Concept Development of Network Display Speaker

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MASTER THESIS

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Abstract

Network Display speakers are used as public address (PA) systems as security devices for effective communication of messages. [1] Lately, one of the industry leading companies within IP network product systems, from here on called “the company” launched their own take on this. This thesis aimed at developing a new display speaker in collaboration with them, focusing on sustainability, user feedback and new features.

The project followed a Double Diamond design process. It started its research by conducting interviews with relevant stakeholders regarding the current product. The data gathered was analyzed and compiled into a technical specification, to act as a basis for the iterative development phase. Development of the new solution was divided into smaller segments that focused on one problem area at a time. Those areas were: Mesh attachment, Display attachment, Sealing, Form & Layout and speaker drivers. Lastly, solutions generated were evaluated and a final concept was chosen and made into a prototype.

The final concept resulted in a portrait-oriented box with two speaker drivers and larger display. The products strobe was located at the top corners, together with a light indicator. At the bottom, a sunken motion detector was set to aid a potential impact protection (IK) rating test. Within the product, printed circuit boards (PCBs) were reduced to three. The inside consisted of two separate chambers, one for audio and one for electrical components, with a seal between them made of compressed silicone. Each chamber was sealed by their respective front-plate, which exploited a radial seal.

Keywords: Product development, network loudspeakers, concept development, display speakers, industrial design

Sammanfattning

Nätverkshögtalare med tillhörande skärm används i publika adresserings system som en säkerhetsprodukt för tydlig kommunikation av meddelanden. [1] För ett tag sedan släppte ett av de industriledande företagen inom IP nätverks produkter, vidare benämt som ”företaget”, egna tolkning av det. Detta examensarbete syftar på att utveckla en ny skärm- och nätverkshögtalare i samarbete med dem, som fokuserar på hållbarhet, användares återkoppling och nya funktioner.

Projektet följde Double Diamond design processen. Det startade sin undersökning med att intervjua relevanta intressanter kring produkten. Datan som insamlades blev analyserad och sammanställd i en teknisk specifikation, för att verka som grund för den iterativa utvecklingsfasen. Utvecklingen av den nya lösningen blev uppdelad i mindre delar som fokuserade på ett problem i taget. De problemen var: Meshfästen, Skärmfästen, Tätningar, Form och Layout och Högtalarelement. Slutligen blev genererade lösningar utvärderade och ett slutgiltligt concept blev valt och gjord till prototyp.

Det slutgiltliga concepten resulterade i en porträttsorienterad låda med två högtalarelement och större skärm. Produktens stroboskop blev placerad i de övre hörnen tillsammans med en ljus-indikator. I nedre delen sattes en nedsjunken rörelse-sensor för att hjälpa potentiella IK tester. Inuti produkten reducerades antal PCB till tre stycken. Insidan bestod av två separata kammare, en för ljud och en för elektriska komponenter, med en tätning mellan de gjort av komprimerad silikon. Varje kammare var förseglad med deras respektive framstycke, som utnyttjade en radial tätning.

Nyckelord: Produktutveckling, Nätverkshögtalare, Konceptutveckling, Skärm högtalare, industri design

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First and foremost, we would like to give our sincerest gratitude to everyone at the company for supporting this project. Without their help and kindness this project wouldn’t have been possible. To all who participated in interviews, who answered our questions and always made us feel welcome, thank you.

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Ella Björklund and Linus Högblom

Table of contents

List of acronyms and abbreviations

US	United States
LCD	liquid crystal display
LED	light emitting diode
PCBA	printed circuit board assembly
PCB	printed circuit board
PIR	passive infrared
IR	infrared
IK	impact protection
IP	ingress protection
ALS	assistive listening systems
PoE	power over ethernet
IEEE	institute of electrical and electronics engineers
PA	public address
CAD	computer aided design
SD	secure digital
3D	three dimensional
DFM	design for manufacturing
UX	user experience
QA	quality assurance
DFP	design for production
TBI	to be implemented
HDPE	high density polyethylene
FOV	field of view
USB	universal serial bus
SPL	sound pressure level

1 Introduction

In the introduction, background knowledge needed to understand the problem is presented together with further information regarding the company and aim of the project. It also presents the structure of the thesis as well as its limitations.

