Improving Tactile Navigation in Public Buildings for Blind and Visually Impaired People

Muyun Xiao

It’s about touch.

Improving Tactile Navigation in Public Buildings for Blind and Visually Impaired People

By

Muyun Xiao

Collaborating with Stichting Geluid in Zicht

Supervisor Team:
Dr. R. van Egmond, Dr. M.W.A. Wijntjes
Hannes Wallrafen, Henke Baars

December 2011

Preface

As a designer, visual design is a realm that I have special interest in. In fact, it was the enthusiasm for exploring aesthetics and styling that motivated me to become an industrial design engineering student six years ago. After starting my master study in Delft University of Technology, I realized that there is another domain that I had never explored before, tactile design. How to design something apart from visual aspect? Bearing this question in mind, I started to search for a graduation project to offer me an opportunity to find the answer.

In front of you is the thesis I have been working on for about eight months. The assignment was developed on behalf and in cooperation with Geluid in Zicht, an organization located in Amsterdam. During the past eight months, I explored the topic of tactility, especially from the perspective of blind and visually impaired people, and practically applied the knowledge to develop a navigation solution for them. I experienced a lot of fun and struggle to iteratively set up researches, build up things for testing and gather participants. My knowledge of the once unknown field was gained, extended, improved and increased all the way along through this project.

Now this project has come to an end. However, this is not the end of my exploration of tactile design, where countless possibilities could be discovered and you would always be surprised at what a designer could do without using visual aspect! I'm sure I will start another journey around this topic soon.

Hoping you find pleasure in reading this.

Muyun Xiao

December 2011

Acknowledgement

This thesis would not have come into existence without the supervision of my mentors at both TU Delft and Geluid in Zicht. Therefore, on beforehand, I am indebted to René van Egmond, Maarten Wijntjes, Henke Baars and Hannes Wallrafen. Thanks for your time, suggestions, and shared enthusiasm. I owe my gratitude to the partners of Geluid in Zicht, Ans Withagen, Robert de Kloe and Marten van Doorn, who gave very helpful insights and advices on tactility and helped me organize studies in the Hague city hall and Bartiméus, Zeist. Additionally, I would like to thank you all people of ID-StudioLab for offering a place for building prototypes, giving your support, showing your interests, and giving me a big smile every time we met. Special thanks to Aadjan van der Helm and Rob Luxen for your kind help during prototyping.

It is an honor for me to work with Xiaowei Wang. Thanks for sharing thoughts, inspiring me, and encouraging me when I was distressed. For all participants either volunteered or invited, I'm grateful for your full support. The insights I gained from you are immeasurable. Finally, I would like to deeply thank my parents for standing by me all the time, my friends for your encouragement and my little cat, Zhunzhun, for your companion during the last three months.

Thank you, Delft. Thank you, the Netherlands!

由衷地感谢我的家人和朋友们。两年来的留学生活离不开你们的支持、鼓舞和陪伴。特别感谢爸爸和妈妈、感谢晓玮、淮淮。

牧云，于鹿特丹

二〇一一年尾

Abstract

The limited accessibility to public buildings and being lack in rich experience of these buildings are the main troubles for blind and visually impaired (B&VI) people when exposed to the unfamiliar surroundings without sufficient guidance. Neither of the current navigation tools nor the accessibility design could fulfil both the functional as well as the experiential demands for indoor orientation. Collaborating with Geluid in Zicht, this graduation project focuses on developing a tactile navigation tool to fill up the above-mentioned blank.

The main approach of this project is research through design, including iterative research and design cycles. At the beginning, a literature research and field explorations were carried out to broadly explore the topic; thereafter several user interviews were done, with a persona made to describe the target user group and a design goal established. Starting from a preliminary concept, the follow-up researches with prototyping and testing involved were conducted with the help of diverse techniques including creative session, generic group session, observation and interview.

The literature suggests that two cognitive processes, (spatial) memory and (object) recognition are distinct when using a tactile navigation tool. Spatial memory is about recording the spatial orientation of the environment. Object recognition is about understanding the meanings of the objects. The insufficient facilitation of the two processes results in the incompetence of the current tactile navigation tools. Based on that as well as the user needs gained from interviews, a design goal was set, which was to develop an intuitive tool offering efficient functional information to facilitate the independent indoor orientation of blind and visually impaired people. Accordingly, the design criteria were developed. Then a preliminary concept was initiated, which is to design a set of haptic icons explaining the common places or objects in public buildings. The icons would be placed on a model base depending on the layout of the building. By touching the icons, B&VI people would intuitively understand the functions of these objects (object recognition) and the locations of these common places (spatial memory). The haptic icons could be standardized, produced and universally applied in public buildings. Certain complements could be made depending on a particular situation. From a long-term perspective, the modular design allows the integration of sound features.

To further develop the preliminary concept, the follow-up investigations were structured in a parallel manner, including a spatial layout study as well as a haptic icon exploration. Both of them started from blindfolded participants and then involved B&VI users. The former study contributed to the latter one. The spatial layout study aimed at comparing the functionality of two-dimensional tactile map and three-dimensional scale model by developing two prototypes

based on the ground floor plan of The Hague City Hall. In the study, a field navigation task was given to examine the functionality of each prototype. The spatial layout research concludes that 3D scale model is superior to 2D tactile map. The spatial information presented in 3D scale model requires less cognitive efforts for spatial visualization. Moreover, the 3D scale model has advantage of potentially integrating sound as well as enriching experience of a building. To conclude the spatial layout study, generic guidelines for designing a model base were given regarding to how to choose a proper size, a using direction, how to incorporate scale, how to embed a sufficient amount of landmarks, and the necessities of including dimension in height, excluding pre-set routes, clearly indicating potential hazards and incorporating material features.

The haptic icon exploration started from a generative group session with B&VI people to see how they perceive the common places of public buildings. After a creative session with 30 design students from TU Delft, several initial ideas were came up and prototyped in both a 2.5D and a 3D version for the first evaluation, which demonstrated the superiority of 3D version. Thus, the second evaluation placed more focus on examining the identification of the refined 3D icons. The haptic exploration manifests that the perception of the 3D haptic icons is accurate and fast. In addition, the B&VI participants are optimistic about the concept. The results also highlight the importance of using representative objects with specific materials to design the icons. To conclude the haptic icon exploration, generic guidelines for designing haptic icons were generated, regarding the form choice, the necessity of integrating material features, how to symbolically represent the haptic icons as a set, how to choose representative objects, how to reach balance between abstraction and complexity, how to embed the icons in context and the promising possibility of combining auditory features.

The outcomes of the spatial layout and the haptic icon exploration resulted in a navigation tool named Haptic Guide. It consists of eight haptic icons for reception, cloakroom, toilet, door, elevator, stairs, café and smoking room of a public building, by means of redesigning the geometry shape of a representative object and incorporating specific material features.

Haptic Guide is used with a 3D scale model. By placing the haptic icons in certain positions, the 3D scale model facilitates B&VI people to recognize the above mentioned eight places or objects and their locations in the represented building in reality. Based on the spatial layout information provided by the model base, users are able to plan routes to these places or objects and to use them as landmarks with their own navigation strategy.

The Haptic Guide could be universally applied to diverse public buildings. The modular design makes it promising to combine auditory or other information sources, which would make it even more functional and interesting.

An experiment was conducted to evaluate Haptic Guide. Ten blindfolded participants performed several navigation tasks. The results suggest that Haptic Guide is a promising navigation tool for indoor navigation. It is intuitive for people to use Haptic Guide and the provided information is efficient and substantially functional. Recommendations were given on future research and design directions, including how to improve the cons of the current design.

Contents

CHAPTER ONE.

INTRODUCTION

Worldwide there are around 161 million people who are visually impaired (B&VI) till 2002, with 37 million blind and 124 million having low vision. This special group has attracted more and more attention from the designers who endeavour to make them live an easier life. Compared to sighted people, B&VI have to rely more on their haptic and auditory perception. These two senses are thus the main interest of designers to crack the daily problems of B&VI. However, no satisfactory solution has been provided to their problem of limited accessibility to public buildings and lack of rich experience of these buildings.

Collaborating with Geluid in Zicht, an organization located in Amsterdam, this graduation project focuses on filling up the blank mentioned above. More specifically, this graduation project focuses on using tactile information to facilitate the orientation inside public buildings for blind and visually impaired people. The initiators of this foundation, Hannes Wallrafen and Henke Baars were actively involved in this project and local partners, Rijksgebouwendienst, Koninklijke Visio and Bartiméus, supported the field research and target group research by providing the access to the public buildings and the blind and visual impaired.

1.1 PROBLEM STATEMENT

The limited accessibility to public buildings and being lack in rich experience of these buildings are the main trouble for blind and visual impaired people when exposed to the unfamiliar surroundings without sufficient guidance. Currently, the accessibility design is limited to the isolated functional needs, such as ensuring designated pedestrian pathways and supporting people with mobility impairments. It has not got into providing a holistic overview of the spatial structure yet. Next to the functional aspect, the experiential aspect is equally important. By enriching their experience of public buildings, their comfort and ease would be increased. However, their demands and many ways they experience buildings and spaces have not aroused enough attention, when designing a building and its furnishment. Besides, the experiential demands of B&VI, which could be fulfilled by leveraging other sensations but vision, have been overlooked as well.

In general, a scale model of the building displays the exterior as to provide an overall perspective. At the moment, the scale models are poorly designed, especially its interactive usage, not to mention that the majorities are visually orientated. When the focus moves from exterior to interior, more unsolved questions appear such as how a scale model could benefit B&VI, especially in an experiential way. The reasons behind could be the complexity of the interior of public buildings, and the neglect of the experiential demands of B&VI towards these buildings.

Through tactile perception, people are able to feel the texture, heat properties of things and pain by means of the cutaneous sensors that we have in our hands and bodies. Haptic perception is the process of recognizing objects, especially the form, by touch. As mentioned, haptic perception plays an important role in B&VI people's everyday life, to compensate for the lack of vision. Based on that, lots of products have been developed and they obtained positive feedbacks from the public. This implies that, for an interior scale model, representing needed information by means of tactility could be helpful to improve the accessibility of B&VI to public buildings. Besides, transferring the interaction in a tactile way could enhance their experience of these buildings as well.

1.2 GOAL

This project aims at improving the accessibility of blind and visually impaired people to public buildings and enriching their experience of these buildings via tactile information. By allowing B&VI to explore the space by hands, in terms of functionality, the tactile scale model would help their navigation and route planning inside the building. On the other hand, in terms of experience, the model would enhance their experiential perception of the building by utilizing touch sensation to compensate their lack of vision.

1.3 SCOPE

A couple of factors are set for the project scope. First of all, the tactile aspect should be placed at the first place; nevertheless other senses such as the auditory perception could also be utilized as compensation. Secondly, the project does not focus on a specific building, which means the end results should be able to apply universally to all public buildings. Additionally, since the project is the starting point of a two-year project, the end results should be able to benefit the Geluid in Zicht. As the last factor, sighted people should also be taken into account for the reason of aesthetics, so the final design should be eye catchy.

1.4 METHODS

To solve the aforementioned problem, the main approach of this project is research by design, which means iterative research and design cycles are included. The whole process is divided into three phases, which is going to be discussed in-depth throughout this thesis. An overview of the method could be found in Figure 1.1.

The problem explorations phase (Chapter 2) consists of a literature research and several initial explorations. The latter includes the first field exploration, an exploration of the Tactual Profile, an instrument for educating blind and visual impaired juniors and a field research for four public buildings. The second phase is a user-centered conceptualization (Chapter 3) of iterative prototyping and testing with real users and blindfolded participants. It consisted of multiple studies, tests, interviews, and observations that focused on the form and content of the final design (Chapter 4). The last phase includes final prototyping and an evaluative study (Chapter 5), as well as a reflection on self-performance and process (Chapter 6).

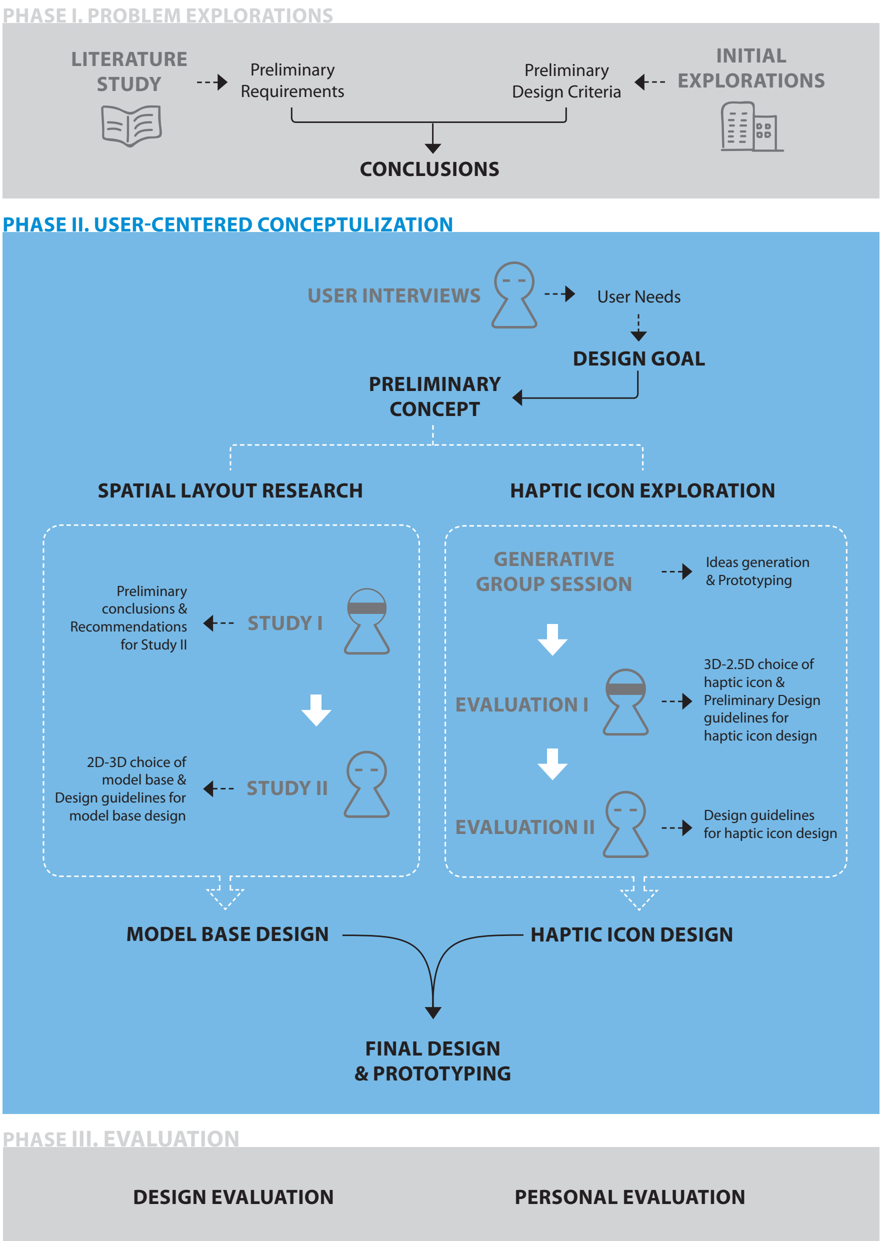
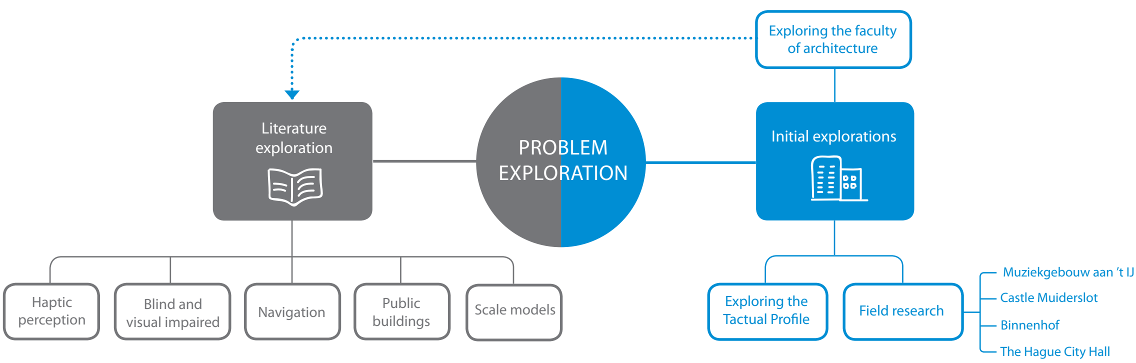


Figure 1.1 An overview of the methods

CHAPTER TWO.
PROBLEM EXPLORATIONS

In order to develop a tool for blind and visually impaired people to use for orientation inside public buildings, it is necessary to understand the aspects related to the topic. A field exploration was carried out at the faculty of architecture, Delft University of Technology (TU Delft) to determine which aspects should be investigated in the literature research. Thereafter a literature research, which focused on haptic perception, the blind and visual impaired, navigation, public buildings and scale models was conducted. At the meantime, to understand the application of haptic perception, an exploration of the Tactual Profile was carried out as well as interviewing the initiator, Ans Withagen. Additionally, a field research of four public buildings was performed to investigate what aspects, in terms of both functionality and experienced, could be implemented in the design to reach the project goal.

Figure 2.1 the framework of the problem explorations phase



2.1 FIRST INSIGHTS: EXPLORING THE FACULTY OF ARCHITECTURE

2.1.1 Goal

To determine what aspects, in terms of functionality and experience, could be relevant to the project, an initial field exploration was performed at the Faculty of Architecture, TU Delft. The findings of the study also contributed to the construction of the literature research carried out later. The building was selected as the case because it has diverse possibilities to explore. Considering the functional aspects, the building exhibits many architectural features such as multiple floors, diverse areas and wings. For the experiential aspect, the interior has diverse materials and the styles differ from area to area. Additionally, the building is easy to access, which means the exploration could be conducted freely.

2.1.2 Method

As one focus of the study is the experiential perception, a mind map (Figure 2.2) was used as the format for taking notes when exploring the tactual experience inside the building. Sonneveld (2007) developped this mindmap to help people describe their tactual exprience [2]. Meanwhile, pictures were taken to record dominant and representative features of different areas. It is notable that the visual input was not excluded in the study. As mentioned above, the initial exploration meant to be as broad as possible and one assumption was that visual input could contribute a lot to the experiential perception of a building. Therefore, it is interesting to see what contribution visual perception has and how these contributions could be compensated by other sensations.

2.1.3 Results

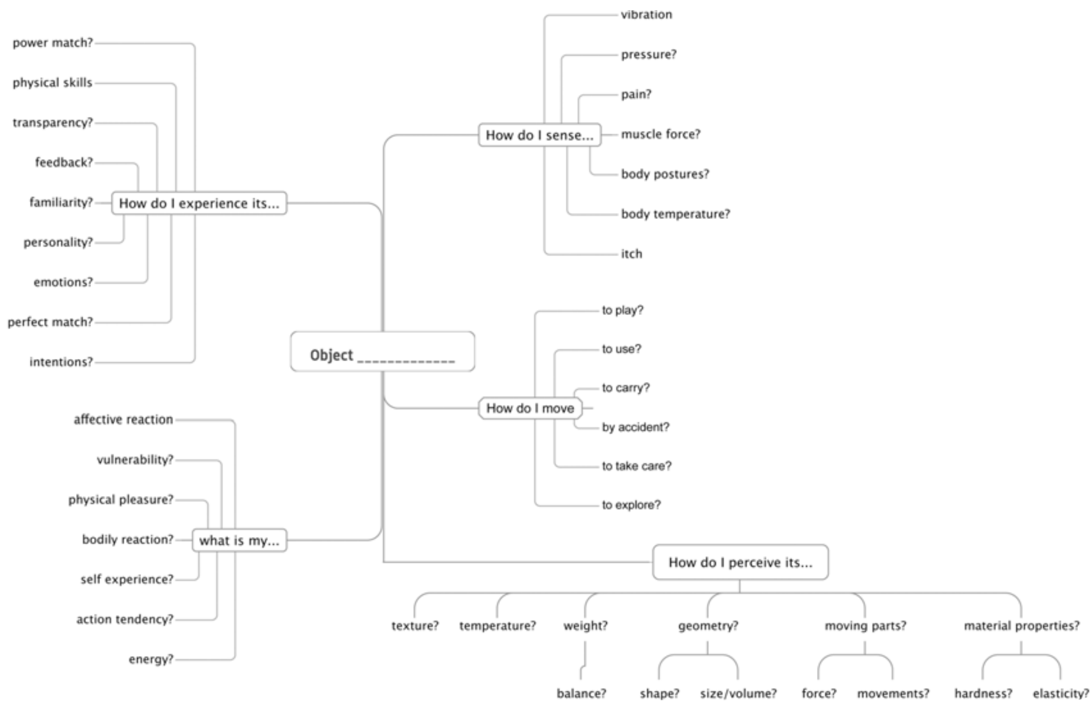
The use of the mind map was modified as planned during the exploration. At the beginning, the focus was on the most representative materials of each area. However, since limited hand movements could be exerted on the wall, floor, table and so on, the insights of diverse aspects of tactual experience could hardly be generated. In contrast, each branch of the mind map could be filled out when reflecting on the overall experience of a space, with the tactual experience involved as well. Therefore, in order to generate as much rich insights as possible, the use of the tool was changed.

In the end, four mind maps were filled out to record the tactual experience of materials and six mind maps were used to summarize the general impression towards different areas of the building (see more details in Appendix I).

2.1.4 Findings

From the perspective of sighted people, the overall experience of a public building mostly relies on the visual perception, which confirms the assumption made before the study. Olfactory, auditory and tactile senses contribute to the personal impression as well, but not that substantially as vision does. The tactual interactions between buildings and visitors mainly take place in stepping on the floor, grabbing doorknob and handrail, sitting on the chair and leaning on the seat back, etc. The interactive way of touching is passive and the tactual experience makes small contribution to the overall experience of a public building. The dominant tactile aspects are texture, temperature, pressure, hardness and elasticity. For B&VI people, the visual dominance is obviously not present. In order to acquire sufficient information, other sensations but vision are more actively involved. However, the gained information is still fragmented and limited. Overall, the situation of the B&VI is much the same.

Figure 2.2 a mind map used for exploring the tactual experience



2.2 LITERATURE EXPLORATION

To lay a solid theoretical foundation for the project, a literature research was executed with five sub topics: haptic perception, the blind and visual impaired people, their navigation issue, current public building design and the scale model development. These are the aspects considered as most relevant and worth exploring.

2.2.1 Haptic perception

Haptic perception refers to the process of perceiving objects through touch. It is a complex perceptual system that encodes inputs from cutaneous as well as from kinesthesic receptors distributed over our body [1]. Haptic perception requires the complementary information from tactual acuity, active movement and spatial cues. The active movement is narrowly linked to perception in the haptic sense. It tends to guide the observer's attention towards the tactual properties, which are related to the substance, the structure, the surface and the moving parts of the object [2]. In contrast, passive movement tends to make the observer focus on his or her subjectively bodily sensations.

It is widely accepted that haptic perception differs from visual perception in many respects. Vision is recognized for providing highly precise spatial and temporal information, whereas the haptic system is especially effective at processing the material characteristics of surfaces and objects. Differentiating from vision, the 'bandwidth' of haptic is much lower: the fingertip's resolution is far less than the eye. When the field is limited, information would be perceived serially by touch.

The vision-touch comparisons, which indicate that haptic performance is poor, are inappropriate to assess haptic object recognition, due to the use of artificial objects or two-dimensional displays [24]. Instead, when using real objects, haptic object recognition can be remarkably fast and accurate [24]. Furthermore, perceiving a three- dimensional object was proved to be more efficient than perceiving a two- dimensional object by Lederman, Klaztzky, Chataway and Summers (1990). When recognizing a three-dimensional common object, no visual translation stage is postulated, but the cutaneous, kinesthetic and thermal apparatus of the haptic system are used to process and represent information without the help of vision [25]. In contrast, when considering the corresponding two-dimensional object recognition, the extent to which the haptic system is forced to extract information sequentially is one critical factor that impairs the performance.

Findings

When associating the above-mentioned theories to this project, it is notable that:

- Active hand movement plays an important role in haptic perception since the focus of the users should be placed on the tactile scale model rather than their own bodily sensation, in order to perceive the spatial information.
- The unique feature of haptic perception, which is about the effectiveness of processing material characteristics, emphasizes on the feasibility of

presenting spatial information in a tactile manner.

- Haptic object recognition could be efficient, especially three-dimensional objects are used rather than two-dimensional ones.

2.2.2 Blind and Visually Impaired

To understand how and why the blind and visual impaired behave differently from sighted people, two critical aspects including their cognitive development and cross-modal plasticity are discussed briefly in the following paragraphs.

Similarities and differences between B&VI and sighted people

Both similarities and difference exist between B&VI and sighted people concerning the cognitive development. Visually impaired or blind individuals free from neurological trauma have similar test results to sighted individuals with regard to the cognitive intellectual processes of verbal comprehension, verbal fluency, inductive reasoning or concept formation, numerical reasoning, memory perceptual speed and spatial visualization. However, during the development of these cognitive processes, the B&VI differentiate from sighted people in certain respects:

- Blind children tend to learn meaning of words through a "decontextualized" manner [4] that the meaning definition is based on the verbally and conceptual relationships of the words.
- The sighted children have a better grasp of the use of contextual information, but a less developed ability to semantically associate those elements together, however, blind children have better developed ability to "link" information.
- Blind children had difficulty in applying the knowledge in everyday situations even when they may have understood visual words.

Morgan (1999) confirmed that blind individuals would often have over-developed abilities in other sensory functions to compensate for their lack of vision. Despite this, in term of cognitive aspects of haptic form recognition, different strategies are applied to encode objects: blind subjects tend to rely more on imagery-coding strategies while sighted subjects encoded use strategies that involved strong verbal components instead.

Cross modal plasticity

The cross modal plasticity is the adaptive reorganization of neurons to integrate the function of two or more sensory systems. For the blind without visual experience, visual system is still active. The information reaching the visually deprived 'visual 'cortex is coming from other sources since all afferents from the eyes to the visual cortex are largely atrophied: the born-blind subjects are capable of using other sensory modalities to integrate these inputs via the visual system to produce concepts capable of graphical representation [5]. To process spatial information, sighted and blind participants both use the dorsal stream which suggest that cross modal plasticity in the blind re-routed the dorsal visual stream to work with the sense of touch rather than changing the overall function of the stream.

Findings

Some aspects of the theories mentioned above might be advantageously used in guiding the final design.

First, it should be noted that there is no huge difference between B&VI and sighted people in their cognitive abilities. However, the B&VI tend to encode objects by using imagery-coding strategies. This conclusion should be taken into account during the design phase since the spatial cognition process of B&VI people lays the theoretical basis for the whole project.

Secondly, the conclusion that blind individuals have over-developed abilities in other sensory functions to compensate for their lack of vision demonstrates the practicability of using tactile information to facilitate their navigation inside public buildings. In addition, the feasibility is confirmed again concerning that the blind utilize the visual system that is still active to work with the sense of touch when processing spatial information.

2.2.3 Navigation

The knowledge of the actual navigational capabilities of B&VI people plays a critical role since the project aims at designing a 'navigation tool'. Therefore, it is necessary to clarify which of the possessed capabilities could be leveraged and what functions should be included in the final design. Additionally, understanding the current solutions for spatial navigation would be helpful to know the potential possibilities and limitations. Thus, the main findings covering these two aspects are reported.

Navigation skills

The navigation of B&VI people subsumes five general processes: sensing, creating a mental trace of route, forming a survey representation of the disposition or layout of spatial features, computing desired trajectories and executing those trajectories [7]. It's worth noting that one or more of these processes could be absent in any particular situation. In general, during the independent navigation, the B&VI need to know where they are and what kind of objects are in their surroundings. Be specific, the information of the layout of a given area, the path segments and angles between them appear to be important for them and they have to recognize them during walking [8]. The B&VI usually prefer not to walk in the centre of a building since there is normally no orientation line for their cane and the avoidance of crowds of people. They have particular interest in objects lying in a range from 0.1m to 3m away [9]. The main problems they encounter during walking include determining ones' own position, determining head direction or movement direction, and the lack of information about the important objects in the near and distant environment [9]. Moreover, they especially have problems with stairs, all kinds of steps, elevators, revolving doors, and doors with an automatic opener, since they all might cause serious injuries [9].

