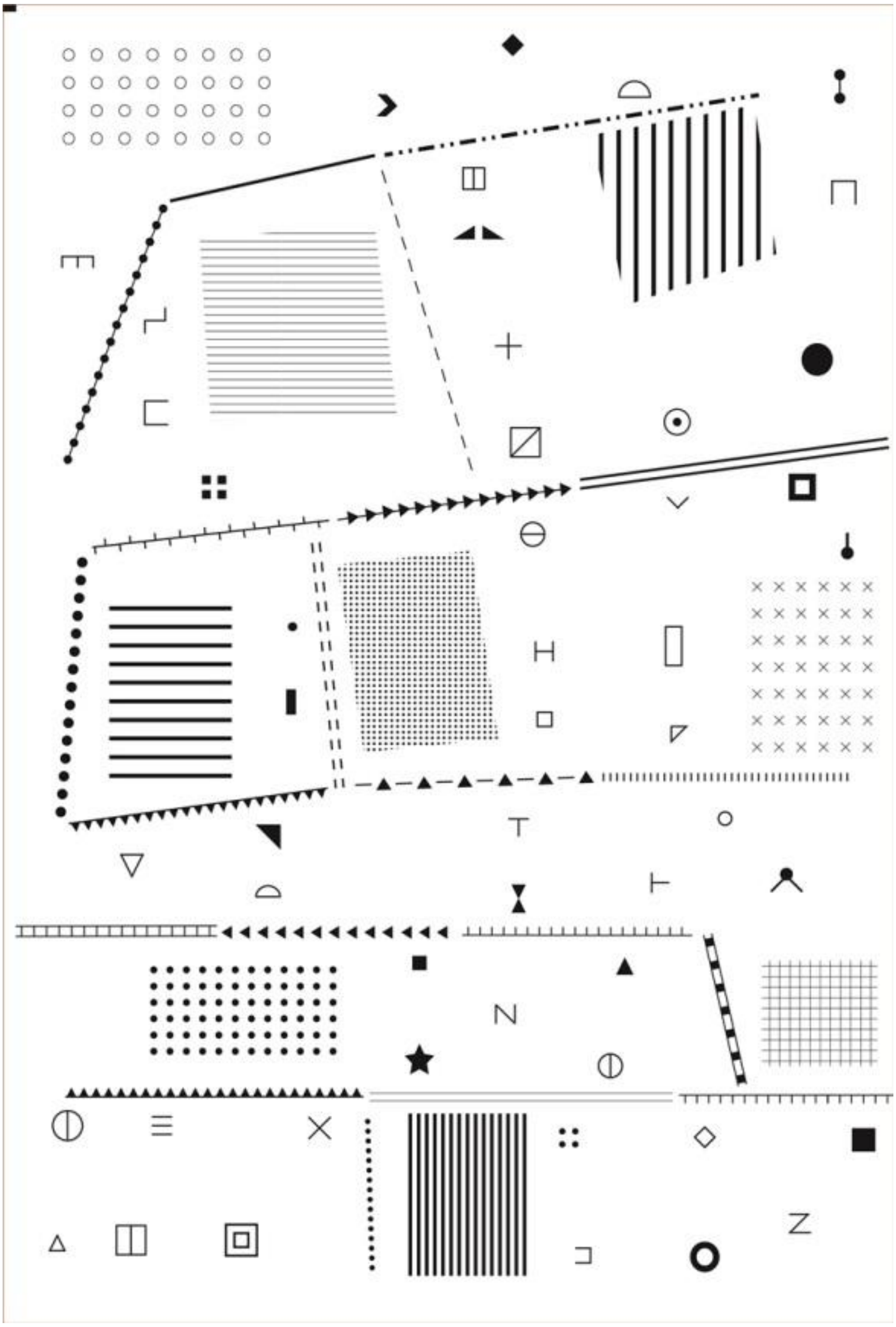
Test_indoor_map_Final_RIGHT



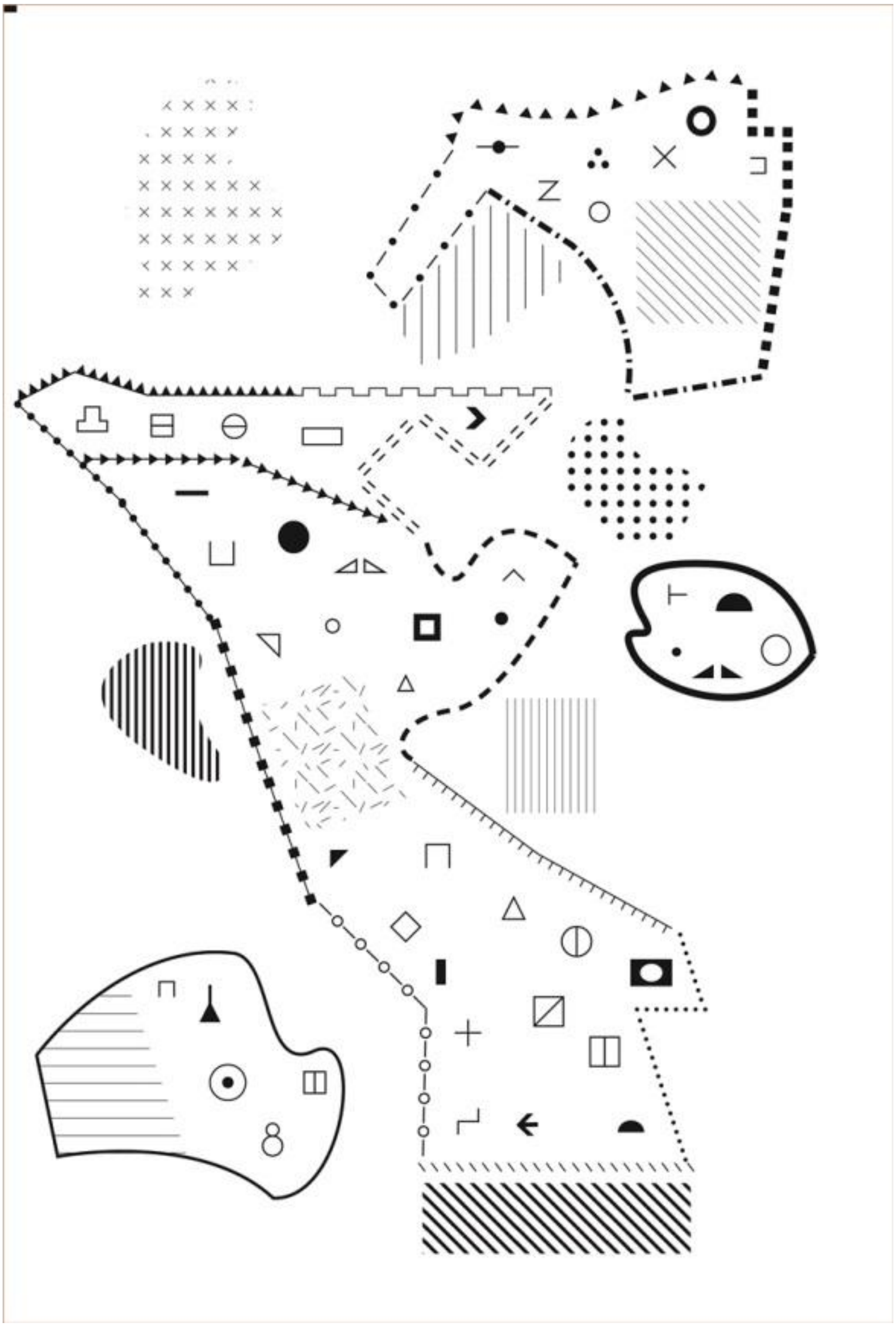
Test_outdoor_map_Final_LEFT