1.1 Background

Network Display speakers can be used in the education system in the United States (US) for visual and auditorial communication. They consist of a combination of speakers, digital display and strobe light to effectively grab attention and forward messages. They are compliant with larger network systems and can alert warnings as well as other devices within the system. With their built-in microphone, they have access to two-way communication, enabling talkback functions. [1]

This type of communication is vital for the educational system, as it plays a central role for everyday happenings such as the bell ringing, student announcements, notifications and alerting emergencies. It provides safer and more effective use of audio for mass communication than analog solutions. [2]

1.2 The Company

This thesis was written in collaboration with an international company that specializes in video surveillance and safety network systems, they will here on forth be referred to as “the company”. Moreover, they also offer solutions in intercom, access control, audio systems and more. The company has since its founding grown into a global industry-leading corporation with thousands of employes.

One of their departments specializes in developing new audio products for the company’s portfolio. The devices are mainly for public address, security and safety usage but can handle background music as well.

1.3 Project description

The product which this thesis builds upon was launched within the recent years by the company and will forth be referred to as "the product" and "current product". It provides features such as combined speaker, display, strobe, two-way audio, remote health monitoring, content prioritization, audio zoning and scale/integration freedom. A schematic image of the product can be seen in Figure 1.

Figure 1 Schematic image of the company's network display speaker

The aim of the thesis is to come up with a new concept for the wall speaker, addressing its current problems and explore improvements. The concept will focus on the product as a whole and will thereby not delve into details, but broader scopes such as

- Sustainability
- Classification
- Ease of manufacturing
- Customer feedback
- Inclusive design
- New features

It is decided that the project will have a large creative freedom and constraints such as regulations from manufactures, standards, and other more detailed oriented requirements will not be focused on in this thesis, due to the limited time. More important will be innovation, aesthetics, and implementation of new functions to improve the already existing product.

1.4 Limitations

Even though it is established that many requirements and regulations will be overlooked in this project, there are still several constraints to consider. The prototyping and testing of new concepts will take place at the company's labs and facilities, meaning they will go under their guidelines. Furthermore, the needs of the stakeholders will act as a primary source when making decisions, and their opinions will be taken into consideration. Constraints on prototyping will also be apparent in the form of limitations of which speaker drivers and cones available at the company. From a sales perspective, the new concept will have to uphold the same functionally or better as the current product.

1.5 Thesis outline

This thesis is based on a scientific report structure and will cover theory, methodology, development steps, results, discussion and conclusion. Each section has its own subsections based on chosen methodology and relevant findings.

2 Framework

The framework is presented in terms of further knowledge about loudspeaker design and other necessary information about the current product.

2.1 Theory

2.1.1 Speaker drivers

A speaker driver converts electrical signals into vibrations by moving a cone-shaped diaphragm back and forth, creating air waves that ears can interpret as sound. A coaxial speaker driver can be seen below in Figure 2.

Figure 2 A co-axial speaker driver

The driver contains several components namely

- Diaphragm (Cone/Dust cap)
- Voice coil
- Magnet
- Spider
- Basket
- Enclosure

As stated above, the diaphragm moves back and forth to change air pressure and create waves. The voice coil is a copper thread wired around the magnet to create an electromagnet. An electric current passes through the wire which creates the magnetic field needed. The spider refers to the structure which enables movement of the cone. The basket is what holds everything in place and the enclosure refers to the reserved back volume the driver needs to improve sound quality and prevent interference. [3] These components together create what this thesis will refer to as a speaker driver.

Depending on how a driver is designed, it reproduces different ranges of frequencies. The typical hearing range for a human is between 20-20 000 Hz and can be categorized into low frequencies, mid frequencies and high frequencies. Drivers that handle low frequencies are commonly known as 'woofers', and for high frequencies 'tweeter'. For mid frequencies, it is called 'midrange'. In praxis, a combination of drivers is preferred as they together can cover a larger range of frequencies. Moreover, characteristics for the different drivers are that woofers usually have a larger diaphragm and tweeters smaller. [4]

2.1.2 Liquid Crystal Display

A liquid crystal display (LCD) is a type of display commonly used today. The display type offers the aspects of high energy efficiency, compact form factor and low weight. [5] The LCD contains 4 different types of layers; the liquid crystal, polarizers, electrodes and backlight. See Figure 3 for schematic image of the layers of an LCD.