There is a controversial debate on how visual experience affects spatial ability since the relevant studies are not totally free of bias: they differ in the manner in which subjects were recruited and sample sizes have often been small. However, some results of the preliminary studies seem to offer certain guidance. The differences between blind and sighted will increase with the complexity of the spatial inference required by a task. Thus, tasks requiring a subject to compute a survey representation or a novel route, or both, might show effects of visual status, whereas tasks based directly on the trace of travel, such as reproduction of a rout, would not [7]. In addition, it has been observed that the difference of navigation skills exists between adventitiously and congenitally blind subjects: Blindfolded sighted and adventitiously blind subjects perform better than congenitally blind subjects on a variety of navigation tasks [7].

When studying the role of touch in spatial coding, spatial representation and navigation of B&VI, one important conclusion from Millar was that the complete absence of vision reduces the information about external reference cues and informational redundancy, meaning that there is less overlap with input from the other senses [10]. This finding implies that the cues used by blind people to solve spatial tasks are body centred instead of external cues. Another important conclusion from Millar [17] was related to how blind people understand space. For spatial coding, it is crucial to get information from reference cues. As she assumed, the spatial processes are activities of the organism that integrate input from diverse sources to act as reference cues. For blind and visual impaired people, this conclusion stresses the importance of exploring and scanning hand movements during spatial tasks. The body-centred cues, which were mentioned above, are generally used by B&VI in spatial tasks and they may increase the accuracy of the recall of distance and location [10].

Findings

As mentioned, the information of the layout of a given area, the path segments and angles between them are particularly important for the blind and visual impaired during their navigations. In addition, the specific patterns of behaviour of B&VI should be taken into account when designing the paths for users to trace. For instance, the paths would be preferable placed along the wall and the important objects that might be used as reference point should be highlighted.

The body-centred strategy used by blind people to solve spatial task is valuable to be utilized in the final design when setting the starting point of exploration on the scale model and embedding some positioning features. From this point of view, the external cues are not that necessary to include. Besides, since hand movements are especially important for users to get enough information, the rich interactions in which those hand movements would be involved should be another essential feature of the final design.

Figure 2.3 A digital map focuses on constructive exploration

Spatial navigation solutions

Two cognitive processes, (spatial) memory and (object) recognition are distinct when using a tactile navigation tool. Spatial memory is about recording information about the environment and its spatial orientation. Object recognition is about understanding the meanings of the objects.

To cater the special demands of B&VI, different spatial navigation solutions were developed. One widely used tool is the tactile map representing the geographical information. It provides data perceived by touch in order to build cognitive map. Jacobson proposed the problems that sighted cartographers are faced with: simplification, generalization, classification and symbolization [15]. As many studies have been conducted to improve the design of tactile maps, a couple of guidance and recommendations with regard to the tactile symbols usage, elevation, scale, substrate, single/double line usage and additional instructions were summarized through the literature research (see the detailed design principles in Appendix II).

In order to help blind users memorize the planned route, an advanced interactive tactile map was developed [13]. This digital map focuses on constructive exploration: the data is not displayed explicitly and statically, but is conveyed during interaction. A set of tools would be provided to construct the planned route and a couple of steps and instructions will be given through acoustic and tactile feedback when blind users interact with the map. Besides, as to stimulate the cooperation between sighted and blind users, the installation would graphically display all information. This feature would benefit sighted people as well.

Meanwhile, diverse electronic travel aiding tools were launched such as "knowwhere" system, "ArcView" and MoBIC preparation system (Mops). These solutions focus on different aspects of the travel of B&VI. For instance, "Mops" gives information on the user's current position through speech and Braille, whereas "ArcView"[15] aims at constructing a spatial system in an audio-tactile manner for visually impaired people.

Findings

The guidance and recommendations would be handy when designing the details of the tactile scale model such as the tactile symbols, the line, the elevation, etc. From the perspective of interaction, the example of the digital interactive map is very inspiring for the project since the importance of active interaction is realized. Besides, the value of graphically displayed information was stressed and it could be subsumed as an essential feature of the prototype as well.

The two above-mentioned cognitive processes haven't been fully facilitated by the existing navigation tools. A tactile map is serially perceived by touch: it is slow and memory demanding. Also, it is overloading due to the included full detailed spatial information. Therefore, it would not be an optimal solution.

2.2.4 Public building

Floor design is regarded as one of the most important elements of public building when considering the issue of accessibility. Barker et al (1995) suggested that floor designs are important to visual impaired people in navigating within environments, since they mostly rely on their haptic perception on the floor. Therefore, many studies with regard to the types of pattern and floor finish were conducted to investigate what features of floor are preferred by B&VI people. Relevant conclusions were drawn that the plain, uniform floors are preferred and that certain types of pattern are best avoided, especially busy, nonuniform patterns and repetitive thin stripes [16]. In addition, the importance of floor finish was confirmed and matte finishes are preferable to shiny and reflective surfaces [16].

Findings

Since the detailed features are perceivable for the B&VI and the floor design plays such an important role during their way finding process, the dominant features of floor designs such as patterns and finishes could be translated and abstracted as the representative features of a corresponding part of the public building as a functional output.

2.2.5 Scale model

Differentiating from the tactile maps which are helpful to plan routes across larger spaces, the detailed models are useful for getting to know a smaller space. A scale model is a physical model representing an object that is larger or smaller than the actual size of the object. It seeks to maintain the relative proportions of the physical size of the original object. At the moment, the scale model is widely used to represent the exterior of building for many reasons, such as the architectural prototyping for educational and commercial purposes. As B&VI people has gained more and more attention from the public, some exterior scale models were designed in a tactile manner that invite blind and visual impaired people to use. Meanwhile, many studies were conducted to improve its usability. Hereafter some design requirements and wishes were drawn with regard to diverse aspects.

Figure 2.4 The scale model of the arrangement of the government district

- Surfaces should neither be too smooth nor too rough, allowing for the rendering of good resolution details and the reproduction of Braille characters in the correct scale [18].
- The importance of determining a reference object and how to represent it in the scale model is unveiled. In the process of model cognition and the formation of the mental image of the space, B&VI people always start with the identification of a reference object in the real world and its corresponding representation in the model [18].
- Certain abstractions and simplifications had to be done, in order to avoid confusion with certain aspects of the spaces [18].
- It is important to allow people freely manipulate the models, bring them closer to their eyes (especially in the case of the low vision volunteers) and rotating them as they move around and compare their features to the objects they can feel and touch [18].
- A tactile model should have certain level of abstraction but at the same time a certain level of details that allows readers to establish a relationship with physical references in the space [18].

Figure 2.5 The scale model of the architecture of the Reichstag

As being one example of the exterior tactile scale model, the model of Reichstag allows the B&VI to get impressive new insights into the arrangement of the government district and the architecture of the Reichstag. It enables them to get an idea of how the plenary hall, the audience gallery, the visitors level and the dome are to each other and high level of the details can be touched. The applied materials are extremely strong and unbreakable. Additionally, people will get the impression of the original building materials as well.

Findings

When critically evaluating the current tactile navigational tools, none of them could satisfy the demands of B&VI users. The existing exterior scale models have a high level of architectural details which are useless for orientation. The tactile maps are functionally orientated while the 2D information is perceived much slower compared to the 3D information, as concluded in the previous section. Meanwhile, an interior scale model is non-existent yet. How can we develop a promising new tactile tool for B&VI people to orientate inside a public building? The most important thing is to achieve a balanced level of abstraction and simplification for the presented information: unnecessary information should be cut down in order to avoid confusion, and the rest could be abstracted and integrated. The proportion is not necessary to be precise.

2.3 EXPLORING THE TACTUAL PROFILE

Tactual Profile (TP) is an observation instrument for charting the tactual functioning of children with a severe visual impairment from birth to sixteen years old. The instrument concentrates on the tactual requirements that the everyday environment places on perception. Tactual perceiving and functioning are explicitly viewed in a broader sense than reading Braille or understanding geographical maps or graphs.

Since the instrument is relevant to the project from the perspective of tactility, an interview with the initiator, Ans Withagen, was held at Koninklijke Visio in order to not only gain deeper insights of TP, but also explore the school itself. During the interview, the author tried the TP out with eyes closed. Additionally, when another researcher was performing some tasks, observations were carried out. Some findings were generated from the interview:

- The texture is important for blind and visual impaired people. Texture is the color for blind.

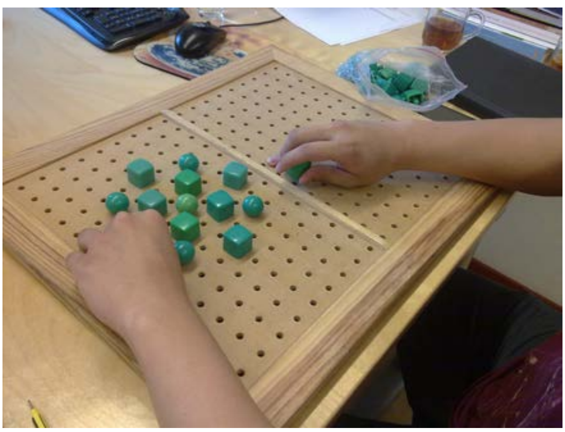


Figure 2.6 A grid could facilitate measuring steps and relative distance.

•For haptic perception, a filled shape combined with texture is more helpful than strokes.

•A grid as a background could help blind and visual impaired people perform the spatial perception task as people could use it to measure the steps and relative distance.

•Significant difference was found between blindfolded sighted people and B&VI, which is exactly in line with the literature: sighted people prefer to use the external cues and blind people always rely on the body-centred strategy. Be specific, when given a spatial perception task, sighted people always start with the upper corner in the left and blind people tend to explore the area right in front of them.

- Objects created targeting visual perception is unknown for B&VI people, especially the congenitally blind. For instance, they have particular difficulties in perceiving a tactile table or diagram by touch.
- Setting a reference point is very important for the B&VI to trace back and start again during the orientation.
- It could be useful for the B&VI to take a map with them during the walk as they could refer to it anytime anywhere. In other words, a portable map could lighten the burden of memorizing information and make it easier to process new information.

Next to the interview, an inspiring guided tour was made inside Huizen, Koninklijke Visio. The building was specifically designed to cater the needs of blind and visual impaired people and some of the details are very impressive.

First of all, a special object representing the function of the room was hung on the doorknob for blind and visual impaired children to recognize by touch. Soft material was applied to create nice touch feeling and contrast colours were used for children who still have residual sight. For instance, a chain of flurry balls and a paintbrush imply that the room is for handiwork and drawing.

Secondly, the building was designed based on an "H" shape In order to simplify the indoor navigation for blind children since fewer turns are needed to take during the walk. Besides, handrails were built along the wall.

In addition, a carpet is placed near the entrance of every area to remind people that they are entering another part of the building. This strategy is widely used and every child studying there was taught at the beginning. It is proved to be useful.

Figure 2.7 The representative object of the drawing room

2.4 FIELD RESEARCH

The field research aimed at investigating both the functional and experiential aspects of a public building. Four public buildings (Figure 2.11) were chosen for the case study: the Hague city hall, Binnenhof, Castle Muiderslot and Muziekgebouw aan't IJ. Each building has more than one outstanding feature, either about its functionality or experience. A lot of thoughts came up during the field research. Below, the most relevant ones are elaborated.


Figure 2.8 One possible location of the scale model in Muziekgebouw aan't IJ

For some public buildings, the location for the model is easy to determine. For instance, the Hague city hall has a special entrance for people with disabilities so all blind and visual impaired people will approach the model if it is placed near the special entrance. However, for some of them, there isn't an obviously satisfactory location to place the model. One example could be Muziekgebouw aan't IJ. The building has two entrances but neither of them is friendly for B&VI visitors: one has a revolving door and the other is connected to a bridge from the outside. For a music hall, the area near the ticket desk seems a good place, where everyone would pass (Figure 2.8). However, the accessibility of the ticket office remains an issue for B&VI people. Thus, no ideal location could be given for the model.

Some public buildings have a particular group of visitors. Thus, the needs and features of the target user group should be taken into account when designing the scale model. Giving Castle Muiderslot as an example, most of the visitors are children and they always come in groups. Thus, designing a tactile scale model should focus more on how to make it playful, interactive and suitable for multiple persons to use.

The exterior scale model of Castle Muiderslot brought some thoughts of the interactive usage of the scale model (Figure 2.9). Some parts of the model are


Figure 2.9 The exterior scale model of Castle Muiderslot

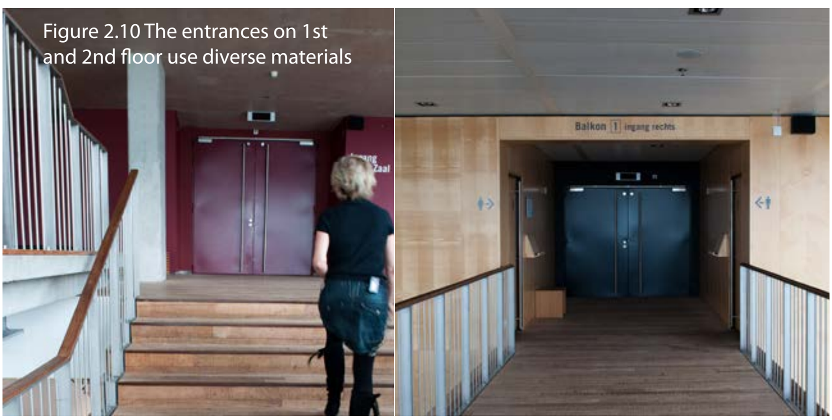


Figure 2.10 The entrances on 1st and 2nd floor use diverse materials

moveable, which enable people to see the highlights of the inner parts. More information is passed to the visitors in this way. From the perspective of users, model is more interesting to them and they experience much more fun than using the traditional scale model.

The diversity in material could work as a complementary information for orientation. Giving Muziekgebouw aan 't IJ as an example, the entrances to the music hall from the first floor and second floor use different materials. This could be an important tactile cue for blind people to find their destination (Figure 2.10).

Figure 2.11 The four public buildings

Castle Muiderslot	the Hague city hall
Muziekgebouw aan't IJ	Binnenhof

2.5 CONCLUSION

Below, all the valuable insights learned from the previous studies are summarized. The first three are conclusion of current situation of relevant tools development and the rest should be taken into account when developing a tactile scale model for indoor navigation.

The needs of indoor orientation could not be satisfied by current solutions

The explorations of current navigation tools shows that none of them could cater the needs of indoor orientation for B&VI people yet. There are practically no existing interior scale models, which suggests an opportunity to develop one to fill this blank.

Tactile maps are slowly and serially perceived by B&VI people

One enormous disadvantage of tactile maps is its slow and serial perception. According to the relevant literature, tactile maps are perceived serially. This will impose a big memory load and thus results in the longer time consumed on perceiving information.

The recognition of 3D objects is faster than 2D ones

In line with the literatures, 3D objects could be recognized faster than 2D ones by means of haptics. This implies the promising use of 3D components in the final design.

Certain level of abstraction and simplification

According to the literature, the level of abstraction and simplification should be considered during the design phase: unnecessary information should be cut down to avoid confusion, and the rest could be abstracted and integrated, not necessarily precise in proportion.

Shapes filled with textures are easy to perceive by haptics

According to the exploration of the Tactual Profile, for haptic perception of 2D objects, shapes combined with textures are more recognizable than strokes. Thus, solely using outlines of the objects should be avoided in the final design.

The body-centred strategy should be utilized

From the exploration of the Tactual Profile, the body-centred strategy is of great importance to B&VI impaired people. So the starting point of the final design should be placed in front of the user.

Including a reference point

Personal experience from performing the tasks of TP convinced the researcher that including a reference point is helpful for positioning and estimating the distance. The reference point is always the starting point and should be placed in front of the user. Relevant literatures also confirm the conclusion above.

Setting routes along the wall

According to the literature, routes should be planned along the wall, with straight paths and 90-degree angles.

Presenting the floor design

As implied by the literatures, the main tactile features of the floor could be translated and abstracted as functional information, which represents a corresponding part of the public building.

Using contrast colour

Contrast colours should be used in the final design to make use of the residual vision of visual impaired people as well as to make the model appealing to sighted people. This is in line with the findings in the exploration of Huizen, Koninklijke Visio.

Determining a location for the model

Based on the field research, two facts should be taken into account when determining the location of the model. First of all, the location should be accessed easily, more ideally, visitors should be able to pass the location naturally.

Considering if there is a particular group of visitors

Another important thing learnt from the field research is to consider whether there is a particular group of visitors when designing. If so, special design should be made to accommodate their featured needs.

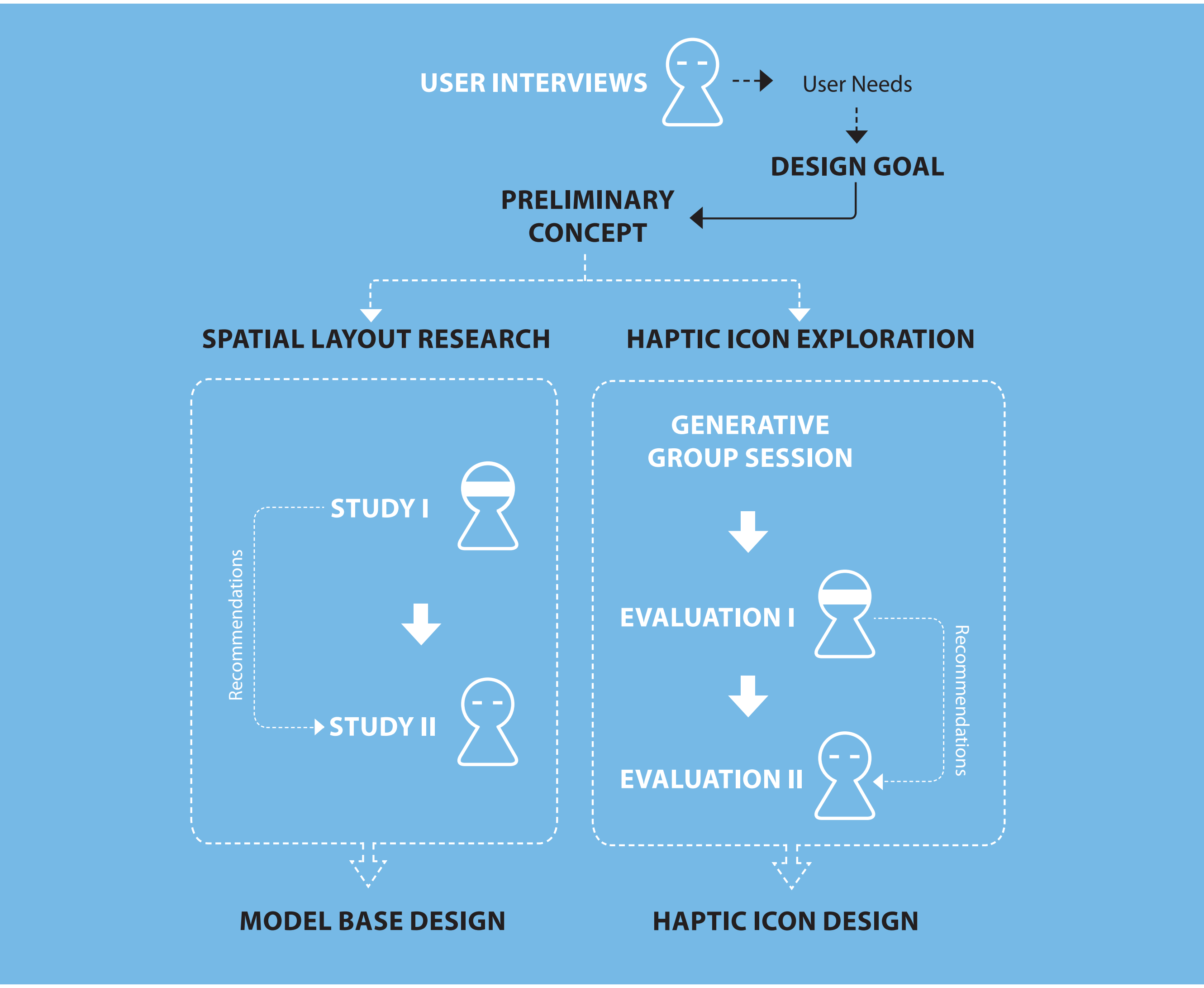
Using material as cue for orientation

Next to enriching the experience of a public building, diverse materials could also be utilized as a functional cue for orientation. This was concluded from the field research in Muziekgebouw aan 't IJ.

CHAPTER THREE.
USER-CENTERED CONCEPTULIZATION

After extensively exploring the defined problem, specific focus would be placed on users. This chapter starts with the user interviews, which resulted in a persona describing the target user group and a design goal narrowing down the scope. Accordingly, the design criteria were generated. Then a preliminary concept of designing a set of haptic icons will be introduced, based on which the follow-up researches were structured in a parallel manner: on one hand, the spatial layout of the model base was investigated; on the other hand, the haptic icons were explored. The two groups of studies both started with blindfolded participants and further conducted with blind and visually impaired people. The generic guidelines for designing a model base and designing haptic icons were given to conclude the studies.

Figure 3.1 The overall structure of the user-centred conceptulization phase.



3.1 USER INTERVIEWS

3.1.1 Goal

To gain general insights into the topic, five user interviews were conducted. Based on the better understanding of the behaviour patterns of the blind and visually impaired people, several specific points that might be valuable for the later on conceptualization were clarified.

3.1.2 Setup

The user interviews were conducted in a semi-structured manner, with the following topics discussed: strategies of navigation, the experiences on spaciousness, the indoor and outdoor orientation and how they experience the navigation tools. The interview questions could be found in Appendix III.

Figure 3.2 One user interview taken in group

Five participants were involved in the interviews. Considering the difference in the diverse conditions of vision, different user groups including the congenitally blind, the acquired blind and the visual impaired were all covered. The participants have diverse travel habits and they use different tools for navigation.

The interviews took place in groups, which enabled the participant to exchange ideas and to complete each other.

3.1.3 Results

The results of the interviews were presented here according to the topics stated above. The summary of each interview could be found in Appendix IV.

Strategies of orientation

To memorize a route, all the participants rely on the landmarks rather than counting steps. The recognition of the landmarks is based on sound, which is emitted by the landmark or made by the cane, smell or touch. The most frequently mentioned landmarks for the indoor navigation of public buildings are the door, the stairs, the lift, the sidewalk, the corridor and the height of the ceiling. These landmarks are also helpful for tracing back when getting lost.

Nearly all the participants mentioned that they have a mental picture of the environment, which contains useful information for orientation. The mental picture differs from person to person. People with more visual experience before tend to have a better overview of the environment, with relevant information integrated. On the contrary, people who are congenitally blind or became blind in early age are more likely to memorize the information in pieces, and it still needs practices. For most of the participants, a clear starting point would help.

All the participants are confident in their sense of orientation and good memory. They don't follow the wall, which is inconsistent with the literature, and they obtain more information from the floor during the orientation. They do notice the material change on the floor based on the sound made by cane, their feet and the feet of guide dog. The pattern of the floor is hard to perceive.

Experience on spaciousness

Nearly all the participants stated that they have a notion of distance based on time estimation and echo, but it is not an important issue. When they enter a space, they are aware of the height and size of the space by echo change as well.

Indoor navigation

People have diverse choices of selecting a starting point, varying from the entrance of the building to its central point. For them, the safety issue always comes first and the functional aspects of the building are more important than the decorative stuff.

Outdoor navigation

Since some of the participants could still perceive the light change even they are blind, they use sun to orientate, with which they memorize the basic structure of the environment. Again, the landmarks are very helpful.

2D Tactile map

All the participants said a legend is necessary for them to understand the meaning of the objects on tactile maps. The starting point should be clearly pointed out for getting started and being referred to afterwards. The information on the map needs to be direct and specific for way finding. Too much information would be distracting and confusing and they don't appreciate letter-by-letter reading.

Nearly all of them mentioned that they need a translation of the 2D information to a 3D image. However, some of them do appreciate its functionality.

3D Scale model

People appreciate 3D scale models since they would be able to have the missed information that sighted people have, as well as it is nice to feel and explore the model. The information presented on the model is more realistic.

However, the current 3D scale models are not ideal for route planning due to the overloading information of the architecture features.

Besides, the scale of the model is an issue, but mixing two scales in one model would confuse the users.

Additionally, the B&VI don't have much association of diverse materials. Instead, they focus more on physical feelings.

3.1.4 Conclusion

The information obtained in the interviews was carefully evaluated and some noteworthy findings were came across as follow:

About the blind and visual impaired

Some of the blind and visual impaired could still perceive light in varying degrees. One participant even uses sunlight to orientate himself in the outdoor navigation, which implies that light, combined with windows, doors or transparent roofs, could be a clue or a reference point integrated in the design to facilitate the indoor orientation.

In line with the literatures, B&VI people are especially sensitive in smell, sound and touch. They manifest this capability in selecting and recognizing landmarks. When abstracting landmarks, specific attention should be paid to the olfactory, auditory and tactual attributes rather than how they look like, such as geometry shapes.

Generalities of orientation strategy

Instead of counting steps, they prefer to memorize landmarks to orientate and position themselves in an environment. This implies that it is not that important to relate the lengths of route segments on the map to their lengths in the reality. What matters here is how to integrate enough understandable landmarks in a balanced level of details.

Most information is gained from the floor rather than the wall. Either using a guide dog or a cane, B&VI people focus more on the acoustic feedback from the floor. This suggests that the focus should not be placed only on the material change tactually, but also how the acoustics differ. Furthermore, if the material change on the wall would be used as a clue, users should be informed beforehand since they won't touch the wall spontaneously.

All the participants reported that they are able to create a mental picture when memorizing a space. Because of the individual differences, the mind maps exist in diverse forms and the degree of integrity varies as well. Therefore, the users with the lowest capability of creating holistic overview of an environment should be the starting point of the design. To help them connect the pieces of information in their mental pictures, besides providing sufficient recognizable information, the final design should also integrate the information to some extent. It is notable that the integrated information should not confuse users.

To include and to avoid

As frequently mentioned in the interviews, landmarks are beneficial for orientation. The permanent sound sources, the doors, the elevators, the stairs, the sidewalk, the corridor and the height of ceiling are the most common ones. Blind and visual impaired people recognize them by touch and sound. The above mentioned landmarks should never be missed in the final design.

The architecture features should be excluded since the overloaded information would make it hard for them to functionally use the model. A uniform scale should be applied because of the importance of the relations between distances and sizes. Also, the starting point should be clearly indicated and easily connected to the reality.

Figure 3.3 A comparison of 2D maps and 3D models

Comparison between 2D maps and 3D models

	2D maps	3D models
Advantages	• Simple and succinct route information • Exclude the interference of longitudinal information, which is not necessary for navigation • Easy to understand for functional use	• Could be freely explored • Direct information • Better impression of how the building looks like
Disadvantages	• Restricted to functional use • Difficult to contain information of multiple floors • Need translation for relating to reality	• Would be confused by too many details of the architecture features

Based on how the participants described their using experience of 2D tactile maps and 3D scale models, a comparison between the two was done to see the advantages and drawbacks of each.

As indicated in the table above, the biggest problem of using a 2D map is the translation of 2D information. For 3D models, the key issue is the confusion that might be brought to users due to the abundance of architecture details that is irrelevant to navigation. Therefore, a user research, which aims at examining the functional usability of a 2D tactile map and a 3D scale model, would be carried out to examine which works better.

3.1.5 Persona

Based on results of the user interviews, in general, the potential users could be categorized into two user groups, with respective representative personalities. One group of blind and visual impaired people tends to rely on the external supports and they are less explorative. They would like to travel with partner and they intuitively turn to other people for help when facing a problem. They always prefer the most efficient and energy saving solution.

Compared to the first group introduced above, the other group of users is more adventurous and independent. They feel proud of themselves since they could travel alone with their own efforts and they feel like to actively explore the unknown things.

Considering that the first mentioned group would more likely to seek help from other people rather than independently using a navigation tool, more focus should be placed on the needs of the active users in the design phase. To better understand their lifestyles, values and strategies of navigation, a persona was created as follow.

Emma

Figure 3.4 Persona

General characteristics

Emma is 35 years old and she became blind when 7 years old. She is capable of reading Braille.

Most of the time, she travels alone. She is an independent explorer with a spirit of adventure. She is negative in help-seeking.

Current situation

Emma is running a self-employed business. In her leisure time, she Loves playing guitar, travelling and walking in nature.

Goal

For Emma, safety is always put in the first place. She wants to live and travel independently.

