University of Twente

Pig farm guidance

Master Thesis on a guidance tool for pig farmers

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Abstract

This thesis aims to study how the farmer can be guided to a pig in need of attention. Preliminary work in this thesis includes literature research and a field visit to study what this tool should look like. The results indicate a potential to speed up the searching process of the farmer in a pig barn. The literature research at the start of the thesis resulted in the hypothesis that outside-in guidance by using light projection would have the most significant potential for guiding a farmer to a sow. However, this had less potential after visiting the farm due to structure and lighting conditions. A first user test studied how these findings translate to the actual environment. The first user test took place in the eventual work environment of the system with a potential future user. This study's goal was to study which guidance method would fit the best into the farmer's workflow and what would work in the environment. This was tested with outside-in guidance with the use of light and inside-out guidance with the help of the farmer's phone. The light-based guidance relies on the division of the barn into sections. One of the key findings of this first user test was that handheld devices were far from ideal to use as guidance aid in the barn environment since these devices demand too much focus from the farmer in a dynamic environment, which leads the farmer to bump into the sows. However, the concept of using light in the barn was received positively and therefore formed a basis for a second user test. The second user test tested three concepts to study how the light indication guidance could be used most effectively and efficiently. The barn consisted of conceptual sections, which were indicated by a light in the centre, four lights in the corners, or four lights in the corner where two would blink to indicate the side of the section where the sow resides. When the number of light points increased, the participants had to interpret the situation for some time, which increased search time. This increase was not observed when two of the four lights were blinking. This was partly because participants did not notice the middle two lights and therefore walked to the blinking lights instead of considering the four lights in relation to each other, which presumably required less interpretation time.

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1 Introduction

The profession of pig farming as it is today, is significantly dissimilar from the profession as it was two decades ago. This change is reflected in the number of pigs per farm in the Netherlands, which has quadrupled in the last two decades (CBS,2020). The reason for this is that the total amount of pigs in the Netherlands remained constant, while the number of pig farms drastically decreased in the last four years due to government regulations and sanitation laws, according to a Dutch news article from 2019.[1] The increase of four times as many pigs is made possible by, amongst others, technological advancements in the agricultural sector. The continuous progress in technology supports pig farmers in efficiently taking care of their livestock and improving the well-being of the livestock while doing so. This is accomplished by gathering and tracking data of each pig and act upon this data, albeit with technological or human intervention.

Role of technology

Currently, technology assists the farmer in efficiently managing the feeding process by gathering data on the food intake and weight of each pig. This is all handled by one pass through a station in the pen. This station is responsible for identifying the animal which enters the station, providing the correct amount of food, subsequently weighing the pig, and finally directing the pig to the correct location. This last step returns the pig to the large pen or separates it in the separation unit if it needs human intervention.

Role of farmer

The primary role of the farmer nowadays is to observe his livestock and act upon data. Like any profession, experience plays a significant role in recognizing cues and irregularities and acting accordingly. In addition, animals do not always behave as theoretically assumed beforehand. When a specific animal does not pass through the station, there is a chance that it requires attention. A reason for this could be that the animal is sick or that there is another health issue at play. Usually, the station separates the animal, but since it did not enter the station, it cannot be separated to the separation pen. At this point, the farmer must find the animal in his barn. The time it takes for a farmer to find a pig largely depends on the barn's size and the number of pigs. In large farms in the US, which in some cases house more than 4000 pigs, farmers employ people to search for specific pigs in the barn during the day. Currently, there is no technology yet to localize pigs and guide the farmer or his employees to the relevant pig.

Company

This thesis aims to study how the farmer can be guided to a pig in need of attention. This research is commissioned by the company Nedap. Nedap was founded in 1929 in Amsterdam, but from 1947 on, it is based in Groenlo. The company develops technology to assist people in different areas of life. The markets in which Nedap is active are Identification Systems, Light Controls, Livestock Management, Retail, Security Management, and Staffing Solutions. As one might expect, this thesis is part of the Livestock management group, a global market leader in animal identification and farm automation.

Barn localization

The field of animal localization in livestock is not entirely new, especially for Nedap. Nedap has already developed localization technology in cow farms, where farmers can localize cows in their barn by tracking a tag around a cow's neck. This tag communicates to beacons in the barn which can track the location of a cow. However, this solution does not translate well to pig localization due to

[1] https://www.ad.nl/den-bosch/duizend-varkensboeren-gaan-snel-stoppen-met-hun-bedrijf~a2636396/

economic and anatomical reasons. As it is currently used for cows, the price of a tag cannot be justified in the sector for pigs since the cost per pig would exceed a reasonable amount. Next to this comes the anatomical difference between pigs and cows. Since pigs have tapered heads, the band would come off way too easily, making these bands unsuitable for pigs.

Goal

The localization of a pig will not be part of this study but will be studied in parallel with this research. This thesis will focus on the interaction with the user to study how the location can be communicated most effectively and efficiently. This results in the following research question:
What tool can be designed to guide a pig farmer to a relevant sow in the pig barn?

2 Approach

The study began with preliminary desk research to guide the design process. The desk research functions as a foundation for the design process. The literature study contains the following Sub-questions:

- *What does the mental model of a person look like when navigating?*
- *What is the best form of navigation?*
- *What interaction are methods currently in use?*

2.1.1 Literature research

Some thought processes happen in the brain while being guided. This is relevant to know when designing for certain users. The literature research covers several research topics separately.

The first topic this research addresses is exploring the mental model of navigation to study the thinking process while navigating.
The second topic addressed is the form of navigation. This can be considered as the depiction of the location or route of the target. Multiple representations are possible, each with its perks and limitations.
The last topic is an exploration of interaction possibilities. This topic will address what interaction methods were already explored, use the strong suits, and learn from other studies' weaknesses. Similar products could form a solid basis upon which the system can be built.
The literature research ended by drawing a conclusion after all topics were addressed, as described in chapter 3.2.4.

The literature research used existing studies on the internet. The topics described above were then searched with several keywords on academic paper depositories. The depositories used in this research are *Google Scholar, Scopus, IEEEXplore, ResearchGate,* and *the ACM Digital Library*. Some main keywords and, additionally, synonyms provided the search results. The leading search terms used in this study are:

guidance, navigation, barn, mental model, on foot, wayfinding, pedestrian, and indoor. Most of these search terms are combined with the word AND to narrow the search down and get articles related to both terms, as seen in Table 1.

Table 1 Amount of hits per search query per search engine

DATABASE	SEARCHTERMS	#HITS	USED
SCOPUS	Navigation AND Barn	14	0
	Guidance AND Pedestrian	810	1
	Guidance AND "Mental model"	1,509	1
	Indoor AND Guidance	1,834	0
	Navigation AND "on foot"	1,685	0
GOOGLE SCHOLAR	Navigation AND Barn	84.700	0
	Guidance AND Pedestrian	181.000	2
	Guidance AND "Mental model"	54000	4
	Indoor AND Guidance	437.000	1
	Navigation AND "on foot"	61000	0
ACM DIGITAL LIBRARY	Navigation AND Barn	105	0
	Guidance AND Pedestrian	6,882	3
	Guidance AND "Mental model"	456,430	4
	Indoor AND Guidance	13,332	4
	Navigation AND "on foot"	4,520	0

It shows the main search terms with the number of hits per database and the number of relevant articles used from these hits. Using multiple academic paper depositories got the most out of the search terms.

Some queries resulted in a tremendous amount of hits. The title served as the first filter for relevant papers. This filter already gave a good indication if a study was relevant. Secondly, the abstracts gave an impression of the relevance of a research and thus served as a filter for relevant articles. Many of these search terms resulted in studies not closely related to the research topics. Many, however, were related to the technology for positioning people inside buildings or their surroundings. Navigation in barns did not provide many relevant articles to answer the research questions since navigation using technology in a barn is relatively new. What provided the most helpful information for this thesis were the studies that other studies referenced. Leading to a chain of papers that further deepened on a certain subject.

A consequence was also that search terms were added as the research progressed, thanks to terms of other studies. These terms are not present in the table since they differ significantly among the databases. Examples are deepening the understanding of grid cells, landmarks and navigation, ATCF (As The Crow Flies) navigation, (projected) AR guidance, and spatial audio.

2.2 Structure of the thesis

The thesis consists of four phases of a double diamond format, as figure 1 shows: *Discover, Define, Develop, Deliver.* The phases are described by Tschimmel (2012). The *Discover* phase is the first divergent phase of the method, which aims at gathering information and insights. Therefore, this phase consists of literature research and a field visit. After the *Discover* phase, the thesis proceeds with a convergent *Define* phase. This phase defines the problem and frames it to focus on the actual problem space. Subsequently comes the diverging *Develop* phase. This phase includes designing solutions and iterating them. Designing and iterating were done by the Creative Technology Design method, as shown in figure 2. The research cycles this process twice, which resulted in performing

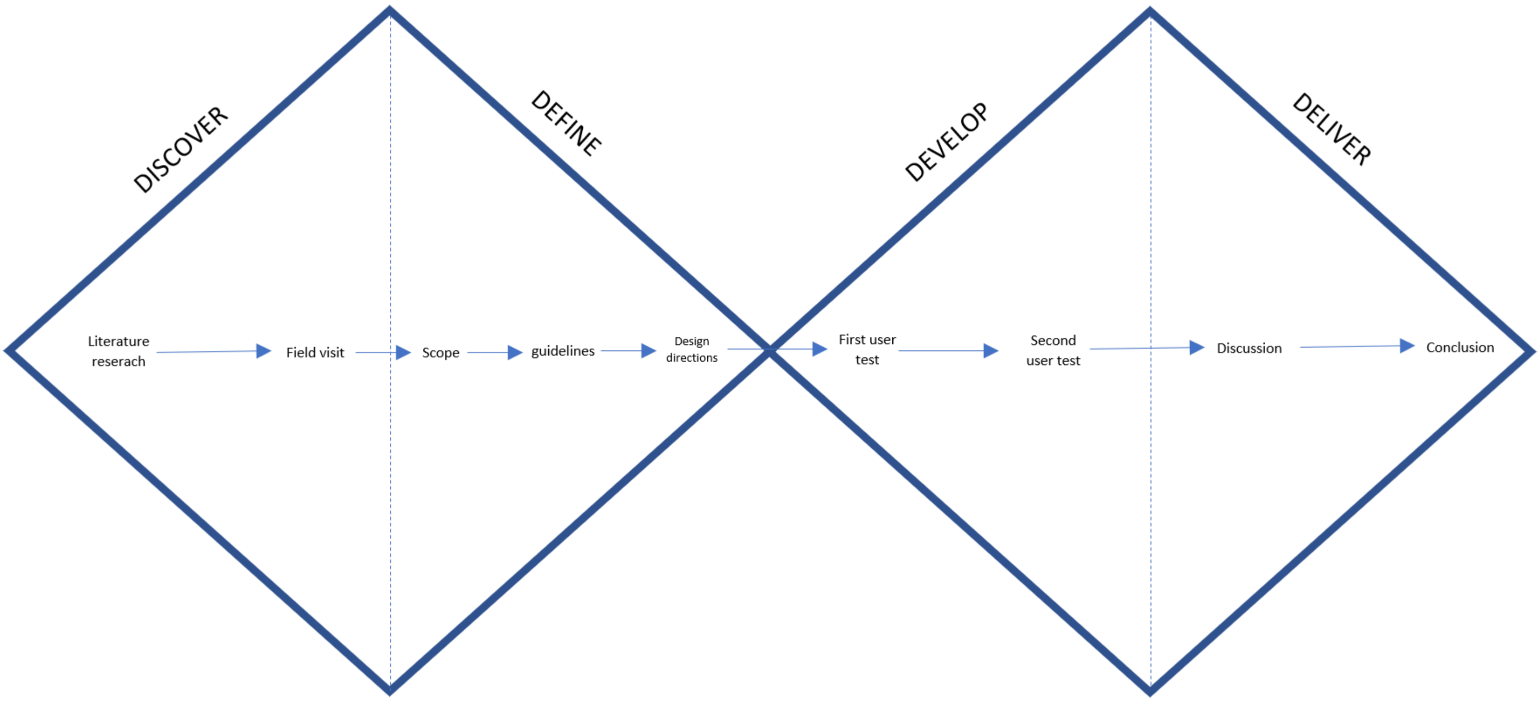


Figure 1 Double diamond. Shape deduced from Tschimmel (2012)

two user tests, of which the second is an iteration of the first user test. The results were then discussed and concluded in the final phase called *Deliver.* The references can be found in the appendices at the end of the thesis.

2.2.1 Design process

The design phase started after the *Discover* and the *Define* phase. The design phase in this thesis uses the Creative Technology Design Process, developed by Mader and Eggink (2014), as figure 2 depicts.

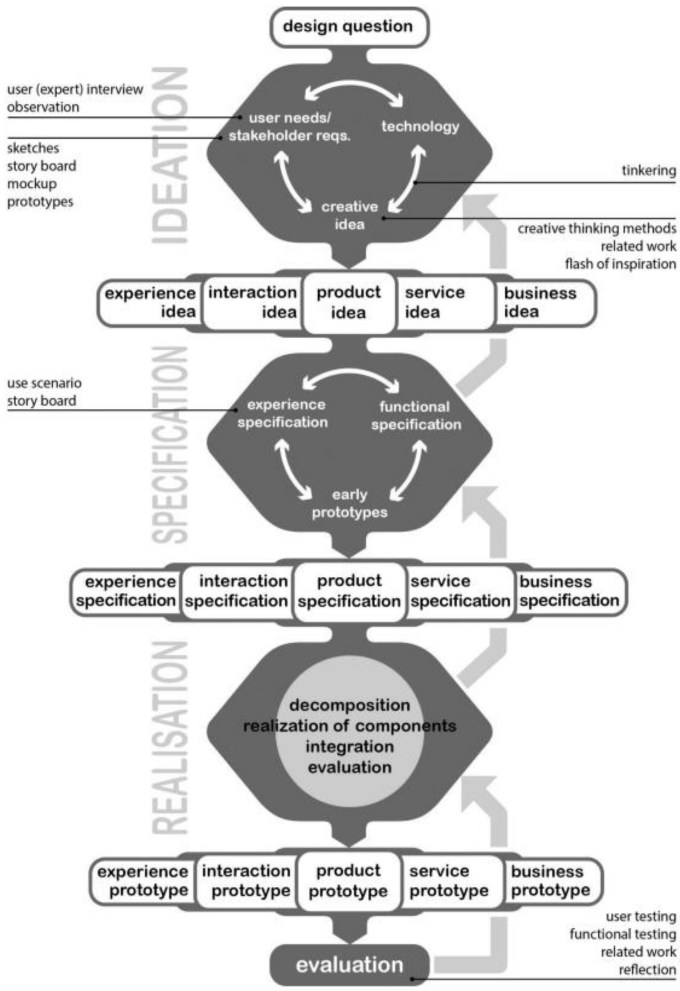


Figure 2 Creative Technology Design Method

Ideation

The Creative Technology Design Process starts with ideation. The starting point could be a design question in the form of a product idea, a problem statement from a client, or a creative inspiration. These should meet the requirements and preferences of the user, goal, or client. Visiting the field, making a storyboard, exploring literature, or constructing a mind map can lead to setting these requirements. The technology part of the ideation functions as a tool to meet the client's needs. The product of the ideation phase is a set of ideas and concepts.

Specification
The specification phase aims to specify the prototypes and explore the design space. It shapes the concepts created in the ideation phase by studying which components are helpful for the realization. The specification finalizes with the focus on a small set of solutions with enough potential to be realized in the next phase.

Realization
The realization describes the process of making a fully functional prototype suitable for testing in the evaluation phase. This phase often includes functional testing to test if all functions work as expected in the prototype. This often combines the functionalities of the different prototypes of the specification phase.

Evaluation
Functional testing can also take place in the evaluation. The most used method of evaluating a system or product is user testing. This will put the prototype through its paces in the real-life environment with real eventual users of the system or in a test situation that simulates this environment and user. This phase concludes if the prototypes meet the requirements, if the design choices were right, or if some choices must be reconsidered. If the latter is true, the cycle repeats, starting in the ideation.

Follow-up
The evaluation at the end of the design forms a scope that is further explored to elaborate on what would be the most effective way of accomplishing the goal set at the beginning of the thesis.

Discover

DEFINE

DEVELOP

DELIVER

3 Discover

The thesis started with studying literature and related work as a preparation for the *Define* and *Design*. This includes desk research, which forms a theoretical basis, and subsequently a field visit to gather information on the work environment and workflow of the farmer.

3.1 Desk research

This chapter will describe the results of the literature research. The chapter consists of subsections covering different aspects of navigating in a barn. The first subchapter will go into the mental model of navigation. The second subchapter will describe which types of navigation there are. The last subchapter will explore different navigation interaction possibilities.

3.1.1 How do people navigate

This chapter describes how navigation works in a psychological domain. People can use technology to aid in reaching their destination. The technology should support the thinking process of the user. It is therefore essential to know what the thinking process is. Perelman et al. (2017) studied mental models in the context of navigation systems. They stated that while users interact with the technology, they build up an understanding of the underlying processes of the technology. This understanding of technology is what the authors refer to as the mental model. According to the authors, this mental model does not have to be in complete agreement with the actual system or technology. If the outcome is in line with the mental model and the system behaves as expected and therefore results in a better user experience. This chapter studies the thinking process, which helps to give an insight into the mental model of a user who must navigate in a certain space. Examples of technologies that support human navigation tasks are a physical map or a digital GPS, which leads the user to the desired location. To use the map or GPS, the user must make some cognitive transformation in its head by converting the reproduction of the route or location from one domain to the other, as Levinew et al. (1984) found in their study on spatial problem-solving in an indoor wayfinding task. The authors concluded that, in general, people navigate in three cognitive steps:

1. Look at the goal or end point of the navigation task
2. Transform the map so that the user sees its current location relative to the goal
3. Create a route from the current position to the goal

Of these three steps, the second step is the most demanding in terms of cognitive resources since this requires the user to transform the map so that the map coincides with the user's viewpoint. This transformation requires much effort from the hippocampus, which is a part of the brain that is, amongst others, responsible for storing new information and spatial awareness. This increase in cognitive effort is especially the case when the map the user encounters is contra-aligned with the user, as Levinew et al. (1984) state. To counteract this, the map must be rotated to be in the same orientation as the user. When the map is aligned, the user only must read the map without any transformations necessary. Hereafter, the user can move along the route it has just created with the help of the map. To do this, however, the brain must rely strongly on visual landmarks along the path to memorize it (Millonig & Schechtner, 2007). In addition, Heidorn & Hirtle (1993) showed in their research on navigation landmarks that in many contexts, a good landmark should be large, stable, distinctive, and independent of the environment. The authors identified the properties by letting people judge the quality of a landmark and subsequently identify good characteristics that make a landmark a good landmark. The findings of the study mean that some key elements from the map and the real-life environment are linked, so the user gets an indication that it is on the right track and knows where it must go using landmarks.

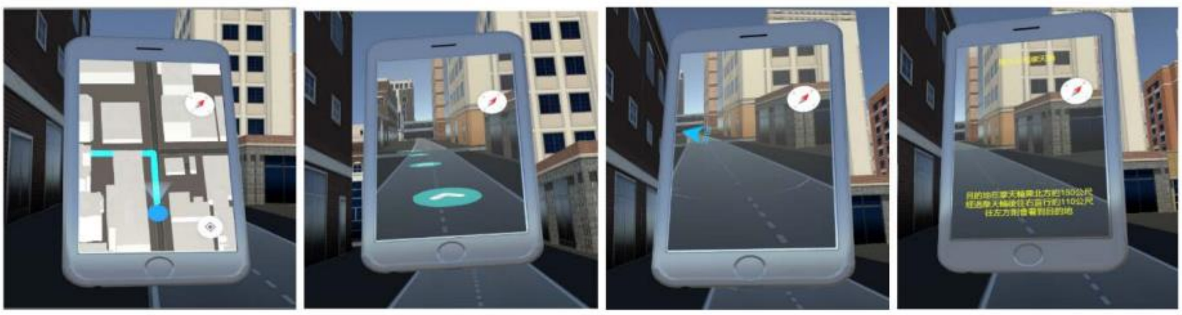
During a navigation task with breadcrumbs, Fyhn et al. (2008) found activity in mice's brains in the grid cells in the entorhinal cortex, which is a part of the brain mainly responsible for long-term memory. The authors of the same study found that these grid cells are not only responsible for tracking the position but also speed and head direction.

Grid cells are also present in the human brain. These cells are ordered in a grid and help to find the relative position of the person itself on a two-dimensional map. This feature can help in personal navigation. When a person steps in a certain direction, the steps are tracked in this part of the brain and placed in a new position on the grid. On average, people can store the position for a couple of hundred meters, according to Hafting et al. (2005), who studied the entorhinal cortex in the context of wayfinding using maps and brain scans. This sense of tracking the north side of the environment has a remarkably similar resemblance to following the direction of the target location. This means that when a person is confronted with the direction of the target location first, it can track the direction of the goal as it is moving in the space (Chadwick et al., 2015). While moving in a space, a person makes a mental map of the environment which becomes comprehensive and complex with extensive experience. This complex representation of a map is stored in the long-term memory, which can be accessed later. This representation can be used for future situations where the person must move in the same space to solve more complex wayfinding tasks. This also means that the person does not have to rely anymore on simple singular motor response sequences (turn left, turn right, etc.), as Taylor et al. (2008) studied in their research regarding personalized navigation systems. An example of such a process can be seen in taxi drivers. They can often navigate around cities without a guiding device. Taxi drivers can do this because they build up a 2D mental map of the city from previous trips, which they can use for the next trip, according to Chase (1983), who wrote a research paper on the experience of the representation of large urban environments.