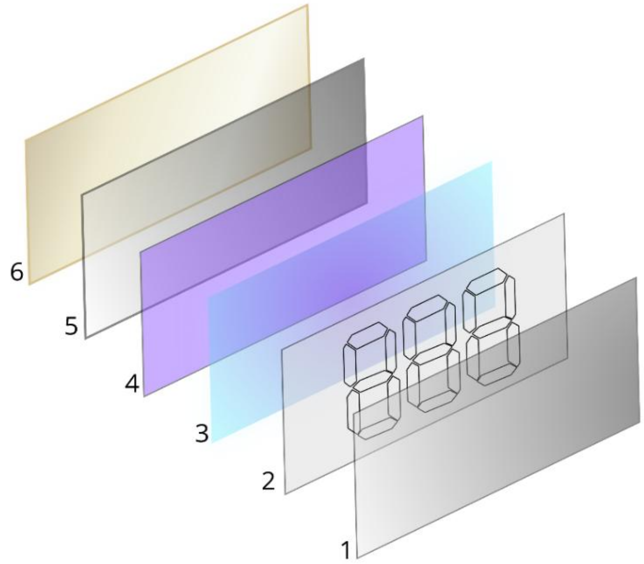

Figure 3 Layers of an LCD numbered from 1-6. Created on canva.com.

The liquid crystal layer (3) is in a state of matter between liquid and solid, it behaves like a liquid but its molecules show properties of a crystal with naturally arranged structures resembling latices. [6] As a result of its lattice structure, light is twisted when passing through the material, giving the liquid crystal optical properties. In the presence of an electric field, the orientation of the liquid crystals changes in accordance with how much the light is twisted. [7]

The liquid crystal layer is contained between two glass planes (2) & (4). Electrodes located on these glass planes can be individually controlled and therefore apply an electric field to specific parts of the liquid crystal layer. The polarizing filters (1) & (5) are oriented with a 90° orientation difference, hindering the backlight (6) through them. [7]

The light emitted from the backlight first passes through the first polarization filter, the liquid crystal layer is electrically manipulated in specific areas to only rotate the lights plane of polarization on some areas of the display. When encountering the last polarization filter only the rotated light can pass through, creating images on the display.

2.1.3 Strobe

A light emitting diode (LED) is an electrical component that emits light when an electric current flows through the component's semiconductor. [8] In this thesis, a strobe will refer to many LEDs that together create a powerful light, that is usually in a blinking state to awake attention.

2.1.4 PCBA

A printed circuit board assembly (PCBA) consists of electrical components assembled on a printed circuit board (PCB). [9] The PCB is used to provide electrical connection between various electrical components in a circuit, it consists of multiple electrically conductive sheets, usually made of copper, stacked on top of each other with intermediate electrically insulating layers. On the conductive layers, multiple mutually isolated paths are created functioning as wires. The conductive paths on different layers can be connected though conductive material allowing paths to cross each other as well as be connected on different layers. [10]

2.1.5 Die cast aluminum

Die casting is a manufacturing method that involves pouring melted metal into a mold under high pressure. The mold is referred to as a die and can produce metal parts with high complexity. [11]

When designing aluminum parts for die cast, several guidelines should be considered. It is important for the part to have a draft angle, so it can be ejected from the die after cooling. A uniform wall thickness will aid the flow of the metal, as will filleted and rounded edges. The wall thickness should not be too thin and- or thick as this may also affect the quality of the cast part and overall should sharp edges and transitions be avoided.

As the part solidifies when cooling, shrinkage will occur, and room for this shrinkage should be considered when designing the part. If the part needs added strength, added ribs are favorable to a thicker wall thickness as they tend not to be as porous as the thicker walls. Regarding undercuts, is it best to avoid it entirely as it complicates the process. However, there are still ways to create undercuts such as added side cores and or special tools with the desired shape. [12]

2.1.6 PIR sensor

A passive infrared (PIR) sensor detects motions by measuring infrared (IR) light emitted by moving objects. When a warm object (e.g. human or animal) moves over the sensors field of sight, the temperature will increase. The change of temperature means a change of infrared light, which the sensor outputs as a change in the output voltage. [13]

Often used together with detection systems are Fresnel lenses, as they gather and focus light by replacing optical lenses with a plastic lens etched with concentric grooves. There exists a wide range of different Fresnel lenses, that comes with varied specifications. [14]