Experience of using navigation tools

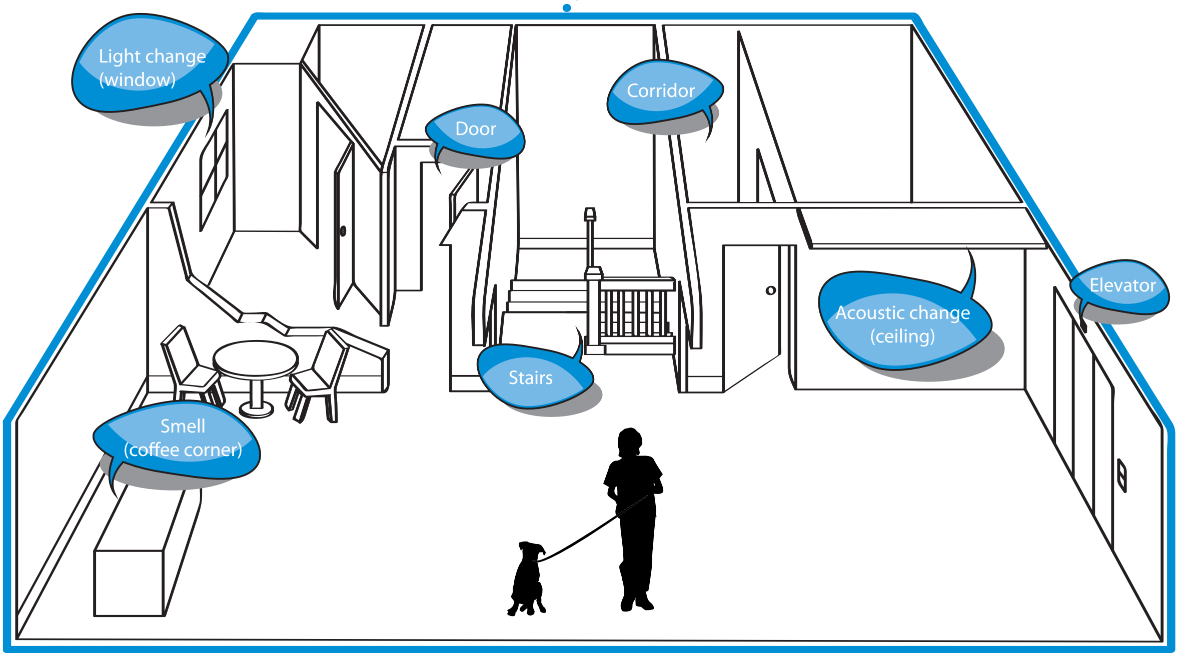
Using guide dog and tracker. Have experience with 2D tactile map and 3D scale model.

Strategies of navigation

In general, Emma is able to build a **MENTAL PICTURE** of a space (as shown in the graphic). The mental picture consists of various landmarks, tactile information and object orientation.

As she said, "different materials tell me where I am." She could notice the material change on the floor based on the acoustic feedback.

During the walk, she prefers following her dog to walking along the wall. *"I could focus on other things rather than paying attention to avoid obstacles."*



3.2 DESIGN GOAL

Based on the previous researches, a lot of fresh insights were accumulated and the scope of the project became wider. Considering the time limitation of the project, specific focus should be placed on certain points of the results, as for further development.

According to the user interviews, one primary user need related to a navigation tool is about the intuitive usage, which could not be fulfilled by the existing legend, for which letter-by-letter Braille reading is required. At the meantime, based on the users' wish, the presented information should be succinct.

Regarding the foregoing needs, a design goal was established. **To develop an intuitive tool offering efficient functional information to facilitate the independent indoor orientation of blind and visual impaired people.** This design goal is in line with the project goal, with a specific focus of the intuitive usage and the succinct given information.

3.3 DESIGN CRITERIA

Based on the above stated design goal as well as the fundamental requirements from the users, which were generated during the interviews, the design criteria were developed.

The safety issue is desired above all the others among the personal values of blind and visual impaired people. As a tool facilitating their independent navigation, the final design should exclude anything that might be potentially hazardous.

To allow them to be independent, the final design should give full scope to the navigation strategies of blind and visual impaired people, which brings their own efforts into full play. Specifically, different kinds of landmarks should be implemented in form of sound, smell or tactile information, with a starting point clearly indicated. A uniform scale should be used in the final design, in order to enhance their awareness of the spaciousness. Due to the lack of associations to certain materials, the material information should be implemented more as a functional input.

Thereafter, a couple of criteria with respect to the usage of the final design were put forward. The final design should be intuitive to use, even for people who have no experience with such kind of navigation tool before. The interaction between the user and the final design should take place naturally, which requires no extra efforts from the user side. The given information should be direct and succinct, with more essence and less decorative things. The final design should allow the users to freely explore it.

Furthermore, the final design should be able to adapt to the using environment. Although the visual appealing is not an issue for blind and visual impaired people, the design itself should be attractive to sighted people as well.

Considering the experiential aspect, the final design should potentially enrich the experience of public buildings for B&VI people.

3.4 PRELIMINARY CONCEPT

As stated in the design goal, the usage of the final design should be intuitive and the functional information should be clearly and briefly presented. The information could be generally categorized into two groups: the landmarks that are helpful for the orientation and the basic layout of the public building. These relate to two distinct cognitive processes: (spatial) memory and (object) recognition. According to what people pointed out in the interviews, a legend is necessary for them to understand the objects while it is effort and time consuming as well as being meaningless for people who are not able to read Braille. Therefore, the current solution could not facilitate the above mentioned two cognitive processes yet.

So, what if a more intuitive approach can be implemented in a broader sense? Derived from the essence of a legend, which is about explaining the meaning of every object, a preliminary concept of **designing a set of haptic icons** was initiated. Sighted people are constantly surrounded by visual information that allows an easy and comfortable orientation in the physical reality. However, for blind and visual impaired people, it is still missing. The haptic icons would be placed in certain places on the final design, according to the specific layout of a public building. With the help of the haptic icons, the users could quickly grasp the meaning of each object as soon as they touch it. Instead of using meaningless forms, the haptic icons would be able to speak for themselves by using specific forms which could be tied to the tangible things people are familiar with in real life. This feature would enhance the intuitive understanding of the haptic icons as well as make the final design more interesting and visually attractive for sighted people.

Additionally, the haptic icons would be able to be standardized produced and universally applied in diverse public buildings. From the perspective of long term development of the project, the modular haptic icons could be easily integrated with sound design.

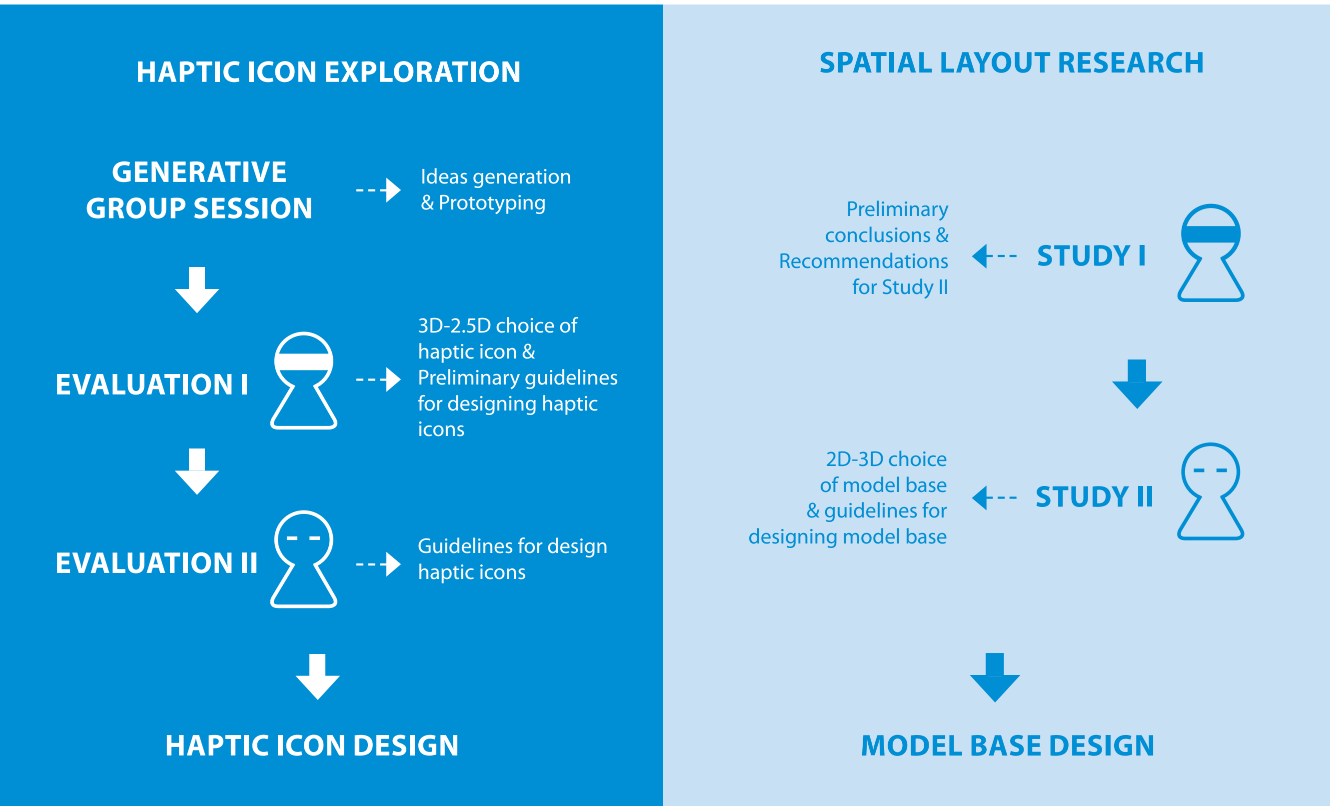
3.5 FRAMEWORK OF THE FOLLOW-UP RESEARCHES

The above mentioned concept aims at facilitating the cognitive process of object recognition. So, how about the spatial memory? As stated in §3.1.4, a comparison between 2D tactile maps and 3D scale models would be useful to clarify which is more functionally for indoor navigation. Next to it, since the specific focus would be placed on designing a set of intuitive haptic icons, respective studies would be carried out at the meantime. Therefore, the follow-up researches were structured in a parallel manner with iterative prototyping and testing involved.

The comparison between 2D tactile maps and 3D scale models was named spatial layout research. The research focuses on examining the functionality of both navigation tools. A 3D scale model and a 2D tactile map were made as research tools, based on the ground floor plan of The Hague City Hall. The spatial layout research was carried out in two rounds. With blindfolded people participated in study I, preliminary conclusions as well as the recommendations for the following study were generated. The real users were involved in study II. The results of both studies contributed to the end results of the spatial layout research: the final conclusion on whether a 2D tactile map or a 3D scale model should be used as well as the guidelines for designing a model base.

The haptic icon exploration started from the generative group session with B&VI people involved to gain insights into how they perceive the common places of public buildings. Thereafter a couple of initial ideas were generated and prototyped for the follow-up evaluations. The first round of evaluation was performed among 15 blindfolded people, with the preliminary guidelines for designing haptic icons generated. Meanwhile, the haptic icons were redesigned for the second round evaluation, which was done in depth with 14 B&VI students from Bartiméus, Zeist. In the end, the guidelines for designing haptic icons for public buildings were delivered.

Figure 3.5 The framework of the follow-up researches

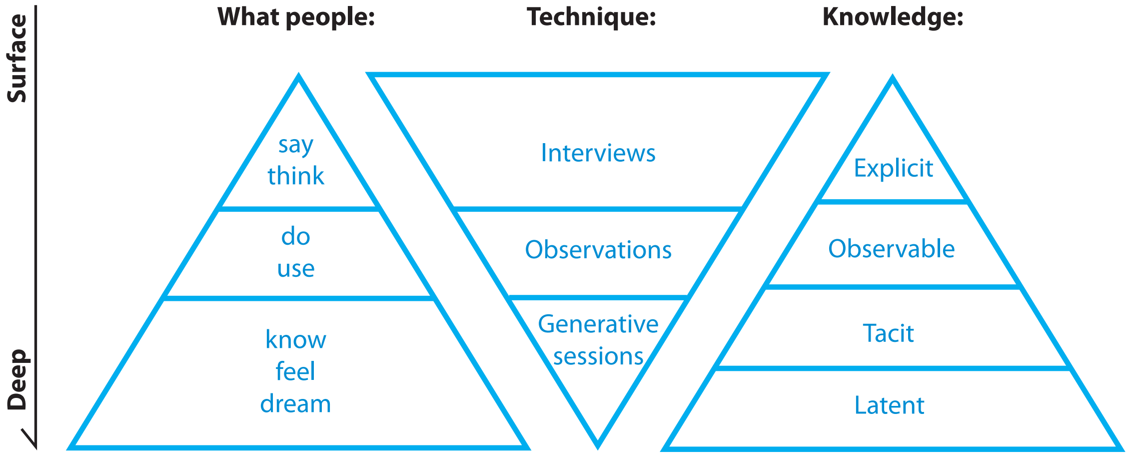


3.6 HAPTIC ICON EXPLORATION

3.6.1 Generative group session

With no (limited) visual input, blind and visually impaired people perceive and experience public buildings in a different way as sighted people do. As a starting point of designing haptic icons of public buildings for B&VI people, a generative session was conducted. According to Figure 3.6, something like an interview with the B&VI would not lead to the information that is needed. To get their latent and tacit needs and knowledge to the surface, generative techniques were used to let the participants make things.

Figure 3.6 Knowledge that is intuitively applied is latent and tacit, which requires generative sessions to get it to the surface (Stappers, 2009)



Goal

First of all, for B&VI people, the importance of the diverse common places or objects of a public building (such as elevators, entrance, reception, etc) would be determined. Secondly, how B&VI people perceive these places or objects and what they"look" like from their point of view would be explored.

Method

The generative session took place in a group of three participants. The session began with a short introduction of the overall progress, followed by a warm-up activity to make the participants sensitized by the topic. Participants were asked about what are the important functional objects of public buildings in their indoor navigation experience. The "Make" part came after the warm-up. Participants were asked to use clay, a special material for rough prototyping, to freely embody their recognitions of the generated six common places of public buildings. The"Say" part came as the last to let the participants exchange the created artefacts to examine their identifications. Meanwhile, they commented on other's designs and reflected on their own as well.

Results

Based on the warm-up activity, six most important common places or objects related to a public building were selected as the subjects for clay modelling. They are the elevator, the door, the cloakroom, the toilet, the reception and the coffee corner. The created artefacts are shown in the figure 3.7 on next page.

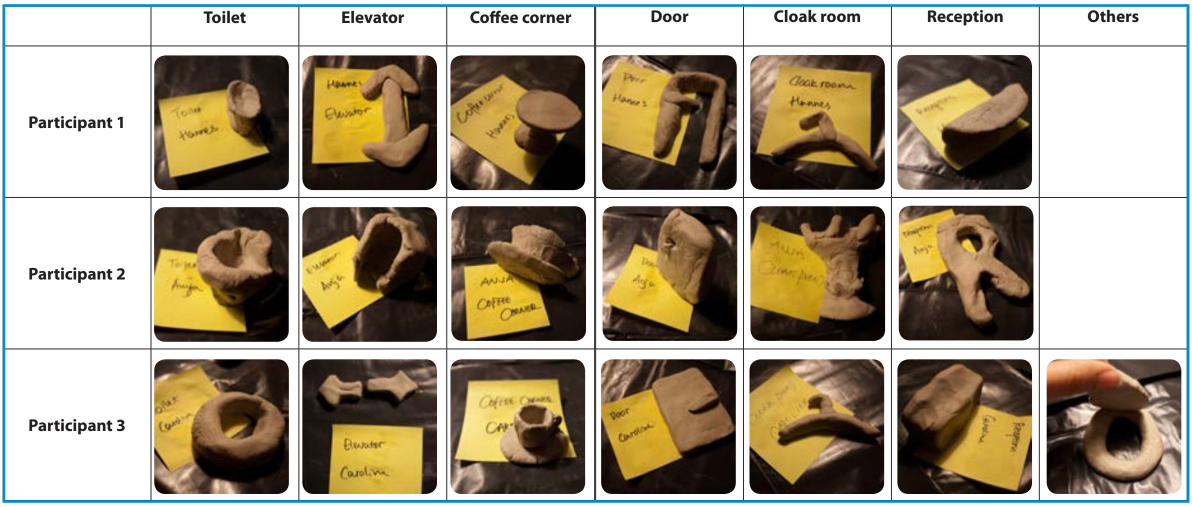


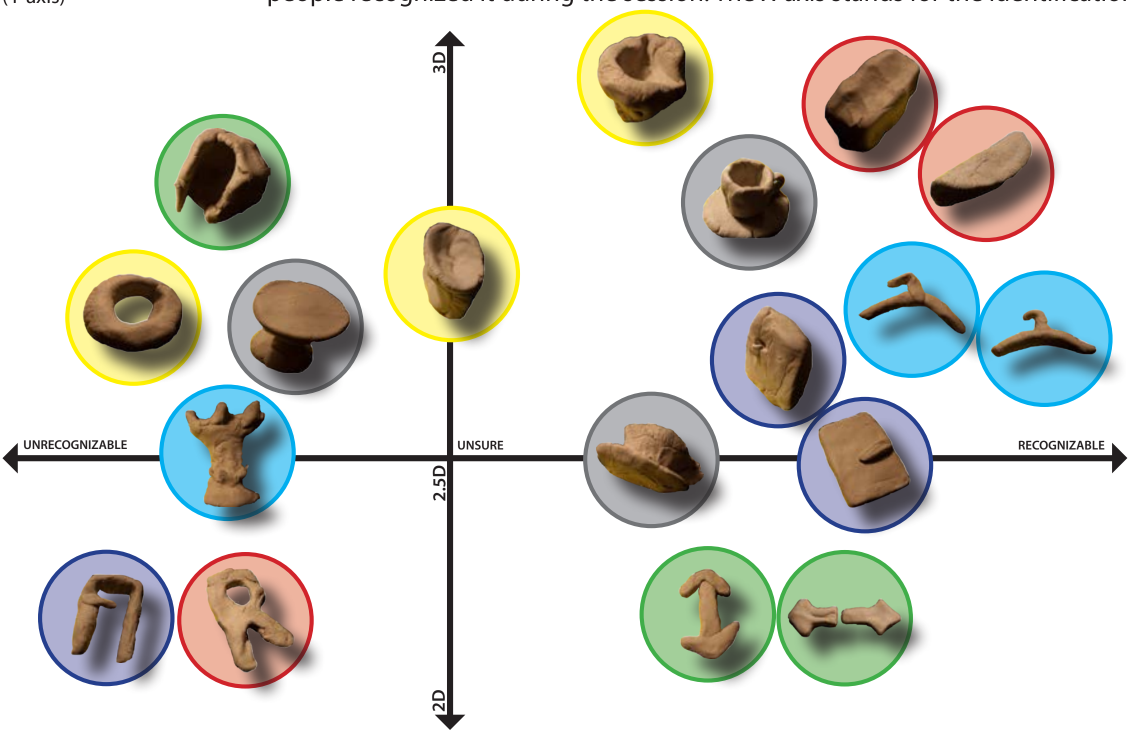
Figure 3.7 The created artefacts

Discussion

The created artefacts were characterised as 2D, 2.5D and 3D by the author in this study. The 2D objects refer to those have uniform height in embossment while the 3D ones include diverse vertical dimensions in one shape. The group named 2.5D covers the objects using a semi 3D form (the cloakroom and coffee corner made by P2), which remains only half of the shape and lies on the table. The following discussion are based on the above-mentioned definitions.

Figure 3.8 The cluster of the outcomes, based on form, defined by the author, (X-axis)and identification (Y-axis)

The created artefacts were clustered in the chart (see Figure 3.8), based on whether they could be recognized and the form they use (2D, 2.5D or 3D). The degree of identification for a certain object was quantified by how many people recognized it during the session. The X-axis stands for the identification



and the Y-axis indicates the applied form, which were defined by the author. The objects were colour coded regarding to the six subjects.

"Oh! It's reception! Well...I knew it's a R, but R could also be restaurant, right?"

According to the distribution of the objects, the participants tend to make 3D objects to embody their ideas and these objects were much easier for haptic perception by other participants. Most of the 3D objects use a representative component of the subject. For example, a coffee cup is used to stand for the coffee corner. Some 3D objects are deprived from the overall appearance of the subject, such as the door and the elevator on the second quadrant. Some objects were made in 2.5D (the cloakroom and coffee corner made by P2). Since the objects were not fixed on the table, these 2.5D ones confused the participants. The 2D objects are much more abstract. The idea of using an outline (the door in the third quadrant) and initials (the reception in the third quadrant) approved to be impractical. The 2D objects could be identified when communicating the essence of the subject (the elevators in the forth quadrant). The detailed discussion of each subject could be found in Appendix V.

Conclusion

To conclude the findings from the generative session, the first version of the guidelines for designing haptic icons was developed. Below, each of them is described.

- Unify the style

To make a set of haptic icons, a uniform style should be chosen. Mixing diverse styles together would make it hard for users to identify the icons. The "style" here is not only about the issue of making it 2D, 2.5D or 3D, but also about using a tangible object, an initial, the outline of an object, etc.

- 3D objects are recommended

People have an intuition to embody their perception of the subjects in 3D. According to the outcomes, people would like to make 2D objects only when the form of the subject is too complex or it is hard to choose a representative object (e.g. The elevators in the forth quadrant). Compared to 3D objects, 2D ones are more abstract and translations are always needed. Using the outline of an object is too visually orientated. People need to exert effort to integrate the sequentially acquired information. In the case of using an initial, the associations of the letter are not universal. For instance, one participants mentioned that letter "R" could be reception, as well as restaurant. However, when one letter has a worldwide meaning, such as "I" means information as well as "P" stands for parking, the initial might work. For B&VI, this hypothesis still needs to be examined further.

- The way of placing the scale model would be influential

When comparing the efficiency of the 2.5D objects to the 3D ones, it depends on how to display the model. In other words, the form of haptic icons should be accordant to the usage view of the model. If the model is hanging on the wall, people will use the model from the front view. In this case, 2.5D haptic icons would be better. Otherwise, the 3D version would have more advantages when the model is placed on the table that people will use the perspective and top view.

- The direction of the object is important

Making an object which is supposed to stand up in a lying position would result in confusions and misunderstandings. The direction of the object on the model should be consistent as how they are placed in the reality.

- Specific materials should be integrated

As mentioned above, the participants pointed out the importance of using the specific material belonging to the object since the material information could be perceived at once. They believed it would be helpful for identification.

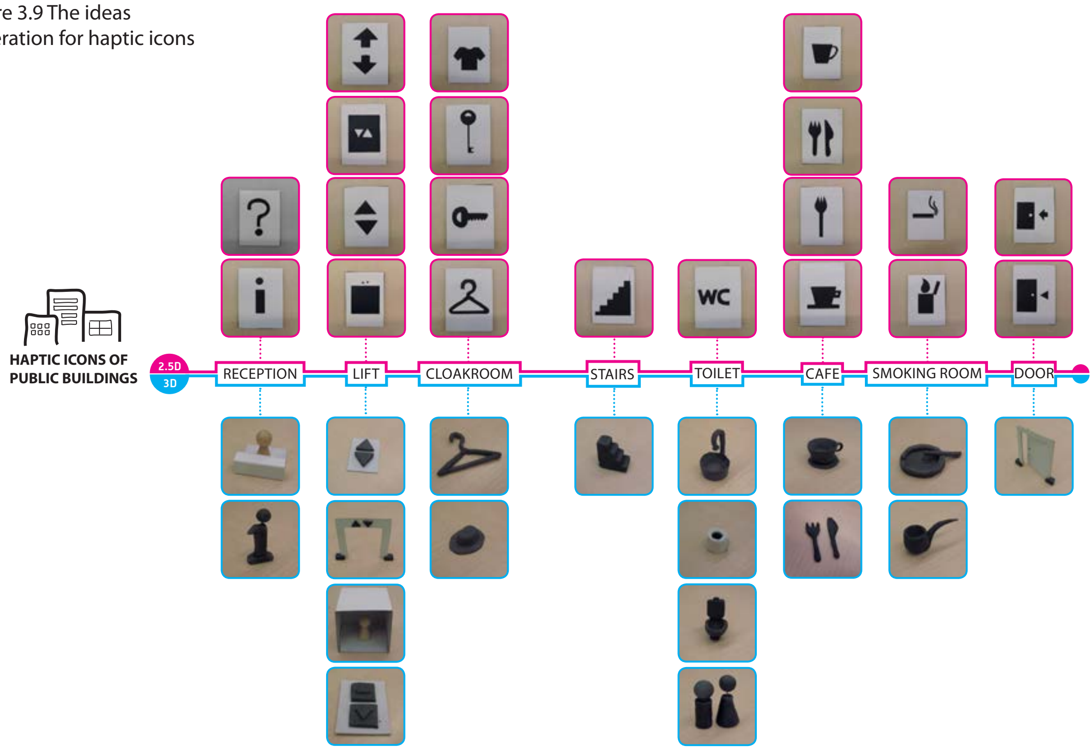
- Making the object interactive

The object could be quickly identified when the representative interactive features are presented. For instance, if the toilet seat could be lifted up and put down, people would catch its meaning instantly since they get used to it in daily life.

3.6.2 Ideas generation and prototyping

To start ideas generation, a creative session with 30 design students from TU Delft was carried out ,with help of cognitive ergonomics, an elective course given by Maarten Wijntjes. Multiple ideas of haptic icons were generated around the following facilities or objects in public buildings: reception, lift, cloak room, stairs, toilet, café, smoking room and door. The haptic icons were designed both in 2.5D (in pink squares) and 3D (in blue squares). In this study, the 2.5D objects refer to those which have a basically flat surface with slightly embossed or concaved details. The detailed description of each idea could be found in Appendix VI.

Figure 3.9 The ideas generation for haptic icons



3.6.3 Ideas evaluation with blindfolded participants

After prototyping the ideas of 2.5D and 3D haptic icons, the first round of evaluation was carried out with blindfolded participants. Starting with blindfolded participants was motivated by the easy accessibility and the amount of test persons. With the test results, the first impression of the ideas was gained and suggestions were put forward, which would improve the second round evaluation with real users.

Goal

The identifications of the solutions for each subject would be studied in order to see which is the best. Besides, which of the 2.5D or the 3D version of haptic icons is more adequate for haptic perception would be identified.

Method

Fifteen sighted students from TU Delft were involved in the tests. Twenty 2.5D icons and eighteen 3D icons were tested for each person. At the beginning, a short introduction of the project background and the concept of haptic icons was given. The eight subjects were not informed in this phase in order to prevent them from making guesses. Then the test person was blindfolded to start identifying each object, which was given in a random order. In order to exclude the influence between each object and to prevent them from being narrow-minded, the participant was not told if the answer was right or not. Meanwhile, the time was measured in order to compare the results. After all the objects were finished, the participant was asked to cluster the objects into three groups, which were named as good, fair and bad, based on how the perceptions matched the original meanings of the objects. General comments on the haptic icons were given in the end.

Figure 3.10 2.5D haptic icons

Figure 3.11 3D haptic icons

Figure 3.12 The evaluation of all the haptic icons

Results

A chart (Figure 3.13)was made to compare the multiple solutions for each subject in terms of time and accuracy. The number on top of the picture indicates the amount of participants who succeeded in identifying the respective icon. Additionally, the object displayed in a bigger size has a higher recognition rate. The circle around the picture mimics the clock dial, with a unit of second. The dash line part of the circle demonstrates the average time that participants took to recognize the object. In order to see the differences between 2.5D version and 3D version, the 2.5D objects are colour coded with pink while the 3D objects were colour coded with blue.

"Being a blind person is so difficult...But I do like this idea, it's fantastic!"

Reception

As illustrated in the chart, both 2.5D icons have higher recognition. The amount of participants who identified the two 3D objects was smaller. The average time of identifying each object was relatively close, varying from 13.4 seconds to 19.5 seconds.