When people build up this 2D mental map, they use multiple senses to perceive the environment. This not only means that people use multiple senses simultaneously, but the brain can switch from visual sensory inputs to auditory or tactile feedback or use multiple of these inputs to navigate to the target location (Do et al., 2021). In addition, people use landmarks to memorize the route and navigate to the desired end location. The usage of these landmarks is not equally present in every organism. It depends on the size of the hippocampus, the region of the brain which plays a significant role in spatial orientation and, therefore, navigation. Landmark recognition plays an important role when trying to reach the goal. According to Aslan et al. (2006), in a study on developing a navigation system for pedestrians, people rely more on landmarks in the environment than their mental map of the environment. This is especially true in unknown areas as the mental map is not extensive enough yet. People rely mostly on landmarks along the way in combination with TBT (turn-by-turn) directions to find their way. When the area is more known, and a user must actively find its way through the environment many times, TBT directions become increasingly obsolete, and the user focuses more on the environmental landmarks. These landmarks can then be easier put into relation with each other in the form of a 2D map.

3.1.2 Type of navigation model

When the user’s relative position to the goal is clear, we should consider the guidance to the destination. This consideration poses the question: What type of guidance model is suitable for guiding the user in the barn? Multiple types of research were conducted to study the best type of navigation in a navigation system. There are various types of navigation: map turn-by-turn, AR turn-by-turn, orientation-based, and reference-based (Kuo et al., 2020). In their study on new navigation interfaces, the authors studied all these types of different representations of the route in the environment. In the map Turn-by-turn representation, the interface is the most well-known of all the navigation types. It shows a top-down view of the world in which it depicts streets and buildings. It shows the user’s current location and a line that indicates the direction in which the user should move. An AR Turn-by-turn interface projects the route onto the real world by using (in most cases) the camera of a mobile phone. It shows arrows or a line in the street the user should follow. Orientation-based navigation does not display a route but only the direction of the goal, which means providing instructions as cardinal directions (North, East, South, West). The last type is reference-based guidance. This type of guidance already assumes some pre-knowledge of the environment and uses wind directions to indicate the goal. An example of a description for this last type could be: “*the goal is 5 meters to the East of the red flag* “. Figure 3 from Kuo et al. (2020) shows what each type of guidance looks like.



(a) Map Turn-by-turn **(b) AR Turn-by-turn** **(c) Orientation-based** **(d) Reference-based**

Figure 3 Types of navigation from Kuo et al. (2020)

The study concluded that the map-turn-by-turn and AR-turn-by-turn guidance was not always the best for guiding pedestrians in an environment. This was because users looked at the navigation device too much, which increased the time it took to reach the destination and decreased the independence to reach the goal themselves next time. The reference-frame turned out to be the most efficient way of navigating to the goal without looking too much on a screen or be distracted by the system itself.

Another study by Savino et al. (2020) on an improved As-the-crow-flies guidance representation partially aligns with this conclusion. Still, it adds an important notion to the comparison between both navigation models. The authors compared TBT navigation with As-The-Crow-Flies (ATCF) navigation on a bike. The TBT navigation gave instructions at each corner, while the ATCF navigation only gave the direction of the destination. Figure 4 from Savino et al. (2020) shows what the ATCF navigation looks like.

Figure 4 ATCF-navigation from Savino et al. (2020)

The results of the study were mixed. The TBT-navigation was more accurate than the standard ATCF, and participants indicated that their confidence in the surroundings was lower with ATCF-navigation. However, the researchers developed an ATCF+-navigation model, which added the functionality of showing that participants followed the correct route. This addition lets the user know if it was on the right track or not. This addition significantly improved the model's performance and gave the user more confidence when navigating to the destination. The study also showed that users preferred the TBT-navigation, especially more when they would have to navigate an unknown environment.

3.2 Interaction possibilities

This chapter explores different interaction methods. This exploration means studying the existing work, building upon this research, and getting inspiration for the eventual system. Multiple studies have already explored different ways to show people the way. Different senses of the users can be used and interacted with from two perspectives, inside-out and outside-in. These interaction possibilities are divided into these two perspectives. These chapters are then divided into senses. This division structures the existing studies and compares them conveniently in the end.

3.2.1 Inside-out navigation

The first guidance perspective is inside-out. An Inside-out perspective means that the navigation is done from the perspective of the user. A system attached to the user or carried by the user gives the instructions. Inside-out guidance, such as ATCF navigation, can instruct the user by making use of multiple senses, which will be described separately below in the subsections.

3.2.1.1 Visual

One way to guide people in an environment in a visual way is to use augmented reality. Augmented Reality means overlaying the reality with a digital visual layer to guide the user. Verma et al. (2020)

Figure 5 AR navigation app screenshot from Verma et al. (2020)

used this digital layer in an indoor navigation task using a mobile phone. Figure 5 shows a screenshot of the application made by the researchers from Verma et al. (2020).

The application worked by converting a 2D map into a 3D environment and overlaying the live camera feed from the back-facing camera with the correct route information. Image recognition tracks the position of the user. The system checks the feed of the camera and compares it to premade images to determine the live location of the user. The result was a fully working system that participants perceived as very user-friendly and intuitive. A requirement for this way of position tracking is that the environment should be constant with not many moving or changing objects. Next, on the back-end side of the system, much computational power is needed to determine the position of multiple users and calculate the best route. Chung et al. (2016) studied another form of augmented reality in a navigation context. The authors compared ordinary turn-by-turn navigation with projective augmented reality navigation. The study aimed to shift the attention from device to environment when navigating the environment. The projective navigation consisted of a phone with a miniprojector attached, which projected an arrow on the floor in front of the user. Figure 6 from Chung et al. (2016) shows what this setup looked like.

Figure 6 Arrow projected on the ground from Chung et al. (2016)

Next to the interaction method is studied how control over the path influences the performance and satisfaction of the system. Participants regarded the augmented reality system as superior to ordinary turn-by-turn navigation since the instructions were more intuitive and gave more confidence in guidance instructions since the projector projected the instructions in the real environment. Next to this, users were less focused on the device but rather more on the environment. The authors state that navigation by using a screen only will divide the user's attention and therefore loses its attention to the environment, which would be needed when the environment is dynamic like a busy street or a crowded hallway. After the authors established this, they tested the control over the path. The researchers observed that users had a strong preference in determining the optimal path themselves. In the navigation task, some users were given a choice in what direction they wanted to go. Participants regarded this choice as more favourable since it felt like the user was still in control. Researchers of this study note that this would be a very useful notion in environments known to the user. The same technique is used by Bai et al. (2017). In their paper, the goal was to guide partly visually impaired users through a building by using augmented reality. This guidance was done by a coloured box, as shown in figure 7 by Bai et al. (2017).

Figure 7 colored box from Bai et al. (2017).

This box not only guides the user in a certain direction but also warns for obstacles that could be in the way. Obviously, this only works for people with compromised eyesight and not blind people. For totally blind people, researchers used audio cues to guide the user. The results show that the coloured area works very well to guide people with compromised eyesight through buildings safely and more quickly than without the system. The same technique is used in order picking, as described in a study by Schwerdtfeger and Klinker (2008). The authors of the study developed an augmented reality interface that indicated the location of the box the users had to pick from. Figure 8 shows the interface.

On the left of figure 8, an arrow points toward the target box. This is useful when the target box is out of the user's field of view. This interface worked well, increased the number of picks, and reduced the number of errors. However, some users found the glasses confusing, so they had to step back sometimes to interpret the visualization. This order picking method could be applied in warehouses to instruct employees on which item to grab.

Warehouse guidance can be done in more ways than only AR glasses, as Baechler et al. (2016)

Figure 8 AR interface of indicating right box to pick from Schwerdtfeger and Klinker (2008).

described in a paper to develop a prototype of a new assistance system for manual order picking. This paper compares pick-by-voice, pick-by-display, pick-by-light, pick-by-projection, and pick-by-paper. The third method discussed in the paper is pick-by-light. When an employee must pick an item, a light turns on under it, making it stand out among the other items on the shelves. Sometimes additional information is shown as the number of items the employee should pick. In pick-by-projection, an arrow is projected on the floor to indicate the target shelf. When the user has reached the target shelf, the target item is projected with light and extra information to display its location and the number of items the employee should pick. The authors compared the systems in terms of workload, completion time, and error rate. The results show that pick-by-projection resulted in the least number of errors but one of the highest completion times. Pick-by-paper was the worst method which meant that an employee received a paper with the location. This method resulted in the most significant error rate, one of the longer completion times, and the second-largest cognitive load.

3.2.1.2 Auditory

Next to Visual guidance, there is auditory guidance. This guidance can be done in multiple forms. The beforementioned study of Baechler et al. (2016) already mentioned a form of auditory guidance instructions in pick-by-voice. In pick-by-voice instructions, the employee got speech instructions on where the target item is and how to get there. In the end, the employee must name the last three digits of the bar-code, ensuring that it picked the correct item. This worked better pick-by-display, which showed instructions on a screen. Spatial audio is one form of auditory navigation. Spatial audio means a sound is perceived as coming from a virtual spatial location. Numerous researchers studied this way of navigation. Simpson et al. (2005) studied this form of navigation in the context of airplane pilots. The authors provided the pilots with a headset that played beeps in the direction of the target. In this direction, the position of the head needed to be considered to keep the beep in the same location when the head of the pilot turned. This way of navigation worked well, especially in combination with other navigation techniques. Pilots made fewer errors with the audio cues than without these cues. The same approach was used by Holland et al. (2002) but in the context of pedestrian navigation. They state that there is a need for a Minimal Attention User Interface (MAUI). This interface should be as minimal as possible to keep the distraction for the user also to a minimum. The researchers studied a way of communicating direction using audio. Spoken directions were avoided since this could lead to an overload in the conversation part of the brain. Instead, the researchers used spatial audio to indicate the direction. The beep communicated not only the direction but also the distance to the goal by changing the interval of a beep. This is comparable to the parking sensors on a car. It became clear from user testing that spatial sound could communicate direction and distance well. And the interaction felt natural.

3.2.1.3 Haptics

Another way to guide users to the desired location can be done by using tactile instructions. Many researchers studied tactile instructions and applied them in various navigation applications. Tactile feedback can be implemented in multiple ways. The location of the vibrotactile feedback can affect the accuracy of the navigation task, as Meier et al. (2015) demonstrated in their study on vibrotactile feedback location on the body. The locations which they tested were wrist, feet, and waist. The accuracy of the navigation differed in the locations as well as the concentration needed. They reached the best accuracy when the participants received tactile cues under the feet. However, this also requires a lot of concentration from the user to recognize the given pattern. The haptic instructions were given by applying different patterns on the sole of the feet. These patterns indicate a direction, as shown in figure 9 from Meier et al. (2015).

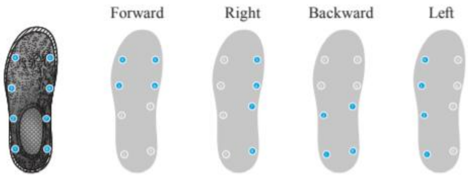


Figure 9 Vibration patterns from Meier et al. (2015)

The study concluded that this way of guiding users could be advantageous, especially as a complementing interaction method. According to this study, using solely vibrotactile feedback would not suffice in a rural, suburban environment or a complex situation. The findings of Schirmer et al. (2015) are in line with the findings above with the addition of the notion that in terms of user experience, the vibrotactile way of guidance is pleasant and fun.

Tactile feedback can also be applied in other novel ways to display guidance information. Frey (2007) developed a tactile feedback system that relies on an intuitive feeling of walking on a footpath in nature. The system makes use of a metaphor that is already known to many people: a well-trodden path. Figure 10 depicts the principle from Frey (2007).

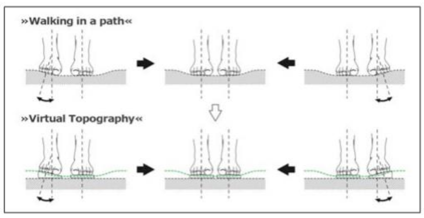


Figure 10 shape of a well-trodden path from Frey (2007).

An actuator inside the bottom of the shoe provides the actuation. This actuator can simulate a tilting feeling of such a footpath. The actuator is still bulky and not fully developed yet, but it is interesting to consider that there are multiple ways of tactile feedback next to only vibrotactile feedback.

In other studies, the waist is used for communicating vibrotactile cues. Pielot et al. (2009) studied the effectiveness of a vibrotactile waistband in guiding the user in the right direction in an outdoor environment. It pointed in the cardinal direction of the destination, as illustrated in figure 11 from Pielot et al. (2009).

Figure 11 Vibration belt pointing to destination from Pielot et al. (2009).

The usage of a vibrotactile waistband was received well among the participants and led to effective navigation. The belt saved much time when trying to navigate to a destination. The primary reason is that time was saved by not having to analyse the map or phone. Participants did not have to look continuously on the map and analyse their position. As mentioned in chapter 3.1.1, transforming and analysing the map takes most of the time in a navigation task and demands the most cognitive resources. This step is taken away when using the belt. According to the study, people would consider themselves more confident in navigation since they keep track of the relative location of the destination. Lindeman et al. (2005) studied the vibrotactile cueing in the waist in an indoor environment to clear buildings in an emergency. It gave promising results, and the researchers stated that vibrotactile cueing could improve how people navigate in an indoor environment. In this research, cueing was done in 8 cardinal directions: N, NE, E, SE, S, SW, and W. This proved to be enough to guide users since participants did not make many errors in distinguishing the directions of the belt. Erp et al. (2005) extended the idea of a vibrotactile belt by studying if it would be meaningful to add distance information to the tactile cues to get a more detailed description of the relative position of the destination. However, this addition did not improve navigation performance. The coding of the direction itself proved to be very effective and was very intuitive in the sense that it did not require any training to understand the cues. An important note is that this study focused on navigation in a motorboat and a helicopter, so mapping these studies directly to navigation on foot might not be fully justified. Some companies have already developed a fully working product to be the mission navigation belt. used in some areas. The army has done pilot studies with the *Mission Navigation Belt* (van Weert et al., 2021). Figure 12 shows this belt.

Figure 12 Mission navigation belt from van Weert et al. (2021)

This belt guides soldiers in an environment where vision is compromised. It is meant as an unobtrusive device that does not hinder the other tasks of the soldier. After some training, the Dutch army received the belt well and currently tests it for its applicability for soldiers. Designers of the belt designed it in such a way that it emitted no light which could be seen by the enemy. Another company took the idea of a compass and made a modern, simplified version of this intuitive idea of an old navigation instrument. The company and app are called *Navibration* (*Navibration*, 2015). The idea of the guiding strategy is that the user is the compass, and the phone of the user is the blade of the compass. The user takes the phone in his hand and holds the phone horizontal. Turning the phone gives a vibration when walking in the right direction. This way, the user is more focused on the environment and does not have to look continuously at his phone to check the route or location of the destination. What is mentioned in all these studies, however, is that haptic instructions require much focus to follow. This is especially true when the vibrotactile cues are given in some pattern to indicate direction. Users had to focus on the pattern to know what the instruction was. We did not consider olfactory and gustatory senses in this thesis due to the context of this thesis.

3.2.2 Outside-in guidance

In contrast to chapter 3.2.1, which discussed the inside-out guidance, this chapter will investigate the outside-in guidance. This means that the input for the guidance instructions comes from the environment on which the user can act. We can also divide this perspective into senses, namely, visual and auditory.

3.2.2.1 Visual

Visual interaction embedded in the environment means that the environment interacts with the user in a visual way. This way of interaction is already studied in different contexts to highlight relevant areas of the environment. Chen et al. (2020) applied this form of visual outside-in interaction in an assembly line of PCB assembly by mechanics. Finding the location of a component could be a daunting task when mechanics must find a location of a chip. The authors of the study tried to reduce the searching time by using projected AR. This means that a projector projects and thus highlights the relevant part of the circuit board, as seen in figure 13 from the study.

Figure 13 Projected white square on the relevant location on the PCB from Chen et al. (2020)

Results show that mechanics made fewer errors, and the time it took to search for the location of a component was drastically reduced. The authors had to deal with a work environment that was relatively brightly lit by ambient light. This made the projected features less visible to the user. This lack of visibility was solved by adding flickering to the square. This way, it was better visible and usable in the environment.

Funk et al. (2015) studied this same idea of projected augmented reality on a bigger scale in warehouses. A projector highlights the box and projects additional information on it to indicate the correct box, which the user had to pick, as figure 14 from Funk et al. (2015) shows.

Figure 14 Highlighting the relevant box by using a projector from Funk et al. (2015)

Van der Vlist et al. (2012) studied this interaction in a smart home environment. The study focused on giving insight to the user on the back end of the smart home system without using complex interfaces. Devices seemed disconnected, and interaction seemed sudden, potentially leading to confusion. The aim was to solve this using projection, as seen in figure 15 from van der Vlist et al. (2012).

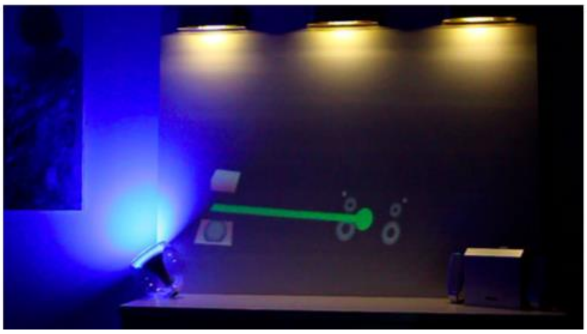


Figure 15 Display connection between devices by projective AR from van der Vlist et al. (2012).

This projection of information resulted in a better understanding of the system's backend without needing a complicated system interface.

Colley et al. (2017) studied another novel way of guiding users by using drones. These drones would indicate the direction of the user's goal by providing different gestures of direction. This study provided an interesting new way of guidance, with users commenting that it was fun to follow directions. However, users also commented on the potential safety hazards. Some users reported that they constantly had to pay attention that the drone did not fly into them or crash against an obstacle even though sensors were present to avoid this. Nevertheless, it provides a new perspective on how to communicate guidance instructions.

A third study by Knierim et al. (2018) combined both techniques described above by a hovering quadcopter with a projector attached to it. The quadcopter hovered in front of the user and, at the same time, projected guidance instructions on the ground. Although users enjoyed the novel approach to guide them to a destination, they arrived later compared to an ordinary way of navigating by, for example, a phone or map.

3.2.2.2 Auditory

While inside-out guidance with audio comes down to wearing headphones and letting the user react to the sound coming from the headphones, Gröhn et al. (2005) studied if spatial auditory cues by using speakers could be used to navigate a person in a 3D environment. Participants had to collect as many gates as possible using a spatial audio cue, a visual cue, or a combination of both. The results show that the participants found twice as many gates with a visual cue compared to only auditory cues, and the search time decreased. Participants found even more gates when the auditory cue was added to the visual cue, and the search time decreased even more. This suggests that using solely using auditory cues does not result in optimal guidance effectiveness and efficiency.

3.2.3 Discussion

This chapter discusses and describes the key findings from the literature research about navigation.

From the literature, it became clear that people already have an innate sense of relative position in their space. However, finding a route by comparing the current position with the goal takes the longest time and demands the most cognitive resources. This is especially true for contra-aligned maps where the user must transform the representation of the environment in such a way that the up direction corresponds with the direction of the user. Furthermore, studies show that while being guided, people pay much attention to the environment to check if the direction they are heading is correct, thus will improve confidence and reassurance in the guiding process. This implies that constant feedback in the guidance process can result in a more confident navigation experience.

Since the user, in this case, the farmer is already familiar with the environment it is working in, providing singular motor responses is redundant; in other words, The system does not need to instruct the user every turn it must take because the user is already confident in its environment. Next to this, the literature stated that users prefer freedom in choosing a route when the environment they must navigate is familiar. If this is ignored, users feel like they are constrained by the route that the system is providing. In addition to this comes the fact that not all farms are structured in such a way that turn-by-turn guidance would work. In farms where all animals are in one big pen, there are no well-defined landmarks on which the user can rely, which is necessary for turn-by-turn guidance. A well-defined landmark is large, clearly visible, familiar, and independent of the environment. When a farm is structured in such a way that turn-by-turn guidance would work, the farmer already knows in which subset of the barn the animal is, making turn-by-turn guidance redundant.

As for the system's interaction, many interactions can convey routes or guidance to the user. The first distinction made in interaction possibilities is inside-out versus outside-in guidance.

In practically all cases of inside-out guidance, the user must wear a wearable to get instructions from the system or carry a handheld device. Visually there are multiple forms in how a system can provide guidance instructions. The most used and best-known way of interaction is a screen that displays directions. A screen disconnects the user from the environment and therefore distracts in dynamic environments, such as a pig farm where the user manoeuvres between moving animals. A static interaction such as a description on paper demanded the most cognitive load from the user.

Furthermore, some studies use augmented reality, which lays a virtual layer on top of the physical world. Research shows that this technology works in many cases. Augmented reality can be applied for inside-out guidance as well for outside-in interaction. In the case of inside-out guidance, the user must wear AR glasses or carry a handheld device. For outside-in guidance, projected AR needs a projector to work, which is attached to the environment. AR glasses are easily visible to the user but require additional hardware to wear. Projective AR is influenced by ambient light, which should not be too bright for this technology to work, and the projection area should not contain obstacles that could block the projection.