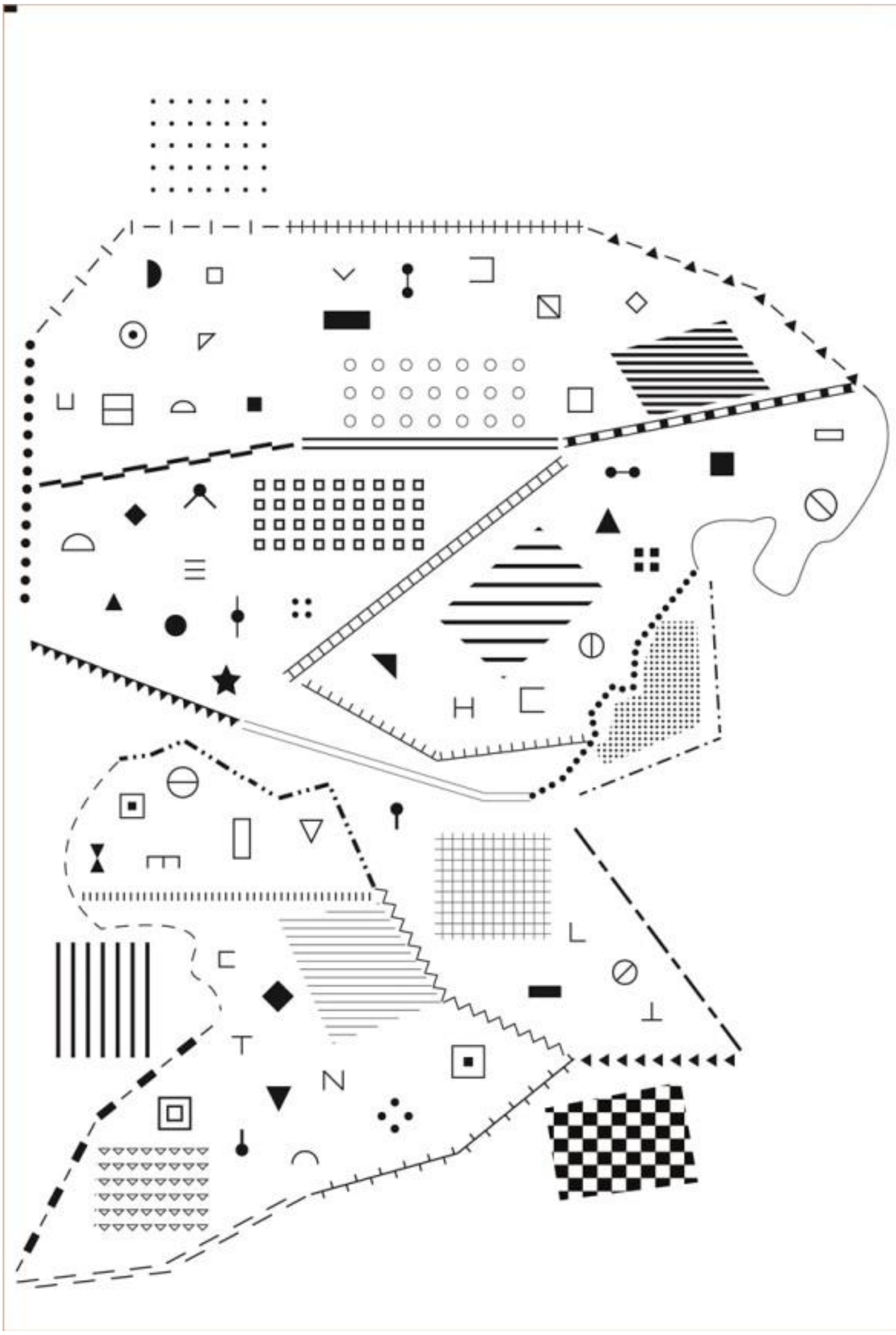
**Test_outdoor_map_Final_RIGHT**



## Test_physical_map_Final_LEFT

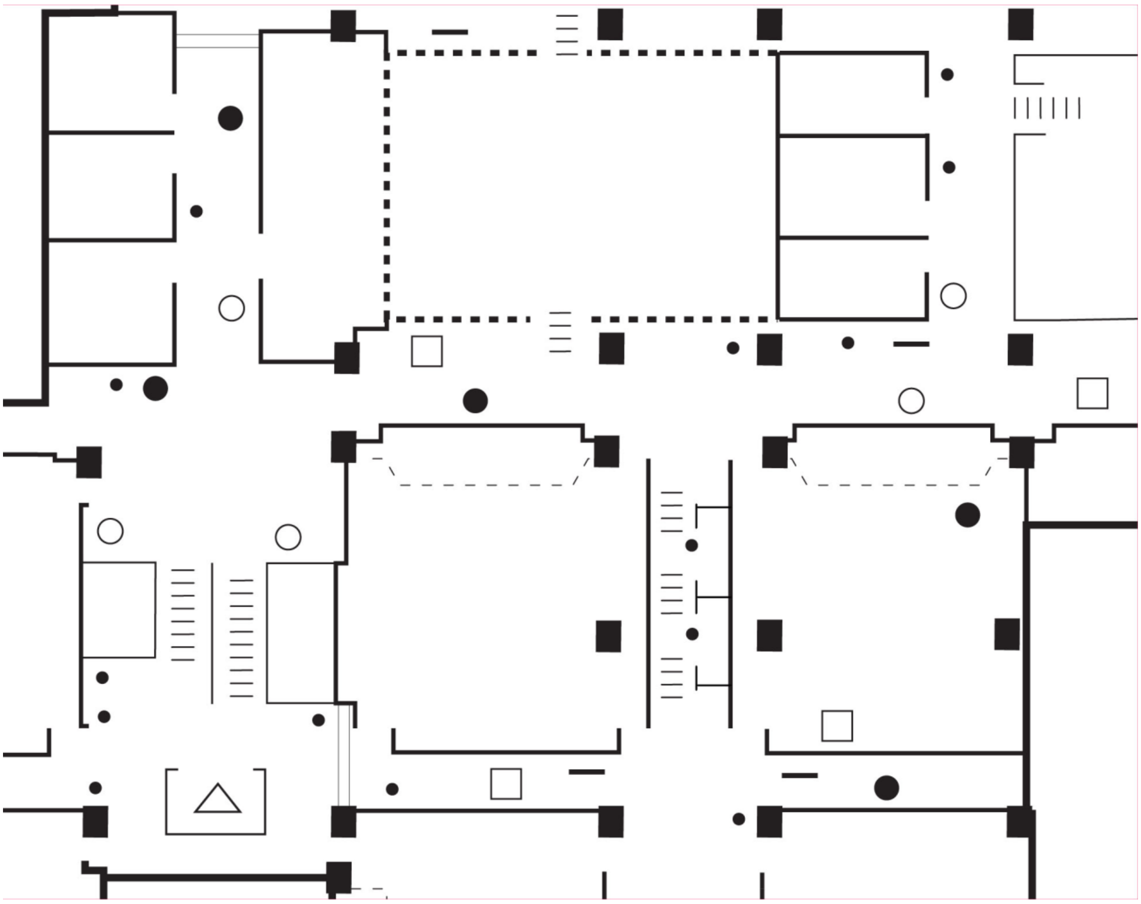


**Test_physical_map_Final_RIGHT**



## Appendix II: Pilot Audio-Tactile maps

### Indoors pilot AT-Map



## Oudoors pilot AT-Map

# Physical pilot AT-Map