Lift

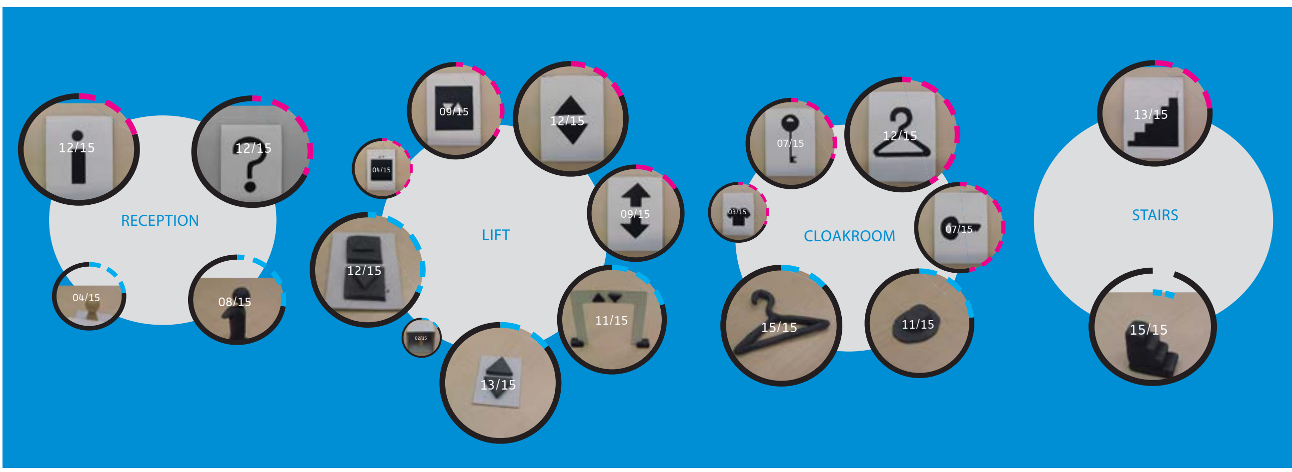
More participants identified the 3D icons while they appeared to have more difficulties in recognizing 2.5D ones. One exception is the idea of putting a dummy inside a semi-open box, which was recognized by only two persons. In general, the participants recognized the 3D icons in shorter time. The two 2.5D icons, which used a pair of arrows or triangles, were identified quickly as well.

Cloakroom

For the cloakroom, the 3D icons were recognized by more participants in short time compared to the 2.5D ones. Overall, the 3D icons had better performance. For instance, the same idea of using a hanger varied greatly in haptic perception when using diverse forms. The 3D one saved 15 seconds than the 2.5D one as well as it was recognized by all the participants.

Stairs

The overall results of both 2.5D and 3D icons were positive, with respectively most and all participants succeeded in identification. In average, the 3D icons saved nearly 10 seconds in recognition.



Toilet

The 2.5D icons turned out to be difficult for arriving into a correct guess, with 8 participants recognized it around 30 seconds in average. The idea of using a female dummy and a male dummy to represent the toilet was less effective compared to the rest of the 3D icons, due to its ambiguity in symbolization.

Cafe

Both 3D icons were recognized by all the participants around 5 seconds. The performance of the 2.5D ones was fair. Compared to the other two, the simplified version of coffee cup and cutlery turned out to be more effective.

Smoking room

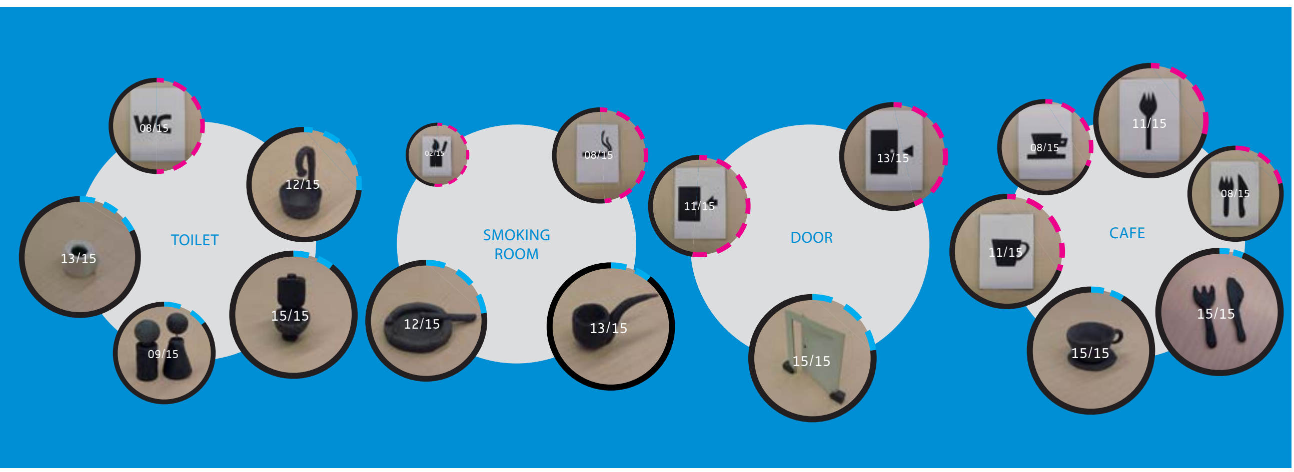
The 2.5D icons were confusing, resulted in low identification and longer time consumed. The 3D icons were adequate for recognition. The pipe is better because of the simple, clear and distinct appearance.

Door

The two 2.5D icons were recognized by most of the participants while relatively long time were taken. On the contrary, all participants recognized the 3D one around 14 seconds in average.

According to results presented, a recommendation was given for each subject, as shown in Figure 3.14 on next page.

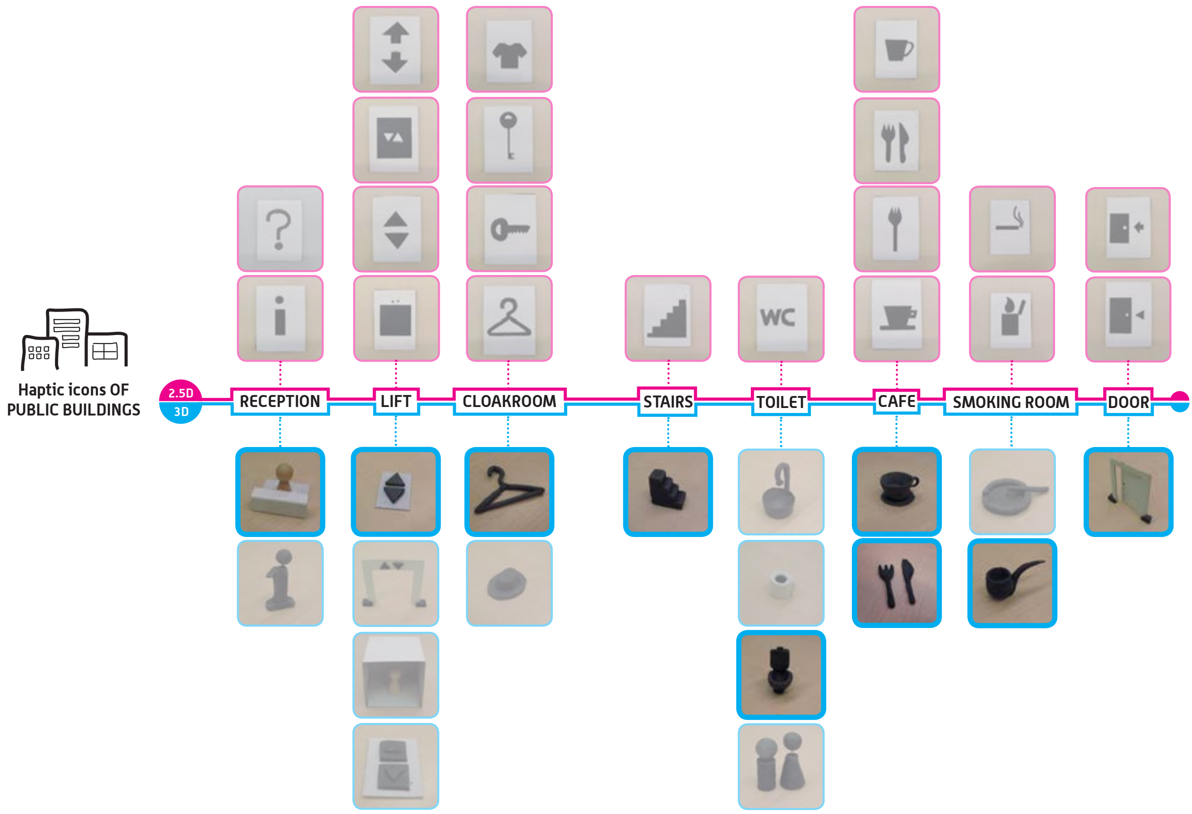
Figure 3.13 The charts for comparing the diverse solutions for each subject.



Discussion

After carefully evaluating the information obtained in the study, some noteworthy findings were come up with. They were elaborated in the following paragraphs, from the perspective of conception as well as how the form influenced haptic perception.

Figure 3.14
Recommendations for each subject



Conception

A lot of insights relating to the design of haptic icons were generated. One interesting finding was that tangible objects were preferred to the abstract symbols because the symbols could have multiple meanings. For instance, more than one participant in the research perceived the "i", which was supposed to represent the reception, as a male toilet. Also, the perception of the abstract symbols could be influenced by culture, spoken language and user's personal cognition. A non-English speaker might not be familiar with the meaning of "i" even it is universally used.

In the research, a lot of confusions was brought along due to the objects' geometry shapes which have multiple interpretations. For example, different participants perceived the dummy as a knob, a controller or a human being. Therefore, these objects should be avoided or improvements should be made to clarify the meaning of the geometry shape. For instance, adding two arms or two legs to the dummy would be helpful to make it more like a human being.

The participants did mention the gap between certain icons and the respective real objects or facilities they referred to. They experienced difficulties in connecting lift, which is relatively huge in real life, to a box in hand size. This is also because relative small objects, such as a hanger, a cup, were used to make most of the signs that people already got used to them.

Talking about the inertia of thinking, people were confused by the diverse styles of the haptic icons: some of the icons using symbols, some using tangible objects and the rest using initials. It was a challenge for them to switch from one style to another, which implies that a uniform style should be used for all the icons. This is in line with one of the conclusions from the generative group session (see §3.6.1).

Some objects were easy to recognize but hard to connect to certain subjects. This can be exemplified with a T-shirt, which was mostly related to the laundry or the fitting room rather than the cloakroom. Therefore, the importance of choosing the most representative object for designing an haptic icon was arisen.

The opinions are divided on the material issue. Some participants argued the importance of adding specific materials to several specific icons. The integration of material and geometry shape is a must. For instance, if the roll of toilet paper were made of clay, it would mean nothing. However, another opinion is also noteworthy. As long as the geometry shape is clear enough to communicate the meaning, extra material features would be useless.

Also, the technique of making 2.5D icons should be improved. The information is difficult to get by going through the concaved shape by their fingers, restricted to the limited breadth of the strokes.

How form influenced the perception

The overall result of the 2.5D version of haptic icons was negative. During the study, the author did notice the limitation of using concave 2D haptic icons instead of making them in relief, which made the haptic perception even difficult. However, enormous differences still existed between the two version of haptic icons. For 2.5D version, first of all, the gap existed in the sequential perception of information, which resulted in extra efforts exerted on integrating pieces of information. This was reflected in their slow perception when touching the 2.5D icons. Secondly, due to the abstraction of information, more efforts were needed for association and imagination. Some participants mentioned that they didn't even have a clue for association. Was it a symbol, an object or something else? They were confused. Another notable problem was about the incomplete perception of information. For instance, one participant perceived one icon of lift, which consists a pair of arrows pointing up and down, as one indicating going down because the judgment was already made before touching the upper part of the icon. For 3D icons, this is not an issue.

Of course, the 2.5D icons also have advantages. As some participants mentioned, the 2.5D icons could be flexibly applied in public buildings, such as put on the wall. Also, one participant preferred the 2.5D icons because less hand movements were involved in the process of information perception.

For the 3D version, it was another matter. The overall experience of the 3D icons was positive. One reason was the objective representation of real objects. Additionally, the 3D icons were recognized very fast, since people could quickly grasp the meanings by perceiving the geometry information as a whole. As

Gibson (1962) stated, when one handles an object, the thumbs and fingers contact it from different sides simultaneously [26]. Thus, various information could be acquired and processed in a synchronous manner. However, some potential cons of the 3D version could be foreseen. The higher cost, compared to the 2.5D version, could be one drawback. Also, the way of displaying 3D icons in public buildings or a scale model could be more complex. The perception of 3D haptic icons, which were designed for a lying position, could be influenced when they are put in a standing position.

Conclusion

The 3D haptic icons were proved to be more adequate than the 2.5D ones regarding the perception of information.

However, problems still existed in the current version of 3D haptic icons and the opportunities for improvement in the design could be foreseen. There is some noteworthy guidance for redesign.

The symbolic representation should be placed in the first place, with the style and size unified. Furthermore, the representative objects should be carefully chosen for each subject. The objects which have multiple interpretations in geometry shape and representation should be avoided. Besides, a balance between complexity and abstraction is the clue that designers must try to achieve. 3D icons need certain amount of details to fit their perceptual reality. Excessively abstracting the objects would lead to multiple interpretations. As the last suggestion, more focus should be placed on the key function of the subject rather than the appearance.

The material issue is a dilemma. As long as the shape of the object is intuitive enough, the material feature would not be a primary basis for haptic icon recognition. Additionally, for the consideration of cutting production cost as well as visual apparel, the 3D icons would better be made of uniform material. The integrity of all the 3D haptic icons as a set would be intensified and the uniform material won't influence other material features on the scale model, which could act as a functional clue for navigation. In this case, the objects strongly connected to certain materials should be avoided when choosing representative objects.

Recommendations

As carrying out the second round of evaluation with real users would be the next step, a couple of suggestions for the research setup are given.

The 2.5D version should be excluded in order to place more focus on the 3D version. Additionally, the size and style of the icons should be unified, as mentioned above. The icons used other materials should be remade by clay to eliminate the influence of material feature. As the last suggestion, the interview after each test should be done in depth to dig out the potential needs of the real users.

3.6.4 Ideas evaluation with the blind and visually impaired

Listening to what real users say is always important. Therefore, another evaluation was carried out with blind and visually impaired users. In this study, more focus was placed on the 3D version of haptic icons. According to the results of the previous evaluation with blindfolded participants, some icons were modified and some remained same. Bartiméus, Zeist offered great help in conducting the tests.

Goal

The study aimed at examining the identifications of the improved ideas of the same eight common places or objects in public buildings. Moreover, the thoughts in depth from blind and visually impaired people on these ideas would be another interest as well. Additionally, the material issue would be explored by asking questions.

Method

Eleven 3D haptic icons were prepared (Figure 3.15). To better focus on shape, all the haptic icons were made of clay and the maximum dimension of each con was five centimetres. Since the icons for elevator and reception turned out to be the most vague ones in the previous study, more versions were provided for comparison.

Nine female and five male students from Bartiméus, Zeist were involved in the tests, with five visually impaired, two acquired blind and seven congenitally blind. All the participants don't have mental disorders. Except for one fifty-nine years old lady, the ages of the rest vary from twelve to twenty. Covering diverse vision conditions, ages and genders was helpful to gather comprehensive data.

At the beginning, the project background and the concept of haptic icons was briefly introduced. Same as the previous study, the eight places or objects were not informed in this phase in order to prevent them from making guesses. Then the participant was asked to identify the icons one by one, which were given in a random order. The participant was not told if the answer was correct right away. The time was measured of each identification for evaluation and comparison. After all the tasks were finished, an interview was carried out to know how they evaluated the concept of 3D haptic icons in general as well as the comments on each design.

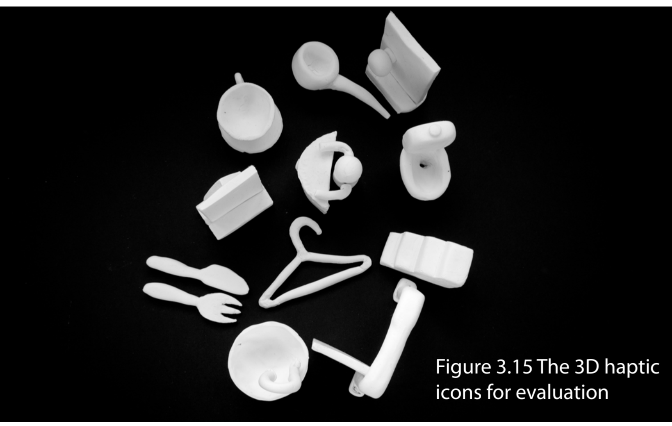


Figure 3.15 The 3D haptic icons for evaluation

Figure 3.16 One participant was commenting on the icons

Results

"I will definitely use it if there is real one! "

The overall result was positive. Most of the participants believed that the haptic icons would work and they would love to use them for navigation. Meanwhile, they did point out the problems of the existing versions. Below, the overall results of each haptic icon are described. The details of how each participant evaluate the haptic icons could be found in Appendix VII.


Figure 3.17 Door 1


Figure 3.18 Door 2


Figure 3.19 Cloakroom


Figure 3.20 Stairs


Figure 3.21 Cafe 1


Figure 3.22 Cafe 2

- **Door 1**

Overall, door 1 is inadequate for haptic perception of a door, with half of the participants failed in identifying it. The most confusing parts of the object are the door frame and the feet keeping the object in standing position. On the one hand, they did not have much chance to touch the door frame as a whole so they were unfamiliar with it. On the other hand, the supporting feet does not exist in real life. Furthermore, they thought a door was fitted in wall and there was supposed to be a knob or handle on the door. These two key features were missing from door 1 as well. The average time of successful identifications was 8.14 seconds.

- **Door 2**

Door 2 could be better identified compared to door 1. The participants took 5.5 seconds to recognize it in average. The confusions mainly deprived from the knob. Firstly, the knob is not in proportion to the door. It was made in a large size on purpose to stand out. But it turned out to be ineffective. Secondly, all the doors in Bartiméus, Zeist used handles instead of knobs. Thus, several participants failed to connect a knob to a door.

- **Cloakroom 1**

Cloakroom 1 worked well, with only two born blind participants recognized it as a pair of scissors. During the test, the researcher gave a real hanger to one of them and the participant still had difficulty in identifying it. Therefore, it could be the limited daily experience which led to their failures. The average time of identification was 8.1 seconds.

- **Stairs 1**

The overall results were optimistic. All the participants succeeded in identification and the average time they took was 6.2 seconds.

- **Café 1**

Café 1 was promising for haptic perception. It took 5.6 seconds in average to recognize it and no one failed. One participant who spent relatively more time on identification pointed out the importance of the saucer: he was confused at first because he overlooked the saucer.

- **Café 2**

Café 2 could be identified well. In average, the participants took 7.4 seconds to recognize the object and only two of them failed. The improper design of the details led to their incorrect guesses. The folk is three-tine instead of having four tines. That was the reason why one participant regarded it as a gardening tool.

- **Toilet 1**

The overall performance of toilet 1 was fair, with 8 participants had the right answers. The participants focused a lot on the U-shape tap and they recognized it as a hook. Consequently the rest part was perceived as a bowl, a pan, etc. The average time of identification was 7.3 seconds.


Figure 3.23 Toilet 1

- **Toilet 2**

Toilet 2 worked better than toilet 1. Only two born blind participants made wrong guesses. One of them mentioned that she was only familiar with three parts of the toilet: where she stands, where she sits and the flushing button. In addition, she thought using specific materials for respective parts of the toilet would be helpful. The other participants took 4.8 seconds to recognize it.


Figure 3.24 Toilet 2

- **Smoking room 1**

Smoking room 1 didn't work for most of the participants. Only four of them recognized it as a smoking room. Reflecting on the reasons behind their failures, it could be the limited daily experience and their young ages. In addition, the pipe is a kind of old fashioned so most of the teenagers had not seen it before. The average time of identification was 5 seconds, which implied that the overall negative results could be ascribed to their limited daily experience rather than the design itself.


Figure 3.25 Smoking room

- **Reception**

The overall results were inadequate, with five participants succeeded in identification in 6.6 seconds. There are several points worth being mentioned here. Firstly, people didn't notice the letter "i" placed on the front side of the desk. Secondly, some participants could not read letter. In addition, the connection between "i" and information was also weak for the participants who recognize the "i". However, it is notable that, thanks to the added representative features such as the arms, the identification rate of the dummy was much higher compared to the previous evaluation.


Figure 3.26 Reception

- **Elevator**

Merely no participant recognized the elevator. It is worth noting that for B&VI people, the meaning of triangles was not intuitive compared to sighted people. Instead, the B&VI participants stated that they were more familiar with the tangible elements of an elevator such as the buttons inside and outside, a box-like shape as well as two sliding doors.


Figure 3.27 Elevator

"It will be very nice to have these placed in the new building at our school."

Discussion

Several issues were noticed during the study and they are discussed in the following paragraphs.

How the participants selection influenced the results

Some noticeable features belong to this special group of participants, who are still young students. For the study, the most influential one is their limited daily experience. As Bülthoff & Edelman (1992) stated, recognition occurs when the percept of an object matches a stored [27]. In other words, if the object hasn't been stored in memory yet, the recognition will not take place. Smoking room 1 was approved to be a very intuitively understandable object during the previous evaluation with blindfolded people, whereas most B&VI participants could not identify it due to the lack of smoking experience. The only four participants who recognized it were those who have smokers as family members or being a smoker himself or herself. The low identification rate of elevator 1 and door 2 could also be ascribed to the limited daily experience: they mostly use staircases at school and they are familiar with the handles rather than knobs.

The times measured for the identifications are not entirely reliable due to the language barrier. For the relatively young students, a interpreter was present since they could not speak English. However, the senior students were independently involved in the test that a considerable amount of time was spent on searching for a right word to give answer in English.

These issues should be noted when selecting participants in the follow up studies.

Difference between the congenital blind and the others

Large differences were seen between the congenitally blind and other participants. The congenital blind students had difficulties in perceiving objects which are relatively large in real life, such as the elevator, the toilet, even the hanger. In their minds, the information of these objects exists in pieces and a holistic picture is absent. The ability of perceiving the objects as a whole could be trained and improved since the older congenitally blind students had a better performance compared to the younger ones.

The connection between triangles and elevator

Differentiating from the results of the first ideas evaluation with blindfolded participants (§3.6.3), the connection between triangles and elevator was weak for most of the B&VI participants. They could hardly link any meaning to a triangle while its direction indication is universal for sighted people. As being asked to describe how an elevator looked like, the participants mostly mentioned the tangible parts such as sliding doors and buttons, both inside and outside an elevator.

The other objects' connections to the respective subjects were clear since those with ambiguous associations from the previous studies were excluded.

Using Braille

The common sense of associating a specific meaning to a letter in visual world is unknown for B&VI people, which disproves the above mentioned hypothesis in §3.6.1. During the study, the benefits of adding Braille to the icons representing the indistinct objects were highlighted. A good example could be the case of reception: adding Braille rather than a letter to the desk could help users better identify it as a reception desk instead of a cashier or normal desks.

Material issue

The results show that the current version of haptic icons is not perfect yet, especially for congenitally blind people. Reflecting on how to improve the current icons, except for carefully selecting and redesigning the representative objects in terms of geometry shape, adding specific material feature(s) could be another promising solution. Referring to the literature, Susan J. Lederman and Victoria A. Metzger (1985) confirmed the importance of material by indicating that global texture was predominantly mentioned as the basis for identification, which followed global shape in the first place. In line with the literature, some participants also pointed out the importance of material considering the insufficient cognition of geometry shapes. In a word, material features could help B&VI people identify the haptic icons faster and accurately.

How hand movements influence haptic object recognition

During this study, it was observed that the participants involved active hand movements to identify the haptic icons. They naturally started from the top surface and continued to the rest by following the contour of the object. This was in line with the contour-following exploration strategy defined by Lederman and Klatzky (1987): it has been noted that for the purpose of recognition, the hands typically follow the contour of a three-dimensional object until the object is recognized [28]. Furthermore, the experiments conducted by Newell, Ernst, Tjan and Bülthoff (2001) demonstrated that when an object is fixed in space, the back of the object would be priorly processed. For the visual system, it is the other way around that the optimal view of an object for recognition is the side of the object facing the observer [29]. Therefore, it could explain why people rarely noticed the letter "i" on the front side of the desk during the study. These empirical and theoretical findings suggest that more representative details on the top and back surface of the object could be priorly considered to include.

Conclusion

Overall, the study manifested that the concept of haptic icons could facilitate the independent navigation for B&VI people in public buildings. Most of the 3D icons could be perceived accurate and fast. As one teacher from Bartiméus, Zeist commented that, in terms of haptic perception, 3D objects are much easier than 2D ones since his students had great difficulties in identifying 2D tactile drawings. The participants also appreciated the delicate design of the objects and most of them were optimistic about its functionality.

Material could help B&VI people recognize the haptic icons. Therefore, it could be helpful to include specific material feature(s) together with geometry shape, especially for the ones which have representative material features.

With regards to the detailed design of haptic icons, a couple of insights were generated during the study. The first one is about the selection of representative objects. Users should have haptic experience with the object. The failure of identifying smoking room 1 supports this statement.

The second one emphasizes on how the object is positioned, which is in line with the conclusion from the generic group session (3.6.1). Although allowing the users to turn around the objects could speed up the process of identification, it is notable that the meanings of some objects would be distorted in other positions, such as the toilet and the elevator. For some objects which are portable in real life, for instance, the hanger and the coffee cup, the placing positions do not matter. However, considering the consistency of all the icons as well as keeping the whole scale model in the initial state after each usage, the haptic icons should be fixed on the model.

Furthermore, the representative details of a certain subject should be clearly presented. This could be exemplified by door 1 and café 2: respectively adding a handle and making the folk four-tine is of importance. According to the literatures, they are recommended to be put on the top or back surface of the object [29]. Additionally, the details should be made in proper size for haptic perception.

Some objects could not stand alone: a context is a must. For instance, without a wall, a door frame led to confusion in the study. Also, placing the elevator buttons on a board does not make any sense to participants since they are normally placed inside or outside the elevator in reality.

Figure 3.28 Two teachers from Bartiméus, Zeist were commenting on the concept.

The tactile information could hardly provide sufficient information for several particular subjects. B&VI people have rare chance to touch the object as a whole. In this case, introducing other features, such auditory, could be a promising solution.

3.6.5 Generic guidelines for designing haptic icons

Synthesizing the insights gained through the previous studies, a list of guidelines for haptic icon design is generated. Each of them is described below.

Haptic icons should be made in three dimensions

3D information is more efficient for haptic perception. When touching a 3D object, B&VI people could utilize their palms together with fingers to grasp the meaning as a whole in a relatively short time. However, the information is slowly and sequentially processed by touching a 2D object. Additionally, 3D objects are more concrete, which could save extra cognitive efforts of users.

Specific material features should be integrated

Compared with the geometry shape, the material feature could be perceived instantly and it is very helpful for object identification. This is supported by the relevant literatures as well.

Haptic icons should be symbolically presented as a set

This guideline emphasizes on the consistency of the haptic icons. This concern is not only aesthetics based, but also functionally orientated. The consistent haptic icons could pop out from the model base and better be perceived. Be specific, the size as well as the style of each icon should be unified.

Using representative objects instead of symbols, words or initials

The previous studies manifest the necessity of using representative objects to stand for a common place inside public buildings. Symbols, words and initials are too abstract and they lack a consistent interpretation. Also, B&VI people have rare experience with symbols and initials. The selection of representative objects should base on the following three criteria. Firstly, they should be the ones in which B&VI people have haptic experience. Secondly, its geometry shape should be distinctive and clear, which could avoid multiple interpretations. Thirdly, small objects in reality are preferred to make haptic icons, because B&VI people have more haptic experience with these objects.

Balance between complexity and abstraction is the key

A certain amount of details is needed to fit the perceptual reality of 3D haptic icons. Excessively abstracting the objects would lead to vagueness while integrating too many details would be confusing. The details, especially the ones on top or back surface, should be representative, accurately presented and perceivable by touch.

Fixing haptic icons on model

The direction and position could influence the perception of haptic icons. Additionally, this guideline also aims at keeping model together with icons in same state after each usage.

Providing a context if necessary

Some objects are vague when standing alone, such as the elevator buttons. Putting them in a specific context would help.

Making haptic icons movable if necessary

A moveable object could tell more than being static, especially when the movement is the key feature of the object. For instance, people would better identify an elevator button if they could really push it.

Integrating auditory features if possible

The tactile information is not always sufficient, especially when the subject is hard to scale and a representative object is difficult to find. In this case, co-working with sound could smooth the process of identification.

3.7 SPATIAL LAYOUT RESEARCH

As some participants involved in the user interviews claimed, a succinct 2D tactile map with a clear route was more functional than a 3D scale model. However, the 3D scale models that they referred to were made either for displaying the exterior of architecture or showing the surroundings of a district. Therefore, a hypothesis was put forward that what confused them was the abundant information that was integrated in the model which has nothing to do with orientation. Thus, a spatial layout research was set up to compare the efficiencies of presenting information in 2D tactile map and 3D scale model. The unnecessary information was excluded in the 3D model for testing.