In auditory communication, spatial audio can provide instructions to the user to indicate direction. This can be done by using headphones or an array of speakers in the environment. In several different contexts, this worked very well. Speakers in the environment require the surroundings to have a constant sound level to better convey spatial instructions. A noisy environment lowers the effectiveness of the directional cues.

Haptic instructions when walking can only be done by inside-out guidance using wearables which use mainly vibrotactile actuators to interact with the user. Studies show that effective guidance is possible with vibrotactile actuators placed in different locations on the body. The actuators can actuate in different ways. Haptic feedback can give turn-by-turn instructions or perform vibration patterns to communicate direction. Additionally, actuators can communicate the distance to the target using haptic signals. Many studies showed that adding distance information to the communication did not significantly influence navigation performance. What can be concluded from these studies is that haptic feedback is a novel, unobtrusive way of guiding people towards a goal. However, this does not come without any weaknesses. Users in multiple studies indicated that they had to concentrate a lot during navigation, especially when the direction was communicated through haptic patterns. Therefore, haptic feedback has more potential to be used as a supporting method of interaction instead of being the primary method of interaction. Using this technology in combination with other sensory stimuli could result in a more reliable navigation experience.

An advantage of inside-out guidance is that the system is independent of the environment and is therefore applicable in many different environments. A disadvantage is that the user must always strap on a piece of technology, creating a threshold for using the system. With the necessity of wearing a wearable comes the disadvantage that communication is only perceivable by the wearer of the wearable. This means that for cooperation, more wearables are needed.

3.2.4 Conclusion of literature research

The literature research shows that a lot of research has been done in the field of navigation and guidance of people towards a goal. The guidance system for a farmer should be designed in such a way that it fits with the user and its environment. This literature research concludes that not all methods of interaction work equally well in the context of indoor navigation in a barn. Using the farmer's vision in the form of projected AR shows the greatest potential. This technique is already successfully implemented in other fields, leading to an optimistic view of using this technique in the field of pig farming. There are no studies yet on the application in this context and therefore could lead to a novel system that assists the farmer in finding specific animals in his barn. The brightness of ambient light could be considered, the structure of the barn as well as the used projection device to create the best experience for the user.

3.3 Field research

From the field research we want to gather information on the work environment in terms of size, shape, environmental conditions. Next to this we also want to inform ourselves on the workflow of the farmer to get a better understanding of the context. First, we will explain the method which was used in chapter 3.3.1. Then, the findings in terms of barn layout and functional areas are described in chapter 3.3.2 and 3.3.3. Hereafter, the environmental aspects are covered in terms of light and sound in chapters 3.3.4 and 3.3.5. Then, in chapters 3.3.6 and 3.3.7 current technology will be discussed and the tools which the farmer uses. After which we will elaborate on the current search process of the farmer in chapter 3.3.8. We will then finalize with a discussion and a conclusion in chapters 3.3.10 and 3.3.11.

3.3.1 Method

We went to a Dutch farm to gather information on the farmers' workflow and user environment. We started with an interview, of which the questions aimed to get information from the farmer. Appendix 8.3 contains the interview questions which were asked during the visit. Hereafter, the farmer demonstrated how his farm operates while getting a tour through his farm. We contacted a US farmer by email with questions on the structure and the search process of finding a pig.

Physically visiting the Dutch farm added significant value to extract information from the farmer and environment. Next to the answers to questions, a physical visit also allowed for the opportunity for us to experience the atmosphere and let the farmer point to the surroundings and explain each element of the barn while standing next to it. In addition, we perceived the sound way better when hearing it directly as compared to hearing it from speakers.

3.3.2 Lay-out

The environment of a pig barn depends mainly on the size of the barn, the number of pigs present in the barn, the barn's age, and the country in which the barn is located. A field visit in the Netherlands and contact with a foreign US farmer provided information on the layout of barns. In the Netherlands, there are no standardized barn layouts for sows since many of these farms are older; therefore, existing structures are already in place. However, an essential and prominent universal element in the structure of a pen is the placement of dividers to create a place for the sows to lay against and shelter. Figure 16 shows a barn layout of a typical European sow farm. Appendix 8.1 contains an enlarged version of this layout.

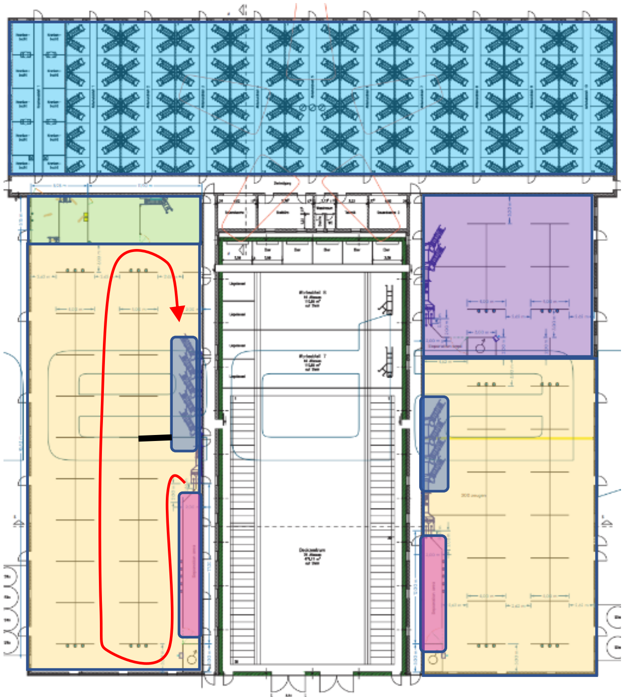


Figure 16 Example of a pig barn lay-out in Europe, adapted from NEDAP. (2021) Bauplanung Bauernhof, unpublished internal company document

In the US, the structure of a pig barn remains mainly the same as the layout in figure 16, but the scale of the farm differs significantly. An enlarged version of this layout can be found in appendix 8.2. Comparing the lay-out of the barn in the US with the layout of the European farm shows that the structure of the gestation pens is the same (the yellow markings in figure 16 and figure 17). The main difference is the number of gestation pens. The figures show that the structure of the US barn is a recurring pattern of the European pen, where the farm in the US has five gestation pens while the European farm has only one large pen and two smaller ones. When a modern farm expands, the same structure is copied every time and pasted next to the existing barn. This results in the recurring structure, which is visible in figure 17. The Dutch barn of the field visit has a structure and size like the purple square in figure 16. What is not visible from the top view is that a wall does not fully separate the pens in figure 16. On the other hand, on the Dutch farm, the separate pens are separated by a wall from floor to ceiling.

The size of a pen differs per farm, but some requirements are bound to certification of the wellbeing of the animals. The Dutch farm has a 'Beter Leven' certificate which requires each sow to have at least 2.25 m^2 of space. This number gets more lenient when there are more sows in the pen. This is because it is not uncommon for all sows to gather on one side of the pen. When this happens, it leaves a lot of open space on the other end. The more sows in one pen, the stronger this effect is.

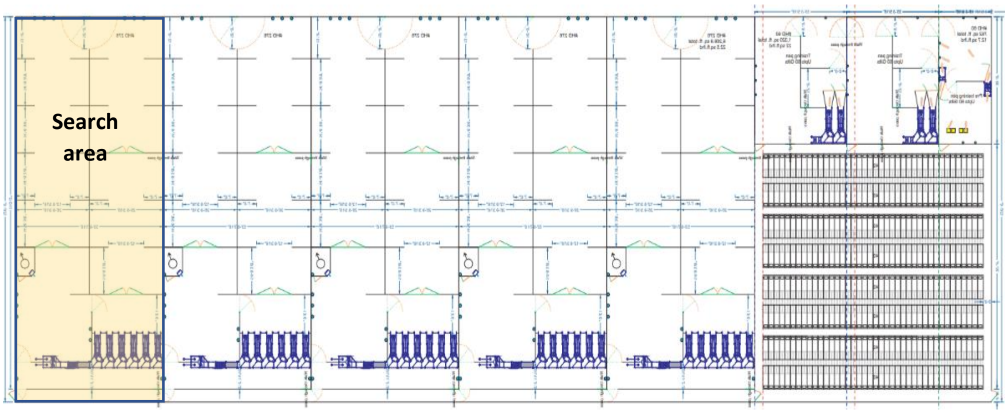


Figure 17 Lay-out of a pig farm in the US, adapted from NEDAP. (2021) US Nedap barn design, unpublished internal company document

3.3.3 Areas

The different functional areas of the barn are coloured in figure 16. The light blue area in the upper part of the figure is the maternity pen, where the piglets are with their mother for four weeks. After this period, the piglets must develop an intuition for the feeding station. This development happens in the green area in figure 16, where a training station is located. In this pen, the piglets learn how to enter and use a feeding station, the same station as in the pen they end up in, called the gestation pen. These pens are marked yellow in figure 16. In the left yellow area, 273 sows are housed, and in the right yellow area, 200 sows. The darker blue area in the figure depicts the feeding stations. After the feeding units, they are weighed in a weighing unit, after which a separation unit can separate them. This unit releases the sows back into the pen or leads them into a separation pen depicted in pink. A reason for separation could be that a sow must be vaccinated or inseminated.

Furthermore, the quickest route from the exit to the entrance of the feeding station must be considered. If the wall in the large pen (the bold black line in the middle of the left yellow pen) would be removed, the sows could run straight from the separation unit to the feeding unit. This wall prevents this from happening. Instead, the sows must take the orange route to return to the feeding station. Hence, the wall prevents the stronger sows from continuously entering the station, prohibiting the less dominant sows from entering. This thesis focuses on the yellow areas. The yellow area is the part of the farm where it occurs most often that a farmer must find a sow, also called the gestation pen.

3.3.4 Sound

The sound level in the barn ranges from very quiet to very loud, as this depends mainly on the conditions in the barn. The sows react to people entering or unexpected movements by exerting loud screeching. Additionally, the pigs occasionally screech and make noise by playing with certain toys placed in the barn, such as a chain. During the field visit, a piglet also screeched when it got stuck, after which the farmer freed the piglet. The machinery in the barn operates nearly silently, apart from the occasional sound coming from the gates of the feeding unit or the separation unit.

3.3.5 Lighting

Lighting conditions are not the same in every pig barn. In the Dutch farm, the ambient light is moderate to light, with daylight coming from a few windows in the barn. Figure 19 shows a picture we took of this farm. In addition to this, light sources produce artificial lighting. The farmer

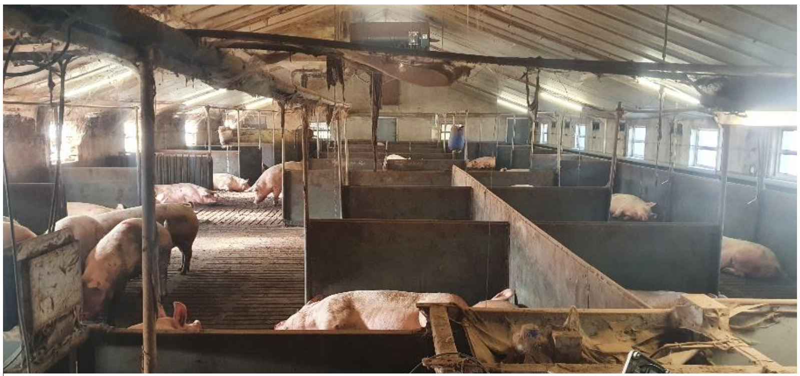


Figure 19 Picture of the inside of the Dutch barn

mentioned, however, that there will be some changes in the future with respect to the lighting. He is planning to install a light 'street' which means adding translucent panels to the ceiling, which will create a lighter environment. Figure 18 shows a pig barn from the US. You can see all the way to the back since there are no wall separating the different pens.

Figure 18 Photo inside a pig farm in the US

What becomes apparent in figure 18 is that the lighting conditions are different compared to the Dutch farm. There is artificial light coming from the ceiling as well as natural light from the windows in the back. However, this is based on a picture that could be deceiving for real-life lighting conditions.

3.3.6 Technology

The Dutch farm contains technology that helps the farmer do his job. Nedap currently uses RFID tags attached to a sow's ear to identify the animals by a unique number that serves to identify the sow. These tags are different from the tags of the cows since the tags of the pigs are solely used for identification. All these numbers are stored in a database with the corresponding sow information.

The farmer can access the database by his phone via a mobile webpage called Velos. The farmer mentioned that he checks this webpage multiple times a day when he wants to get data on a specific sow. Next to these regular checks, the farmer also gets notifications when an animal needs attention. These notifications appear multiple times a day, which is representative for most farmers using the Velos system.

To scan the ear tags of each animal, a station with three units is placed in a line to form a 'hallway' where the sows walk. The sows enter by the gates in front of the station. These two entrances are built so the sows cannot turn around and exit from the other entrance. When they walk through the gate, the units scan their ear tag, and the sows get the appropriate amount of food from the feeding unit. After the feeding unit, the ear tag is scanned again, and the sows enter the weighing unit. Here, the weight of the sow is stored in the database. Before the sows enter the separation unit, their ear tag gets scanned again for the system to determine where the sow needs to exit the station. The sow either ends up in the separation pen or returns to the regular pen back in the group. Figure 20 depicts all three units and is an adaption of pictures taken from the product catalogue.[2]

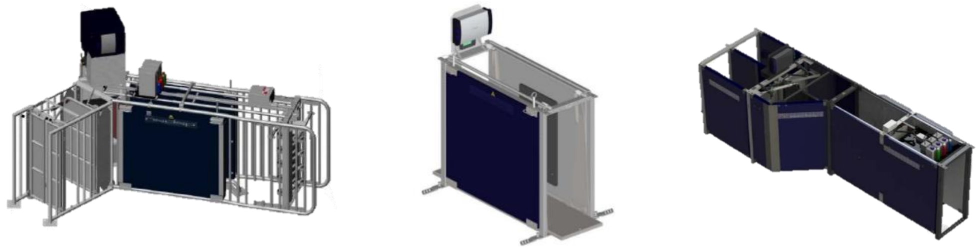


Figure 20 feeding unit, weighing unit and separation unit respectively, adapted from NSG catalog.2

The farmer's former experience with technology also gave some evident insights into what he dislikes about technology in his work. As he mentioned former experiences with technological systems, he noted the unwieldiness and the extra hassle of AR glasses he had tried before. The glasses were a concept for locating pigs in his barn. This implies that the system should reduce the extra steps and devices to a minimum.

3.3.7 Tools

The farmer does not frequently carry tools while walking in the barn. The only thing he does sometimes carry in his hand is his phone which displays information about the eating habits of each sow, weight, and other relevant data.

3.3.8 Current Search process

The Dutch farmer mentioned that he spends approximately 5 minutes finding a sow but also said this can fluctuate a lot depending on the location of the sow. He currently searches sows by entering the pen and looking at or scanning the individual ear tags. We have learned from the US farmer that currently; he uses only the app to help him find a specific animal. He said that the location is displayed in the app, and therefore, the search area is confined a lot as the farmer already knows in which pen the sow is located. It rarely happens that this information is wrong since the employees carefully enter every displacement of a sow in the system. Figure 17 shows an illustration of the

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2 https://static1.squarespace.com/static/5d5429b7d6a9210001d1c6c6/t/5f5a4a3290dcc743f4432c11/1599752772359/NSG_Parts_Catalog_09_2020.pdf

confined search area. After the phone displays the right pen on the phone, the farmer walks through the pen, looking at the ear tags until he finds the right sow. This results in a searching time of approximately 10 minutes to find the right sow, depending on the location. However, it isn't easy to define a precise search time since it depends on the sow's location. If the sow is near the pen entrance, the farmer finds the sow way faster than if it is on the end of the pen. The farmer must search for sows multiple times a day on the farm in the US. Staff and routine

The Dutch farmer works on his own on the farm most of the time. Once a week, a helper assists him with chores on the farm. The number of users of the system is limited to approximately three people, the farmer himself, the helper who helps once a week, and the inseminator who visits the barn once a week to inseminate the pigs. Only one person works on the farm simultaneously, but this could change when the farmer expands his farm. The task of finding a pig is most of the time done by the farmer himself. In the US, this is different because of the difference in scale. In the US, some employees spend a large part of the day finding pigs. These employees can change over time.

The farmer explained how he currently finds his pigs in a pen and when he must do this, which is important to verify that there is indeed a problem in finding pigs in the barn. Most of the time, the reason for a farmer to find a pig is that the Nedap application, Velos, warns the farmer that an animal has an insufficient food intake or that it did not enter the feeding station for a while. The reason for this is that a young pig does not have much experience with the feeding system and, therefore, potentially does not eat enough. For this reason, the farmer marks these younger sows on the back to make them stand out and make sure he monitors these sows regularly. Currently, the farmer marks the younger animals on the back so he can find them faster and keep an eye on them while they are in the pen. If he must find a certain sow number, he must go in the pen and look at the individual ear tags of each sow to know which animal requires attention, which can take a lot of time. Figure 21 shows the farmer's workflow for finding a pig. We constructed this diagram according to the gathered information.

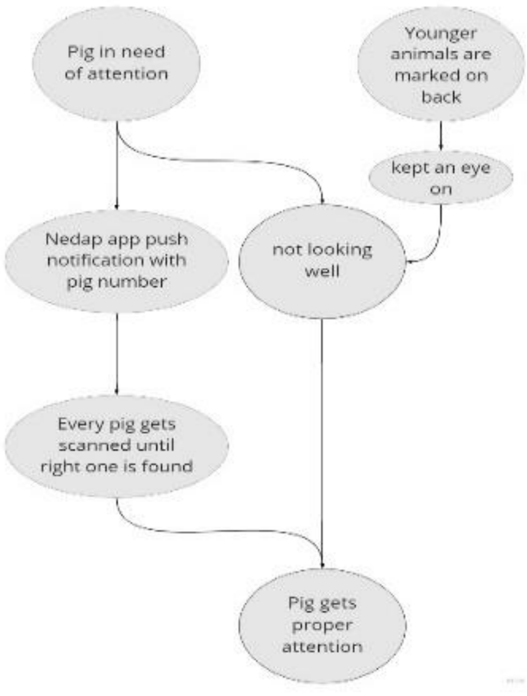


Figure 21 Workflow of a farmer when finding a pig

3.3.9 Other remarks

We noticed that there was a lot of dust collected on the tools and machinery. This should be considered when designing a system that must work in these harsh conditions. The device can be potentially covered in dust when it is placed inside of the barn.

3.3.10 Discussion

The field visit gave valuable insights. Starting with the insights concerning the layout of a pig barn with group housing. Although the layout of pig barns is not standardized, it is generalizable over most farms since they all include dividers. These dividers are not only in place for the sows to lay against and shelter but also help prevent the more dominant sows from continuously entering the feeding station and therefore prohibit other sows from entering. The recurring “H-pattern” of these dividers is the same for group housings of traditional and modern farms, and the structure is maintained when a new farm is built or when a farm is expanded. This makes the structure generalizable over most pig farms as the Dutch farmer confirmed.

The sound level in the barn was not constant but instead ranged from quiet to loud due to the screeching of the pigs. This screeching was caused when someone entered the pen, walked nearby, or if the sows played with toys. The machinery in the barn did not cause loud noises other than an occasional slam of the gates of the feeding station. This station consists of three sequential units, each with a different function: feeding, weighing, and potentially separating. These units act on the needs of a sow by scanning the ear tag in each unit. The units communicate with a database which is stored locally and on the servers of the Nedap. The farmer can access the database by visiting a webpage on his phone.

For this reason, the phone is often used in the farmers’ workflow since it provides alerts for sows that need attention, and next to this, he can manually check the database when he notices that a pig potentially needs attention. The last case can occur when he sees an undernourished sow. Finding an undernourished sow frequently happens in the case of younger sows who still must get used to the feeding unit. For this reason, the farmer marks these younger sows on the back to make them stand out and make sure he monitors these sows regularly. However, when the phone gives an alert to find a specific sow, the farmer must enter the pen and search from start to end, looking at all the ear tags. Since the scale of the Dutch farm is different from that of the US farm, the search process is also different. In the US farm, people are employed who often must find a sow in the pen. Finding a sow can take up to 10 minutes in the case of such a large farm. On the Dutch farm, it is not necessary to find sows daily, but it can take up to 5 minutes when it needs to be done. Finally, the work environment stood out in the amount of dust in the air and on the machinery, which could make moving installations vulnerable.

3.3.11 Conclusion

The comparison between multiple farms in different countries shows that the main common element is the barn's structure. The same structure is handled in other countries on a different scale. The sound in the barn ranges from low to high but is generally increased when for example, the farmer enters the barn. When the farmer has entered the barn, he uses his phone as his primary tool to keep an eye on irregular eating habits of his sows since he carries this with him in the barn. In case of an alert from the phone, the farmer searches for a sow which can take up to 10 minutes in the case of a farm in the US and 5 minutes on the Dutch farm. The design of the first user test should consider this environment and the current tools the farmer is currently using.

DISCOVER

DEFINE

DEVELOP

DELIVER

4 Define

In the *Define* phase we define the problem based on the insights of the *Discover* phase. The *Define* phase consists of three sections: the scope, guidelines, design directions, and the conclusion. First, we scoped the problem to define the problem space (chapter 4.1 to 4.2). Then, we set guidelines to establish what the solution should adhere to (chapter 4.3). After the guidelines, design directions are determined to direct the solution space in a more promising way (chapter 4.4). The phase will end with a conclusion (chapter 4.5).