2.1.7 Impact protection (IK) rating

Impact protection rating originates from the international standard IEC62262 or its European equivalent EN62262 and measures a device's ability to withstand mechanical impact. The rating consists of a number between 00 and 10, where 10 have great resistance to impact and 00 no protection. Products with high IK rating are favorable in environments with higher risk of damage, such as schools, public areas, prisons etc. [15]

A products rating is decided from a test, where a certain amount of impact is created, measured in joule. To pass the IK04 for example, the device must endure an impact of 0.5 joule, which in the test is equivalent to dropping 0,25 kg mass from 200 mm. A higher IK rating requires higher impact. For an IK08 rating, this would mean 5 joules which is 1,7 kg from 300 mm. [15]

2.1.8 Ingress protection (IP) rating

Ingress protection refers to an electrical device's ability to resist liquids and dust. It stems from the standard IEC 60529 and consists of two numbers, one for liquids and one for dust. The first number, referring to dust protection, ranges from 0 to 6, where 0 is no protection and 6 is full dust ingress. The second number for liquids ranges from 0 to 9, where 9 is the strongest protection. A rating of 9 means that the device can be subjected to hot water from multiple angles at high pressure. [16]

2.1.9 Auracast

Aura cast is a wireless communication technology which is built on the Bluetooth wireless communication technology audio standard. Whereas traditional Bluetooth requires pairing between the transmitting host and the receiver, Auracast removes the required one to one pairing enabling one device to broadcast audio to many devices. The Auracast technology has two main use cases; broadcasting for audio sharing and broadcasting to Assistive Listening Systems (ALS). The latter is still in a development and standardization phase but will allow for broadcasting an audio feed to the hearing aid devices of people with hearing loss. [17]

2.1.10 Power over Ethernet (PoE)

Power over ethernet is a technology which allows direct current of low voltage to be transmitted over ethernet cables alongside data to both power and transmit information to a connected compatible device. To combine data and power in a cable, a network switch must be used, the network switch takes power in the form of alternating current which is transformed to a direct current and combines it with supplied data to a single Ethernet cable transmitting both.

There are many different standards and classes of PoE that define the maximum available power. The Institute of electrical and electronics engineers (IEEE) have defined 9 different power classes for PoE Specifications of these can be seen below in Table 1.

Table 1 IEEE PoE classes available power (data gathered from [18])

IEEE Class	*Available Power to Device*
0	0.44 - 12.95 W
1	0.44 - 3.84 W
2	3.84 - 6.49 W
3	6.49 - 12.95 W
4	25.5 W
5	40 W
6	51 W
7	62 W
8	71.3 W

2.2 Current solutions and competitors

2.2.1 Product description

In Figure 1, a schematic image of the product is shown. Its dimensions are 275x405x107 mm and it weighs 6,4 kg. It is mainly made of die-cast aluminum and contains a coaxial 8-inch speaker driver and an 8-inch display screen. It has a built-in microphone for two-way communication with full duplex and a PIR sensor for adjusting display settings. Furthermore, an LED strip with four colors is located beneath the display for signaling. The product is powered via PoE in class 6, providing a maximum power of 60 W. With the products, a wall mounting bracket is included. The bracket is from bent sheet metal out of steel.

2.2.2 Use case

The display speaker is used mainly in schools as a public address (PA) system. It is designed for grabbing attention and communicating important messages for indoor environments such as emergencies, lockdowns, bell sirens but also displaying the time and date. In case of emergencies, the talk back function enables calling for help. It is proposed to be mounted to the walls inside of classrooms next to the teachers in front of the class. [1]

2.2.3 Competitors

There currently exist several other wall mounted display speakers designed for the same use case, these will be referenced to as *Competitor 1*, *Competitor 2, Competitor 3 and Competitor 4.* An overview of the competitors can be found in Table 2. The benchmark covers several data points such as sound pressures, weight, available features etc. If a product misses information, a question mark acts as placeholder.

As seen in Table 2 below, the current product matches or exceeds its competitors in most categories. Most distinguishable is the weight of 6,4 kg, being twice as heavy as some competitors. Many competitors lack information about their specifications, hindering a complete comparison.

Table 2 Benchmark of five display speakers. All data was found in [19], [20], [21], [22] and [23].