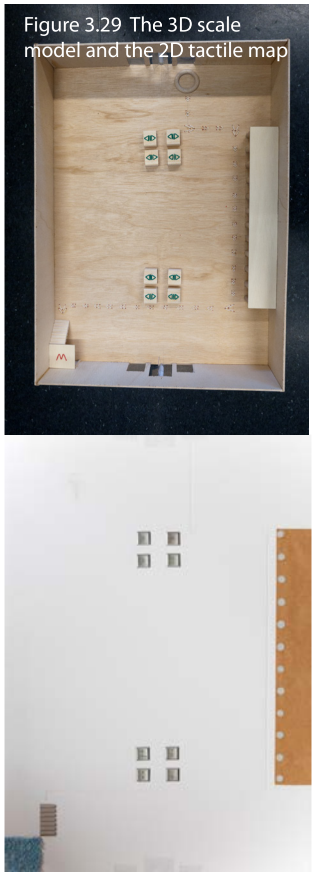


Figure 3.29 The 3D scale model and the 2D tactile map

3.7.1 Spatial layout study I

Goal

The study aimed at comparing the functionality of 2D tactile maps and 3D scale models. Additionally, the recognition of several haptic icons for the landmarks on the 3D model would be examined.

Setup

Considering the accessibility of blind and visually impaired people, the first round of study was carried out with blindfolded participants. The results would contribute to improving the setup of the second round study with real users involved.

To achieve the research goal, a 2D tactile map and a 3D scale model was built based on a simplified version of the ground floor layout of the Hague city hall (see Figure 3.29). Both prototypes consisted a route connecting the starting point and the destination. A legend was given to explain the meanings of the diverse shapes combined with different materials on the 2D tactile map,

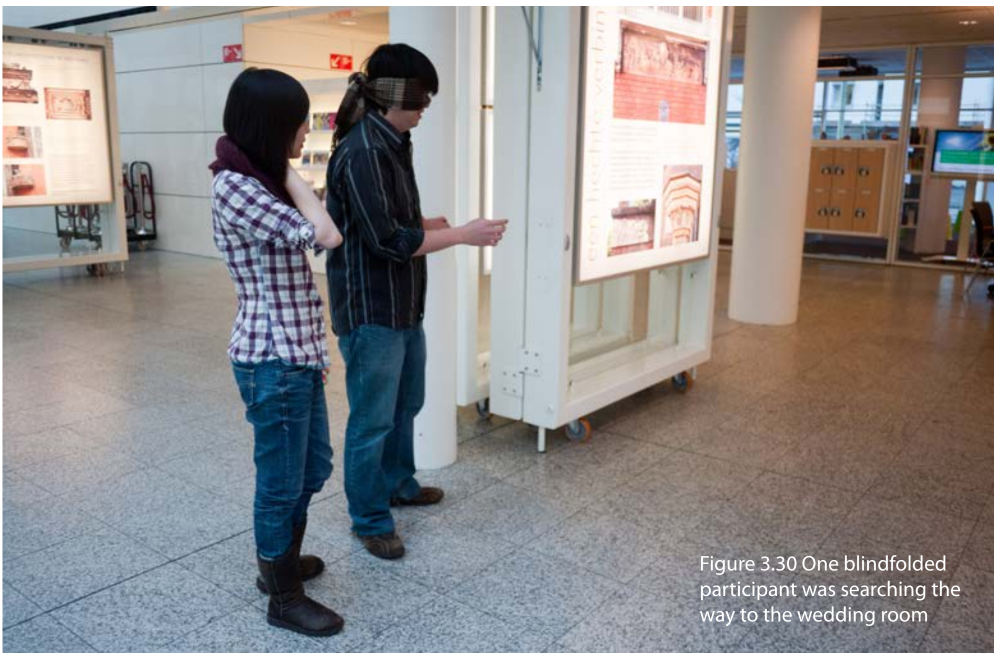


Figure 3.30 One blindfolded participant was searching the way to the wedding room

whereas the participants needed to independently understand the objects on the 3D scale model since the recognition of the haptic icons was another focus. Thus, three extra haptic icons for the route, three for the wedding room, and two for the elevator were tested (see Appendix VIII).

In this study, the main research question was ”A 2D tactile map and a 3D scale model, which one is more functional for blind and visually impaired people to use for navigation inside a public building?” To answer it, two groups of questions were generated regarding the use of the 2D tactile map and the 3D scale model. The details of the research questions could be found in Appendix IX.

Five participants got involved in the research, with two tested for the 2D tactile map and three tested for the 3D scale model. They had not been to the Hague city hall before the test so the indoor navigation experience of the building was brand new for them. During the study, three of the blindfolded participants were asked to explore the 3D scale model first to memorize the route. Then they were led to the starting point to search for the destination, the wedding room on the first floor. After that, the 2D map was explored and based on that, a short interview was conducted to evaluate both prototypes. For the other two participants, the 2D tactile map was explored first.

Multi- modal qualitative methods were used in this research, including interviewing and observation, both in real life and through video analysis. Observations were carried out to see how they used the 3D model and the 2D map and how they navigated inside the building. After that, a semi-structured interview was given to find out how they evaluated the prototypes. The details of the procedure could be found in Appendix X.

Results

Exploring the model and field way finding

In Figure 3.31, the time that each participant took to learn the information from the model/map was presented, as well as whether they could tell the starting point and the destination on it. All of the participants succeeded in finding way to the wedding room after exploring the model/map.

No huge difference was found between the time of exploring the 3D model and the 2D map. The most time-consuming part of using the 3D model was

Figure 3.31 The detailed results of all the participants

	3D model	2D map	Exploring the model/map			Field way finding	
			Time	Starting point	Destination	Time	Way finding
Participant A	✔		6min30s	✔	✔	15min	✔
Participant B	✔		4min40s	✗	✗	19min	✔
Participant C		✔	3min30s	✔	✔	25min	✔
Participant D		✔	7min10s	✔	✔	17min	✔
Participant E	✔		3min05s	✔	✔	35min	✔

figuring out the meanings of the objects on the model. For the 2D map, most of the time was spent on learning the legend, with which they could understand the objects on the map.

Model evaluation

In this part, how the participants evaluated the model and the map are summarized from four aspects. First of all, the information presented on the model and map will be discussed. Then the functionality as well as the using experience of the 3D model and 2D map will be evaluated. The final part includes the discussion of the navigation problems occurred in the way finding process.

- Information on the model/map

All the participants mentioned that the information is not enough for navigation. It could be sufficient only when they were able to follow the given landmarks on the model/map from the starting point to the destination, which turned out to be very difficult. Once getting lost, they couldn't refer the landmark, which they could recognize nearby, to the model or map. Therefore, they were not able to crack the problem by positioning themselves in the building. For example, one participant could tell there was a door on the left side when he got lost and stopped somewhere in the building. However, he failed in finding the door on the model.

- 3D scale model

With no legend given, the participants could basically understand the objects on the 3D scale model. Some of the objects confused them at the beginning. However, when they moved to the rest of the model and associated the elements together, everything fell into place. Therefore, the exploring process of the model was iteratively. The details of the discussion of each haptic icon could be found in Appendix XI.

People were able to search for landmarks near the route when they were at the turning point. One participant mentioned that the connection between the route and landmarks was not close enough and she nearly missed the first set of elevators since she was totally focusing on the route.

The 3D scale model is helpful for spatial learning of an environment. People are able to intuitively build a mental picture of the space, especially for the multiple-floor situation. Also, people could associate the objects on the model to the reality, especially for those designed in a realistic style, such as staircases, pillars and additional ceiling. This has something to do with the ability of thinking and visualizing in three dimensions as well. As mentioned above, the process of understanding the 3D scale model was iterative. People were more likely to explore the model in their own way. In other words, the route doesn't lead the user but the user touches the model in a free style.

- 2D tactile map

Due to the indirect connection between some of the objects on the map and what they look in real life, the participants needed to memorize the meanings of the objects by using the legend for a while. The specific material applied to each object approved to be helpful for memorizing. People didn't need to go back to the legend when exploring the map. They supposed that they could

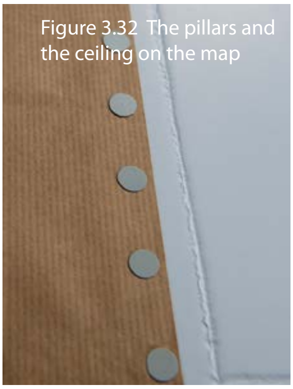


Figure 3.32 The pillars and the ceiling on the map

memorize up to around 15 objects without going back to the legend during the use.

The important information could stand out on the map pretty well. People especially appreciate the clear and continuous route on the map and they felt secure to follow it. Differentiating from the iterative process of exploring the 3D scale model, people used the 2D map at one go, from the starting point to the destination.

People were able to visualize the space with help of the 2D map when everything is located on the same plane. Compared to the 3D model, they did point it out that the spatial relationship between the pillars and the additional ceiling is not that clear on the map (see Figure 3.32). Also, how the first floor connects to the ground floor with the stairs is better demonstrated in the 3D scale model. People could associate the objects on the map to the real situation, but some key features of the objects were missing when presented in 2D form such as the revolving door.

- Navigation

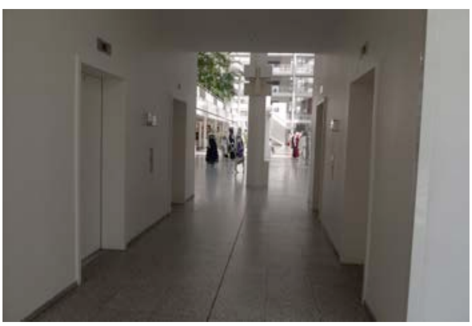
In this part, the navigation problems that the participants encountered were discussed. The problems were categorized into three groups: inadequate ability of nonvisual navigation, landmarks recognition and cracking the problem of getting lost.

The problems relating to the inadequate ability of nonvisual navigation could be generalized as lacking sense of direction and lacking sense of distance. The blindfolded participants were not able to walk in a straight line and once they turned around, they could hardly turn back to the last direction they faced. Some of the participants were able to judge the direction based on listening to the walking sound of people who came by them. However, due to the spaciousness and multiple doors on four directions, telling the direction still remains a problem. Also, people were not able to sense the distance very well. For instance, on the model/map, the first segment of the route is very short compared the whole length of the route. However, some of them hadn't realized that they should have started looking for the landmarks near the first turning point until there was only halfway up.

"Where are the elevators? I have no clue at all!"

In the study, the participants experienced various problems with landmark recognition. The elevators turned out to be the most difficult one. Due to the silent design, the elevators were working noiseless. Also, the four elevators were built inside a semi-open space (see Figure 3.33), which even cut the sound off from the outside. One participant succeeded in telling the elevators by listening to the sound of people's walking and talking. In addition, the pillars could be learned quickly when they were exploring the map/model. However, in field, finding the pillars was a little bit more difficult than assumed. On one hand, people didn't have a cane to detect the obstacles so they had to feel the environment with open arms. On the other hand, there are too many pillars in diverse sizes inside the building and some of them just locate next to the ones which were marked on the map/model. Thus people were confused. Furthermore, the participants didn't have the intuition to listen to the acoustic change of the environment when they were walking

Figure 3.33 the four elevators were built inside a semi-open space



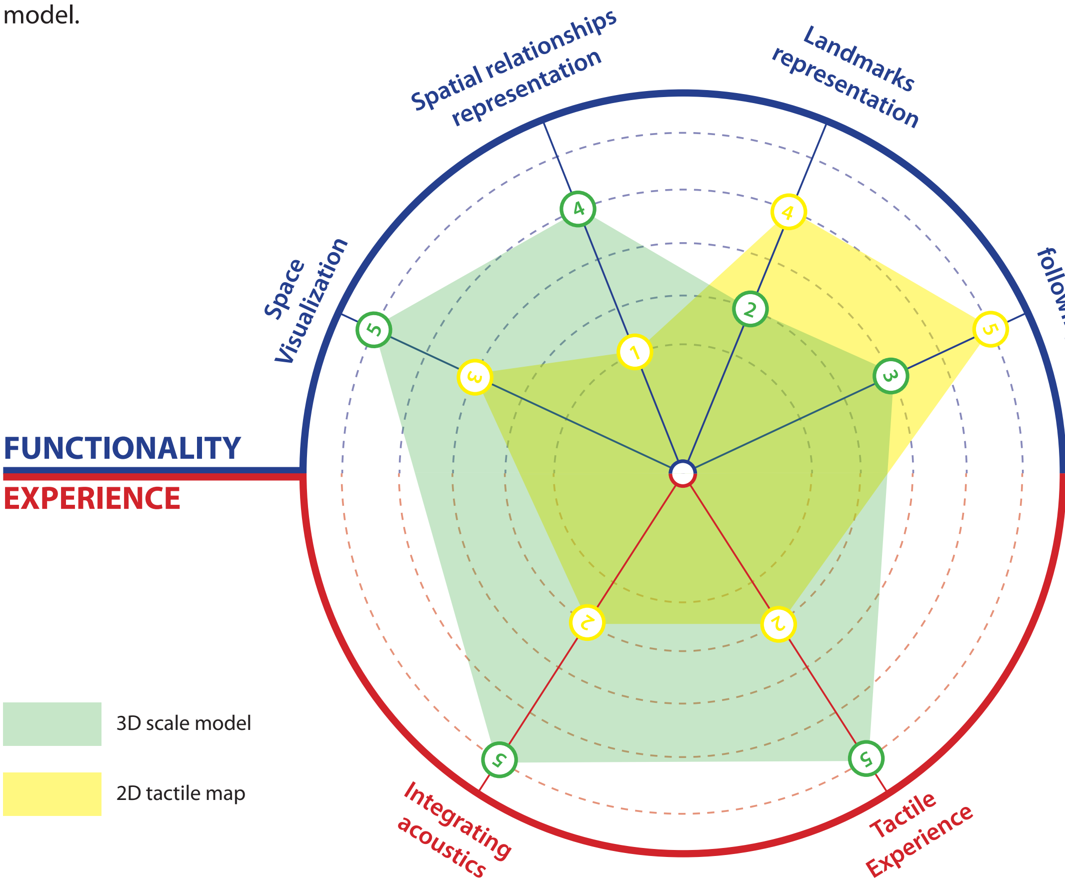
underneath the additional ceiling.

As mentioned at the beginning, the major problem is about the insufficient reference points given on the map/model. When they couldn't find the next landmark on the route, they failed in positioning themselves even they could tell some landmarks near them. A lot of landmarks approved to be recognizable during the study. For instance, nearly all the participants noticed that there are side entrances on both sides, since they could feel people walking past and the flow of air. The billboards with light boxes are recognizable as well, because of its relatively high temperature and material. The sound of cashier reminded people of a shop locating nearby.

Conclusion

In the following wheel, the 3D scale model and the 2D tactile map were evaluated by the author and a comparison was made between the two. From the perspective of functionality, both prototypes were evaluated based on the criteria of route following, landmarks representation, spatial relationships representation and space visualization. Since the end goal of the project also includes the experiential aspect, the tactile experience and the possibility of integrating acoustics were evaluated in the wheel as well. Although these experiential aspects were not tested out during the research, the potential possibility of being implemented in the final design was examined. A scale from 0 to 5 was applied. The higher score, the better performance. The yellow area stands for the 2D tactile map and the green area represents the 3D scale model.

Figure 3.34 The comparison between the 2D tactile map and the 3D scale model, in terms of functionality and experience



Overall, the 3D scale model is better than the 2D tactile map, both in terms of functionality and experience. Displaying the basic layout of a building in 3D won't confuse users.

The 3D scale model could give a better overview of a space where the spatial relationships between the objects are clearly presented. It could also facilitate the process of space visualization, which could be even more difficult for the blind and visually impaired than blindfolded people in the real situation. In accordance with what we learned from the user interviews, the translation is not needed when using the 3D model.

As observed in the research, people tend to use the 3D scale model in an explorative way. This behaviour pattern would allow some features, such as interactive and playful, to be implemented in the final design. Diverse materials could be applied to the objects made in a realistic style, which could enrich their experience of the space. The integration of sound would make the 3D model more playful and interesting, and better mimic the real life situation. It is worth noticing that the 2D tactile map could be able to include sound as well, but the abstraction of information representation on the map doesn't match the sound in realistic style very well.

At the moment, the 3D scale model has its drawbacks as well. As shown in the comparison wheel (Figure 3.34), the 3D scale model performs not that good in route following and landmarks representation. This probably has something to do with the poor design of the landmarks, which was the focus of haptic icon explorations that was being carried out in parallel.

However, it is notable that 2D tactile maps have advantages in particular situations: on one hand, the objects should not be too many in total; on the other hand, all the objects should locate on the same plane. As mentioned above, when all the objects are on the same plane, the 2D map could display the information very well since the important information could stand out. Also, people could learn it quickly with a legend when the number of the objects on the legend is relatively small. Therefore, combining with the background of the project, the 2D tactile map could be used to **self-aid**, which would help users to solve problem of way lost, as long as they could still tell a landmark nearby. In this case, they could quickly refer to the legend and find the possible location of the landmark on the map, based on which they would be able to relocate themselves in the environment. Since the usage of the map in this situation is more like looking up a dictionary, the number of the objects on the legend is under no restriction. Accordingly, the place where people could get the self-aid handbook on each floor should be marked on the 3D scale model. The 2D map should be portable and disposable.

Discussion

The blindfolded participants were used during the study, which would influence the results to some extent. The navigation problems were amplified since sighted people don't practice walking in the dark as much as B&VI do. Their strategies and skills are not that well developed as well. On the contrary, people with normal sight have higher performance in spatial thinking and visualizing, which is related to the rich visual experience. This raises the higher demand on the prototype, which should facilitate the users to carry out this task. In this case, the advantages of 3D scale models are better revealed.

3.7.2 Spatial layout study II

Following the previous research, the second study with blind and visually impaired people involved was carried out. According to the results of study I, one substantial difference between the 3D scale model and the 2D tactile map was about how they presented the spatial relationships between the objects. Considering this as an opportunity to optimise the functionality of the final design, in this research, more focus was placed on how blind and visually impaired people require the spatial information from the prototypes. Furthermore, by including specific sounds to explain the meanings of the objects, the possibility of integrating the auditory aspect was investigated in this research. Additionally, the issue of navigation strategy was explored during the study.

Goal

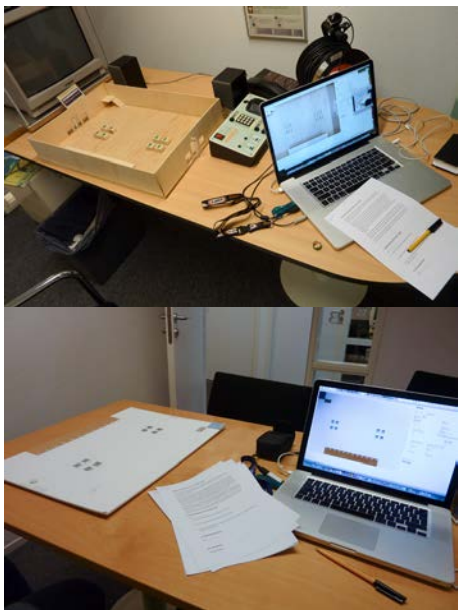
The study II has three goals:

- To examine how blind and visually impaired people require the spatial information from the 3D scale model and the 2D tactile
- To explore the possibility of combining sound
- To deepen the insights of how the B&VI leverage their strategies to orientate inside public buildings, with a concrete example, the Hague city hall

Method

The main research question was in line with the previous one. In addition to the same questions for the use of the 2D tactile map and the 3D scale model, another group of questions were generated for sound and strategies of orientation, in terms of building mental picture, problem solving and how landmarks were involved in the way finding process (see Appendix XII for more details).

Figure 3.35 The setup for the spatial layout study II



In the previous research, a legend was given for the 2D tactile map while no explanation was provided for the objects on 3D scale model. In this case, enormous difference existed in terms of the cognitive efforts that the participants spent on object identification for both prototypes, which weakened the direct comparison of the two prototypes regarding the efficiency of presenting spatial information. In order to eliminate the influence of object recognition, a sound-based explanation of the objects was given for both the 3D scale model and the 2D tactile map, which was also because the haptic icon design was proved as a promising direction based on the positive results of the haptic icon exploration (see §3.6.4).

Except for the auditory input, the physical testing materials remained the same as the previous study although certain disadvantages were found in the design of both prototypes, which was about providing insufficient information of the target building. The reason behind this was that, first of all, the cons of both prototypes didn't have direct influence on reaching the research goal; secondly, with less information given, the participants were assumed to make most of their strategies of orientation, which would benefit the second goal mentioned above.

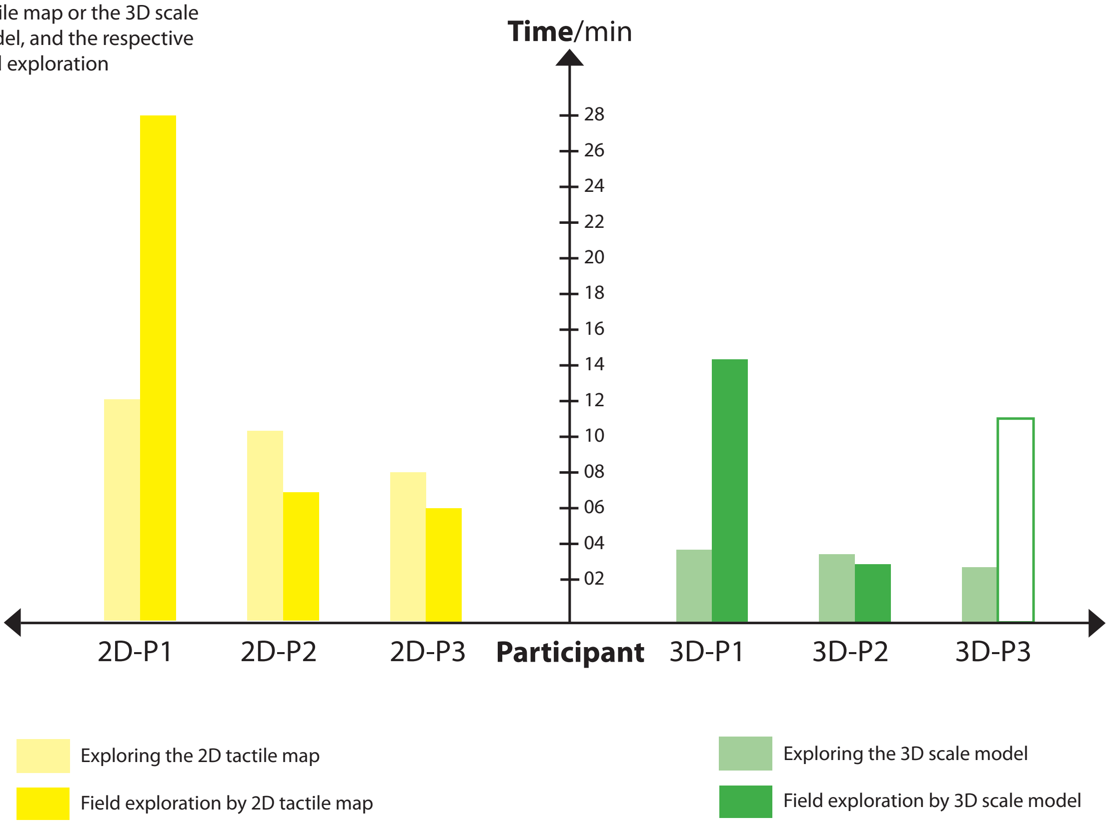
Six participants got involved in the research, with the half tested for the 2D tactile map and the half for the 3D scale model. The distribution of visually impaired and blind people was even for each prototype.

First of all, the participants were asked to explore the prototype to get familiar with the building. Then they were brought to the starting point and the independent field exploration started. Observations were carried out to see how they used the prototype and how they navigated inside the building. After that, a semi-structured interview was given to find out how they evaluated the prototypes. As to compare the results, the time spent on exploring the prototype and finding the way in field were measured.

Results

Five participants succeeded in finding the wedding room while one participant using the 3D scale model failed. The time spent on exploring the prototype as well as finding the way in field for each participant was illustrated in Figure 3.36. Enormous difference was found between the 2D tactile map and 3D scale model in terms of prototype exploration, which reveals that the 3D scale model is comparably easy to understand. The times spent on field exploration varied from person to person, which could not lead to a convincing conclusion due to the small size of sample and the individual differences in orientation strategy.

Figure 3.36 The comparison of time spent on exploring the 2D tactile map or the 3D scale model, and the respective field exploration



Overall, the participants were positive about the 3D scale model because of the clear spatial information presentation, especially when combined with sound. The confusion of the objects was largely eliminated by the respective sound integrated. The 3D spatial layout of the model is helpful for perceiving the environment as a whole and clearly displaying the specific information, such as the spatial relationships between the pillars and the ceiling and how the wedding room and the stairs are connected together.

"The scale model is good enough, but not perfect, could be better. "

In line with the previous study, the 2D tactile map is weak in presenting spatial information. One participant thought the wedding room was on the first floor since how it is linked to the stairs is vaguely presented on the 2D tactile map. All the three participants had difficulties in understanding the pillars, the ceiling as well as the spatial relationship between them.

Some sights were gained regarding to the model base design, which could be applied to both the 2D tactile map and the 3D scale model. Firstly, only two participants noticed the route on the prototype even they were informed of its existence beforehand. In the field exploration, only one participant followed the route and the other five people designed their own routes. The only participant following the route stated that when searching the nearby landmarks, she had to deviate from the route and the resulting turns made it hard for her to be back on the route with the right direction. Secondly, nearly all the participants used the entrance as the starting point rather than the ring on the 3D model or the round embossed shape on the 2D map. Thirdly, people felt confused when encountering the unexpected objects during the field exploration. Additionally, most of the participants reported that they didn't get an idea of the distance and the spaciousness from the prototype, which could be useful for orientation as well.

Regarding to the strategies for orientation, the blind and visually impaired participants are more sophisticated than the blindfolded sighted people. First of all, the B&VI are good at landmark identification. More participants recognized the elevators in the research even the identification of the elevators was still lower compared to other landmarks. Moreover, the B&VI participants could keep walking in one direction. They took advantage of the objects in the building as a reference, such as the counters in the city hall (see Figure 3.37). The permanent sound resource, for instance, the sound of revolving door on another side, could be used as a reference as well. At the meantime, the participants mentioned that too many turning points would confuse them.

Figure 3.37 To keep walking in one direction, B&VI participant used the counters as a reference

Discussion

In this part, some remarkable findings relating to the special cases from the research are described. Furthermore, the feasibility of combining auditory and tactile features is critically discussed as well.

One of the participant (P1) use guide dog and it made him a special case to study. Because of the dog, the cane is more like a signal of being a blind person rather than a tool to detect obstacles. In this case, he was not able to identify some landmarks such as the pillars by cane since the dog led him away from them. Another thing was the dog always brought him directly to a door. During the research, the participant went back and forth for a couple of times by following his guide dog, which resulted in the relatively long time taken to find the wedding room. Additionally, it was impossible for him to follow the designed route during the navigation.

One participant had an interesting thinking pattern when exploring the 3D scale model. When touching the pillars and the ceiling on the left side, she intuitively interpreted them as obstacles rather than landmarks. Thus, she took the way on the other side, where is empty on the model. Reflecting on the design of the model, the unbalanced distribution of the landmarks could be one reason behind her situation. Certain landmarks should be given on the right side even they are irrelevant to the given route, since it is always hard to anticipate the user's thinking pattern.

The potentials of combining tactile and auditory information were confirmed during the research. The users could better recognize the landmarks and perceive the spatial information when the sense of touching and hearing are working together. The tactile and auditory information is able to compensate for each other. In some cases, the sound is more helpful than haptic perception. For instance, the mechanic sound plus the ding sound of door opening could represent the elevator better than its geometry shape. However, for some objects, it was another way around. For instance, the revolving door was very difficult to identify by sound while the geometry shape could explain a lot. This also leads to one disadvantage of the 2D tactile map that the abstract objects could not contribute to the identification even the respective sounds are combined.

The functionality of the 3D scale model was confirmed while the experience of the building is not enough yet. Since the comparison in functionality between the two prototypes is the main focus of the research, not too many material features were integrated in the model. In addition, the height of the building could be included as to enhance the overall impression of the architecture.

Conclusion

In the following paragraphs, the choice of using a 3D scale model or a 2D tactile map will be stated and argued. Furthermore, several design decisions will be concluded regarding to the general model base.

- Comparison between the two prototypes

Overall, the 3D scale model is superior to the 2D tactile map. It is revealed in the following facts:

Users could intuitively understand the spatial information by using the 3D scale model, especially for the multiple-level situation and the spatial relationship between the pillars and the ceiling. By using a 2D tactile map, users could not get the complete information for constructing the environment in their minds. In line with one finding of the user interviews, 2D tactile maps always need a translation. In other words, the 2D tactile map calls for extra efforts for spatial visualization.

The 3D scale model could integrate the auditory information to fulfil each advantage to better present the functional information, while the 2D tactile map is weak in closely connecting to the sound.