4.1 In scope

The eventual product should guide the user to the target location in a barn environment. The concept will be most valuable in a pig barn employing group housing in a gestation pen. This is because group housing causes the most problems since the sows are not always located at the same location and can move in a large area. Next to the type of farm, it is essential to specify the tools used by the farmer. Existing tools can function as a starting point for concept ideas. As the field research showed, a farmer's primary tool through the barn is his phone. The farmer uses his phone as the main access point of data of his livestock. From the literature, the most promising guidance was guidance using projection. This does not require the user to carry or wear additional hardware and is the least noticeable for the pigs. However, since the smartphone is already heavily incorporated in the farmer's workflow, inside-out guidance is also part of the potential solution space.

4.2 Out of scope

Determining a sow's position was out of this thesis's scope. Placeholders emulated the positioning system throughout the study. Research shows that users who must navigate an environment familiar to them prefer to determine their own route. This means that creating a route from starting point to end point has less potential for a guidance system in the barn. Therefore, the thesis was limited to a more promising guidance solution and did not consider route generation as part of the potential solution space.

Guidance using sound was also not part of the thesis since the sound level in the barn was deemed too loud, and the amount of burden of sound for the sows could not be sufficiently estimated. Next to this, we saw in the field visit that screeching of a pig can mean it needs attention. Using headphones would increase the risk of missing these signals coming from the sows. After the literature research, projective AR seemed a promising way of showing the location of a sow to the farmer. However, the field research decreased the potential for this solution since the projection would be less visible in the environment than expected due to environmental conditions and structure. Therefore, we did not consider projective AR for the first concept generation.

4.3 Guidelines

The research extracted a few guidelines for the development phase from the field visit and the literature research. They form a framework that leads to the highest possibility of successful integration.

The first guideline is that the product should **avoid including extra hardware** that the user should wear or carry. This guideline emerged from the dissatisfaction over an earlier product the farmer used regarding managing and finding his livestock.

The second guideline is that the product **can be used in any barn with their environmental conditions**. This guideline emerged from the findings of the field visit and the contact with the US farmer.

The third guideline is that the product should **anticipate moving sows in the large pen** since they do not reside in a predetermined area corresponding to an individual sow.

The fourth and final guideline is that the product should **fit in the structure of the pen**. This means that the type of guidance should be able to guide the farmer in the pen by considering that it is not an open space with no obstacles, but also note that there is no free walking route through the pen.

4.4 Design directions

The scope and guidelines discussed in the previous chapter determined the design direction of the development phase. The development phase was directed towards visual guidance since auditory guidance is out of scope because of the unpredictable burden for the sows. Also, the environment can be relatively loud because of the screeching of the sows, which can include the screeching of a sow in need of attention. Haptic signals were also not considered since research showed that haptic cues require a lot of concentration and cognitive resources, which should be avoided as much as possible to keep the farmers' attention on the environment. For the perspective of guidance (outside-in or inside-out), we will not exclude one but test both, since both perspectives seem promising in successfully guiding the farmer to the correct location.

4.5 Conclusion

The *Define* phase is the basis of the following phase to steer the development in the right direction. The solution space was defined by fencing off what is in and out of scope. The product will be designed for group housing of sows. To accomplish this, the define chapter steered to visual guidance since this is deemed most promising. The eventual product must adhere to four guidelines: avoid extra wearable hardware, the tool must be generalizable among most barns, the tool must consider the movement of sows, and finally, the tool should be suitable for the structure of the pen.

DISCOVER

DEFINE

DEVELOP

DELIVER

5 Develop

In this development section we will describe the outcomes of the *Develop* phase. This phase consists of three steps: idea generation, realization and evaluation. Together with two members of the Innovation Team of Nedap, we initiated the idea generation with a mind map of the use case after which we brainstormed on solutions. The result were two prototypes which could improve on the pig finding task (chapter 5.1 to 5.3). We will then describe how we implemented these ideas to functional prototypes (chapter 5.4) Finally, we will describe our first evaluation of these prototypes (chapter 5.5).

5.1 Mind map of use case

The development started with a mind map to get insight into the farmer's workflow and work environment. This mind map depicts all the relevant components of the farm in relation to each other and therefore gives structure to the different elements in de barn. Appendix 8.4 contains the full-size mind map. The mind map aided in structuring the various aspects of the barn and workflow and then links them to understand the current situation. This helped to get insight into where the guidance system could be integrated. The mind map depicts how the app is related to the search process by storing a database of all the sows with, amongst others, their eating behaviour. When a sow has an abnormal eating pattern, the farmer gets notified and takes appropriate action. This practically always starts with searching the sow inside of the pen. The bottom right branch of searching for a sow was the most relevant for this thesis since it relates to the search process and shows the strategy as the farmer incorporates it. A portion of the relevant part of the mind map is shown in figure 22.

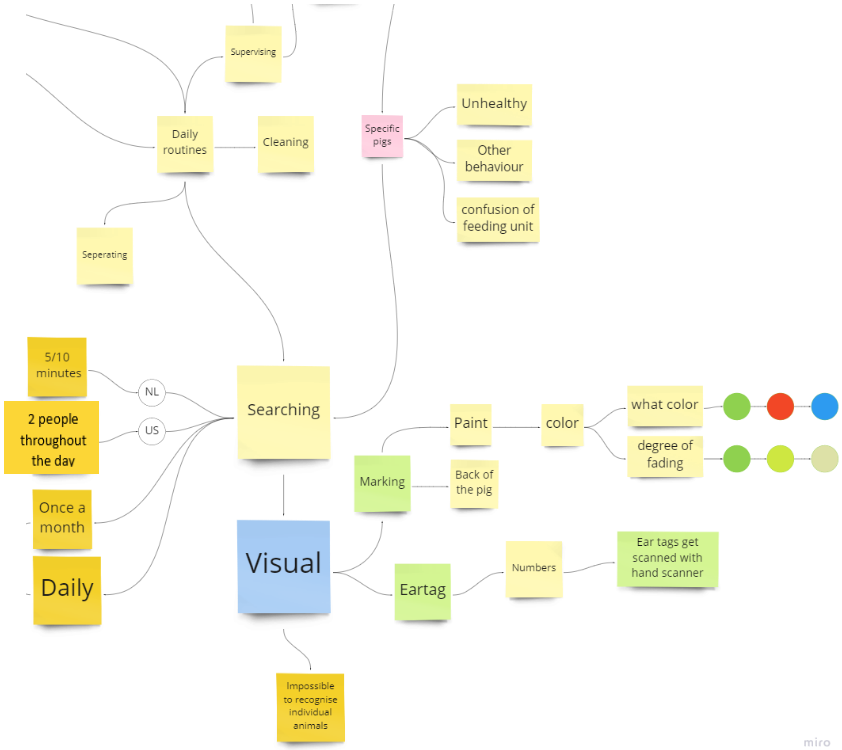


Figure 22 Mind map section

The guidance system can make some steps in the workflow easier or even redundant. Currently, the younger pigs are marked to be easier to recognize. It is essential for the farmer to monitor these younger sows since the possibility of them being unhealthy and undernourished is the highest. The farmer must mark these younger animals since the sows are visually identical to the human eye, even for an experienced farmer. When the farmer must search through the barn for a specific number, he uses a hand scanner to scan all the pigs individually. This step could be made more efficient by using a guidance system.

5.2 Brainstorm ideas

This chapter describes the process and outcome of a brainstorm, resulting in potential ideas and solutions for solving the problem. A mind map with different branches of technologies generated a variance of possible solutions. The starting point for this brainstorm was the question: *What are the technological possibilities to guide a farmer to a sow?* Figure 23 shows the mind map which resulted from the brainstorm. Appendix 8.8 contains an enlarged version of this mind map.

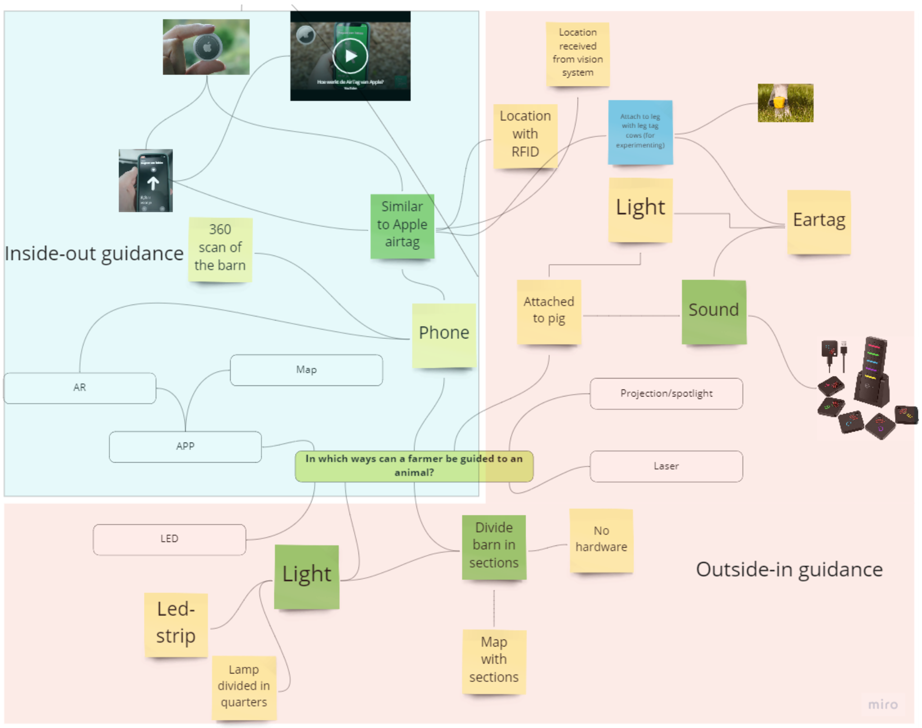


Figure 23 Brainstorm concept generation

The mind map started with tools and technologies which have the potential to mitigate the guiding process. One of which is the phone, which the farmer always carries with him and plays a prominent role in the workflow as visible in the mind map of the use case. This branched out to existing guidance solutions for a phone, resulting in location tags used to find lost objects. In addition, a farmer can use a phone to incorporate Augmented Reality to project a digital layer on top of the real world using the phone's back-facing camera. Additional branches formed with light and sound. The mind map also includes the concept of dividing the barn into sections which then connected to the technology of light. Ultimately, the mind map is categorized in outside-in guidance and inside-out guidance.

5.3 Specification

In the specification phase, I elaborated on the ideation and discussed the potential solutions that emerged from the brainstorm. Two possible solutions from the brainstorm emerged, which will be addressed in subsections.

5.3.1 Concept selection

The specification phase narrows the number of concepts down to two, which were realized and tested in the following stages. The ideas which match the guidelines from the *Define* phase the best, are perceived as the ideas with the highest potential. The user test eventually helps to define what guidance method works best in the environment and workflow of the user.

5.3.2 Direct light indication

The potential for a projection or spotlight was not that high since the lighting was too bright, making the projection probably not visible enough to see. The contrast of the light will not stand out enough. Also, the dividers in the barn would block the projection. Direct light is brighter and does not require the need to be reflected by a surface, which causes a brighter visual cue. A variation of projection is direct light. Direct light can restrict the search area of the farmer by indicating a section of the barn, as the mind map in figure 23 shows. This idea requires the need for the barn to be divided into sections. A light then indicates the section where the relevant sow is located. Figure 24 visualizes this concept.

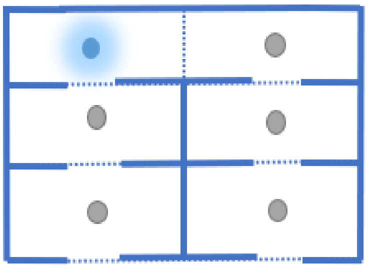


Figure 24 visualization of direct light indication

The light can be coloured to make the light more visible between the other lights in the barn. This idea of guiding landmarks builds upon the study of Aslan et al. (2006), which stated that people continuously scan the environment for landmarks to navigate their way to the target. This landmark should be clearly visible and independent of the environment, as Heidorn & Hirtle (1993) studied.

5.3.3 Phone guidance

The second guidance method makes use of the mobile phone. It will display the position of the relevant sow on the farmer's phone, inspired by current location tags. Researchers such as Savino et al. (2020), have already studied how to guide people in other contexts using a phone. The guidance should perform well in an environment with no predefined walking routes. A guidance method that looks promising is by depicting relative location and direction. Figure 25 visualizes the concept of phone guidance.[3]

Figure 25 Vizualization of phone guidance.

[3] Icons adapted from flaticon.com

This guidance method is in the literature known by the name As The Crow Flies (*ACTF) guidance*. Savino et al. (2020) studied the user experience of ACTF guidance in an urban context with promising results.

5.3.4 Expectations

A strength of the direct light guidance method is that the farmer can walk hands-free to the target location and that the farmer can see the pig's location immediately. Based on the field visit, observing the layout as a whole could be problematic from some angles and positions the light could not be easily linked to a section in the barn.

A strength of the phone guidance is that this method uses the already existing technology and hardware available in the barn and is used by the farmer. He already carries his phone in the barn and therefore does not require additional hardware. A potential weakness could be that the farmer is distracted by his phone while walking through the farm and, therefore, cannot focus on the environment, including moving pigs.

If these presumed strengths and weaknesses translate to a real-life environment will become apparent in the user test with actual prototypes, which will be designed in the following chapter.

5.4 Realization

This chapter discusses the realization process of the prototypes. The user used these prototypes at a later stage, meaning they had to convey at least the basic functionalities of potential future use.

5.4.1 Light guidance

The light concept had to be controlled unnoticed by the participant. So ideally, the researcher could control the light from a distance. Distance-controlled led strips enable the researcher to turn the led strips on and off from a distance without the participant noticing what will happen in the barn. These led strips are controlled by an IR remote, which can cause the led strips to light up the corresponding section of the barn. Because these strips require 5 volts, they were powered by power banks, making it convenient to place them anywhere in the barn without needing long cables. The led strips are wrapped around a 3D printed base and then placed inside a 3D printed shade to partially diffuse the light. Figure 26a shows the physical prototype and figure 26b shows a cross section of the model of the prototype.

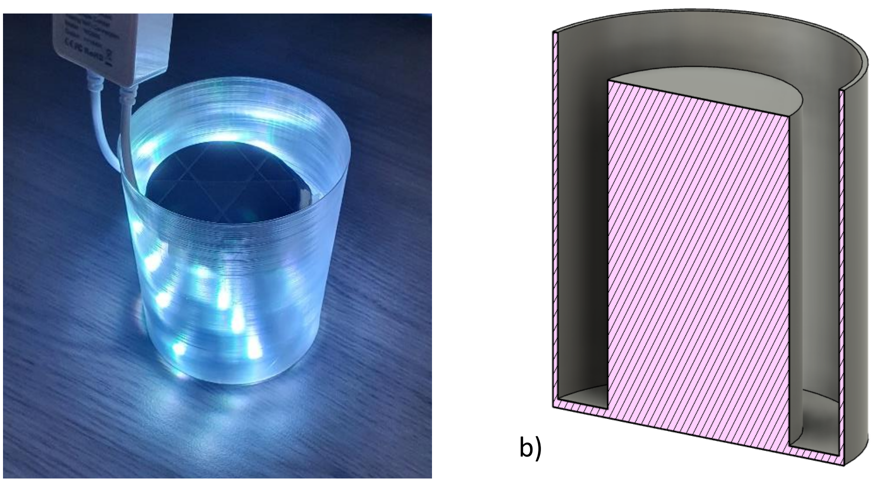
a)  b)

Figure 26 a) Indication light b) cross section of prototype

As mentioned in the specification, the lights indicate a section in the barn. The concept defines a section as an area separated by the partitions in the pen, as shown in figure 27.

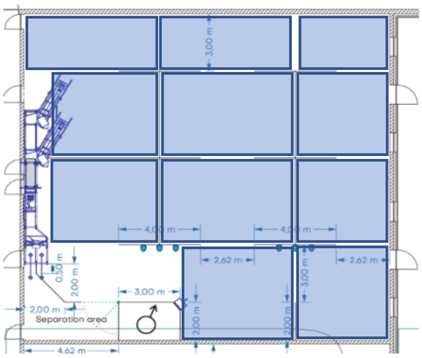


Figure 27 depiction of sections of the

Figure 27 is a snippet from the European farm in figure 16. The layout of this pen is very similar to the one of the field visit, in which the farmer will test the prototypes. Larger farms handle the same structure but copied in multiple rows and pens. The main differences of the layout in figure 27 as compared to the layout in the farm of the field visit are the location of the separation pen, which is located along the left side of the test barn instead of the bottom left corner, and the orientation of the partitions, which is turned 90 degrees with respect to the feeding stations. The idea of the sections, however, remains the same.

5.4.2 Phone guidance

The phone guidance concept involved a location tag that the phone could localize. In the first instance, the preferred option was to use a location tag with an open API to develop a custom As The Crow Flies (ATCF) interface. However, these open API tags were not available yet at the time of this thesis which were precise enough for the purpose of this test. Instead, the solution resorted to an off-the-shelf solution from Apple. This solution is the Apple Airtag, as seen in figure 28.[4]

Figure 28 Apple AirTag

This tag can show its relative location on an app on the phone in terms of distance and direction. This resembles the guidance of the ACTF+-navigation method of Savino et al. (2020). Literature refers to this as "*As The Crow Flies*" (ATCF) navigation, which displays an arrow in the direction of the target. Ultra-Wideband frequency, also known as UWB, in combination with Bluetooth, is responsible for the tags' localization. By combining this tag with a phone with a UWB receiver chip, the tag can be precisely located with an accuracy of 2.5 centimetres. This is more than enough precision for the task of finding a pig. For this to work, an iPhone 11 or newer is needed since a U1 Ultra-Wideband chip is required to display a precise location.

[4] Figure copied from https://www.apple.com/nl/shop/buy-airtag/airtag

Therefore, for the case of this thesis, we used an iPhone 11. It is important to note that the AirTag was a placeholder for the eventual sow locating system. In the future, a locating system can make use of some form of Ultra-Wideband technology incorporated in the ear tags of the sows. But it is not economically feasible to fit every sow with an AirTag as used in this study. This also means that the *'Find My'* app was a placeholder. This app comes pre-installed on an iPhone. The visuals and navigation principle can be similar but should be custom-made to work in the existing app the farmer currently uses. A possible integration is discussed later in chapter 5.4.3. The "*Find My*" app first only depicts a distance indication. The user must walk in the direction where the distance gets smaller. The theoretical range of an AirTag is advertised to be 100 meters with no obstructions. This range was probably less in the case of a sow farm since the sows are always lower than the partitions in the pen. However, this did not pose a problem in this use case since the farmer was not further away from the target animal than a maximum of around 20 meters. Precision Finding is activated when the user is within reach of 10 meters, which shows an arrow on the screen that indicates the precise direction and distance to the target. Figure 29 shows what the *"Find My"* app looks like.[5]

Figure 29 Precision Finding of an AirTag

A sensor band that Nedap currently uses for monitoring the step count of cows was used to house the AirTag and attach the Tag to a sow. This case was necessary since this ensures that the band can be closed and therefore stays on the paw of the pig. This band will not be a permanent solution since pigs have the tendency to get the bands of their paws after a while. Usually, this case is filled with electronics in combination with filler material. The case is normally almost filled to the top so that the electronics are isolated from environmental conditions such as moisture and dust. The antenna is not submerged in the filler material since this blocks the signal. The cap forms an extra layer of protection against these conditions. For the set-up of this study, the top was left open. This circumvents the need to glue the cap on the case, which could break off during the experiment. The AirTag is IP67 certified, making it water- and dust resistant, and therefore does not need the cap to protect it from dust and dirt. A custom 3D-printed mount was needed to securely attach the AirTag to the case to better fit the shape. Figure 30 shows the 3D model of this mount.

Figure 30 3D-model of first AirTag housing

[5] Figure adapted from https://www.macrumors.com/how-to/use-precision-finding-airtag/

It is essential to consider that no sharp edges should be present outside the case to prevent it from hurting the sows. The cap attaches to the base using M3 bolts and brass inserts to open the mount when the AirTag must be removed. An M4 bolt and nut attached the 3D-printed mount to the case. In the first design, the printed mount was attached to the outside of the case, as seen in figure 31. This made the AirTag easier to mount.

Figure 31 First prototype of AirTag housing

However, the result turned out to be too bulky. A second iteration solved this by housing the AirTag on the inside of the case without ends of screws or bolts on the outside of the housing. This iteration resulted in a new version depicted in figure 32. This housing mounts to the inside of the case by brass inserts on the bottom. This band is much more low profile and does not contain sharp edges outside the housing.

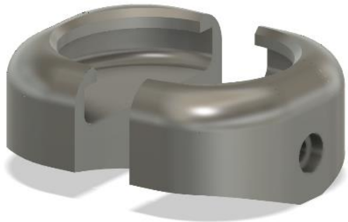


Figure 32 Second iteration of AirTag housing

Figure 32 shows the 3D model of the final AirTag housing. This design made it possible to slide the AirTag in and out by removing one M3 bolt on the top and therefore makes the AirTag easy and fast to remove when it is already attached to the sow in case the tag is faulty for some unforeseen reason. A picture of the total sensor housing with the band is depicted in figure 33.

Figure 33 Total set-up of sensor housing with band

5.4.3 App integration

The two prototypes should eventually be integrated into the app to build upon the pre-existing database and tools of the farmer. An illustration of the button in the app clarified how the prototypes would potentially work in combination with the app. The button was placed in the menu where the app shows the specifications of a sow. Figure 34 illustrates the eventual workflow in the app.