Competitor no.		*1*	*2*	*3*	*4*
Weight [g]	6400	3600	4800	2700	2890
Back Material	Aluminum	?	?	Plastic	Plastic
Front Material	Aluminum	?	?	Aluminum	Aluminum
Max sound pressure level [dB]	110	95	95	106	110
Frequency response	85 Hz – 20 kHz	60 Hz – 17 kHz	60 Hz – 17 kHz	?	86 Hz - 15,5 kHz
Display size (B x H) [mm]	219 x 55	274 x 83	297 x 114	344 x 194	?
Motion sensor	PIR sensor	No	No	Yes	No
- Max Range	10 m	?	?	?	?
Microphone	Yes	Yes	Yes	Yes	Yes
- Range	28 Hz -20 kHz	?	?	?	?
Streaming	Two Way, Full Duplex	Two Way	Two Way, Full Duplex	Two Way	Two Way, Full Duplex
Led Indicator	Yes	No	No	Yes	?
Signaling LED (Strobe)	Yes	Yes	Yes	Yes	Yes
Shape	Square	Square	Square	Square	Square
Orientation	Portrait	Portrait	Portrait	Landscape	Portrait
Drivers	Coaxial	Single	Single	Single	Coaxial
- No.	2	1	1	3	2
Speaker Size	8 in	8 in	8 in	?	8 in
Mesh Material	Steel	?	?	Steel	Steel
- Fastening	Snap fit	?	?	Screws on inside	?
Color	White	White	White	Black	White
Sound Dispersion	120°	?	?	88°	105°

2.3 Product development process

The project methodology is based on a double diamond process which consists of four different stages, each with different sub tasks and goals. The four stages are discover, define, develop and deliver and represent a design and innovation process developed by Design Council in 2004 [24]. A Schematic image of the double diamond process can be seen below in Figure 4.

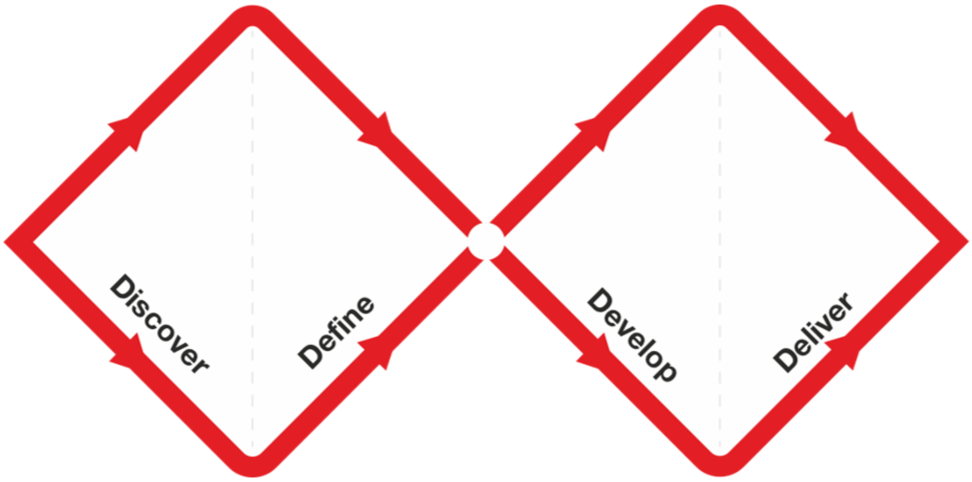

Figure 4 Visualization of the Double Diamond Design Process. [24]

The first phase 'discover' focuses on understanding as much as possible about the problem and the product. Substantial background information is essential to find the most critical problem and user needs.

The next phase defines the information found in the previous phase into key issues and a new technical specification. In doing so, perspectives and considerations are summarized into a clearer picture and help aid the process of finding the right solution without wasting time on irrelevant topics.

The 'develop' phase explores as many different solutions as possible to the problem. As the concept development process is a highly iterative process, this phase is difficult to define in terms of what order the sections will be conducted and how long they will take before a satisfactory concept is found. Therefore, this phase stands for most of the project.

Alterations are made to this phase. To strategically follow through the development process, concept generation is performed individually on the identified problem areas, rather than on the entire product itself. This way, concepts for each problem area are found separately, potentially allowing possibility to be used in other products as well. By dividing the idea generation into small studies, solutions can be evaluated based on their respective areas, not to the likes of the other problems statements. Solutions in these small studies are referred to as sub-concepts. A visual representation of this modification is shown in Figure 5.