The 3D scale model has the potential to let users feel the building in its entirety. An idea of the whole space would be better expressed by means of presenting the height of the architecture next to its length and width.

- Model base design

Scale and distance is important: although the importance of landmarks overweighs the issue of scale and distance, which was revealed from the user interviews, blind and visually impaired people should be able to estimate the distance of the destination by using the scale model. Additionally, it could enable them to feel the spaciousness of the building from the perspective of enriching experience. To achieve this, a scale should be given. It is notable that no specific strategy would be required to use the given scale to measure the distance. For instance, the distance should not be estimated by counting footsteps, which is not a universal method for all blind and visually impaired people.

The position of the starting point should be where the scale model is inside the building. It should be highlighted by means of embedding the tactile features of the scale model, such as its overall appearance, rather than using an abstract object with vague meaning in its geometry shape. Furthermore, auditory input could also be used to better stress the position of the starting position because of its significance.

According to how the participants behaved during the study, the route is not always necessary to include in a scale model. First of all, following a route would interfere with searching for particular landmarks. Secondly, different users have their own orientation strategies and thinking patterns. What a scale model should do is to provide sufficient information for users to utilize their ones instead of making a choice for them. Thirdly, in practice, there could be a lot of popular destinations in public buildings. In this case, embedding multiple routes on one model would be confusing and disturbing for stressing the most important information. As the last concern, for the users with guide dog, the route would be useless.

Irrelevant landmarks for a certain destination could be helpful for positioning. The needs of users on landmarks could not be anticipated. For instance, some landmarks would be used as a reference point for walking in one direction, although they are not directly linked to the destination. Therefore, their existences on the model should be a necessity.

3.7.3 Generic guidelines for designing a model base

The haptic icons would not be able to use alone: a model base as the using context is needed to bring their values into full play. Thus, a list of generic guidelines was generated. The development of the guidelines was based on the outcomes of the literature research, the field research and the spatial layout studies with blindfolded and B&VI users. Below, each of them is described.

The model base should be designed in 3D

Referring to the spatial layout studies (§3.7.1, §3.7.2), 3D model is superior to 2D map in terms of functionality, not to mention the differences in experience.

Choosing a proper size

Based on the literature research, blind and visually impaired people tend to use the body-centered strategy for exploring the model, which is in line with what the B&VI participants behaved during the spatial layout study II (3.7.2). This implies that users should be able to reach any corner of the scale model without changing the standing or sitting position. In practice, the using position of the model should be determined first. Then the relevant ergonomics data should be referred to, such as the hip height and arm length of the target users.

Paying attention to using direction

The scale model should be placed according to the spatial layout of the represented building in reality. Thus, users would be able to match haptic icons on the model to objects in the real life intuitively.

Including height of building

According to the spatial layout study II (§3.7.3), including height of building next to its length and width could help users to have an overall idea of the building, thus to enrich experience.

Incorporating a scale to allow users to estimate distances

The importance of scale and distance was highlighted in the second spatial layout study (§3.7.3), although they were underappreciated in the previous user interviews (§3.1). Therefore, a scale should be incorporated in the model. Precisely positioning a starting point, where the scale model would be placed in reality, could be an effective solution of giving a scale to users. By measuring the distance from entrance to the scale model on the model, users would be able to estimate distance to their destinations and to feel the spaciousness of the represented building.

Planed routes are not always necessary

How participants behaved in the second spatial layout study (3.7.3) revealed that predefined route was of less importance to include in a 3D model, at least for a public building like the Hague city hall. Since B&VI users have diverse navigation strategies and thinking patterns, a scale model should not make decision for users. Multiple routes might confuse users because it would be difficult to follow one of them.

Including a sufficient amount of landmarks to avoid blind spot

Blind spot here refers to the area on the model where neither landmark is given nor special material is applied. According to the spatial layout studies (§3.7.3), the landmarks that are irrelevant to the destination are helpful for positioning. The studies illustrated the ability of identifying certain amount of landmarks of B&VI people. These landmarks either should be able to be detected by cane, such as pillars, or they make identical and representative sound, such as elevator, café, and door. Placing enough landmarks on the model could make the information complete and continuous, thus to exclude blind spots.

Clearly indicating potential hazards

According to the outcomes of the user interviews (§3.1) and the spatial layout study II (§3.7.3), safe issue always comes in the first place. Therefore, to B&VI people, the potential hazards inside a public building, including stairs, escalators, etc, should be clearly marked on the scale model.

Incorporating material features

Although the material issue of the scale model has not been tested in the previous research, its value could be foreseen based on the field research (§2.4), the user interviews (§3.1) as well as the spatial layout study II (§3.7.3). According to what B&VI participants stated, including material features could benefit functional as well as experiential use of the model. The material change on the floor could work as a cue of to indicate the position. Furthermore, using specific materials matching the reality could help users better experience the environment since they are not able to touch the building in a whole.

CHAPTER FOUR.
FINAL CONCEPT & EVALUATION

This chapter describes the final concept of the haptic icons, named Haptic Guide (§4.1.1), and how they are integrated in a three-dimensional model base (§4.1.2) which is designed for a conference center. Based on the previous evaluation (§3.6.4), adjustments were made to certain icons. Additionally, specific material features were incorporated. The model base consisting two floors was designed to manifest how Haptic Guide could work in a context for a navigational use. The design of model base was referred to the results of the spatial layout research (§3.7). A drawer structure was used to cope with the multiple-floor situation.

§4.2 describes an experiment, aimed at examining if Haptic Guide, used in a 3D scale model, could facilitate independent nonvisual navigation inside a public building. Referring to the design goal established in §3.2, the experiments focused on whether the usage of the Haptic Guide is intuitive and how it works on a 3D scale model base. Methods and results could be found in §4.2.1. The experiment is discussed in §4.2.2.

4.1 FINAL CONCEPT

Haptic Guide is a set of haptic icons which could facilitate the independent indoor orientation of public buildings for blind and visually impaired people by giving tactile information. Haptic Guide symbolizes the common places or objects of public buildings in hand size, based on using a representative object or a component. By touching the icons placed on an interior scale model, B&VI people will intuitively perceive the locations of the most functional places. In the current version, eight common places or objects are developed, including reception, toilet, cloakroom, stairs, elevators, door, smoking room and café. The following picture (Figure 4.1) shows how Haptic Guide is integrated in a three-dimensional model base.

There are several main features of Haptic Guide.

Intuitive usage

A legend full of Braille is not needed because Haptic Guide could speak for itself. With the help of symbolizing a certain object or component in a hand size, B&VI could perceive the efficient information fast and accurate. Less cognitive efforts for object identification are needed and required memory load is substantially decreased.

Not only shapes, but also materials

For some objects, only the geometry shape is not able to provide sufficient cues for identification. Therefore, specific materials of a certain object are integrated in Haptic Guide. For instance, ceramics is applied to the icon of toilet.

Figure 4.1 Haptic Guide integrated in a three-dimensional scale model

It could move, like what it does in reality

Movable components are integrated for some icons to make them more recognizable. The movements of the objects should be related to what they are in reality. For instance, the haptic icon of door could be open with a handle; the flushing button on the toilet could be pushed.

Easy adaptation

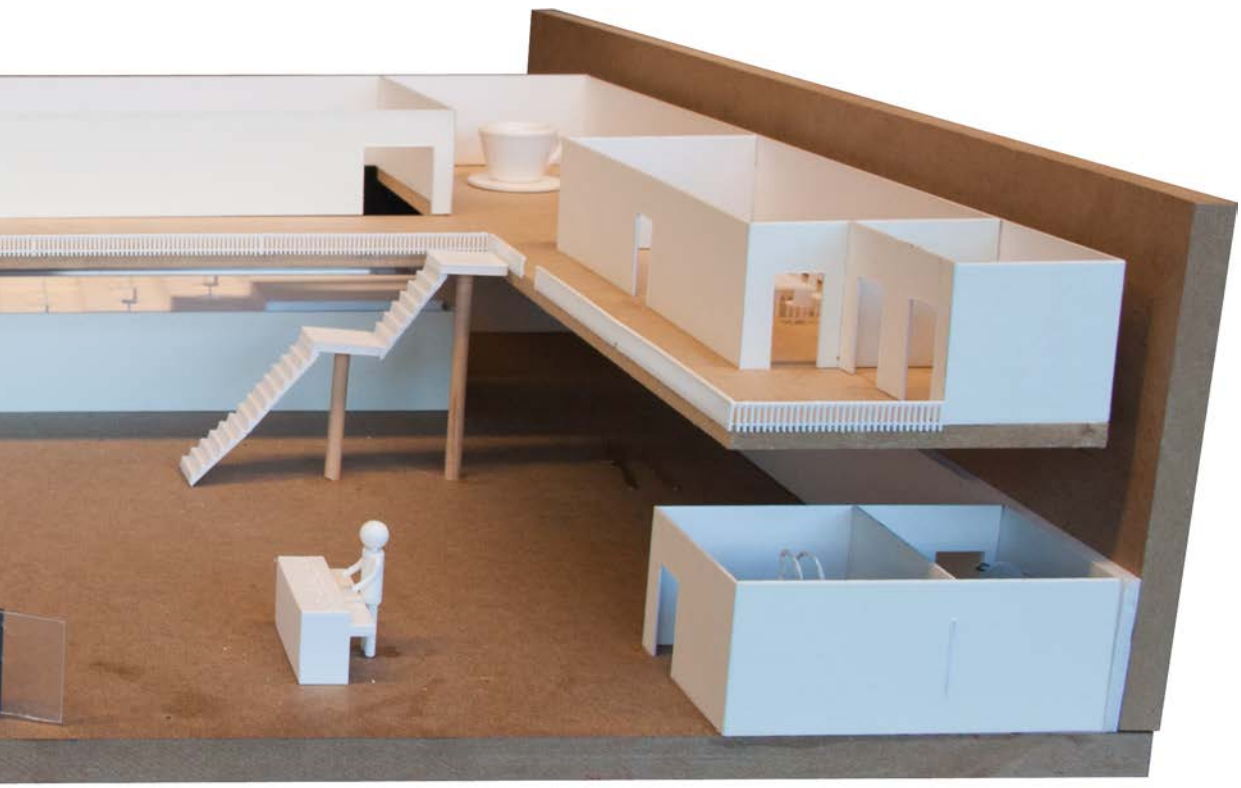
Haptic Guide could be universally applied to most public buildings since the selected subjects are the most common ones. It is possible to upgrade the current version if the target building has other unique functions.

Potential of integrating auditory features

The modular components of Haptic Guide allow for the possibility of integrating auditory representation, which could even better facilitate the object identification. Integrating sounds would make Haptic Guide more interesting and attractive.

Visual appeal

Blind and visually impaired people are target users of Haptic Guide. However, how to make it attractive for sighted people was also taken into account when designing Haptic Guide. To make Haptic Guide looks like a set, all the icons are consistent in dimension and style. Except for the parts with representative materials, the rest parts use uniform material and colour.



4.1.1 The Haptic icons of public buildings

Below, Haptic Guide is introduced respectively. The object selection and material choice are described.

Reception

A person standing behind a desk represents reception (Figure 4.2). To characterize the dummy, two arms and two legs were added. Since the use of desk is common in different contexts, the reception in Braille is added to the top side of desk.

Toilet

Two designs are provided for toilet (Figure 4.3). One is a toilet including a toilet seat and a flushing button. Specific materials are added to facilitate the identification: plastic for the seat, ceramics for the rest and metal for flushing button. The other one uses a roll of toilet paper together with a hook which fixes it on wall. Paper and metal material are applied to this icon.

Cloakroom

A hanger is selected for the icon of cloakroom (Figure 4.4). To give it a using context, a big rack is built as well. Both are made of plastics.

Stairs

The icon of stairs is consistent with the one in reality. This icon could be adjusted according to the height of the floor. Figure 4.5 shows the one made for the model base of a conference center.

Door

The door icon uses a flat wooden board together with handles on both sides (Figure 4.6). The handles are made of metal material. The doorframe was removed since B&VI people have limited haptic experience with it (see §3.6.4).

Elevators

The elevator consists of a semi open metal box with open sliding doors(Figure 4.7). Two big buttons are placed on the wall inside. The choice of making the inside buttons are based on the results of ideas evaluation II (see §3.6.4). The buttons could be pushed and the floor indication in Braille is placed next to each button. The buttons are made of plastics.

Figure 4.2 Reception

Figure 4.3 Toilet

Figure 4.4 Cloakroom

Figure 4.5 Stairs

Smoking room

An ashtray together with a cigarette is chosen for making the icon of smoking room (Figure 4.8). The initial idea of using a pipe was discarded because it is too old fashioned and the shape could be easily recognized as a spoon. The cigarette feels real by touch.

Café

Two haptic icons were developed for Cafe (Figure 4.9), depending on the particular using situation. If the place is more likely for a drinking area, a coffee cup together with a saucer could be used. If it is a dining area, another icon consisting a folk and a knife could be chosen.

Figure 4.6 Door

Figure 4.7 Elevator

Figure 4.8 Smoking room

Figure 4.9 Cafe

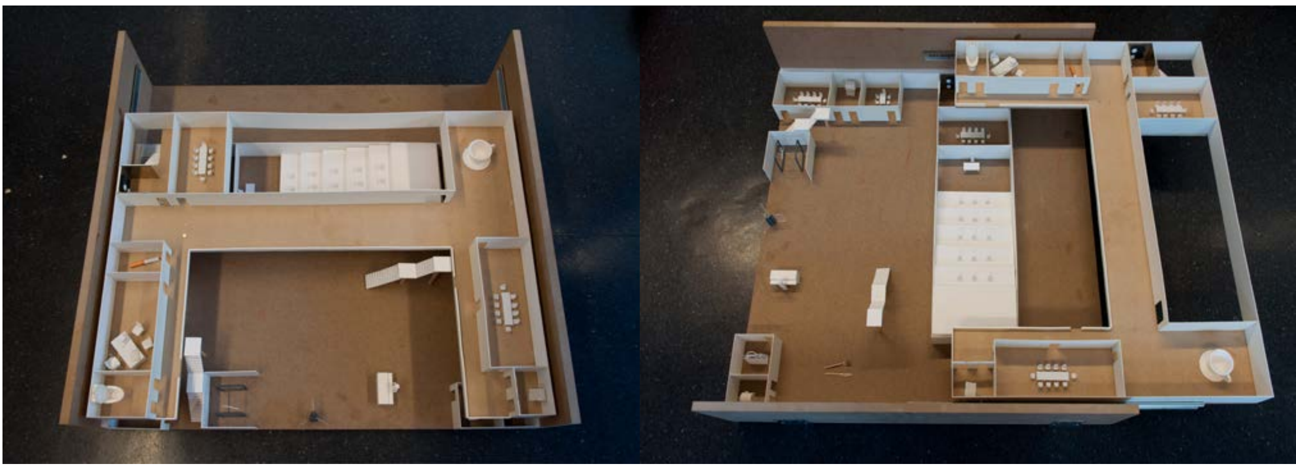
4.1.2 Model base design

The model base (Figure 4.10) was built based on a factitous public building, a conference centre. The building contains two floors with an atrium located in the centre. A drawer structure (Figure 4.11) was designed to make the upper floor moveable, in order to allow enough space for users to explore the ground floor. To ensure users could reach any corner of the model without using standing position, the dimensions were set within the mean measurements of reach depth fingertip and arm length, based on the standing position and the sample of "international mixed" and "Dutch adults mixed" (see Appendix XIII for more details). The model is 800mm in length, 600mm in width and 200mm in height. For each floor, the wall is 60mm high and extra 40mm was left between the two levels to ensure the smooth movement of the drawer structure.

Several haptic icons were designed for lecture hall, meeting room, office and souvenir shop to characterize the building as a conference centre. On the ground floor, the model contains a revolving door (Figure 4.12) as the entrance. Around the atrium, there are two meeting rooms, two toilets, a shop, a cafe and a cross-floor lecture hall. The first floor is connected to the ground level by two staircases in the atrium and one staircase together with an elevator in a closed space in the upper left corner. On the first floor, except for the lecture hall, an office, two meeting rooms, a smoking room, a coffee corner and two toilets are located.

Certain objects represent the special places of the conference centre: the meeting room contains a long table together with several chairs (Figure 4.13); the lecture hall has a pitched floor with multiple seats on it (Figure 4.14); a desk together with a chair characterizes an office (Figure 4.15); a shopping bag made of paper represents the souvenir shop (Figure 4.16). The haptic icons are applied to the rest of places or objects inside the building. Since each room has one or more doors, the haptic icon of door is only used for the hallways connecting the elevator and staircase on both levels, which is an important landmark. The other doors are represented as a rectangular hole to simplify the information.

Figure 4.10 The Haptic Guide used on a three-dimensional model base designed for a two-level conference center.



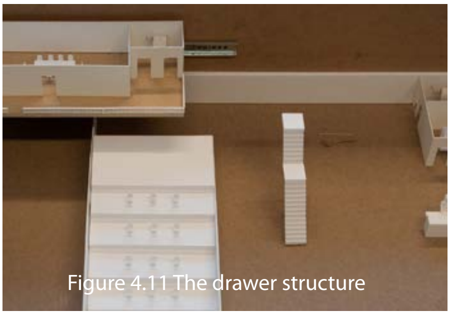


Figure 4.11 The drawer structure

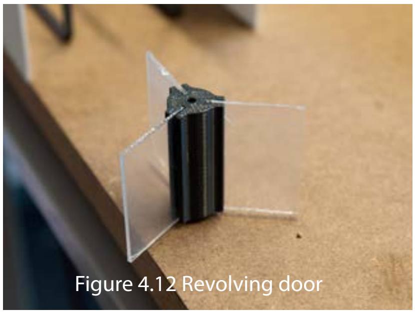


Figure 4.12 Revolving door


Figure 4.13 Meeting room


Figure 4.14 Office

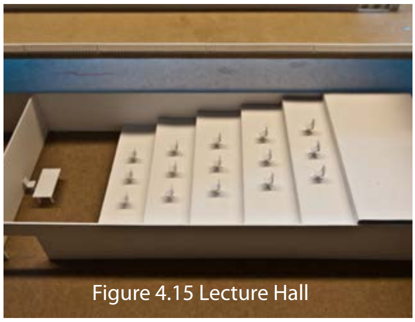


Figure 4.15 Lecture Hall


Figure 4.16 Shop

4.2 EVALUATION

This section describes an experiment, aimed at examining if the final concept, Haptic Guide, used in a 3D scale model, could facilitate independent nonvisual navigation inside a public building. Referring to the design goal established in §3.2, the experiments are focused on whether the usage of Haptic Guide is intuitive and how it works together with a 3D scale model. Methods and results could be found in §4.2.1. The experiment is discussed in §4.2.2.

4.2.1 Goal

According to the design goal (§3.2), the experiment had two focus. Firstly, the experiment aimed on whether people could intuitively use Haptic Guide. Secondly, examining whether the given information on the model is clear and succinct would be another focus.

4.2.2 Method

Participants

Ten blindfolded participants were involved in the experiment. Eight of them are educated as Industrial design engineering and two of them are architecture majored students. Nine participant had no smoking experience before and none of them had experience with a tactile scale model.

Apparatus

The experience took place in a quiet room. The scale model was placed on a 110 centimetres high table and a video camera was situated in front, which recorded their hand movements. The participants could freely touch the model by bare hands and no extra help were received during the experiment.

Assignments

A story relating to the context, conference centre, was set, which consisted of ten navigation tasks of point-to-point route planning. The participants were supposed to attend a lecture in the buildings and the first task was to look for the **reception** to check time and location for the lecture. Then they were asked to go to the **cloakroom** to store their jacket. After that, they needed to enter the lecture hall from its **back door**. During the break, they were structured to search for a **coffee corner**, a **smoking room** as well as a **toilet** nearby. When finishing the lecture, they went to a **office** to look for a friend of them to have lunch together in a **canteen**, by using en **elevator** to get to the ground floor. Before leaving, they were asked to look for a **shop** to buy some souvenirs.

Procedure

The experiment consisted of four stages: introduction, exploration, performing tasks and interview, taking approximately 2, 3, 15 and 5 minutes, respectively. The participants were blindfolded before entering the room. The introduction provided the participants with a general idea about what the model is about and the concept of the Haptic Guide. Besides, the participants were briefly instructed to practise using the drawer structure. They were asked to think aloud and raise questions during the process, even the researcher were not going to answer them instantly.

Prior to performing the tasks, a three-minute exploration was carried out. The participants were told to focus on the general layout of the model and they would have time to go back to the model afterwards.

After exploring the model in general, the participants were instructed to perform the tasks one by one. The researcher gave the tasks separately and sequentially. The participants were not informed that the time of performing each task would be measured. The time was measured afterwards when analysing the video clips.

A semi-structured interview was held to end the experiment. General questions about how they evaluate the model, Haptic Guide, the drawer structure as well as the visual appearance were discussed.

The participant instruction could be found in Appendix VIII.

Figure 4.17 One participant was performing the task.

4.2.3 Results

In general the tasks were performed well and most of the participants responded positively.

Quote 1: *"The haptic icons are quite intuitive to understand."*

Quote 2*: "The ones have special material are especially clear. I can recognize it instantly."*

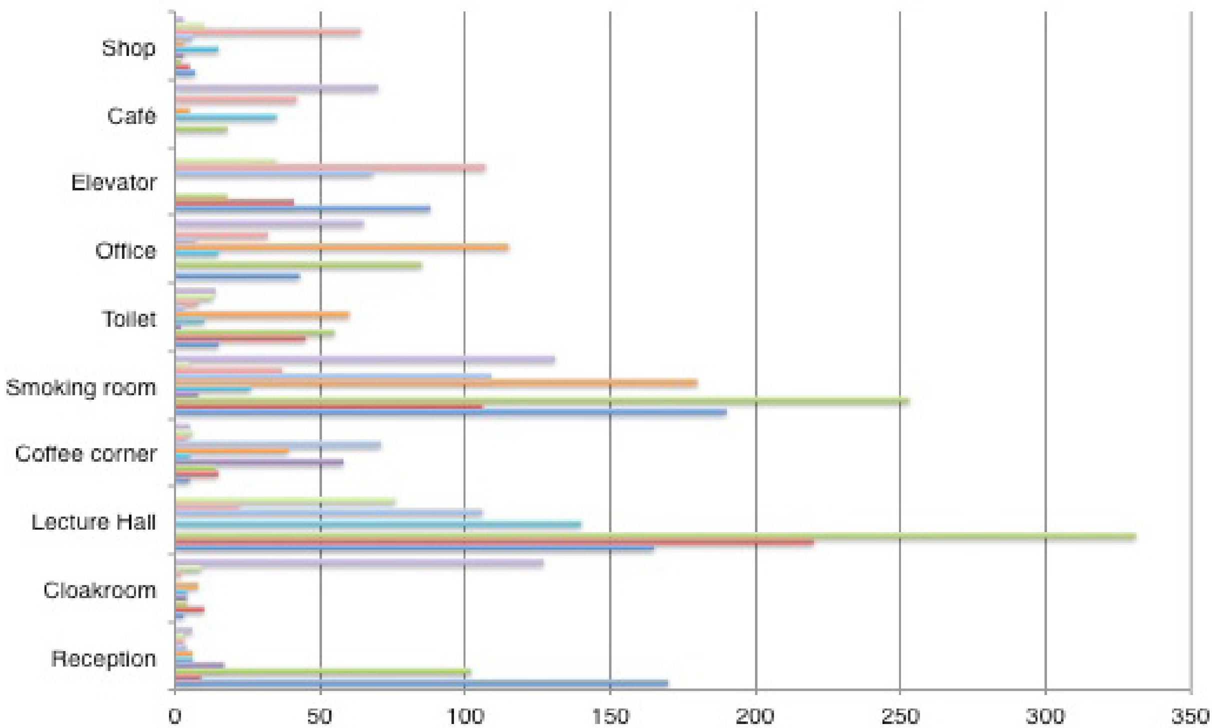
Quote 3*: "The haptic icons information and the spatial layout are both clear for me. They are very functional!"*

Quote 4*: "It looks very cool, indeed!"*

Quote 5*: "The drawer structure is easy to use, but my coherent mental picture of the spatial information was broke by the moveable structure. It's like all pieces are suddenly shuffled when playing puzzle."*

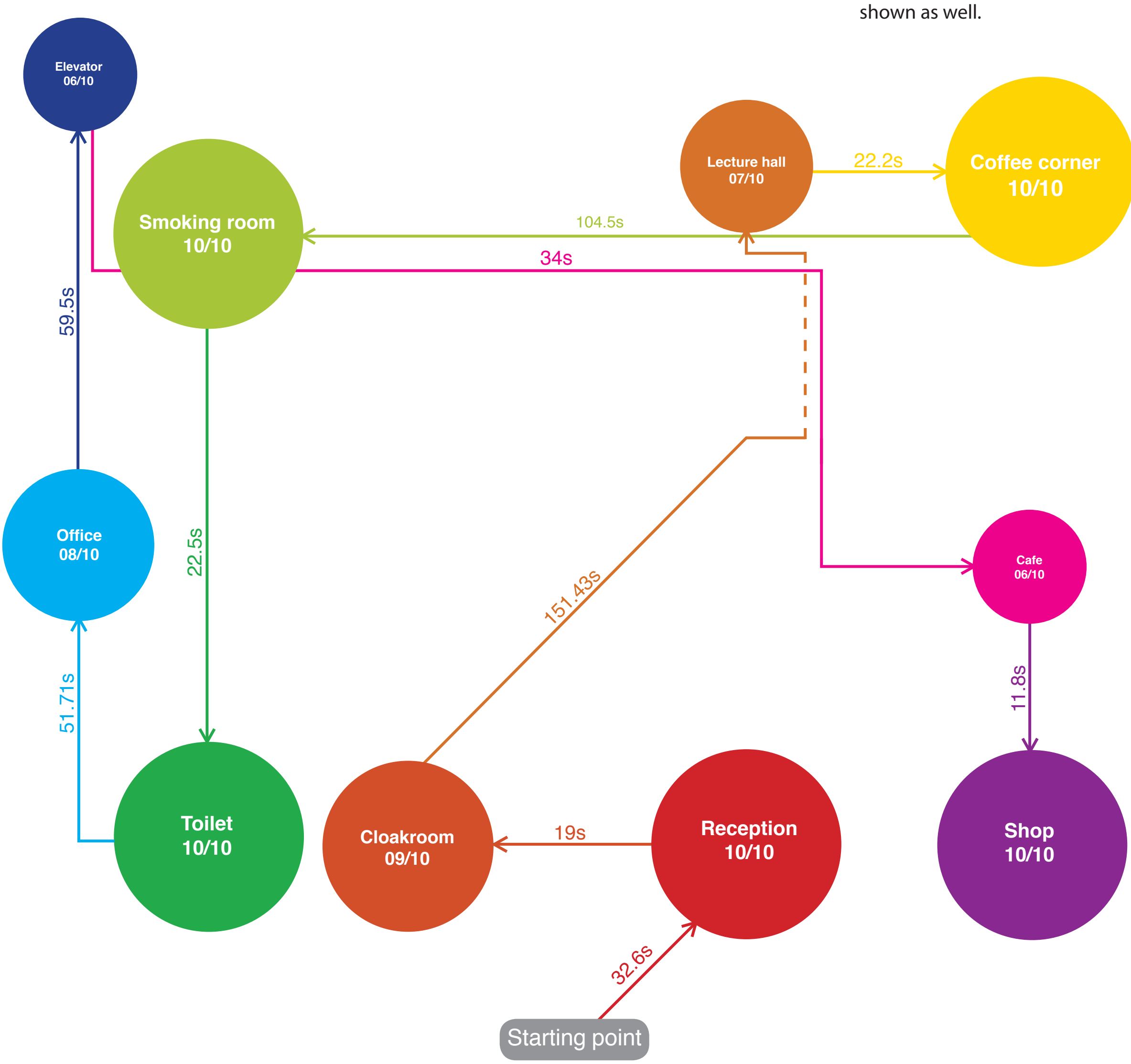
A chart (Figure 4.19) on the right page demonstrates the results from three aspects: the accuracy rate, the average time and the relative positions of the places. The reception, the cloakroom, the back door of the lecture hall, the coffee corner, the smoking room, a toilet, the office, the elevator, the café and the shop was successfully located by 100%, 90%, 70%, 100%, 100%, 100%, 80%, 60%, 60% and 100% of the participants, respectively. The shop turned out to be the fastest one to find, which consumed 11 seconds in average, followed by the cloakroom (19s), the toilet (22.5s), the reception (32.6s), the coffee corner (22.2s), the café (34s), the office (51.71s). The smoking room and the back door

Figure 4.18 Time consumption of each task by participant



of the lecture hall were the two which were slowly located, manifested in the significant time difference: each took 104.5s and 151.43s respectively. The detailed information of the time each participant took to locate each place is shown in the Figure 4.18. The different colour used in the figure represent different participants.