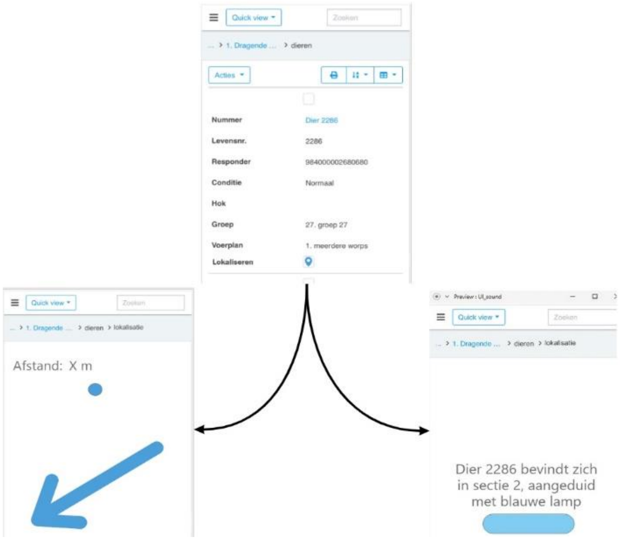


Figure 34 Workflow in the app

When the farmer taps the button ‘*lokaliseren’* [localize], the app follows with one of the bottom screens, depending on the prototype. The left screen shows the ACTF guidance while the right points out that there is a light lighting up above a section in the pen with the text: ‘*animal 2286 is located in section 2, indicated by the blue light*’. This illustrated a potential future use case of the concepts. The number of the sow is in the case of the experiment not displayed on the app but called by the researcher.

5.5 First user test

The user test aimed to study the type of guidance with the highest potential to guide a farmer in an actual work environment. The test took place in a real environment to best approach the eventual use case of the system.

5.5.1 Location and participant

The same farm as the field visit served as a test environment for the prototypes. As mentioned before, Nedap uses this farm to test product ideas and concepts to study if they perform as expected. The participant is the farmer working on that specific farm.

5.5.2 Set-up

Phone guidance

The initial plan was to attach the AirTags to the sow so the app could display the location. Four AirTags and two bands with their housings completed the setup. The separation unit separated two sows in the separation pen to make the attachment process easier. This would make attaching the band significantly more manageable since the sows were separated in a controlled pen with fewer sows. We first tested if the Tag worked as expected in the barn. This turned out to be different than expected since the Tag could not handle moving objects precisely enough. It would not be a problem if the sows were lying down in the same place, but since there were unfamiliar people in the barn, the sows moved, which did not result in a usable output for locating the sow. If this technical shortcoming could be overcome in the future, we still tested the phone guidance, by placing the tags in the pen, and the farmer had the task of finding these tags. This test still represented the eventual interaction behaviour of the system while it ruled out any disturbances of moving sows due to limitations to the technical platform.

Light guidance
Three lights hung from the iron pipes for the test with direct light indication. This would not translate directly to the actual use case since the real use case requires a light above every section of the pen. For testing purposes, however, this was enough to test the farmer's experience. In this user test, the lights were attached to the iron pipes on the left side of the pen, as seen in figure 35.

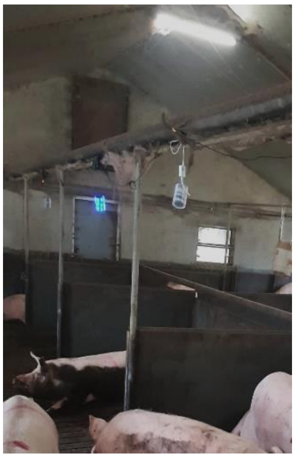


Figure 35 Test set-up of direct light indication

5.5.3 Method
This chapter elaborates on the method of the first user test. Before performing both tests, the farmer signed a consent form. This study was ethically approved under reference number RP 2022-63. The consent form can be found in appendix 8.6. prototypes were explained to the farmer so he knew what he could expect and to ensure he understood each prototype's principle. Next, we encouraged the farmer to verbalize thoughts and feelings during the searching process. The farmer performed the finding tasks twice to allow the user to get used to the prototype. He first performed a baseline test, then the phone guidance and the direct light guidance at the end.

Baseline
Before testing the concepts, a baseline had to be set to compare the results of the concepts with the current situation. A baseline required the farmer to find a pig in the way he does it in the current situation. This resulted in two search times which the prototypes should reduce. First, the researcher selects a sow based on the ear tag's number and repeats this once.

Phone guidance
In the case of the first prototype, the relevant sow would have been already chosen beforehand by attaching the sensor band, but now the tags were hidden in the barn. The farmer had to follow the directions on the phone's screen and try to reach the tags. The researcher monitored the search process to spot any confusion or remarkable behaviour.

Direct light indication
With the direct light indication, the researcher selected a specific sow based on the ear tag number. This sow should be in the pen below one of the light indicators. When the researcher chose the sow, the farmer started the search process. While the farmer searched for pigs in the barn, the researcher monitored the search process to spot any confusion or remarkable behaviour.

5.5.4 Analysis

The analysis of the concepts includes the following measures: *effectiveness, efficiency,* and *satisfaction*. The definitions and usage of these terms are defined by the ISO (International Organization for Standardization), *ISO (2018*) and will be elaborated on below. Together, these measures give an adequate impression of the usability of both concepts.

The *effectiveness* has two components: Accuracy and completeness. Completeness is: ‘’*The extent to which users of the system, product or service are able to achieve all intended outcomes”.* (ISO, 2018, p. 10). In the case of this study, the intended outcome is to find a pig. Accuracy is: “*The extent to which an actual outcome matches the intended outcome*” (ISO, 2018, p. 10). According to (ISO,2018, p10), “*Inappropriate decisions based on inaccurate, unclear, or incomplete outputs can cause inaccuracy*.” This links to mental models. A designer has an idea of how to complete this task and how the different components work together and interact with the user. The user also has a view on this. According to Fok et al., (2013), when the mental model of the designer and the user coincide, the product or system is well designed and will probably work as intended by the designer. When the two models do not coincide, it should be studied why there is a discrepancy and if this forms a problem in the usage of the system. The mental models are described below.

The mental model of the prototype with light guidance from the designer's perspective is as follows: The farmer is looking for a pig that, according to the Velos app, needs attention. In the menu with the specifications of the pig, the farmer taps on *‘localize,’* as is shown by the concept screenshots beforehand. This action will cause a light to turn on above the corresponding section in the barn where the sow resides. When the farmer notices this, he mentally connects the light with the pig's location, after which he will walk to the section and give the proper attention to the pig.

The mental model of the concept with the app from the designer's perspective is as follows: The farmer is looking for a pig that needs attention. He taps on the ‘*localize*’ button, which displays an arrow on the screen representing the direction of the target sow. In addition, the distance to the target sow is displayed, indicating that the farmer is moving in the right direction. When the distance is equal to zero, the farmer knows that he is at the correct location of the pig. Figure 36 shows and summarizes both mental models of the concepts.

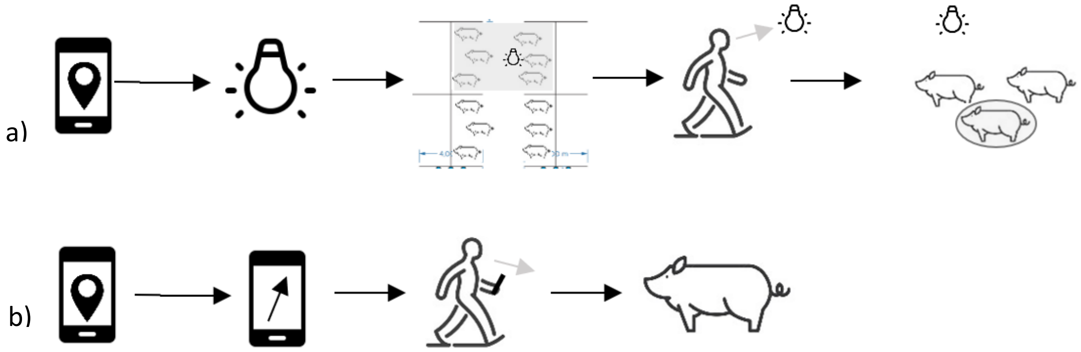


Figure 36 Mental models of designer. a) direct light guidance b) phone guidance

We built the models with the navigation steps of Levinew et al. (1984) in mind, which described the three steps of navigation. According to the study, transforming the map, so the user sees its current location relative to the goal requires the most time and cognitive resources. These concepts aim at replacing step two of the mental model of navigation. There is no need to transform a mental map to create a route to the goal. The route still needs to be determined by the user.

Next to the observational analysis of the sow finding task, there will also be a quantitative measure to analyse the *efficiency* of the concept. According to ISO (2018), efficiency is defined as "*the resources used in relation to the results achieved*" (p. 10). This includes time, human effort, money, and materials. This study compares the time to find the right sow with the prototypes to the time it takes for the farmer to find the right sow without any tools. A shorter time to find a sow could indicate that the concept could be a valuable addition to the farmer's workflow.

When the farmer has completed the task, the *satisfaction* of the concept is determined. Satisfaction is defined by ISO (2018) as "*the extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user's needs and expectations*" (p. 11). Typically, satisfaction is measured based on ratings given by the user. In this study, the rating is done by ten questions. These questions are also known as the *System Usability Scale* or SUS, which aims to quantify a system's ease of use. Appendix 8.6 contains the questions of the SUS.[6] The eventual score is calculated by deducting one from the odd question and subtracting the value of the even questions from 5. Subsequently, the total value of the scores is multiplied by 2.5. The result is the eventual score with a maximum of 100. It is important to note that the resulting score does not represent a percentage. On average, the score is 68[7]. If the score is above this number, the system is considered to work reasonably well. If this is below 68, the concept needs adjusting. Not only does the scale provide information on the usability of a single concept, but it also enables the prototypes to be compared to each other. It is important to realize that the SUS is not a diagnostic tool. It does not uncover the usability issues in the system but instead performs a benchmark on the concept. Therefore, it is important to ask the user to elaborate on some answers in the questionnaire. Scrapping a prototype might be too extreme since the concept could work in combination with another prototype.

5.5.5 Results

The evaluation chapter discusses the findings after the user test. It will go into the strong suits and weak points of the two prototypes and will form a base for further improvements for future iterations. This chapter will go into each concept separately.

5.5.5.1 Baseline test

For the baseline test, the farmer received the instruction to search for an animal in the pen without any tools. He searched sows twice to compare the search time of the concepts with the current situation. The first search time was 90 seconds. The second search time was 230 seconds, resulting in an average of 160 seconds. These times come with the important side notes that the first time the user noted that this was faster as usual. The second time the user missed the number of the sow, which made him check twice, which took more time.

5.5.5.2 Phone guidance

The farmer started with the first prototype, phone guidance. Instead of searching for specific sows, the farmer had to search for the tags in the barn.

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[6] The farmer received a Dutch translation of this form

[7] https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html

Efficiency
The farmer had to search for two AirTags. The first try took 83 seconds. The second try resulted in a search time of 40 seconds. This comes down at an average of 59 seconds.

Effectivity
To check the system's effectiveness, the user's mental model is compared to the designer's mental model. From the think aloud data, observations, and review after the test, we can deduce what the mental model of the user was while using the system. The user's mental model was the same as the designers, which means that it resembles the mental model depicted in figure 36b. However, the guidance process did not work as expected. Prior to the test, the hypothesized process did not include any obstacles along the way. The user could not follow the path of the system since sows were moving in the way and made the user deviate from the course, which distracted the user from the phone and, therefore, the direction. The prototype was conceptually clear by the farmer, stating: *"De afstand wordt kleiner en het scherm wordt groen, dus ik denk dat ik de goede richting loop" [The distance becomes smaller, and the screen turns green, so I think am walking in the right direction]" (personal communication, May 6, 2022)*.

Satisfaction
The SUS indicated how user-friendly a system is and how satisfied a user is regarding a certain system. The System Usability Score of the app turned out to be 90.

***Other* remarks**
During the app guidance, the user understood that the arrow pointed to the target and therefore had to follow the direction in which the arrow pointed. The video data shows that the user was focused on the screen of the phone, which led to some situations in which he almost stumbled over a pig or could just avoid a pig that walked in the way. The farmer also mentioned this after the test by stating: *"Ik had geen overzicht tijdens het zoeken, ik was vooral gefocust op de pijl*" [I did not have an overview of the situation while searching, I was focused on the arrow].

5.5.5.3 Direct light
The set-up of the direct light indication remains the same as described in chapter 5.4. Three lights are hanging from the pipes above the pen. A remote control can turn on each light. The ear tags on the sows were readable enough to discern and follow a pig.

Efficiency
The farmer had to find a pig two times. The first time the farmer had to find a pig with the help of this concept was 31 seconds. The second time it took 25 seconds. This comes down to an average of 28 seconds.

Effectivity
The user mentioned after the test: "*Ik zag dat ik aan de rechter kant van de sectie moest zijn dus ik heb daar maar gezocht en gevonden*" [I saw that I had to be on the right side of the section, so I just went looking over there and found (the sow)]. This exposes an incongruency after the study in the conversation with the farmer. In the study itself, the incongruence was not immediately apparent since the right sow was found after some short searching. Figure 37 depicts the mental model of the designer and user of the system.

Figure 37 shows that there is not a complete congruence between these models. For a major part, the models agree with each other, which means that the user understood the overall idea of the system. The only difference in mental models was that the division of sections was ambiguous for the user. In the designer's mental model, a section defined a rectangle between the pen divisions. Since the lights hang from the pipes, they were not in the middle of this rectangle, which could cause confusion in the division of sections.

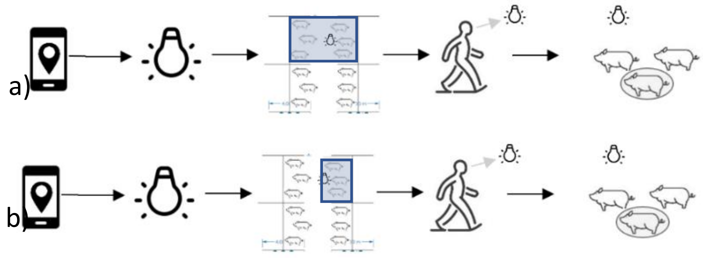

Figure 37 a) Mental model of the designer b) mental model of user

Satisfaction
Like the previous prototype, a SUS is used to measure satisfaction. This score can be compared to the app guidance and provide information on which prototype the farmer perceived as most user-friendly. The calculation of the usability scale resulted in a score of 97.5. This means that the user perceived the lights as more user-friendly and that the satisfaction was significantly above average.

Remarks
During the test, the user noticed that a light lit up in the barn, which he connected to the location of the pig he had to find. After the study, he mentioned that he preferred the light over the app. The main reason was that he had an overview of the barn and could see the target location in a blink of an eye. This meant he did not have to walk between the pigs while searching, which saved him time and would be less of a hassle because he did not have to walk between the sows. What he also mentioned was the situation in which the sow would move. The farmer said that the lights would be intuitive given that it would be necessary that the lights would move along with the sow.

5.5.6 Discussion
Both prototypes are quantitatively compared in terms of efficiency and satisfaction. The efficiency should be as high as possible, meaning the time it takes to find a pig should be as low as possible in the graph. Next to this, the usability score expresses the satisfaction. The higher this score, the better the concept is. Figure 38 depicts the time it took on average to find a pig next to the usability score.

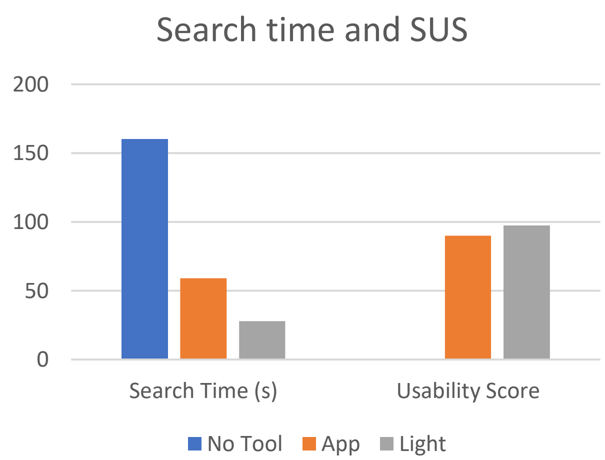

Figure 38 Search times and usability score

Figure 38 shows that the time it took for the farmer to find a pig is less with the direct light indication. This suggests that the instructions from direct light indication were quicker to follow for the farmer. This difference was mainly due to the need for the farmer to walk all the way through the pen to find the pig as seen during the user test. This was not the case with the light since the farmer immediately knew where the target sow was and therefore could walk in the walking way and find its way quicker to the animal. The usability scores of both concepts were high. The mental models of the user of both prototypes were very similar to those of the designer except for some ambiguity in the sections in the second concept. The first user test was limited in the sense that every prototype was only tested twice and therefore, does not provide information on the performance of every prototype over time. Even though the light guidance seems the most promising option, it is less scalable than phone guidance, since phone guidance does not depend on infrastructure in the barn and therefore, a larger barn does not increase costs or complexity.

5.5.7 Conclusion

The results of the user test are in line with the conclusion of the literature research in terms of what sort of guidance should be used. According to the literature, outside-in guidance based on light has the most potential. This conclusion also resulted from the user study. The farmer regarded inside-out guidance as less efficient and less user-friendly. The reason was that the user was focused on the device and therefore could not anticipate on the environment.

The following design should build upon the findings of the first study. A few requirements emerged from the first user test:

First, the concept should enable the user to **see the location of the sow in one glance**, which means that the farmer should not have to translate a representation to the real world. This also enables the user to determine the path which is most convenient for him and thus avoids him having to walk through the whole pen between the sows, as the farmer described as problematic.

The second requirement is that the **system should not demand too much focus from the user.** When the system requires too much focus, the focus on the dynamic environment is less, which could lead to manoeuvring issues as described above.

Both requirements steer towards **outside-in guidance** by using direct light indication. The form of this direct light indication is yet to be explored. This exploration is the subject of the second user test.

5.6 Second user test

This chapter explored different concepts of light guidance to study which would have the most potential in guiding a farmer to the correct section in the barn.

5.6.1 Requirements

The requirements of the new design came from the findings of the first user test, described in chapter 5.5.7. The new concepts should enable the user to oversee the barn and show the sow's location immediately. This iteration should minimize the time the farmer has to walk between the sows. The system is not required to indicate an individual sow but can confine the search area to a few square meters. However, the system should visualize clearly what the confined search area is. The research question for this chapter is: *what is the best representation of a search section in the barn using light as an indicator?*

5.6.2 Ideation

The research question in the chapter above initialized the ideation. A mind map depicts different technologies and corresponding representations. The mind map resulted in five technologies: light points, led strip, spotlight, projector, and laser. In addition to the technologies are different applications of the technology, as seen in figure 39.

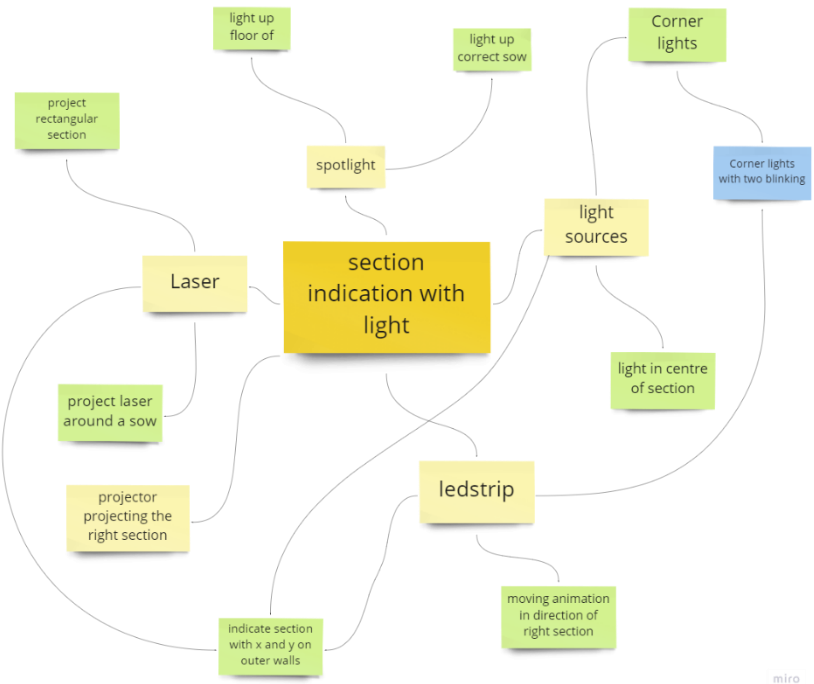

Figure 39 mind map: section indication with light

The upper part of the mind map shows the idea of using spotlights. A spotlight could be used in two ways. Namely, the spotlight could shine on an individual pig, or it could highlight a section in the barn to indicate in which section the animal is located. Another application of light is using lasers which can project a rectangular section on the floor to restrict the search area or project a laser around a sow. An additional application of lasers can be to form an x and y grid and let the laser point at the walls at the corresponding coordinates of the section or location. Other lighting techniques such as light sources or led strips can also accomplish this concept. Addressable led strips can visualize one-dimensional animations that can direct or point the user to the correct section. The last light technology is an ordinary light source such as a lamp which can be used by hanging them in the middle of the relevant section, like the first user test, or on the corners of the section.

5.6.3 Specification

According to previous literature findings, field visits, and the first user test, I extracted the most promising concepts from the mind map. The laser was the first concept that was ruled out. Lasers can harm the eyesight of sows and humans if they shine directly in the eyes. Users follow instructions to avoid looking directly into the laser, unlike pigs, who can accidentally watch directly into the laser beam. The second and third concepts are the projector and spotlight, which can be ruled out since previous conclusions pointed towards the problematic visibility due to the structure and lighting conditions in the barn.