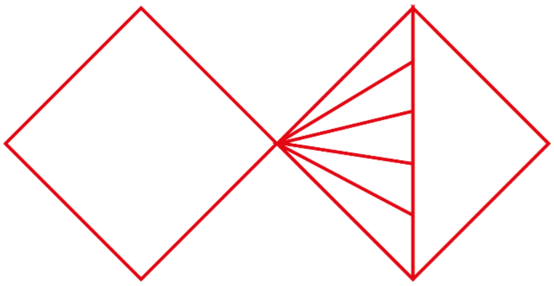

Figure 5 Visual representation of modified double diamond methodology used in this thesis. Created in Adobe Illustrator.

The last phase 'deliver' narrows down generated solutions into one and produces a refined concept. This phase includes both the decision itself in terms of screening and scoring matrixes, but also the refinement of the concept, i.e. creation of a high-fidelity prototype, a computer-aided design (CAD) and testing of the product.

Methods used within the design process were taken or inspired by methods described in *Product Design and Development* written by Ulrich and Eppinger [25].

3 Methodology

In this part, an in-depth description of how the project went about is presented. At the end of the chapter, a complete flowchart is presented to summarize it.

3.1 Discover

The First phase is about investigating and finding the real problem. This was done with a stakeholder analysis, interviews, deconstruction of units, literature reviews and a thematic analysis.

3.1.1 Stakeholder analysis

The phase started with defining relevant stakeholders in the products development and lifecycle. This was done to identify which people were needed for interviews to gain a complete picture of the product. The analysis also provided insight into the lifecycle and context of the product. The stakeholder table was continuously updated throughout the process as new information emerged. These people were, among others, Specialists in Audio and Signal Conditioning, Project managers, Mechanical engineers and Product owners.

3.1.2 Interviews

When the primary stakeholder analysis was completed, interviews with the relevant identified people with close relations to the existing product were performed. The interviews aimed at understanding the current product better and finding what areas were explored and which were not. The interviews were also used to discuss potential improvements in the product.

The interview was either held in office or over video conference call and consisted of either one or two interviewees and two interviewers. One interviewer oversaw the questions, while the other wrote down the interviewee’s opinions, feelings and statements.

When planning the interviews, attention was given to having a wide scope of questions, to cover as many different relevant fields as possible. This was to provide a broader view of the problems and to understand where the potential improvements lay. Sample questions were defined as a basis to the conversation but could be deviated from when needed. The discussions were noted for future reference.

3.1.3 Deconstruction of product

To grasp the inside of the current version of the product, deconstruction of a unit was conducted with a mechanical engineer from the company. A faulty unit was given the team to dissemble. The deconstruction took place in a mechanical lab equipped with relevant tools needed such as screwdrivers, wrenches, knives etc. As the product was put apart, components like screws, aluminum parts, PCBs, cables etc. were grouped and mapped out and noted for future reference. The speaker assembly was analyzed from a technical perspective and noted.

3.1.4 Literature study

A comprehensive study of literature was carried out, covering technical specifications of the current product, former research conducted for its development and previously defined specifications of requirements. Deepened knowledge in various areas such as screen and text size, sustainable product development, display vibration isolation, and research of different speaker categories were needed for optimal results. Information regarding these topics was found searching online and in books. Literature such as previous master thesis were used to aid in the writing of the master thesis itself. Results from literature study were presented in the previous chapter.

3.2 Define

The second phase was about defining the problems into a concise brief. This was done with quantitative data gathering, reward and effort scoring, priority list, need statements, and technical specification.

3.2.1 Quantitative data gathering

Answers from the interviews were compiled into a list of problem statements and given a number. Thereafter, those same statements were marked with an 'X' next to the interviewee's name if said interviewee happened to mention that problem. This way, the quantitative response of each statement could be found.

3.2.2 Scoring Reward and Effort

Another way of evaluating statements from the interviews was to compare its potential reward versus its effort to solve it. Reward indicated how valuable a solution to the problem was and effort reflected the perceived difficulty and time required to find a solution to said problem. [26] To achieve this, each statement was given a score for its reward and another score for its effort. The two scores could then be combined and compared to each other.