Figure 4.19 The chart presents the accuracy rate and the average time of planning route to certain place. Besides, the relative positions of the places are shown as well.



4.2.4 General Discussion

The discussions below are structured based on Haptic Guide design, the model base design, how Haptic Guide worked with the model base, visual appearance, and how the experiment setup influenced the results.

Is Haptic Guide intuitive to use?

In general, Haptic Guide was clear and intuitively understandable for most participants. As Quote 2 indicates, the specific materials applied to certain haptic icons accelerated the process of recognition, such as the paper roll for toilet, the cutlery for café, the metal compartment for elevator and the ceramic cup on a saucer for coffee corner. The geometry shapes of the cloakroom and the stairs are also clear enough for identification even these objects were all made in plastics.

Figure 4.20 The details of the dummy on the front side are not touchable

Some participants had confusion in the elevator and the reception. The open front side of the elevator made them recognize it as an open space instead of a compartment. Three participants expected the outside buttons instead of the inside buttons provided. This is contradicted with the results of haptic icons evaluation with blind and visually impaired people (§3.6.4). Also, one participant mentioned that his confusion was caused by the relative big buttons, compared to the size of the compartment. For the reception, the dummy caused certain confusions, mainly because it was placed too close to the desk that the details of the dummy on the front side are not touchable (see Figure 4.20).

Could the model base clearly communicate the spatial information?

By using the model, the participants were able to perceive the functional information about the spatial layout of the presented building. People could perceive the relative size of each room. As the participants reported, the atrium in the center and how to go upstairs turned out to be clear. One problem remained in the lecture hall: although all the participants could perceive the steps inside, they still encountered difficulty in figuring out that the hall was built across double floors, which led to their overlook of the back door on the first floor. Reflecting on the model base design, the confusion could be caused by the space left between the two floors for the drawer structure. This made the back door illogically lead to an empty area (Figure 4.21).

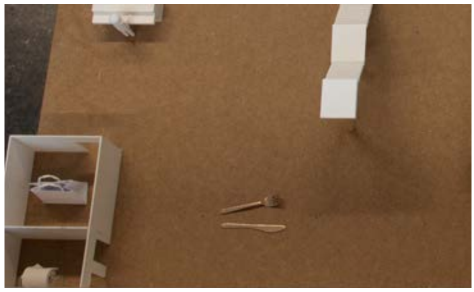
Figure 4.21 the wall of the lecture hall is not one piece on the back, which brought confusions.

The usage of the drawer structure went well. It was easy for the participants to push and pull it by grabbing the first floor. Two cons of the drawer structure are worth to mention here. Firstly, the moveable upper level breaks the coherent perception of the building, as Quote 5 indicated. Without a reference point, the connection between the two floors is weak. Secondly, one participant reported that when the first floor was left in the half way, she was not sure which floor she was touching.

How does Haptic Guide work with the model base?

In general, the use of Haptic Guide on the model base was positive. By touching the certain object in a certain room or an open space, participants were able to get the idea of what the place was for. Based on the spatial information given by the model base, they could also know how to get there. The absence of ceilings for the rooms didn't confuse participants and they had the intuition to explore the rooms from the top and noticed where the doors were. The major problem of the layout is the height of each floor. For the current model, the space of the smoking room was limited, which led to the overlook of the icon placed inside. This fact substantially increased the time of planning the route from the coffee corner to the smoking room (134.9s), although the icon itself was clear, supported by its high accuracy rate of haptic perception. Most participants went over the smoking room from the top quickly without touching the haptic icon inside. Considering that the size of a room is determined by the represented building, the height of wall, which is more experience related, should be modified in order to allow each space for touching.

Figure 4.22 the haptic icon of canteen could hardly be noticed by quick scanning



Another issue is about the placement of the haptic icon of canteen. Due to the fact that the cutlery is relatively flat compared to the others, when it is placed on the ground, the participants could hardly notice it, especially when they were scaned quickly across the open area (see Figure 4.22).

Is the model visually attractive?

Most of the participants responded positively to the visual appearance of Haptic Guide and the model base. They especially liked the color combination of both and they thought the important information was standing out. Besides, they commented that the model looked functional as well.

How does the setup limit the results?

The author noticed limitations of the setup of this experiment. Below, how the setup influence the results are discussed from the aspects of participants choice, material as well as the provided instructions.

Because it was difficult to gather B&VI people in a relatively large amount and to make a tight schedule for tests, blindfolded participants were used instead. Except for the issue of visual experience, the tests with sighted people mainly influenced the results from the following two aspects. On the one hand, the Braille on certain haptic icons, such as the button of the elevator and the reception desk, turned out to be the confusing part since sighted people could not read Braille. They spent extra efforts on associating the dots to other irrelevant things. On the other hand, they could hardly evaluate the use of the scale model objectively. In fact, they would naturally compare the use of the model by touch to the experience of using a navigation tool by sight. That’s why one participant reported that she was very desperate and helpless during the use, even though the tasks went well, with 90% correct.

The table, where the model was put on, was relatively high for participants. Although all the participants were able to reach any corner of the model, they didn’t reach the left upper corner much during the experiment, which led to the overlook of the elevator by two participants. The selection of participants could also be related to in this issue: most participants are Chinese females, whose heights are mostly lower than the average height of the international mixed sample.

CHAPTER FIVE. CONCLUSION

In this chapter, with respect to the design goal (§3.2)and design criteria (§3.3), Haptic Guide and the three-dimensional scale model are evaluated, based on the results of the previous experiment. In §5.2, recommendations are given for further development, in terms of research and design.

5.1 HAPTIC GUIDE

Haptic Guide is a set of haptic icons made for eight places, including reception, cloakroom, toilet, door, elevator, stairs, café and smoking room, which can be universally found in diverse public buildings (Figure 5.1). Each haptic icon represents an above mentioned place or object, by means of redesigning the geometry shape of a representative object and incorporating specific material features.

Figure 5.1 The rendering of Haptic Guide

Haptic Guide is used based on a 3D scale model (Figure 5.2). By placing the haptic icons in certain positions, the 3D scale model facilitates blind and visually impaired people to recognize the above mentioned eight places or objects and their locations in the represented building in reality. Based on the spatial layout information provided by the model base, users are able to plan routes to these places or objects and to use them as landmarks with their own navigation strategy.

The Haptic Guide could be universally applied to diverse public buildings. The modular design makes it promising to combine auditory or other information sources, which would make it even more functional and interesting.

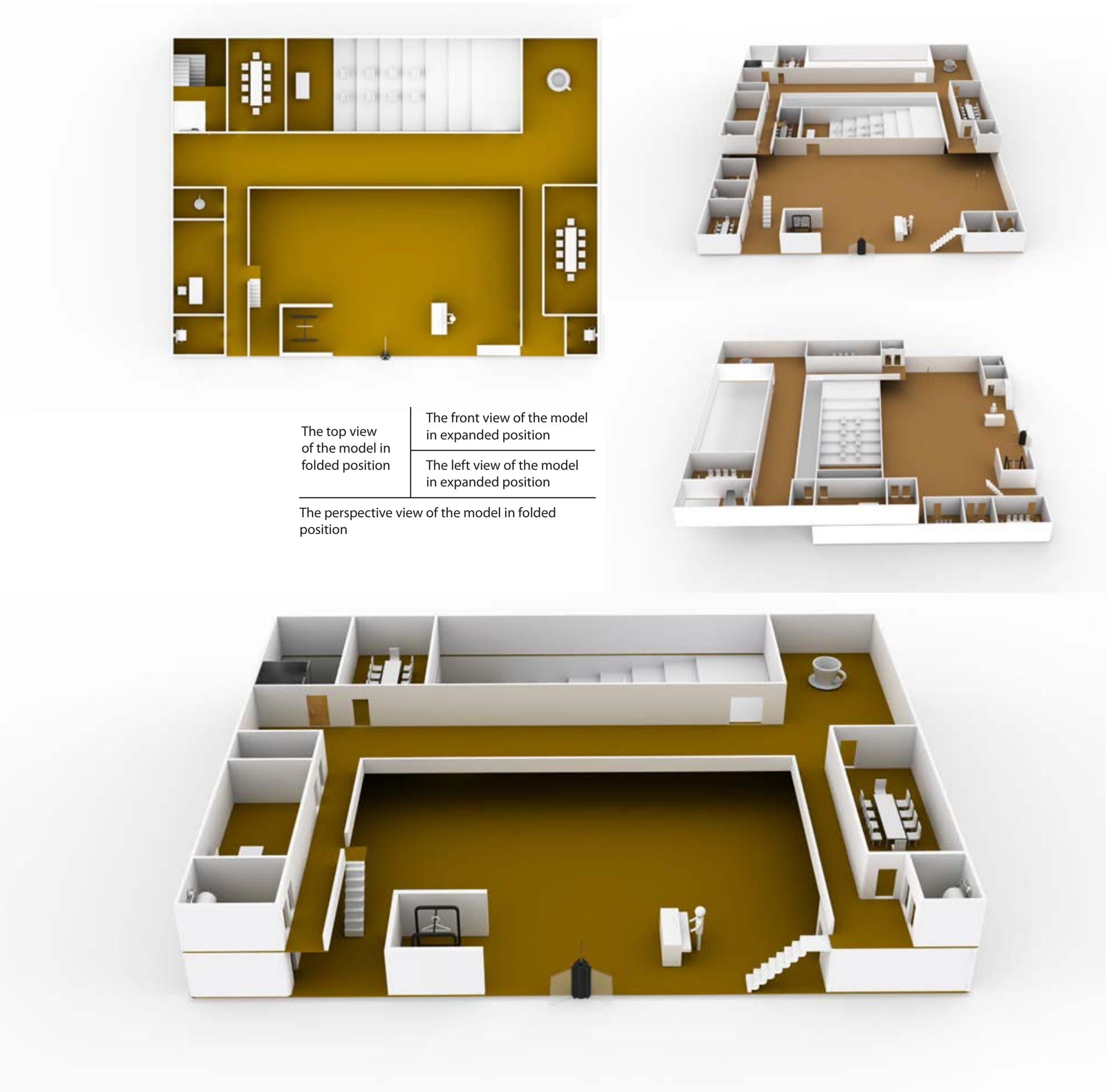


Figure 5.2 Haptic Guide displayed in the 3D scale model of a two-level conference center

Is Haptic Guide intuitive to use?

The evaluative study (§4.2) indicated that Haptic Guide is intuitive to use. Not much cognitive efforts are required to identify the haptic icons and to understand the spatial layout of the represented public building. No instruction and none experience of using a scale model is required. The specific material feature of the haptic icons saves much time of recognizing the icons. Moreover, using the most representative objects benefits the identification as well.

Is the given information functional and efficient?

All the information presented on the model is functional, without any decoration. The ability of reading Braille is not required for using Haptic Guide: the combination of geometry shape and specific material allows Haptic Guide to speak for itself. According to how the participants planned routes in the experiment, Haptic Guide could work well with the 3D model base. Integrating the object information of Haptic Guide and the spatial information of the model base is intuitively understandable. Thus, it is a promising solution for understanding the location of a certain destination in reality (where) as well as the way to get there (how).

Is the prototype visually attractive?

The current visual appearance of Haptic Guide together with the 3D scale model is appreciated by sighted people. They highly liked the neat layout and the clear presented functional information.

5.2 RECOMMENDATIONS

As starting point of a two-year project, the scope of this graduation project is how to help B&VI independently navigate inside public buildings by using tactile information. From the perspective of future development, this section provides recommendations on future research and design.

Recommendations on research

The following topics have not been researched yet while attentions should be required for further development.

- The combination of Haptic Guide and the model base should be further tested with B&VI participants, with a field way finding task added.
- To better perceive Haptic Guide on 3D scale model, the relation between height of wall and size of haptic icon should be further determined.
- Regarding fulfilling the functional aspect as the first step, the current version of Haptic Guide was designed for navigation use, based on which the simplification and the abstraction was made. Since enriching the experience of public buildings is part of the end goal of the project in long-term perspective, it would be necessary to research how to design haptic icons to cover experiential aspect. Specifically, when selecting representative objects and specific material features, how to simplify and abstract information to match the need of enriching experience should be analysed.
- The current size was chosen based on the ergonomics database. The dimension of the model base should be further analysed by modifying and adapting the theoretical data to practice by determining the height of table.

Recommendations on design

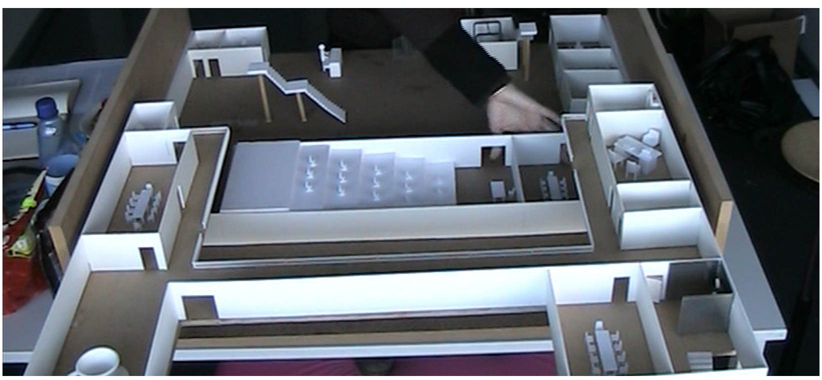
Below, the recommendations are given regarding the topics that have not been worked out for the current version of Haptic Guide and the model base, as well as the issues arose during the design process.

- Improvements should be done to intensify the haptic icons as a whole, to make them further stand out from the model base by haptic perception. In current version, the objects that don't have representative material features were made of plastics and they could be isolated from the ones with diverse materials incorporated. Therefore, suggestions are given on using special materials for all the icons, no matter whether they were the representative feature of the object or not.
- By observing the hand movements of the participants during the experiment, the author noticed that people tended to carefully follow the wall (see Figure 5.3). This implies that information could be incorporated there to make use of the use pattern. The information on wall could be the hints leading users to important information. In this case, people would not likely to miss the haptic icons.
- A 2.5D portable and disposable map, which has slightly embossed objects and made of paper, could be a solution for compensating for the limited

memory capacity as well as cracking the problem of getting lost. The map could contain lots of information since it will only be used when a specific search goal is already there. After determining the nearest landmark, people could look it up in the legend and refer to the map to know where they are. This 2.5D map should be designed for each floor and where people can get it should be marked on the scale model.

- Suggestions are given on how to improve the current used drawer structure. Firstly, a usecue could be made to make the usage intuitive. It should be noticed that the usecue should be able to perceive by haptics and its existence will not bring confusion. Secondly, reference points could be set to indicate the relative position of both floors. Thirdly, a click mechanism could be made to provide hints for the two important positions: the folded position and the expanded position. Moreover, in the current model base, the drawer structure was incorporated as a first try out of how to cope with multiple-floor representation. The pros and cons were both revealed during the experiment. It would be interesting to see what other solutions could be and probably merge the pros of each, in order to offer an optimal solution.
- The material choice of the current model base was made mainly based on easy prototyping, touch friendly and visual appeal. Besides, whether the material is durable and strong enough for use is another significant issue to consider. Thus, further investigation on this issue should be carried out.
- Adding auditory information would make the Haptic Guide even more functional, especially for the ones which are difficult to represent by solely tactile information, such as the elevator. In addition, people would have more fun when using Haptic Guide.
- Due to the limitation of time and prototyping techniques, some moveable parts of the haptic icons haven not been realized in the current prototype, such as the movable toilet seat. Bringing the moveable features of the real object to their haptic icons would provide functional information as well as make it more interesting.

Figure 5.3 People tend to carefully follow the wall when exploring the model



CHAPTER SIX. REFLECTION

Before starting my graduation project, I did not even know what “haptic“ and “tactile“ meant, and had no idea of how blind and visually impaired people live. Through eight months working on this topic, now I can even dream tactilely. As a designer, it is hard to step out the comfort zone to totally dive into a nonvisual world. However, this is exactly what triggered me to think critically and be open-minded to listen from what users said. I think this is one of the main reasons why I enjoyed the project so much.

Apart from the topic, the development of a scale model was new for me as well. Therefore, I was keeping facing new problems and cracking them all the way along. With respective to approach, I never individually conduct a research and analyse the results in such a scientific manner before. When looking back at the moment, I would say that all these new things turned out to be fun even though it was a struggle at the time.

Another aspect that kept me learning was how to first do things and then to discard things. During the process, what I did was far more than these a hundred pages thesis. When composing this, I was struggling with leaving out the things by carefully considering their relevancy to the final concept.

Reflecting on the process, the beginning of my graduation project in which I tried to find focus gave me some frustrated moments. In the phase of user-centered conceptulization, I was struggling with finding B&VI participants. However, when looking back, I do think that all the effort was worthy and without it I could not go through a complete project and deliver a useful end result.

The phase with which I’m most satisfied is the user-centered conceptulization phase, especially the way that I carried out the study of spatial layout and haptic icons in a parallel manner first and then came to the final concept by combining the results of both. It was very helpful to do research with both blindfolded and B&VI participants. The two groups of participants behaved differently during the studies. The comparison between them revealed the underlying behaviour or thinking pattern of B&VI people, and thus guided the development of the final concept.

Certain improvements could have been done on two aspects of the project. When doing the spatial layout study, I realized that what people think and what they do are sometimes two different matters. Some results of the study in which a practical task was performed was contradicted with what the participants reported during the interviews. Therefore, I think if the general user interviews could have been done with several navigation tasks, more valuable insights could be generated. Secondly, due to the time limitation and the difficulty of gathering B&VI participants, the final evaluative study was carried out with blindfolded participants. Therefore, some aspects of the final design could not be precisely tested, such as the general experience of using the scale model to plan routes. The final prototype could have been better evaluated by the target users.

The fact that the graduation project was collaborated with Geluid in Zicht was probably one of the best things of the whole project. A lot of help was offered during the process. Apart from getting access to the target user group, I also got the chance to listen to the opinions and advices from the experts in the filed of tactility, architecture, education of blind and visually impaired children. These different voices kept inspiring me and made the final concept became better.

Many people see their graduation project as a milestone of their master programs, but I felt that it was just as important as other projects that I did before, for which I always spared no effort. Now looking back at the process I went through and the end result came out of it, I have no regret and I'm proud to graduate by this project!

REFERENCE

[1] Lederman, S. J. & Klatzky, R. L. (2009). Haptic perception: A tutorial. Attention, Perception, &Psychophysics 71(7): 1439-1459.

[2] Sonneveld, M. (2007). Aesthetics of tactual experience.

[3] Withagen, A., Vervloed, M. P. J., Janssen, N. M., Knoors, H., & Verhoeven, L. (2010). Tactile Functioning in Children Who Are Blind: A Clinical Perspective. Journal of Visual Impairment & Blindness.

[4] Hupp, G. S. (2003). Cognitive differences between congenitally and adventitiously blind individuals.

[5] Bértolo, H. (2005), Visual imagery without visual perception? Psicológica 26: 173-188.

[6] Ramachandran, V. S., & Brang, D. (2008). Tactile-emotion synesthesia. Neurocase 14(5), 390–399.

[7] Loomis, J. M., Klatzky, R. L., Golledge, R. G., Cicinelli, J. G., Pellegrino, J. W., & Fry, P. A. (1993). Nonvisual Navigation by Blind and Sighted: Assessment of Path Integration Ability. Journal of Experimental Psychology: General, Vol. 122, No. 1.73-91.

[8] Schneider, J. & Strothotte, T. (2000). Constructive Exploration of Spatial Information by Blind Users. The 4th ACM SIGCAPH Conference on Assistive Technologies Arlington, VA, USA.

[9] Hub, A, Diepstraten, J, Ertl, T. (2004). Design and Development of an Indoor Navigation and Object Identification System for the Blind. ACM SIGACCESS Accessibility and Computing, Issue 77-78.

[10] Withagen, A., Vervloed, M. P. J., Janssen, N. M., Knoors, H., & Verhoeven, L. (2010). Tactile Functioning in Children Who Are Blind: A Clinical Perspective. Journal of Visual Impairment & Blindness.

[11] Rowell, J. and Ungar, S. (2003). The world of touch: an international survey of tactile maps. Part 2: design. British Journal of Visual Impairment, Volume 21.

[12] McCallum, D., Ungar, S. and Jehoel, S. (2006). An evaluation of tactile directional symbols. The British Journal of Visual Impairment, Volume 24.

[13] Schneider, J. & Strothotte, T. (2000). Constructive Exploration of Spatial Information by Blind Users. Proceedings of the fourth international ACM conference on Assistive technologies

[14] Jehoel, S., McCallum, D., Rowell, J & Ungar, S. (2006). An empirical approach on the design of tactile maps and diagrams: "The cognitive tactualization approach". The British Journal of Visual Impairment, Volume 24.

[15] Jacobson, R. D. (1998). Navigating maps with little or no sight: An audio-tactile approach. Proceedings of Content Visualization and Intermediary Representations.

[16] Bright, K., Cook, G. & Harris, J. (1993). Building Design: The Importance of Flooring Pattern and Finish for People with a Visual Impairment. The British Journal of Visual Impairment 17:3.

[17] Millar, S. (2008). Space and sense (Essays in Cognitive Psychology).

[18] Celani, G. & Milan, L. F. (2007). Tactile scale models: three-dimensional info-

graphics for space orientation of the blind and visually impaired. Virtual and rapid manufacturing: advanced research in virtual and rapid prototyping, pp. 801-806.

[19] Perkins, G. (2003). Emotions & Environment. TSA in the Caregiver Companion.

[20] Kaya, N.(2004). Relationship between colour and emotion: a study of college students. College student journal.

[21] Ramachandran, V. S., & Brang, D. (2008). Tactile-emotion synesthesia. Neurocase14(5): 390–399.

[22] Ballast, D. K. (2002). Interior design reference manual. Professional Pub. Inc.: Belmont, CA.

[23] Saito, M. (1996). Comparative studies on colour preference in Japan and other Asian regions, with special emphasis on the preference for white. Color Research and Application 21 (1): 35-49.

[24] Lederman, S. J. & Metzger, V. A. (1985). Identifying objects by touch: An 'expert system'. Perception & Psychophysics 37(4): 299-302.

[25] Lederman, S. J., Klatzky, R. L., Chataway, C. & Summers, C. D. (1990). Visual mediation and the haptic recognition of two-dimensional pictures of common objects. Perception & Psychophysics 47(1): 54-64.

[26] Gibson, J. J. (1962). Observations on active touch. Psychological Review 69: 477–490.

[27] Edelman, S. & Bülthoff, H. H. (1992). Orientation dependence in the recognition of familiar and novel views of 3-D objects. Vision Research 32, 2385.

[28] Lederman, S.J. & Klatzky, R.L. (1987). Hand movements: A window into haptic object recognition. Cognitive Psychology 19: 342–368.

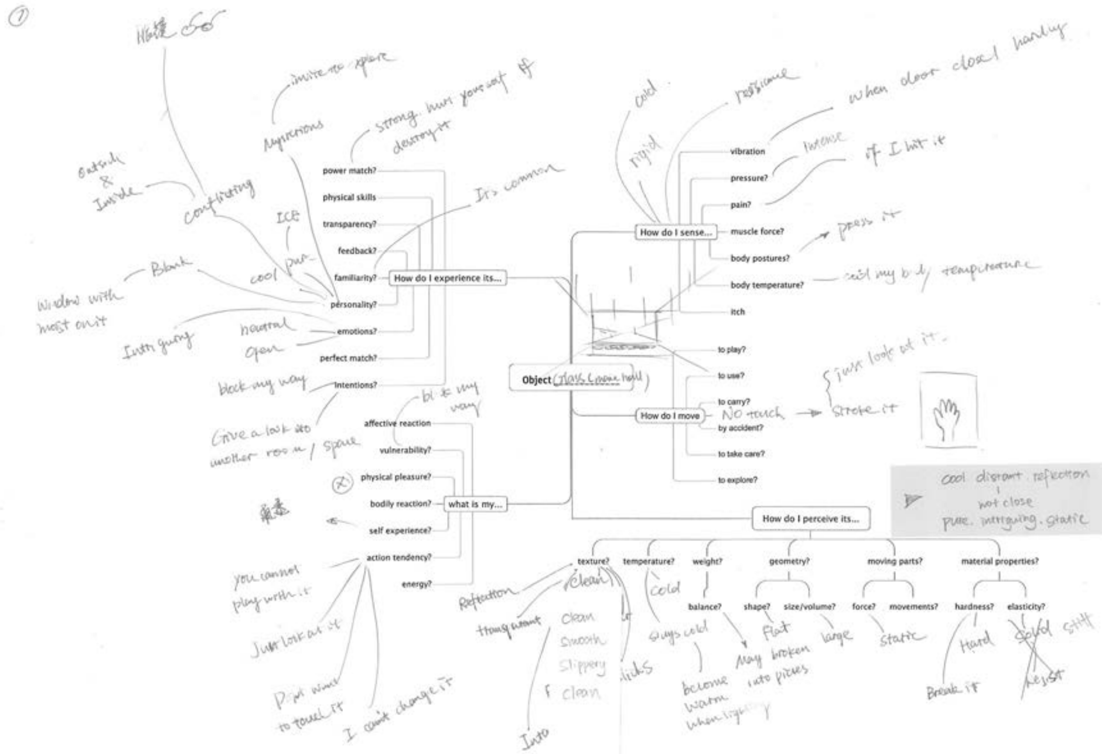
[29] Newell, F. N., Ernst, M. O., Tjan, B. S. & Bülthoff, H. H. (2001). Viewpoint Dependence in Visual and Haptic Object Recognition. Psychological Science VOL. 12, NO. 1: 37-42.

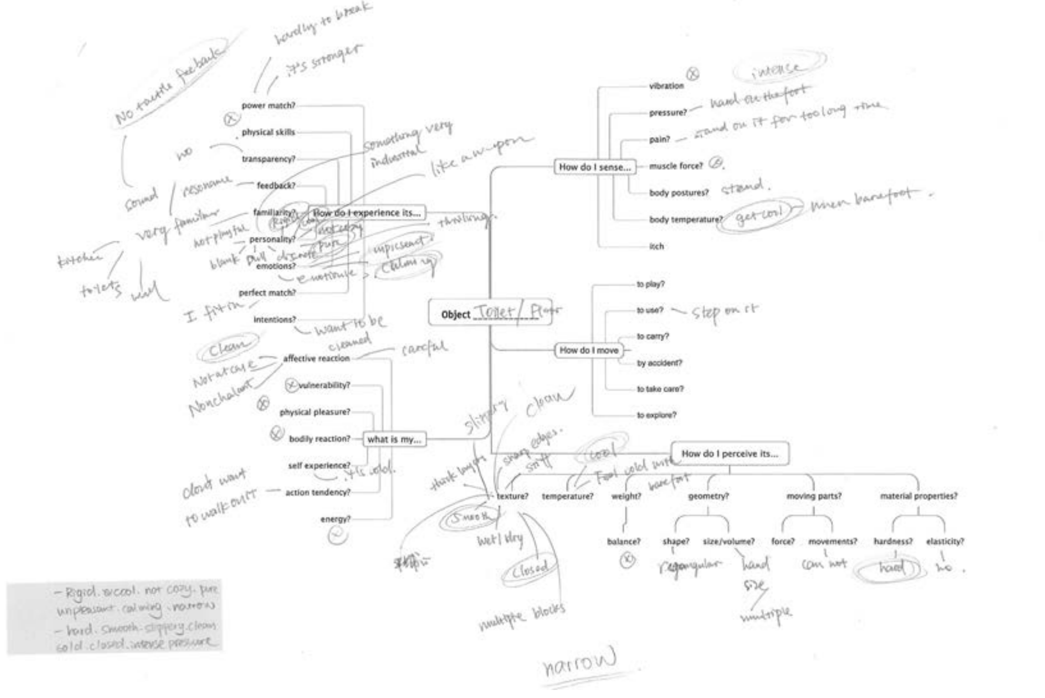
[30] http://dined.io.tudelft.nl/dined/

APPENDIX

APPENDIX I. MIND MAPS

Two mind maps are given as an example, which record the tactual experience of materials and summarize the general impression towards different areas of the building.





APPENDIX II. DESIGN PRINCIPLES OF TACTILE MAP

A couple of guidance and recommendations with regards to the tactile symbols usage, elevation, scale, substrate, single/double line usage and additional instructions are given as follow.