5.6.3.1 Centre light

The first concept is like the method used in the first user test. There will be a light hanging in the centre of the section. In the user test, the light was off-centre, which caused some confusion for the farmer. By hanging the light in the middle of a section, the right section could be less ambiguous for the user. Figure 40a visualizes this concept.

5.6.3.2 Corner lights

The farmer noted that the sections were ambiguous. To better convey the section to the farmer, lights in the corners of the search area can be attached in the farm at sections in the pen. These lights show the rectangle in which the sow is located. Figure 40b visualizes this concept.

5.6.3.3 Corner lights with subsection

The third representation is a variation on the corner lights of a section. The additional value of this third set-up is that two lights will blink to indicate a subsection where the relevant sow is located. A subsection defines the area of the user's mental model in figure 37b. This concept tested if indicating a more specific location significantly decreased the search time. Figure 40c shows the third and last concept where the two right light points blink.

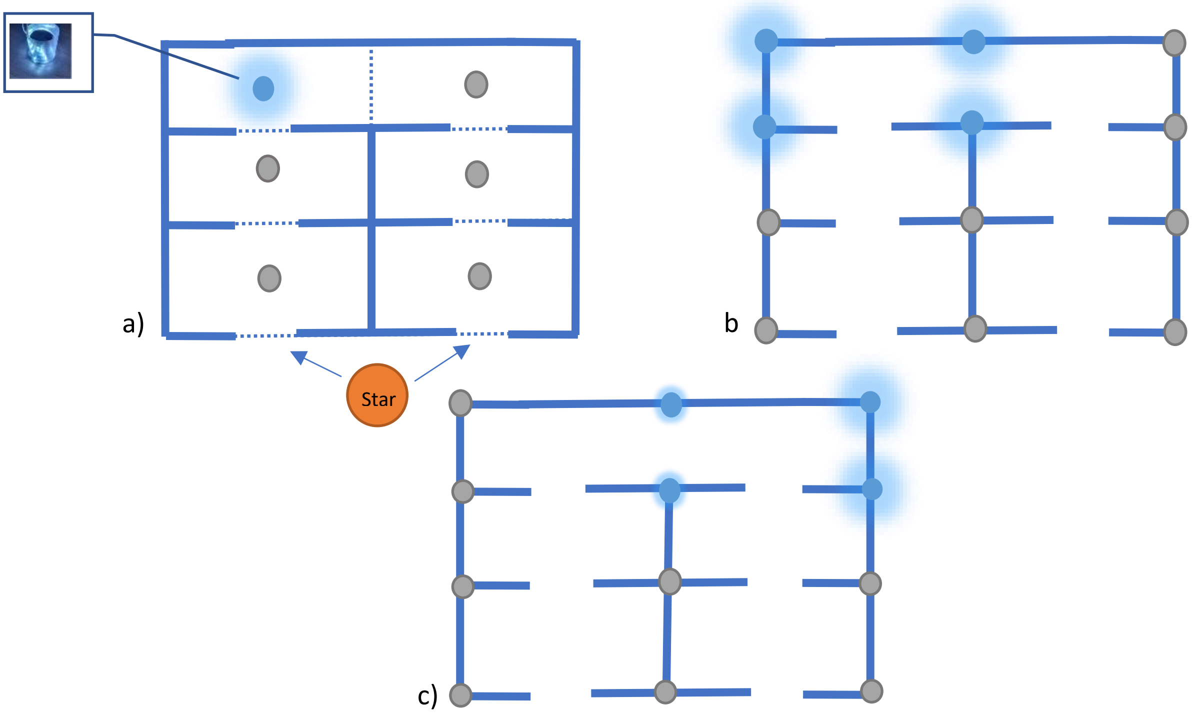

Figure 40 Test set-ups of different light methods: a) center light, b) corner lights, c) corner blink

5.6.4 Method

A test set-up that simulates the barn environment put these three concepts to the test. The reason for creating a test set-up instead of testing the methods in a real user environment is that more people can test the different concepts. Inviting tens of people to a farm is impractical and cumbersome for the farmer, considering the added risk of spreading diseases by introducing so many people inside the barn. The instruction room in the Nedap office functioned as the environment for the test set-up. In this room, the light level was adjusted to reflect the actual environment by comparing the visual data from the field visit with the test layout.

Figure 40 shows the layout of the test setup. In the layout, there were only two active sections. This reduced the complexity of the setup, and it should be enough to test every method. Next to this comes the normalization of walking time. By having two active sections in the corners, the difference in walking time was minimized among the concepts since the walking time to the section is the same for each one. Chairs were placed inside the pen to simulate sows. Each chair got a sticky note with a number that identified each sow. The sticky notes were stuck to a 'sow' on the backrest of the chair, after which the chairs were placed randomly throughout the set-up. Figure 41 shows a photo of the setup.

Figure 41 Picture of second user test set-up

The participant received an explanation of the layout when he or she entered the room to place the setup into context. After the setup was clear, the participants received an information letter and a consent form. This form can be found in appendix 8.9. This study was ethically approved with reference number 2022-75. After participants signed for consent, they tested the concepts in an order created by the Latin square to normalize the learning effect. The participant received the instruction to find sow number X with the help of the concept. After completing the task, the participant received a short questionnaire with three questions: *What did you like about this concept, what did you dislike about this concept,* and *how difficult would you rate the task with the use of the concept on a scale of 1 to 10.* The same steps were repeated for the other two concepts. The search process was video, and audio recorded, provided the participant gave consent.

5.6.5 Materials

The second user test used the same lights as the first user test. In this test, however, they were hanging in the middle of the section. The corner lights consisted of the same type of led strips used in pairs, meaning three controllers were needed to indicate two sections. The separation walls were made such that the post-it notes were not immediately visible from the other sections. We used vertically folded tables to separate the sections which approximates the height of the separations in the Dutch barn from the field visit.

5.6.6 Data collection

Multiple usability metrics compared the concepts with each other. The first tested metric was efficiency. The efficiency measured the time from the moment the participant turned around and observed the layout to the moment they touched the right chair. This was measured by analysing the videos if the participant consented. If this was not the case, a stopwatch tracked the time. The second metric was the number of sows checked to observe if there was a significant difference between the concepts. A short questionnaire collected the final data with the three questions as elaborated in chapter 5.6.4. This saved time as compared to an interview, while still provide the most important findings. These metrics gave a good impression of which set-up would work best in a pig barn.

5.6.7 Plan

We performed a statistical analysis with SPSS[8] to determine if the search time was significantly different between the concepts. First, the Shapiro-Wilk test had to conclude if the search time data is normally distributed. If the data is not statistically significantly different from a normal distribution, the times can be analysed using repeated measure ANOVA after which a post-hoc analysis relates the set-ups with each other. If the data was not similar to a normal distribution, the Friedman test could determine if there was a significant difference in the data. The responses to the open-ended questions were analysed by manually categorizing the responses and counting the number of occurrences of each category. In addition to the statistical analysis and open questions, the video data was analysed to spot any remarkable findings which could be relevant to the study. The analysis focussed mainly on walking speed, consistency of walking speed, remarks of the participant, and the number of sows checked.

5.6.8 Results of second user test

This chapter describes the results from the exploration user test per light indication method as described in the chapter above.

5.6.8.1 Number of checked sows

Figure 42 shows the distribution of the number of checked sows per concept.

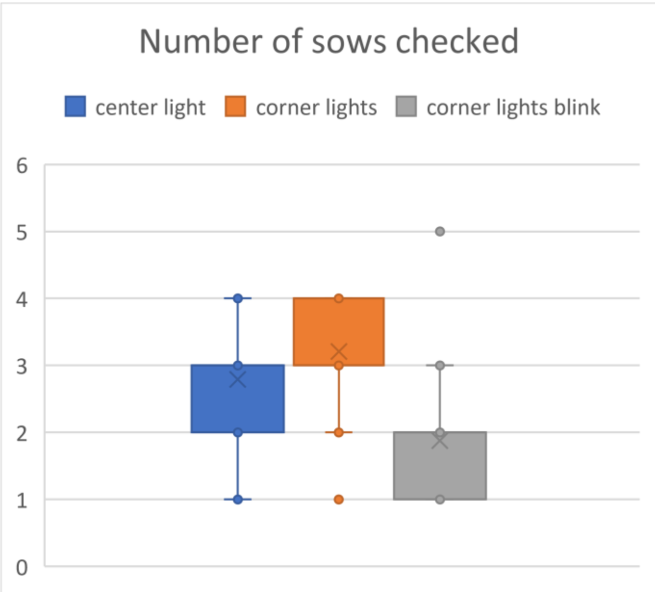

Figure 42 Number of checked sows. Crosses are the means. The medians are: 3, 3, 2 consequently

The average of the centre light, corner lights, and corner lights with blinking are 2.8, 3.2, and 1.8, consequently. The medians are not directly visible from the boxplots since they coincide with the quartiles.

[8] SPSS version 26

5.6.8.2 Search time

The search time of the participants is determined by watching the video of the participants after the study is completed. Figure 43 shows the distribution of the search times in a violin plot.

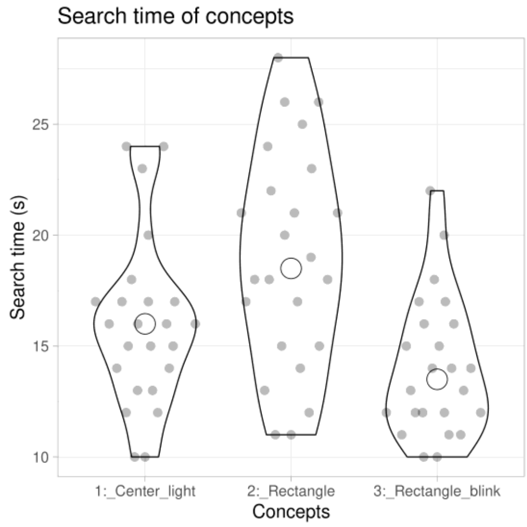

Figure 43 Distribution of search times depicted in a violin plot. Circles depict the means

The violin plots show that the mean of concept 1- center light, concept 2 – corner lights, and concept 3 – corner blink are: 16, 18.96, and 14.04 seconds respectively. Statistical tests compared the concepts. In the following statistical tests, α = 0.05 is used. The first test is the Shapiro-Wilk test which showed no statistically significant deviation of a normal distribution in the search times of the centre lights, *W(24) = 0.926, p = 0.079*, the corner lights, *W(24) = 0.974, p = 0.754* and the corner lights with blinking sides, *W(24) = 0.920, p= 0.060*. These results imply that repeated-measure ANOVA is the appropriate test to prove a significant difference in the search time of the concepts. An assumption for using repeated-measure ANOVA reliably is that the data is spherical. To test if this assumption is true, Mauchly's test of Sphericity is performed on the dataset and proves that the assumption of sphericity of the search time data is not violated, $\chi^2(2) = 2.122, p = 0.346$. The results in the ANOVA table, in the row '*sphericity assumed*', show *p = 0.000*. This shows a statically significant difference in search time between at least two concepts. Table 2 with pairwise comparisons shows which concepts are statistically significantly different.

Table 2 Pairwise comparisons of the three concepts

Pairwise Comparisons

Measure: MEASURE_1

(I) Concepts	(J) Concepts	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-2,958*	1,088	,037	-5,767	-,150
	3	1,958	,873	,105	-,296	4,213
2	1	2,958*	1,088	,037	,150	5,767
	3	4,917*	1,102	,001	2,072	7,761
3	1	-1,958	,873	,105	-4,213	,296
	2	-4,917*	1,102	,001	-7,761	-2,072

The results show that there is a statistically significant difference in search time between concept two and three, *F(2, 46) = 11.63, p = 0.001* and between concept one and two, *F(2,46) = 11.63, p =*

0.037. A significant difference could not be measured between concepts one and three, *F(2,46) = 11.63, p = 0.105.*

In addition to the difference in search times between concepts, we can study the difference in search times between the runs, which shows if there is an order effect occurring in the study. Figure 44 compares the means of each run to study if this effect is occurring. Figure 44 shows that the average times of the runs are close together and that there is no order effect occurring. The average search time is the highest of the first run, lower in the second run, but increases again in the third run. This shows that the average search time does not decrease as the participants repeat the test in the setup.

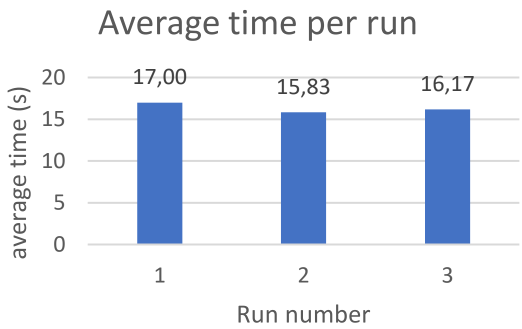

Figure 44 Means of every run

5.6.8.3 Questionnaire

The questionnaire potentially explains the difference in search times by giving the possibility to comment on positive aspects and negative aspects of the concept. The questionnaire provides insight into the user's subjective experience using three short questions.

Difficulty rating

The difficulty rating shows how difficult each concept was to understand on a scale from 1 to 10. This means that the lower the number, the easier the concept was to understand. The participants rated the first concept with an average difficulty of 2.92/10. The second concept of 3/10, and the final concept 2.54/10.

Questionnaire

The positive and negative questions sorted the answers to the open-ended questions in the questionnaire into positive and negative categories. The negative categories are coloured red and the positive categories green. After all the answers had been gathered, they were sorted into groups with similar responses. Appendix 8.9 shows the groups of answers. Figure 45 shows the responses in bar charts.

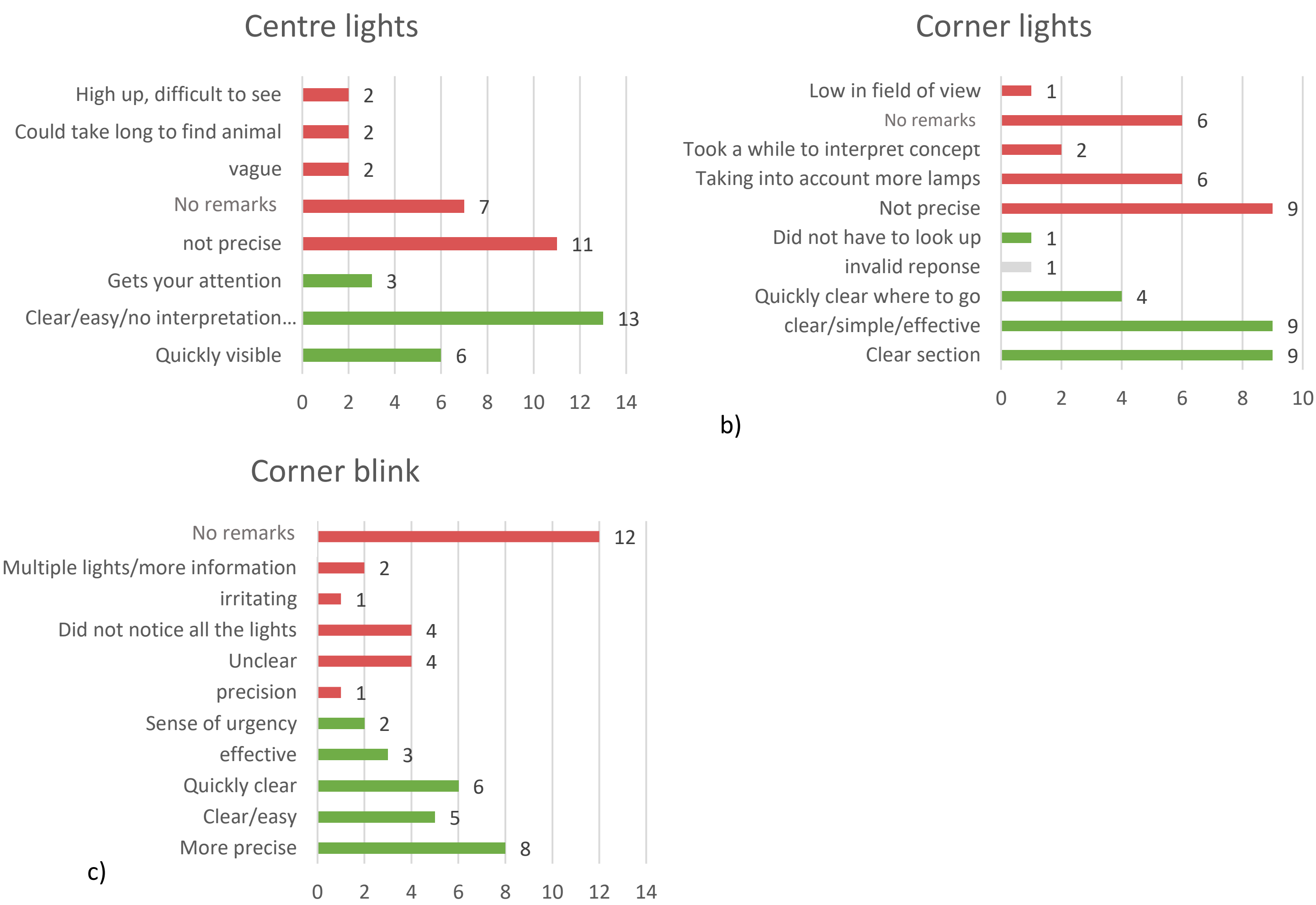

Figure 45 Questionnaire response a) centre lights b) corner lights c) corner blink

5.6.8.4 Video analysis

Most participants agreed to gather video material during the study, except one participant who preferred not to be filmed. The video material of the other 23 participants made it possible to analyse walking speed, consistency in walking speed, the number of sows checked, and other findings during the analysis. The user test resulted in 23.5 minutes of audio-visual data. Every video was observed for every metric taken. This means that the video is watched once for measuring the time, once for counting the sows, and once for other potentially important observations.

Pre-*search*

The video material showed that the time before entering the layout differs between the concepts. This time is longer in concepts 2 and 3. Many participants first observed the layout for a few seconds before entering the layout. This was not the case with all participants. Three participants did not wait to observe the layout first, and therefore, the same participants reported that they missed the two lights in the middle after the test.

During the search
During the searching process, participants mainly focus on their route to avoid collisions with chairs since they mostly look down. Multiple Participants had to confirm during the search that they were on their way to the correct section by looking up or around them to focus on the right light. Three participants did this when using the centre lights, six with the corner lights, and one participant did this while using the corner lights with blinking lights. The participants were instructed to walk at a normal pace through the layout to avoid trampling over the chairs. This resulted in a consistent walking speed during the search process with all the concepts apart from the 11 participants who stopped a few times to verify the section. The video data provided information to summarize the separate steps in a workflow diagram in figure 46.

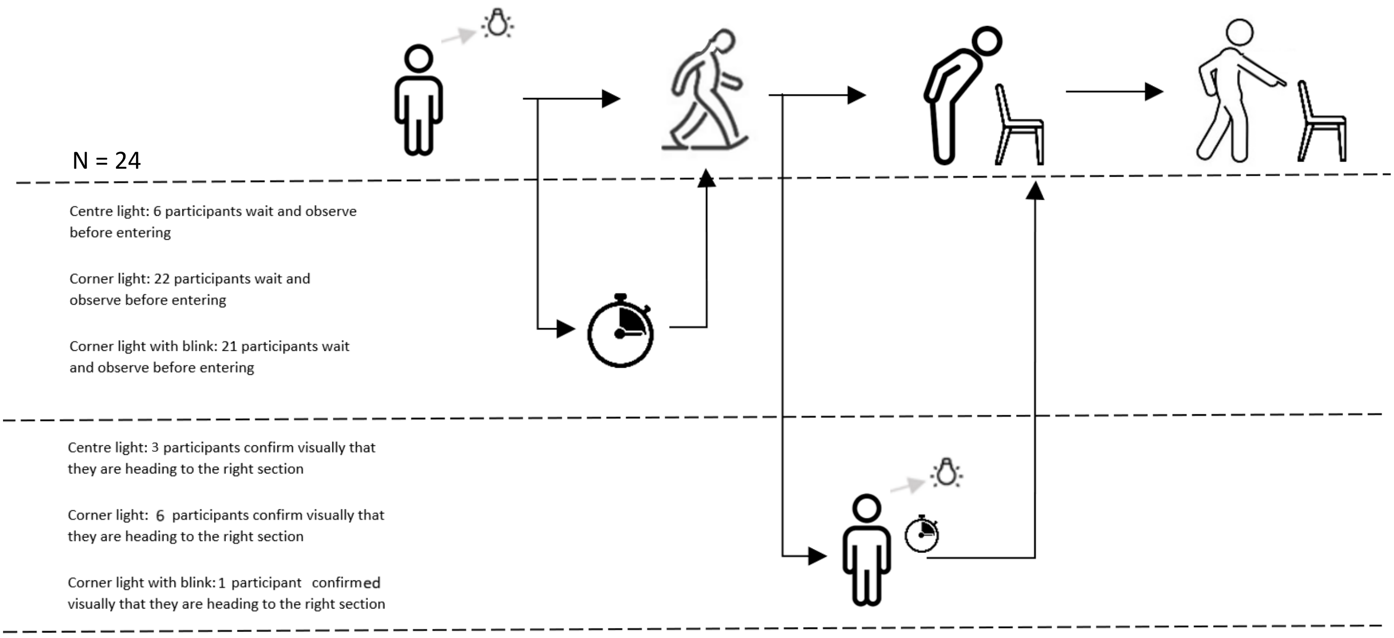

Figure 46 workflow diagram second user test

5.6.9 Discussion second user test

Finding a pig with the help of the concepts was successfully done by all participants with every concept. This was as expected since this would also be the case when there was no additional way of indicating the location of the sow. The difficulty rating does not provide much information on the difference between the concepts since the task itself was not very complicated, and therefore the difficulty was perceived as low for all the three concepts. This phenomenon is also known as the *ceiling effect.* In the case of these results, it is technically a *floor effect*. This means that the task was too simple to observe a significant difference between the concepts. We can conclude that the participants perceived the task itself as easy with all the concepts; consequently, no discernible difference can be observed between the concepts.