The identified problems were given a score from 1 to 5 where 1 was the worst/lowest and 5 the best/highest. The scores for the two parameters were decided by the team through discussions based on the interviews. To give the problems a score that considers both effort and reward, their respective value of each variable were placed in the equation below. The reward was weighed as more important than the effort, hence the multiplier of 0.8.

$$Score = Reward - 0.8 \times Effort$$

This score was later put into a reward-effort matrix with four quadrants 1-4, where quadrant 4 was considered a "quick win" and quadrant 1 a "thankless task". [26] With this, a problem statement could be prioritised based on the impact it yielded for the project.

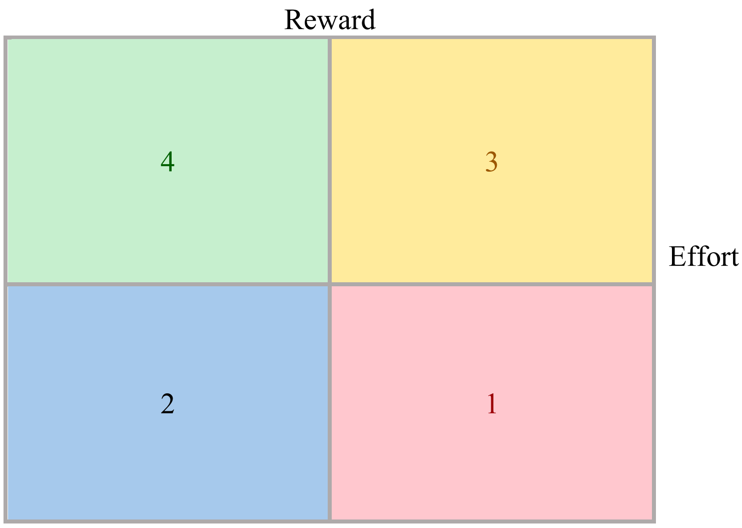

Figure 6 Reward-Effort diagram with four quadrants where 4 is the best possible and 1 the worst.

3.2.3 Priority list

A priority list was brought forward by discussing the value of statements based on benchmarking, reward-effort scoring, thematic analysis, deconstruction of unit and literature review. Statements were given a score of 1-10 where 1 is the lowest priority and 10 the highest. The list was shown to stakeholders to validate its relevance, where the changes needed were accounted for. Results were summarized into a table. This complete list showed more accurately what problems were most important to solve and acted as the basis for the next phase entirely.

3.2.4 Thematic analysis

The thematic analysis consisted of finding common areas or themes in the interview answers, grouping them and analyzing their quantity, overlaps and patterns. [27] After defining what topics or groups existed, a circle on a whiteboard was drawn for each one of them, representing the respective theme. After reading a statement, if it fitted under a certain topic, it was added to its corresponding circle. This was repeated until all statements were in at least one circle. If statements regarded more than one topic, the borders of that circle were extended to overlap the common statement. The analysis resulted in a Venn diagram. Decisions on where a statement should fit were ultimately based on team discussions.

3.2.5 Needs

Each problem statement in the priority list was translated into a need statement and given a score reflecting its position in the priority list. Some problems fell under the same need. Results were summarized into a table.

3.2.6 Technical specification / Requirements

The requirements were summarized into a metric table and were based on metric unit table from Product Design and Development by Ulrich K. and Eppinger. S [25]. All requirements found were based on research conducted in the literature review, product description and interview statements. All requirements were listed in the table with their corresponding unit and marginal value. If no unit could be found, it was marked with “Subj.” and with a marginal value ranging from bad – neutral – good. The previously stated needs were added next to the requirements, if they were affected by them.

3.3 Develop

The third phase was about finding solutions. To spike ideas, several brainstorming methods like Rapid Ideation, Mind Mapping and SCAMPER were used. With this, a series of prototypes and tests were also conducted.

3.3.1 Brainstorming

This thesis generated solutions primarily using brainstorming. Several methods were used for yielding as many concepts as possible, but this project mainly focused on rapid ideation, SCAMPER and mind mapping.

3.3.1.1 Rapid Ideation

This method was performed by setting a time limit for how much time one had to come up with new ideas. The time limit forced participants to come up with better solutions faster, and sort out unnecessary ones in the process. [28] Ideas were sketches and or written down on paper or whiteboard. When the time limit was up, combinations of the generated solutions were created.