2.1 Tactile symbols usage

- The highest ranked symbol criteria, pattern/texture and separation/spacing, represent fundamental aspects of touch and tactual discrimination [11].
- Heller (1991) has also suggested that increased variation in the third dimension could improve tactile displays.
- Many arrows adopted from visual design were found to be effective tactually [12].
- It is likely that familiarity with common arrow shapes influenced both sighted and visually impaired participants [12].
- Earlier studies by TIMP have suggested that 0.4 mm is more than adequate for symbol recognition, and therefore it is unlikely that increased elevation would have improved the directionality of the symbols [12].
- The use of increased three-dimensional manufacturing gave modest increases to the level of agreement of 'up' for symbols intended to represent stairs [12].

2.2 Elevation

- Elevation is used to enhance the discriminability [11].
- Johansson and LaMotte (1983) proposed that the minimal elevation for fingertip: a single edge can be detected at an elevation of 0.85 microns (0.00085mm).
- Tactile features can reliably be identified on a tactile map at elevations of as little as 200 microns (0.2mm).
- At a certain elevation, further increases in elevation were not expected to improve performance significantly.

2.3 Scale

For larger-scale mobility maps, where a sense of distance is likely to be important to the user, some means of representing scale should be given higher importance. There are ways that this could be done without resorting to complex numeric representations of scale, for instance a standard large object such as a bus, with which the user is familiar, could be included on the map page at the appropriate scale [11].

2.4 Substrate

- Rough substrate is better than smooth one for scanning speed [14].
- Microcapsule paper and rough paper are the most suitable [14].
- Durable substrates such as plastic and aluminum may still be more suitable for use in public places [14].

2.5 Single and double line study

- Smallest gap that is detectable by touch to be somewhere in the range from 0.87mm (Johnson and Philips, 1981) to 2.81mm (stevens, Foulke and Patterson, 1996).
- Vertical double lines are more easily perceived as horizontal ones [14].
- Participants were most likely to explore lines in a left-to-right motion, regardless of the orientation of the line [14].
- Performance is better on thin double lines than on thick ones (the thin line felt 'sharper' and produced a finer pattern of neural stimulation) [14].
- Wide single lines are sometimes incorrectly identified as double lines (edges generate a high level of neural activity) [14].
- The use of a separation distance of at least 1.3mm [14].
- Single lines that are wider than 2.2.mm might be perceived as double lines [14].

2.6 Additional instructions

All respondents supply tactile maps with at least supplementary means to access the information [11].

APPENDIX III. USER INTERVIEW QUESTIONS

The interview questions below were used in the user interviews.The topics include strategies of navigation, the experiences on spaciousness, indoor and outdoor orientation and how they experience the navigation tools.

3.1 Background information

- Did you have any visual experience before? If so, how long was it?
- How do you travel for daily activities? In group, couple or on your own? What about exploring unfamiliar areas or buildings?
- If you tend to travel in couple or group, are you motivated by functional or experiential purpose?
- What kind of tools will you travel with? (cane, dog, tracker, etc.)
- Do you have experience with tactile map, scale model or any navigational tools?

3.2 Strategies of orientation

- Do you have any plan before your travel? If you have, what kind of information or source do you want?
- Do you need a clear starting point to get started or prevent you from getting lost? If so, how to select the starting point?
- How do you memorize a route?
- How do you choose landmarks? And how do you recognize the landmarks (sound, touch, smell, etc.)?
- Do you have an overview of the route with landmarks in your mind? If you have, could you please describe it?
- Do you refer to any object or special spot to localize yourself during the navigation? If you do, what kind of reference do you use? e.g. turning points, starting points, etc.
- What will you do if you get lost? Sequentially trace back to the last reference point or directly to the starting point?

3.3 Tactile map

- Have you ever used a tactile map or tracker before? How do you feel about the experience?
- How can you link the points marked on the map with reality?
- What do you think about the scale of a tactile map? Is it an important element for you?

3.4 Experiences on spaciousness

- Are you aware of height and size of a space? If so, how do you measure or perceive it?
- Are you aware of the distance of a route? If so, how do you measure it?
- Do you have special acoustic memories of buildings?

3.5 Outdoor navigation

- How do you plan an outdoor route? What is your focus and concern?
- What kind of source(s) do you use during your way finding process? e.g. tools, starting point, reference point, landmarks, acoustics, etc.
- Will you use tactile tiles designed for guidance?

3.6 Indoor navigation

- Generally speaking, how do you evaluate the accessibility of public building?
- What kind of problems do you encounter? stairs, doors, automatic doors, elevators, etc.
- How do you plan a route inside a building? What is your focus and concern?
- Do you have personal preference when making the plan? Walking along the wall or going directly to destination?
- What kind of source(s) do you use during your way finding process? e.g. tools, starting point, reference point, landmarks, acoustics, etc.

3.7 Scale model

- Do you have experience with 3D model? How do you evaluate it?
- How do you compare the 2D display(tactile map) to 3D display?
- Are you aware of the material features of public building? How do you perceive them?
- Do you have preference of materials? Could you explain your preference in terms of material attribute? e.g. hardness, smoothness, flexibility, temperature, etc.
- Why are you familiar with certain materials? How do you recognize them?
- How do you associate the materials to other things?

APPENDIX VI. SUMMARY OF USER INTERVIEWS

Below, how each participant responded to each topic are summarized.

	Dick (congenitally blind)	Asha (Acquired blind)
Background info	• 63 years old • no visual experience before • always travel with partner • use cane instead of dog • can feel the light • have interest in music • prefer to use quick and convenient way to solve problem; not an explorer • doesn't have particular interest in materials	• 48 years old • 45 years blind • travel alone • use cane • totally blind • prefer wood and fabrics because of temperature • she dreams in smell, sound, and tactile

Susanna (partially sighted)	Anja (Acquired blind)	Caroline (Visual impaired)
• lost color perception since 5 yrs old with 3% sight remained • started learning Braille when 7 yrs old • attended special primary school and regular high school • rich experience in using tactile map • running self employed business in tactile graphics training program for 3 yrs • love travelling • mostly travel independently with guide dog • she doesn't use tactile things much • she has an exploring character of taking risks • prefer smooth materials such as wood and glass; also like the sound and warmth of wood	• 65 years old with 40 years bad sight • Travel on her own • Want to be independent • Like walking in free nature • Use both guide dog and cane; the cane is not functional but signal • Using guide dog for the concern of safety • Use tracker for outdoor activities • Experienced with tactile map and scale model	• Became visual impaired since 7 years old • Travel alone, don't want to be dependent though sometimes travel in couple or group • Feeling safe when traveling in group • Use cane and sun glasses • Don't have experience with tactile map and scale model • Always stick to the thing she know, less adventurous

	Dick (congenitally blind)	Asha (Acquired blind)
Strategies of orientation	• memorize the landmarks • create a tactile picture in mind, not visually, but pieces of information; It needs practice • he memorizes the tactile maps by memorizing certain points in it • he doesn't measure the distance by feet • he has a good memory to trace back and good sense of orientation • always remember the important objects • recognize the important objects by listening to the sound made by cane • acquire information from wall • never always follow the wall by hand • use the tactile tiles when there is no wall to follow • floor design is more important than wall: much more information • the starting point is very important for finding way back • trace back based on the last landmark, instead of the starting point • time is not important; landmarks are useful	• safety is the most important • listen for directions; she would choose those permanent sound source • use cane for sound and detecting obstacles • need legend for maps to translate from two dimension to three dimension • try to avoid using of stairs • use sound to recognize the material (mostly by tick of cane) • memorize the landmarks • doors (location and type) are most important when preparing for a trip • she can memorize the route as long as she can walk; she only memorize the way she walks • "feet are my eyes": different materials tell me where I am • when she got lost, she would refer back to the previous landmark rather than the starting point • she creates mental picture • when facing difficulty, she would touch the wall by hand and hear the difference • she creates a 3D tactile model in her mind, which could be touched by hand

Susanna (partially sighted)	Anja (Acquired blind)	Caroline (Visual impaired)
• rely on the guide dog for obstacles • using a guide dog makes her put more energy on focusing on other things, looking further ahead and enjoying the environment (experiential aspect) • using a cane makes her focus on the route and obstacles (functional aspect) • she has different strategies for exploring unfamiliar areas or buildings depending on the specific purposes: for clear and functional purpose, she would find someone else to guide her to the exact destination; for those she have to travel alone for long time, she prefers to figure out the environment by herself: using cane or guide dog and walking after someone else by following the sound and voice • she has the intuition to create mental map by listening to the environment. The map illustrates an overview of the details of an environment, rather than a route map • she doesn't count steps • doesn't have plan before travelling except for using the website for planning a train route; always follow people, ask for directions and use tactile map • using elevators/stairs as landmarks • she said the learning abilities don't differ very much between born blind people and acquired blind people, but they store the information differently: the born blind rely on verbal description for route mapping and the acquired blind utilize their past memory of visual capabilities • In case of getting lost, she would get back to the mental map and go back until reaching the landmark she is familiar with • when using guide dog, she get information from the floor by listening to the acoustic feedback from her feet and the dog's feet	• always make plan before traveling, basically about the travel information which could be acquired from internet • don't have a clear starting point during the navigation "I will never get lost" • she is sensitive to the moving tram, cars, smell and sound of shops, also she notices the way going up and down (crossing a bridge, etc) • She listens to the echo change when stepping on different floor covers • She uses the sound of a passing by tram as an indication for direction • She doesn't have a mind map, just follow her dog • She prefers to ask for help when getting lost, or just listen around to find reference point instead of going back.	• She doesn't have plan before visiting a building; just ask • She doesn't think that she has a starting point during the navigation. "maybe I do need it, but I didn't notice it." • She could memorize a route based on verbal based instruction • Became more sensitive to sound • She has a mental picture, like a map, which is not visual like, but consists of a points • She notices the way going up and down and the material change • She would trace back to the last reference point when getting lost

	Dick (congenitally blind)	Asha (Acquired blind)
Experiences on spaciousness	• The verbal based description could give him a holistic picture, which is hard to get by exploring by himself	• she has a notion of distance, but it is not an important issue for her • she could feel the material of floor by feet, but the pattern is hard to perceive • she creates general impression of a space based on landmarks, smells, sound
Indoor orientation	• the functional aspects are more important	• echo plays an important role when measuring distance • she uses mostly the entrance as the starting point
Outdoor orientation	• use a tracker for outdoor navigation • use sun to orientate • memorize the structure of the streets based on the orientation	• identify and remember landmarks by sound and smell

Susanna (partially sighted)	Anja (Acquired blind)	Caroline (Visual impaired)
• use ear to feel distance and orientate • she estimates the distance by time and she would like to focus on the land-marks for most of the time • use echo to localize, but sometimes it is unreliable, such as in pool • Her mental map is 2D, like photo of printed map. Each photo represents one floor and she moves on the photo (Hannes's mental map is a movie) • she do notice the height of ceiling • the atmosphere (surroundings, people, whispers, etc), smell and acoustics cre-ate her memory of a building	• she is aware of height and size of a space by echo change • she is aware of time which help her estimate the distance of a route. She has intuition of time measuring • the nice listening experi-ence of a building, such as the reflection from the wall, foot steps, will leave her special acoustic memories. • She uses echo for locali-zation	• She could feel the height of a space, not with sound • She is able to aware the distance of a route by estimating the time or by route planner
• she doesn't tend to walk along the wall and she doesn't touch the wall all the time • use sidewalk, door, corridor as refer-ence, both acoustically and tactilely • use the height of ceiling as a reference point, based on acoustic change • she prefers to use the central point of a building as a starting point and a landmark • she doesn't use moving stairs because the guide dog is not allowed there; she would use it as a landmark • she notices different floor covers by echo change		
• she has problem with bike road since it is hard to hear the traffic		

	Dick (congenitally blind)	Asha (Acquired blind)
Tactile map	• the map makes him independent • the map should have sufficient information • a legend is necessary • need to indicate the starting point, which would be referred to afterwards • scale means nothing • distance means nothing • need direct and specific information to find my route • it's difficult to translate the 2D information to 3D information • the 2D information should be abstract: signs, descriptions • Less tactile information, more essence, more Braille • verbal based information is preferred	• she needs to translate the 2D information to 3D image • 3D map is more helpful; she could freely explore it
Scale model	• would be nice to have the missed information that sighted people have • 3D "real" building would be nice to feel and explore • more than 3 floors would be too much information	• • scale model for the blind is photograph for the sighted • • it is difficult to distinguish glass and metal (both cold and smooth) • • she doesn't have association to material; she focuses on physical feelings

Susanna (partially sighted)	Anja (Acquired blind)	Caroline (Visual impaired)
• 2D map is more functional than 3D scale model • 2D map is easier to read • she needs a translation from 2D map to 3D information		• Too much information, which needs letter-by-letter reading. She couldn't go smooth and she doesn't like the material
• 3D scale model has too much details for route planning • 3D scale model should include the architecture features, the route with doorway, room, corridor, elevators, etc involved. • the decorative things are not necessary to be included in 3D scale model • the scale of the model is not important, but the relationship between the distance and size is necessary to be accurate • never mix two scales in one map • she would perceive the material features by listening to the sound and echo • like natural stuff • interesting to feel that the glass is cold but the temperature would change and tell you something about the environment	• she likes 3D models and she is looking for them all the time • she prefers 3D model since she could really feel it. • 3D model could give her a good overview. • 3D model is more realistic • she doesn't have preference of materials	

APPENDIX V. DISCUSSION OF THE CREATED ARTEFACTS

Below, each created artefact from the generative group session is discussed in details.

Toilet

All of the participants thought of a toilet bowl when talking about toilet (yellow circle in the chart above). Due to the complex form that the toilet bowl has, some of the features were missing in their created artefacts, which led to the confusions. Only the toilet seat could not be identified (in the second quadrant) since it doesn't make any sense without the hinge on the back connecting the seat to the toilet bowl. Also, it is too thick with round edge, which differentiates from the toilet seat in real life. The toilet bowl itself could be recognized and the pottery material would help the identification, as the participants suggested.

Elevator

The elevator (green circle in the chart above) is the most difficult one. One participant used a half enclosed container but it couldn't be identified as an elevator since the form is not unique for elevators. With this object, other participants could only tell that they could enter a space. The pair of arrows approved to be more efficient since it embody the movements of an elevator. The participants might get inspired by the buttons.

Coffee corner

The participants all chose one element of the coffee corner (gray circle in the chart above), either the coffee cup or the table. The table appeared to be too general that people would not associate it with the coffee corner specifically. Again, the participants suggested that using ceramic materials would help them recognize the coffee cup sooner and easier.

Door

All participants used the overall appearance of a door (dark blue circle in the chart above) instead of one element, such as a knob. The idea of using outline is apparently too visual-oriented. The door in the first quadrant is more recognizable than the one on the X-axis because it was made in the standing position with two knobs on both sides, while the other one is lying on the table with only one knob.

Cloakroom

The participants all chose one representative object to stand for the cloakroom, as we can see in the light blue circles above. Two participants made a 3D hanger and one participant made a 2.5D clothes stand. The hangers in the first quadrant turned out to be recognizable and the clothes stand on the X-axis could not be identified. On one hand, the form of the clothes stand is too complex. Due to the limitation of time and raw material, the details of the clothes stand couldn't be perfectly made, which blurred the overall perception of the shape. On the other hand, the clothes stand was made in the lying position, which deviates from the common sense.

Reception

One participant used the initial letter of reception and two participants made a reception desk (as shown in red circles in the chart above). The participants had diverse misunderstanding of the letter R. One participant said according to the form he thought it was a scarf. Later on he realized it was a letter, but he still could not associate it with the reception. When touching the desk, the participants could quickly identify it as the reception, probably because they had the same idea.

APPENDIX VI. DESCRIPTION OF HAPTIC ICON IDEAS

The initial ideas of haptic icons for reception, lift, cloakroom, stairs, toilet, cafe, smoking room and door are described as follow. Additionally, the prototyping techniques are explained.

Reception

The 2.5D ideas of the reception were initiated by its function in form of abstracted symbols. One of the 3D ideas, a man standing behind the desk, is in accordance with the outcomes of the generative creative session that all the participants made a desk to represent the reception.

Lift

Since the lift turned out to be the most difficult one during the session, more ideas were generated for testing. As shown in the chart, three of the 2.5D signs were initiated by the movement of the lift: going up and down. Diverse symbols were tried out to translate the meaning of "up and down". For the 3D signs, more tangible objects relevant to the lift were used such as the button. Also, its overall appearance was duplicated.

Cloakroom

Both 2.5D and 3D signs were designed based on the representative object of the cloakroom: a key, a hanger, a T-shirt or a hat.

Stairs

The ideas for the stairs are uniform: the simplest style of the stairs was duplicated.

Toilet

The 2.5D idea for the toilet is copying the visual sign, which could be universally found in public buildings. One of the 3D signs also refers to the signs placed on the toilet doors: a boy and a girl. Three representative objects, a basin, a toilet and a roll of toilet paper, were chosen for designing the other 3D signs, because these are the objects that people mainly physically interact with.

Café

The initiation of making a sign for café is identical, both in 2.5D and 3D form. These objects are regarded as the most representative things for a café. Tiny difference was made such as using diverse size for the handle, whether there is a plate underneath the cup.

Smoking room

For 2.5D signs, a cigarette and a lighter were used. The burning cigarette with two threads of smoke demonstrates the activities belong to the smoking room. An ashtray with a cigarette and a tobacco pipe were used to make 3D signs.

Door

Both ideas for 2.5D signs contain a door with a knob on it. In one sign an arrow was placed next to the door while the other one used a triangle. The 3D sign was made in a more realistic style: the frame of the door was built and the door with a knob could be open.

The 2.5D haptic signs were made of cardboard in A6 size. The top layer was hollowed out and glued on a black one. The contrast colors were used to facilitate the identification of visual impaired people.

Nearly all the 3D haptic signs were made of clay in hand size. One exception is the roll of toilet paper, which directly used the real toilet paper. This is because without the specific material, the geometry shape of the object would be very ambiguous.

APPENDIX VII. RESULTS OF IDEAS EVALUATION II

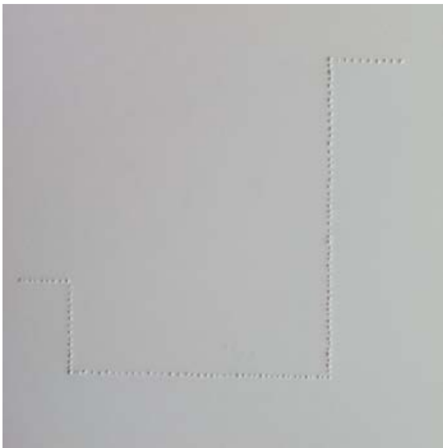
In the following chart, how the B&VI participants evaluated each haptic icon during the study are summarized.

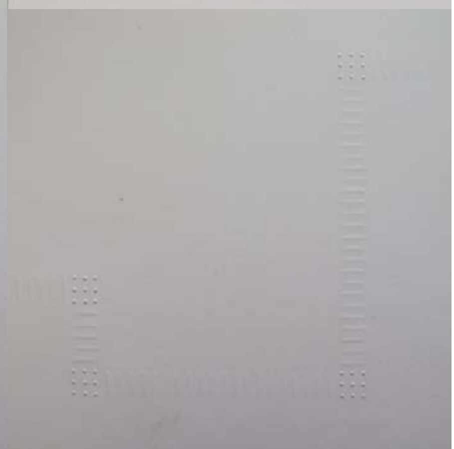
	P1: 12 years old; Visual impaired	P2: 17 years old; Born blind	P3: 13 years old; Visual impaired	P4: 13 years old; Acquired blind	P5: 14 years old; Visual impaired	P6: 13 years old; Born blind	P7: 12 years old; Acquired blind
Door 1	4s	The knob is missing	No clue	9s	8s	No clue	The open position is confusing
Door 2	10s	5s	10s	6s	The knob is too big	A handle would be better	4s
Cloak-room 1	4s	6s	7s	4s	5s	Scissor	4s
Stairs 1	9s	3s	4s	2s	2s	4s	2s
Cafe 1	3s	4s	5s	3s	6s	7s	4s
Cafe 2	3s	10s	6s	3s	6s	7s	7s
Toilet 1	10s	9s	15s	4s	5s	a hook to hang clothes	3s
Toilet 2	3s	6s	4s	3s	3s	It's a table	2s
Smoking room 1	It's a spoon.	7s	It's a res-taurant	It's a pen	It's a spoon	It's spoon	5s
Recep-tion 1	4s	9s	4s	16s	Did recognize the person and the desk	a man and a chair; didn't find and un-derstand the "i"	"Oh! Right! It's the re-ception!"
Eleva-tor 1	An adver-tisement sign, could be eleva-tor	No con-nection between arrows and lift	Focused too much on the button part	9s	Didn't rec-ognize the triangles	Unfamiliar with it by touch	Triangles are clear; not sure if it is a button

P8: 14 years old; Born blind	P9: 20 years old; Visual impaired	P10: 15 years old; Born blind	P11: 15 years old; Visual impaired	P12: 17 years old; Born blind	P13: 12 years old; Born blind	P14: 59 years old; Born blind
a walking person	2s	6s	28s	The handle is missing	The frame is confusing	No clue
No clue	4s	Should be handles on both sides	3s	The knob is unknown	Unfamiliar with the knob	6s a bell on a door!
Scissor	3s	10s	8s	20s	6s	20s
20s	5s	11s	3s	7s	6s	5s
5s	4s	4s	11s "Saucer is important"	6s	13s	2s
8s	4s	20s	5s	Recognized the folk as a hand	10s	For gardening
a bowl for food	4s	a pan on the wall	8s	A hook for hanging clothes	No clue	a pan; tap->hook
Only know part of it	3s	3s	5s	9s	4s	12s
It's a tea cup	3s He smokes!	a kind of cooking tool	For watering plants	For washing hands	"What is pipe?"	5s
Only recognize the person	3s	Didn't recognize the dummy	Did not notice the "i"	Didn't know the letter "i"	Didn't know "i", could read Braille	a person behind a desk; didn't recognize the "i"
"Something with two triangles"	a boarding shows the directions	a house with roof	Couldn't link triangles to elevators	She could understand the triangles	Feel like two arrows	Didn't recognize the triangles

APPENDIX VIII. HAPTIC ICONS FOR SPATIAL LAYOUT RESEARCH

The haptic icons used for the spatial layout research I are shown in the pictures below.





APPENDIX IX. RESEARCH QUESTIONS OF SPATIAL LAYOUT RESEARCH I

The following questions were used for the spatial layout research I.

9.1 For 2D tactile map

- How do they experience the 2D tactile map?
- With a legend, can they understand the objects on the map?
- Can they find the starting point of the route?
- Can they follow the route and reach the destination?
- Are the materials helpful for object identifying?
- How do they evaluate the 2D tactile map?
- Can they find the wedding room by using a 2D tactile map?
- How do they retell the route after using the map?
- How long do they take to find the wedding room?
- Can they associate the objects on the map to the real things in the building?
- What kind of problem(s) do they have with finding the wedding room by using the 2D tactile map?

9.2 For 3D scale model

- How do they experience the 3D scale model?
- Without a legend, can they understand the objects on the model?
- How do they evaluate other alternatives of haptic signs for the same object? (route, elevator and wedding room)
- Can they find the starting point of the route?
- Can they follow the route and reach the destination?
- How do they evaluate the 3D scale model?
- Can they find the wedding room by using a 3D scale model?
- How do they retell the route after using the model?
- How long do they take to find the wedding room?
- Can they associate the objects on the model to the real things in the building?
- What kind of problem(s) do they have with finding the wedding room by using the 3D model?

APPENDIX X. PROCEDURES OF SPATIAL LAYOUT RESEARCH I

The spatial layout research was conducted according to the procedures below.

First, the participants were given a brief introduction of the research. The introduction covered the general process of the research, what the model and the map are about, and where the route starts and ends. The details of the map and the model were not included in the introduction. This information was withheld to see the intuitive usage patterns of the participants.

After the introduction the participants were asked to explore the model/map, the additional haptic signs and to perform several tasks as follow:

- To figure out where the starting point is.
- To figure out where the wedding room (destination) is.
- To indicate what landmarks they use to memorize the route.
- To sort the haptic icons by the easiness of recognition (for the 3D model).

The tasks were given since they closely relate to the functionality of the model/map and how they leverage the given information to build mental picture of the building. To understand the participants' thinking patterns, they were asked to "think out loud" (as described by Lewis, 1982) while performing the tasks.

After performing the tasks, participants were asked to find their ways to the wedding room inside The Hague city hall. They were taken to the starting point, which is in front of the entrance for the disabled. After that, they navigated inside the building without any guidance.

The whole research ended with an interview, in which the participants were asked to give their opinions on the model/map, explain what went wrong in their field exploration and how they evaluated the connection between the virtual and reality. The participants for the 3D model were also asked about their using experience of the haptic icons.

APPENDIX XI. DISCUSSION OF HAPTIC ICONS USED IN SPATIAL LAYOUT RESEARCH

Below, how the participants evaluated the haptic icons are described.

The route should be designed in a simple, continuous and abstract style, either in 2D or 3D form. This is because people would better perceive it as a route rather than something real in the field.

Some details of the objects could be integrated in the haptic icon design, in order to give people more practical information. For instance, the facing direction of the elevator should be indicated on the 3D scale model. Also, the height of the elevators should be relative to the height of the first floor that people would better identify it.

Some confusion of the haptic icons is chargeable on simply copying the visual icons. One example could be the icon of wedding room which consists of a pair of hearts (see figure 7.1). The overlapping of the two hearts appeared to be ambiguous by haptic perception. The participants suggested that separating two hearts would be better.

Figure 8.1 the icon of wedding room

APPENDIX XII. RESEARCH QUESTIONS OF SPATIAL LAYOUT RESEARCH II

2D tactile map

- Could you memorize the meanings of the 8 objects on the map by using the legend once? How many objects could you memorize?
- What do you think of the materials used for different objects on the map?
- Could you link the relevant landmarks to the route when using the map? If not, why?
- Could you construct the environment in your mind by using the map?
- What do you think of the 2D tactile map? Please evaluate it from both the functional and experiential aspect.

3D scale model

- Could you construct the environment in your mind by using the model?
- Could you link the relevant landmarks to the route when using the model? If not, why?
- What do you think of the 3D scale model? Please evaluate it from both the functional and experiential aspect.

Sound

- Do you think sound is helpful or not? What objects did you recognize by sound?
- Did you have any confusion about the sound?
- What do you think of the sound? Please evaluate it from both the functional and experiential aspect.

Strategies in general

- Do you have a mental picture of the route? If so, what does it look like?
- How do you keep the right direction during the walk?
- Did you encounter any problem during the way finding process? If so, how did you deal with it?
- During the field way finding, how did you recognize the landmarks? Could you associate them to the ones on the prototype?

APPENDIX XIII. THE PARTICIPANT INSTRUCTION OF EVALUATIVE STUDY

First, I would like to give you some idea about what this test is about. Sighted people have different kinds of visual signs to guide them navigate inside a public building, my graduation project focuses on designing the haptic guide system for blind and visually impaired people to help them independently navigate inside public buildings. My concept is to design a set of hand size icons which represent the common places of public buildings, such as toilet, elevator, café, etc. These icons will be used together with a 3D scale model of a public building.

In front of you, there is a double-level model of a conference center, you can feel the length and width of the model to have an impression of the dimensions. Diverse haptic icons are placed on the model to show the locations of the most important places of the conference center. The ground floor and the first floor are connected with a drawer structure that you can push the upper floor to touch the under level better.

You have 3 minutes to freely explore the model. During these 3 minutes, you should explore the general layout of the buildings. You will have time afterwards to go back to this model to do several navigational tasks so you don't need to remember everything on the model within 3 minutes. During the process, please think aloud. If you have any question, feel free to ask.

Now I would like to ask you to do several navigational tasks. Supposing that you come to this conference center to attend a lecture. By going through the revolving door, you entered the building and now you are standing in front of this scale model and this is the starting point of your route. First, please go to the reception to check when the lecture starts. Then you want to store your jacket so you go to the cloakroom. Since the lecture already started, you want to enter the lecture hall from the back door. One hour later, now it's break time. You go out the lecture hall and grab a cup of coffee at the coffee corner; and you want to smoke so you are looking for the smoking room; also use the toilet. Now it's time to go back to the lecture hall. After another hour, the lecture finished. Now you are heading to the office to find a friend of yours to have lunch together. This time, you two take the elevator. Before leaving, check the shop for some souvenirs.

Now I would like to ask you several questions.

1. How do you evaluate the scale model in general? Is the information clear and sufficient?

2. How do you evaluate the haptic icons in general? Are they clear? Did you have confusions about them?

3. How do you evaluate the drawer structure?

4. What kind of problems did you encounter in planning the routes?

5. What do you think of the appearance?