The search times show that there is a significant difference among the concepts. The statistic test proves a statistically significant difference between concepts 1 and 2 and between 2 and 3. This means that considering the means of the search times, the results show that the search time is significantly longer when participants used concept 2. There was no significant difference between the search times of concepts 1 and 3, even though the search times of concept 3 were almost always shorter than the search times of concept 1. This was expected since the search area of concept 3 is half of the search area of concept 1. An explanation for the lack of a significant difference is that it took participants longer to understand where to go when more lights were visible. Participants confirmed this in the questionnaire, where multiple participants indicated that multiple lights required more time to process the information.

In addition, the video material of the search process backs this up. Multiple Participants first look for a few seconds when they have to search with the help of concepts 2 and 3. Numerous participants also stated after the test that they could imagine more than one light being difficult to follow when sows are moving between sections by quotes such as: *“Ik vind did concept goed werken in deze opstelling, maar ik zou me voor kunnen stellen dat dit lastiger wordt wanneer een zeug loopt tussen de secties*” [I see this concept working in this test situation, but it can imagine this being confusing when a sow moves through the pen between sections.]. These results conclude that adding more lights to the pen could not be justified; therefore, only one light would be enough to guide the user more efficiently to the sow than without the light. The influence of the order on the test results can be considered negligible since the test order was determined by a Latin Square in combination with an analysis of the average search times per run in the layout. The average search time of the run did not decrease when the participant went through the layout before.

Even though the total of four lights could not be justified as presented in the study, the set-up provided some interesting findings regarding the four lights of concept 3. Participants noted that the blinking of concept 3 gave some sense of urgency to finding the correct sow and drawing attention. This shows from a participant quoting from the questionnaire: “*I liked the attention it drew by blinking, it catched my eye at first”* and *“Blinking lights have a higher sense of urgency and attention.”*. Next to this, concept 3 confined the search area to half of the other concepts, which participants perceived as beneficial. This was the main critical point made by participants on concepts 1 and 2, the relatively large search area, which made the participant go through more sows before finding the correct one.

5.7 Conclusion

The second user test concludes that guidance by using one light in the middle of the section is enough to guide users to the correct section. Four corner lights caused a significantly longer search time, presumably mainly due to the necessity to consider four lights every time a user wants to confirm that the right section is indicated. When the search area is smaller, the time to find a sow is decreased in the tested population, in a physically similar but simulated environment at first time use but not by a significant amount compared to only one light which proved to be enough to find the correct animal quickly. The questionnaire showed that blinking lights grabbed the users' attention and even made them overlook other lights which indicated the correct section.

DISCOVER

DEFINE

DEVELOP

DELIVER

6 Deliver

The final chapter, *Deliver,* will go into the findings and describe the study's outcomes and how to interpret them.

6.1 Guidelines

The findings of the research done in this thesis form a set of guidelines for a guidance system in a pig barn. The first guideline is to *avoid using multiple visual cues* in the guidance system. This would result in confusion in the user tests and presumably increase the search time. In addition, participants indicated that they did not like to check multiple lights when walking through the barn.

The second guideline is to use an interaction that does *not demand too much attention from the farmer*. This includes visual attention and cognitive attention. Since the environment is very dynamic with pigs walking in the way and moving unpredictably, ideally, the farmer should be able to observe the environment and the visual cue at the same time as much as possible. This guideline was not adhered to in the first user test, leading to difficulties in manoeuvring through the pen.

The third guideline follows from the second guideline. To adhere to the second guideline, the results point towards using *outside-in guidance*. This guidance is done by providing guidance instructions from the environment to the user. As a result, the user can focus on the environment for guidance cues while still being able to see and anticipate on the movement of the sows. This guideline is not absolute but should be considered as a trade-off. Outside-in guidance looks more favourable but is less scalable due to changes in infrastructure in the barn. Inside-out guidance based on a phone does only depend on the phone of a farmer which is more cost efficient but might results in distractions during navigation in a dynamic environment. This guideline comes from the first user test, where the outside-in guidance outperformed inside-out guidance.

The fourth guideline focuses on the type of guidance instructions. Since the structure of the barn consists of a walkway and a (dynamic) pen with the sows, the *farmer should be able to determine his own route* and therefore decide where he wants to enter the pen. This can be accomplished by showing the target location in one glance. Since the user is familiar with the environment, they know how to find their way and get to the target location by the fastest route.

6.2 Possible future study

The second and last user test resulted in a set of guidelines that are useful for a third user test. A third user test can address another variation on pig barn guidance which builds upon the results of the earlier user tests. The second user test concluded that the visual cues should be minimized and that reducing the section to half of the area resulted in a constant shorter search time, even though this reduction was not proven to be significant, presumably because of the processing time of the setup. A new test setup can combine these findings into a new concept.

6.2.1 Setup

A new concept should be as precise as half the area of the whole section while reducing the visual cue to only one. This can be accomplished by indicating half of the section with one light, as figure 47 shows. The indication lights can be the same as the remote-controlled lights from the first and second user test and hang them in the configuration as depicted in figure 47

The same layout of figure 41 can function as a test environment, and the same test method of the second user test can be used to determine the effectiveness and efficiency of the guidance method and compare it to the centre light and the two blinking corner lights.

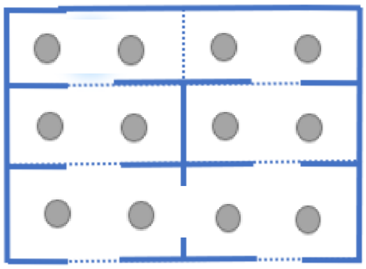

Figure 47 future test setup

6.2.2 Hypothesis

The setup nicely fits in the mental model of the user of the first user test, which figure 37b shows, where the user interpreted the light indication as if it was indicating half of the section while the designers' intention was to indicate the whole section. This ambiguity is also the potential weak point of the design since users could find the sections unclear or not logical. A strong suit of this future concept is that the costs are significantly reduced by circumventing the need for moving the lights in the barn. Chapter 6.3.4 will elaborate on the financial component. The expectancy is that this concept will result in shorter search times and that participants will like the simplicity of using only one light. If these hypotheses translate to the actual perception of participants will become apparent after performing the user test.

6.3 Implementation

The guidelines for a guidance system in a pig barn form a theoretical basis for a practical application of the system. For a possible implementation of the product, the market group Lighting controls provided information on the possibilities of their smart lighting system. The Lighting controls market group is specialized in UV-disinfection light and implementing IoT functionalities in lighting fixtures in an industrial environment by the Luxon ecosystem. They provide IoT lighting solutions, such as warehouses and enormous shopping centres, to efficiently manage their indoor and outdoor lighting.

6.3.1 Components

Lighting Controls adds IoT functionalities to lighting fixtures by adding Luxon IoT nodes to (existing) light fixtures. Figure 48 shows two of these nodes.

Figure 48 Luxon IoT nodes

These nodes can be implemented with any ordinary light source resulting in a smart working light capable of IoT functionality. Multiple lights can be controlled wirelessly by one single Luxon control box in the barn capable of controlling up to 500 light sources. It might be possible to program the software of the Luxon controller on a control box that manages the current technology in the barn related to the livestock; however, this is not tested yet.

Every node attached to a light source acts as a repeater of the signal from the control box, which forms a mesh configuration of the lights. The advantage of this mesh configuration is that the total system only needs one control unit to control all the lights in the barn. The light sources should withstand the barn's dusty conditions and therefore require an IP rating of IP65 to avoid dust entering the unit and damaging it. An advantage of modern barns such as the US farm in figure 18 is that there are already suitable light fixtures in the barn. The control box can virtually link the light fixtures to sections to turn on the right light.

6.3.2 Process

Figure 49 shows the complete searching process. The farmer initiates the process by selecting a sow in the Velos app and tapping the localization button.

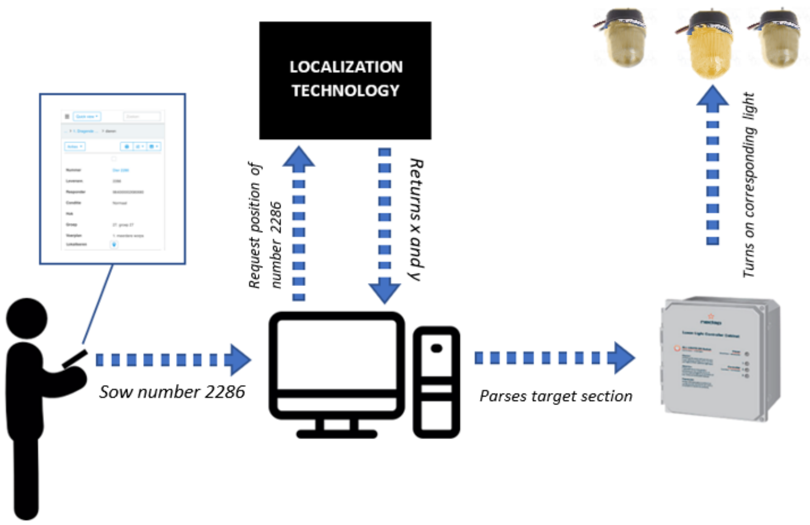

Figure 49 Workflow of the system

This action sends a request with the ID of the sow to the server at Nedap. The server will request an *x* and *y* position of the sow in the barn from the localization system. Depending on the localization technology, the position of the sow can be expressed in terms of *x* and *y* or expressed as a section ID. The localization technology is, for now, a black box, but it can be any technology that tracks the position of the sow. The *x* and *y* positions are returned to the server, which converts this position to a section ID in the barn. The Luxon controller cabinet is connected to the internet, meaning it can communicate with the server of Nedap. The controller can be programmed in such a way that it can operate on conditional statements coming from the server and thus control the lights in the barn accordingly. Since the IoT nodes enable control of all the light sources, the options for section indication increase. The aim of section indication by using light sources is to let the user discern one relevant section from the rest. The user tests accomplish this by turning on a separate (coloured) light above the relevant section to stand out against the other sections. Since the IoT nodes can control all the light sources in the barn, the same effect can be accomplished by dimming the irrelevant sections while leaving the light above the relevant section unchanged. This changes the idea from turning on a light of one section, to dimming the lights in all the other sections. This leads to a situation, as figure 51 shows, where the relevant centre light remains unchanged while the other lights dim to a lower intensity. This landmark indication violates the property of Heidorn & Hirtle

Figure 51 Visualization of center light

(1993) namely that a landmark should be independent of the environment. If this poses a real issue should be studied in the future. Figure 50 visualizes the indication of a subsection in the case this

Figure 50 Visualization subsection light

proves to be equally efficient and effective as the centre light indication.

To terminate the guidance instructions, it depends on the localization software. When we use AI in combination with video data, the system can track the farmer and check when it has reached the desired location and turn on the lights again to normal brightness. Another possibility is that the farmer manually indicates on the phone that he found the pig by tapping a button.

6.3.3 Potential side effects for sows

A farmer tries to control the environmental factors in the barn as much as possible to ensure the optimal well-being of his livestock. Environmental factors also include the light on which the guidance is based. The system should be as unobtrusive for the sows as possible to not interfere with the optimal environmental conditions. Baldwin and Start (1985) conclude in their research on illumination preferences of pigs that when pigs can control the lighting in the environment, they prefer dim light over bright light. This preference suggests that pigs would not suffer from dimming the light in the environment to a lower level for a short time. In the same study, the authors also tested if the sows experienced the stimulus change from light to dark as rewarding. This was not the case since pigs were not motivated to activate the luminance change by passing the IR beam. Therefore, the stimulus of light change of the system, as described in chapter 6.3.2, cannot be proven to be rewarding for the pigs, nor can it be said that the change of light is experienced as unpleasant, according to the study by Baldwin and Start (1985). In addition to this, Zonderland et al. (2008) studied the effect of light intensity on the visual acuity of pigs in a controlled environment where pigs had to discern and choose the correct symbol on a picture. The study concluded that decreasing the light intensity of the environment did not significantly reduce the sows' acuity; instead, the size of the image mainly had a significant influence on the acuity of the sows. In the context of this thesis, this means that decreasing the lights for a few minutes might not influence the acuity of the sows in the barn.

Since the lighting in the pig barn is explicitly controlled to adapt to the day and night cycle of the sows, it is crucial to avoid any disturbance in this cycle. Tast et al. (2001) studied the relation between the illumination level expressed in lx (lumen) and the melatonin (sleep hormone) concentration in the blood of sows. Their study concluded that the luminance must be lower than 1 lx to activate the melatonin levels related to the scotophase (dark phase of the light-dark cycle). To influence the melatonin concentration, the luminance should be higher than 40 lx with the addition that higher luminance does not significantly affect the melatonin concentration in the blood. What this means for this thesis is that the light level during the day should not decrease below 40 lx for a long period of time to avoid influencing the day-night cycle of the sows. As a result, this could impact the discernibility of the relevant section light for the farmer. This could potentially be solved by using color to make the relevant section stand out. This would require the light sources to switch color which will add some complexity to the system. The effectivity and discernibility of different colors of light in this context is yet to be studied.

When the visibility proves problematic, the lights can draw attention by, for example, blinking or flashing. As Laxar & Benoit (1995) proved in their study on using flashing lights during navigation, flashing lights draw significantly more attention than solid lights. Even though the context of their research differs, namely marine navigation, the findings will still translate to a large extent to other contexts. In addition to this, participants of the second user test also indicated that the blinking lights drew attention in the test setup, as discussed in chapter 5.6.9. Because blinking lights draw more attention, the potential for the blinking lights to influence the sows is also higher. The influence of blinking lights on the sows should be minimized as much as possible. Hutson et al. (2000) studied the effect of multiple stimuli, including flashing lights, on pigs. These stimuli were visual, audible, olfactory, and tactile. The authors observed measurable adverse effects with only two visual stimuli involving a standing cross and a rotating cross, but not with the blinking light. This suggests that a blinking light source does not adversely influence sows. However, further research is needed to verify whether discernibility is an issue.

6.3.4 Cost

The total cost of the implementation varies depending on the extra features and size of the barn. This cost estimation is based on the barn in the US since this barn is representative of many modern large farms. As figure 18 shows, the light fixtures are not located in the exact centre of a section which was the case in the second user test. An electrician needs to shift the lights approximately a meter to translate the outcomes of the second user test directly to real life. An electrician's hourly rate in de US ranges between 35 to 75 dollars per hour.[9] Relocating a light fixture does not require much time since the wiring is already in place. Nedap Lighting estimated that an electrician could relocate three lights in two hours. The barn in the US consists of 120 lights, of which half of them should be relocated. Relocating lights would take an electrician 40 hours, resulting in an average cost of 2400 dollars.

[9] https://www.costowl.com/home-improvement/electrician/electric-fixtures-cost/

Additionally, all lights in the barn connect to a Luxon IoT node which costs 25 dollars per node which adds up to 3000 dollars in total for the nodes. The last component is the Luxon control box which costs 1500 dollars. The total cost of the system results in an estimate of 8700 dollars. This estimate is based on the ideal situation where half of the lights are moved to the centre of a section where the other lights dim when a farmer must find a sow. Table 3 shows the total cost estimation.

Table 3 Total price of center lights

Component	Price per unit	Quantity	Total price
Relocating lights	60	40	2400
Luxon IoT node	120	25	3000
Connecting nodes	60	20	1200
Luxon Control Box	1500	1	1500
Total			8100

As discussed in chapter 6.2, there could be potential in subsection division with one light as an indicator to show the relevant subsection of the location of the sow. Suppose the future study concludes that one centre light is not significantly better than one light indicating subsections. In that case, it is more economical not to move any lights and use subsection indication. This reduces the cost of the system to 4100 dollars. This thesis did not study the effectiveness and efficiency of this type of guidance but may be a consideration to reduce expenses. Table 4 shows the cost estimation of the total system when the lights do not have to be moved.

Table 4 Total price of subdivision light

Component	Price per unit	Quantity	Total price
Luxon IoT node	120	25	3000
Connecting nodes	60	40	2400
Luxon Control Box	1500	1	1500
Total			6900

6.4 Discussion

This chapter will discuss the findings found throughout the thesis. It will go into what the results imply, what they mean for the field, what was surprising, the goal reached as described in the introduction, what worked and what did not work, limitations, and future work.

6.4.1 Validity

The first user test aimed to compare two prototypes in a real user environment to study what method of interaction has the highest potential for a working guidance tool and therefore determine what the second user test should be based on. The first user test took place on a Dutch farm with one farmer, and thus the validity is decreased. In the ideal scenario, multiple farmers tested the prototypes on numerous farms. However, even though the first user test only included one user, it gave a good idea of which interaction has the highest potential.

The second user test builds upon the first user test and tests three guidance concepts using light. Participants tested the concepts in a test setup that reflected the actual environment as accurately as possible. Twenty-four employees of Nedap in the office building volunteered to participate in the user test. Based on the number of participants in the test, it is not unlikely that the results of this test would be similar when one replicated it or when more participants were recruited. The actual search times will not directly translate to the real environment since this test setup is only a fraction of a real pen. However, the goal of the user test was to determine the relative performance of the concepts. The user test tested the concepts in the same environment with enough participants to confidently perform a statistical analysis which means that the test is considered valid.

6.4.2 Interpretations

The thesis will discuss the results of the overall thesis and whether they are in accordance with assumptions made before the thesis. The first user test made clear that the user did not prefer inside-out As The Crow Flies (ACTF) guidance over the outside-in guidance with the direct light. The ACTF+ guidance required the user to start in the pen and walk through the pen among the sows, following the arrow. The user indicated this was not ideal since he wanted to see the end goal to determine his own path. This is in line with the study of Chung et al. (2016), which found that users prefer to decide on their own path when walking in a known environment. The user test shows that the advantages of ATCF guidance do not translate to all contexts, such as the dynamic barn environment. This is presumably mainly due to the barn's structure since the barn has very distinctive walking areas: A walking area in the pen, where the pigs reside, and a walkway on the side of the pen, free of obstacles. Because of this difference in walking paths, the farmer has a preference in the route he takes, which is difficult when the exact location remains uncertain until the farmer reaches the target location. The direct light indication, however, does enable the farmer to see the end location and can therefore determine when he leaves the walkway and enters the pen. Additionally, the light source indication adheres to the requirements of Heidorn & Hirtle (1993) being clear and independent of the environment. This immediately shows the sow's location and allows the user to determine his route.

After the first user test we performed a second user test which studied how to improve the light source guidance by testing multiple concepts of representations of the confined section in which the sow is located. Two of these concepts represented a whole section, and one represented half of the section. For two concepts, four lights indicated the right section or part of the section. We expected that the halved section would have the shortest search time since this included a smaller search area, and therefore fewer sows must be checked. In addition to this, we expected that the four lights would give a clearer idea of the section, and consequently, the participants would perceive it as clearer. As expected, the half section's search time was consistently shorter than the other two concepts but not significantly shorter than only one light in the centre of a section. This was against the expectations. We expected the search time to be considerably shorter, but since participants had to consider more, participants stopped and looked for a moment and observed where they had to go. This was also the case in the four corner lights, resulting in a higher search time. An important notion to this interpretation is that we observed this with users who used the concepts for the first time. We expect this time to reduce as the experience grows. People who did not observe prior to entering the layout also missed the additional two lights and therefore walked straight to the blinking section since this was the visual cue that stood out. Laxar & Benoit (1995) confirm this observation by concluding that blinking lights are more noticeable than solid lights, which may have caused participants to overlook the other two solid lights.

6.4.3 Implications

Researchers have already done extensive studies in the field of guidance and navigation. However, research in the field of guidance and navigation on farms was yet to be explored. This thesis fills in the gap in this field. This is needed since nowadays, farmers or their employees can spend a long time finding pigs. The system, as proposed in this thesis, potentially reduces this search time. Even though, on small farms, the search time may not decrease significantly; in large barns in, for example, the US, the system can drastically reduce the search time. This may not be directly visible in search times for individual sows, but when considering that employees are sometimes burdened all day with finding pigs, this decrease adds up significantly. This thesis provides a solution that decreases the search time in pig barns by incorporating light sources in the barn, confining the search area to a fraction of the original search area.

Suppose the results of this research are not incorporated in the future. In that case, the searching process of a pig will remain unchanged and thus will result in unnecessary expenses and time spent to find sows. In addition, the farmer will take longer to find an animal that is in potential need of attention. This would not be favourable for any farmer who aims to improve his livestock's efficiency and wellbeing.

6.4.4 Limitations

The research done in this thesis does not come without limitations. The generalizability of this study is limited in the way some concepts were tested and by the limited nature of only one field visit. The field visit was done at a local Dutch farm. This scopes the experience to only this Dutch farm. The farm in the US is different in its environment in terms of scale and light, as was shown by pictures and videos. In the US farm, the light appeared to be brighter with the use of more artificial lighting. Even though the environment was visible on a screen, the impression on the foreign farm will never be as extensive as on the Dutch farm since the environment of the US farm was only visually perceived instead of experienced. The second user test did not have the full size of a barn. This is justified by the fact that the concepts were based on the structure and layout of a pig barn which is generalizable among most group housing layouts for pig barns. The environment of the test set-up reflected the actual environment as accurately as possible. Still, it is inescapable that the experience of the office building is different than a pig barn. Furthermore, it should be noted that the concepts were tested with employees of Nedap, which may not be representable for the target group. On the other hand, this is partially justified by the fact that the participants were not entirely unrelated to the topic since the employees have a lot of experience with pig farmers and their work environment.

6.4.5 Recommendations

The limitations of the previous chapter leave room for recommendations for further studies to fill in the limitations and shortcomings of this thesis. Future studies should study the effect of regular use on the search time. We expect that the processing time decreases for the corner lights when the farmer uses the concept more often. However, there are still more lights to consider compared to the centre light, which participants stated was unfavourable.

This thesis shows that the number of visual cues should be minimized to convey the information as effectively and efficiently as possible. One light can already effectively guide the farmer to the correct section. For more precise guidance, further research could study how the subsection can be indicated by one light only, providing more precision with fewer additional visual cues.

Further research is needed to study the practical generalizable implementation of lights for section indication. This could include a field test in real and diverse environments such as larger farms in the US or a large European farm. Further studies should include real users who work on the farm to see how the concept would work on a day-to-day basis in the farmer's workflow in the actual environment.

6.5 Conclusion

This thesis aims at answering the main research question: *What tool can be designed to guide a farmer to a pig in the barn?* The research initiated with a literature study with the sub-questions on what the mental model looks like when navigating, what is the best form of navigation, and what interaction methods are already used in other contexts. The literature study concluded that transforming and translating the position of the target location to the current location requires the most time and cognitive demand. Therefore, the most promising form of navigation resulted in outside-in guidance since this does not depend on the user's perspective; thus, transforming a representation is unnecessary. Other contexts employed outside-in guidance in the form of projected AR, which had the highest potential after the literature study. After the field visit, this solution was rejected due to the structure and environmental conditions in the barn.

Based on a real user test and subsequent follow-up quantitative and qualitative user tests with employees of Nedap in a simulated barn setting, this thesis concludes that light sources placed in the barn can effectively and efficiently guide a farmer to the correct section in the barn. If these results generalize, pig farmers can manage their livestock more efficiently and economically since the process of finding pigs will be significantly shorter compared to the current situation. This will result in a quicker response time for a pig needing attention and a more efficient workflow for the farmer, which is beneficial for farmer and pig. This research suggests adding light controls above sections in the pen to confine the search area of the farmer. This confines the search area, which reduces the search time significantly. This study shows that section indication can be done by one light in the centre of the relevant section. Alternatives, other applications of light, or combinations of interaction methods are yet to be investigated.

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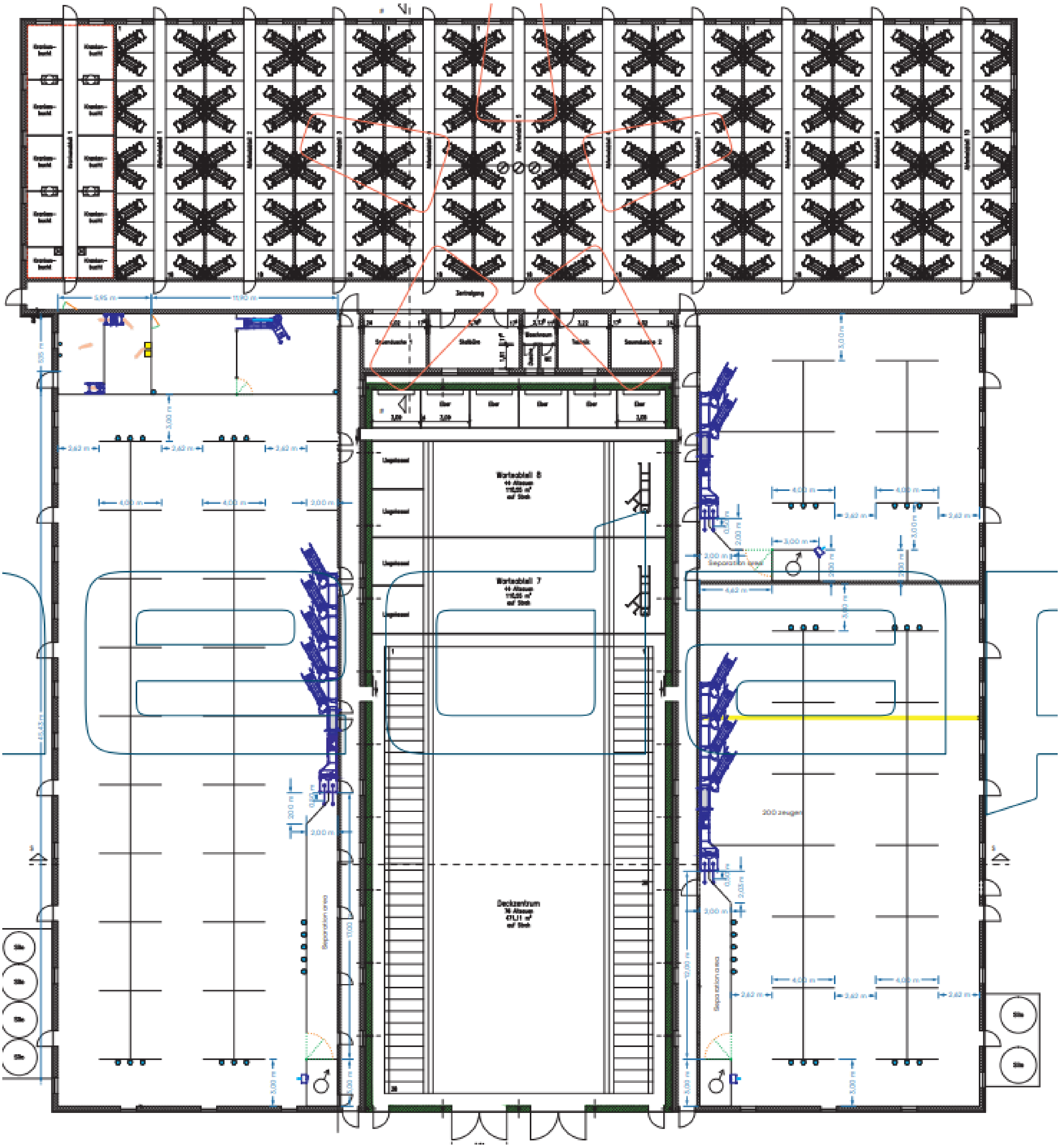
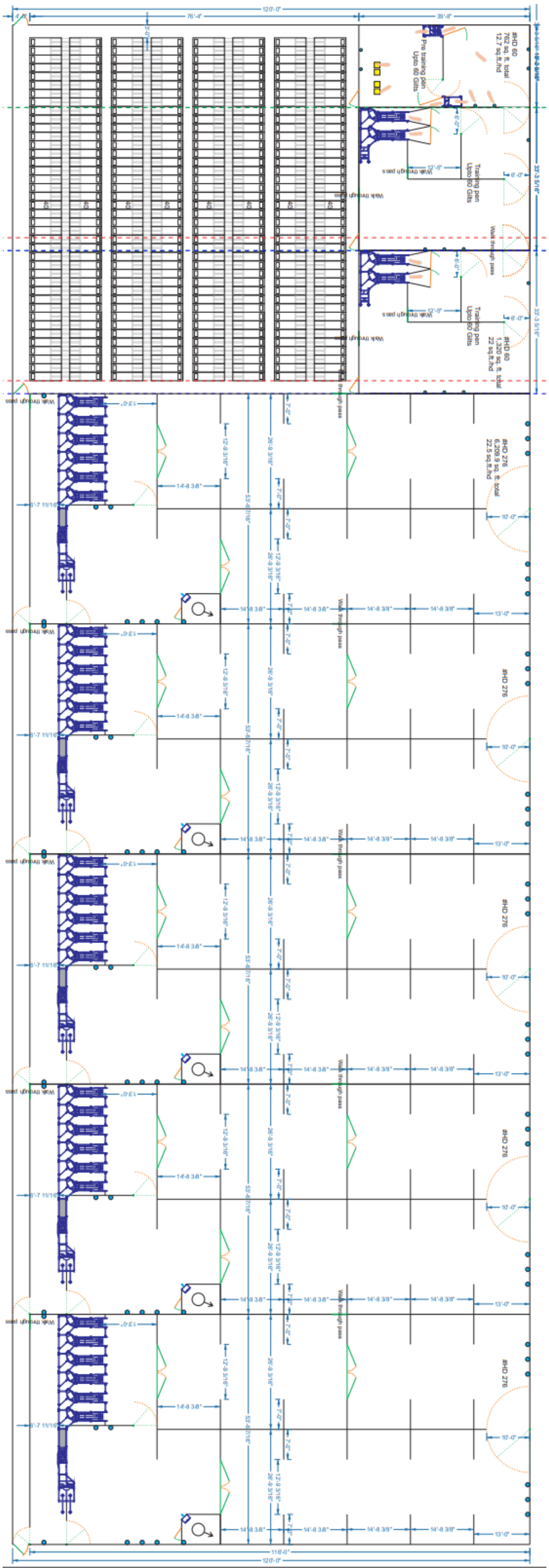
8 Appendices

8.1 Example of barn layout in a European pig farm



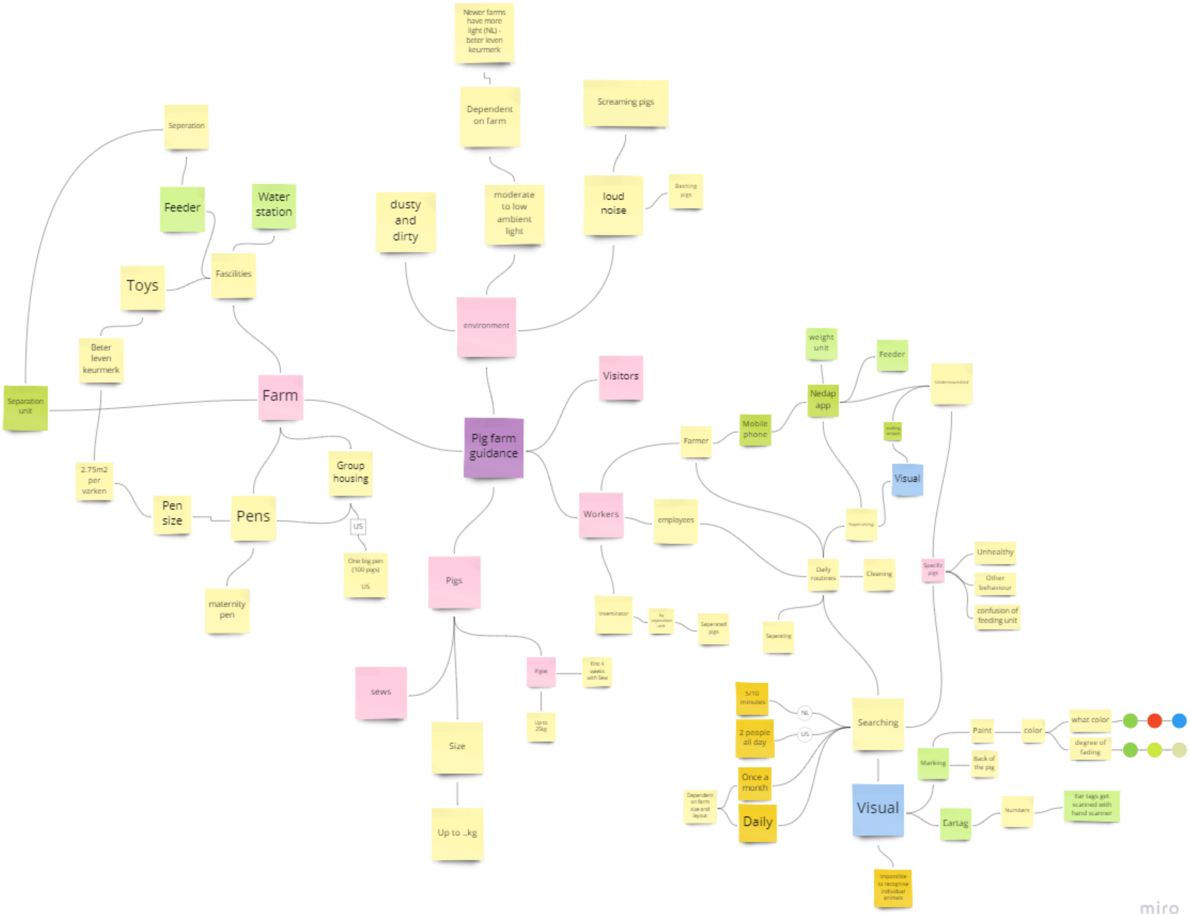
8.2 Lay out of a farm in the US



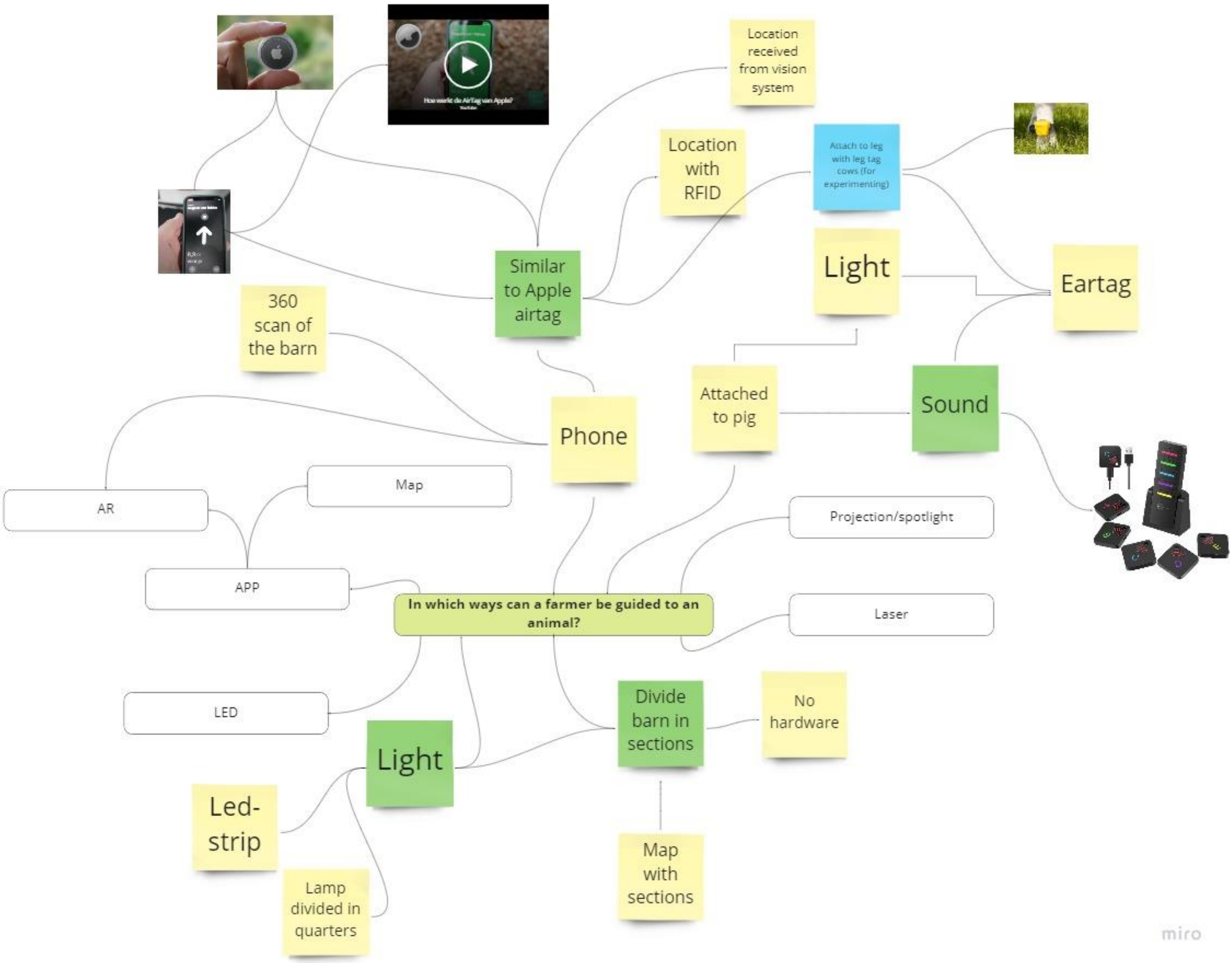
8.3 Interview questions

Staff:	
How many people are employed at the barn?	Farmer is mainly working alone in the barn. However, multiple external people can come in the barn such as an inseminator who comes inside the barn once a week to inseminate the sews which are in the separation pen.
How many people are working in the barn at the same time?	The farmer is almost always working alone in the barn. When farmer wants to expand his business, he probably hires people to help him manage the pigs in the farm.
Can a situation occur in that multiple people have to do something with one single pig?	No this situation does not occur as of the current situation since the farmer is doing all the work by himself.
How do you currently find a pig?	Currently, most of the time, the farmer needs to find a pig in the pen where the younger sews are located. It can happen that these sews are not eating enough because they do not understand the feeding system enough. The younger sews are sprayed with a color marker on the back so that the farmer can visually keep an eye on these individual pigs. When the farmer must find a certain pig, he currently walks through the barn and checks the numbers of the pigs individually.
Do the employees often walk around with equipment/tools in their hands?	Mechanical tools are mostly not carried around when walking through the barn. The tool which is used a lot during walking is the phone of the farmer.
The barn:	
What is the size of a pen?	The size depends on the amount of pigs which are in the pen. In the case of the interviewed farmer 2.75 m^2 per sew
Is this size standardized?	This size is standardized for the “label” that the famer has. The farmer which was interviewed has a “Beter Leven” label which requires pigs to have a pen where each pig has at least 2.75 m^2 of space. The more pigs there are in the pen, the more lenient this number becomes. (This is because it is not uncommon that all pigs gather on one side of the pen, which leaves a lot of open space on the other end of the pen.
How many pigs are in the pen?	40
Can something be easily mounted to the ceiling?	Mounting something to the ceiling will not be ideal since the ceiling consists mostly of insulation panels which will be difficult to mount something to. However, there is a possibility for a rail above the pen since there are already iron tubes and other mounting points above the pen.
What technology is currently present in the barn?	The most prominent piece of technology present in the farm is the weighing system and the separation pen. These are all coupled to the Nedap system which is coupled with an app which stores and displays information of all the pigs.

8.4 Mind map of use case



8.5 Mind Map of brainstorm



8.6 Consent form first user test

Consent Form for *Pig farm navigation*

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 6/3/2022, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves carrying out a certain task, in the case of this study, finding a pig. Findings will be documented by written notes of the researcher.	○	○
I understand that there is a small additional risk of transmitting viruses by having additional people in the barn.	○	○
Use of the information in the study		
I understand that information I provide will be used for a Master Thesis on pig navigation.	○	○
(Consult information letter for elaborate explanation)		
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	○	○
I consent that there will be sensor bands attached to my pigs	○	○
Optional:		
I agree to be audio/video recorded. Yes/no	○	○
I agree that quotes during this research can be used in the study	○	○

_______________________ _______________________ _________

Name of participant

Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Ale Blauw

__________________________ ____________________ _________

Researcher name Signature Date

8.7 System Usability Scale (SUS)

Satisfaction analysis

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently.	○	○	○	○	○
2. I found the system unnecessarily complex.	○	○	○	○	○
3. I thought the system was easy to use.	○	○	○	○	○
4. I think that I need technical support while using the system	○	○	○	○	○
5. I think the system would be well integrated	○	○	○	○	○
6. I think that there is too much inconsistency in the system	○	○	○	○	○
7. I would imagine that most people would learn this system quickly.	○	○	○	○	○
8. I found the system cumbersome to use	○	○	○	○	○
9. I felt confident with the system	○	○	○	○	○
10. I needed to learn a lot before I could get going with the system.	○	○	○	○	○

8.8 Mind map: section indication with light

8.9 Consent form second user test

Consent Form for *Pig farm navigation*

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated ../5/2022, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves carrying out a certain task, in the case of this study, walk to the correct section in the set-up. Findings will be documented by written notes of the researcher.	○	○
Use of the information in the study		
I understand that information I provide will be used for a Master Thesis on pig navigation.	○	○
(Consult information letter for elaborate explanation)		
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	○	○
Optional:		
I agree to be audio/video recorded. Yes/no	○	○
I agree that quotes during this research can be used in the study	○	○

________________________ ________________________ _________

Name of participant

Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Ale Blauw

___________________________ _____________________ _________

Researcher name Signature Date

8.10 Frequency of comments on the concepts

Concepts		Group	frequency
1	Positive	Quickly visible	6
		Clear/easy/no interpretation needed	13
		Gets your attention	3
	Negative	not precise	11
		empty	7
		vague	2
		Could take long to find animal	2
		High up, difficult to see	2
2	Positive	Clear section	9
		clear/simple/effective	9
		Quickly clear where to go	4
		invalid reponse	1
		Did not have to look up	1
	Negative	Not precise	9
		Considering more lamps	6
		Took a while to interpret concept	2
		empty	6
		Low in field of view	1
3	Positive	More precise	8
		Clear/easy	5
		Quickly clear	6
		effective	3
		Sense of urgency	2
	Negative	precision	1
		Unclear	4
		Did not notice all the lights	4
		irritating	1
		Multiple lights/more information	2
		empty	12