3.3.1.2 Mind Mapping

Mind mapping helped visually map out ideas for a specific topic and had the possibility to be branched out with sub-branches when associations occurred. It helped open and dissect the problem at hand. [28]

3.3.1.3 SCAMPER

The SCAMPER method was highly suitable for this project as it is aimed at improving already existing products. [29]

To perform the practice, seven prompts were reflected on, namely Substitute, Combine, Adapt, Modify, Put to another use, Eliminate and Reverse (SCAMPER). By thinking in accordance with these topics, many perspectives were taken into consideration. [28]

- Substitute, here one was tasked with reflecting upon what could be replaced. This applied to all aspects such as the product, the function and the problem itself. [29]
- Combine, what can be combined in the problem or solution? One thought in terms of; can any aspects, parts or solutions be combined in any way to create a synergy or new solution? [29]
- Adapt, this prompted the authors to reflect on solutions from other industries, products and solutions to other problems. Could any of these be adopted to fit the problem? [28]

- Modify, here the task was to reflect on what could be changed about the product, problem or service. This included for example, aspects in physical design, the function or the process. [28]
- Put to another use, could the solution be used elsewhere to reach other audiences, how does the product function in other contexts, could it solve other problems? [29]
- Eliminate, here it was reflected on the questions; what is excessive? Can something be removed, reduced, simplified or minimized? This prompt forced focusing on solutions to the most critical aspects. [29]
- Rearrange, the participants asked themselves what and how the solution or product could be restructured. Could the product or problem be rearranged, solved in reverse or flipped? [29]

3.3.2 Prototyping

Generating ideas on paper was not sufficient to fully visualize generated concepts and ideas. Physical prototypes were therefore also part of the development process. Prototyping the initial ideas for concepts was of a low-fidelity nature as the purpose was to visualize and test the ideas rather than demonstrate and showcase an entire fully refined solution.

The prototyping methods consisted of modelling with a CAD model. The model was then exported to a secure digital (SD) memory card and uploaded to a three-dimensional (3D) printer that used plastic filament. For silicone parts, a mold was modelled, printed and then filled with silicone. For electronic features components, PCBs, drivers and cables were borrowed from the existing products. Models were downscaled for minimal material consumption.

3.3.3 Testing

As stated before, testing of prototypes was essential to find further problem areas that may have been concealed at first glance. The testing performed during the development phase of this thesis both served to validate the feasibility of concepts and to find new perspectives and considerations to keep in mind during the further development of ideas and concepts.

3.4 Deliver

The fourth phase was about making decisions and evaluating what solutions to keep for the final concept. Evaluation methods included screening matrixes, combination workshop and a scoring matrix. When the decision was final, a complete CAD model and prototype was also created.

3.4.1 Sub concept selection

After performing necessary validating tests of prototypes to find whether the concepts were feasible, the concepts were evaluated from a set of perspectives in form a screening matrix.

3.4.1.1 Screening matrix

To narrow down a list of solutions, sub-concepts were graded against each other in different criteria. If the concept performed well in a specific criterion, it was given a +, and if it performed poorly a -. In a situation where a concept performed neither good nor bad, a 0 was given. By calculating the sum of each character, where a + is regarded as +1 and - is regarded as a -1, the concepts could be compared to each other via a score.

The criteria for every screening matrix were not the same, as they covered different aspects of the problems. Generally, they consisted of perspectives like design for manufacturing (DFM), compatibility, cost, simplicity and aesthetics.

3.4.2 Combination workshop

With sub-concepts defined, one could freely mix and match them into functioning concepts with potential for finalizing. The mixing method was based on Ulrich and Eppinger's concept combination table, to explore concepts systematically.

The concepts were workshopped with supervisor present over the course of one day, where three concepts were chosen for further evaluation. The time pressure of one day was necessary to avoid lose-ends and critical thinking.

The workshop was carried out by cutting out pictures of the sub-concepts in paper and arranging them with each other on a larger piece of paper. This enabled easy switching of sub concepts and visualized the whole concept.

3.4.3 Final concept selection

After multiple concepts for the entire product were defined, the number of concepts were to be reduced to a final concept. To aid that decision, a scoring matrix was used to provide objective comparison of the concepts. This was done to efficiently find the most beneficial solution.

3.4.3.1 Scoring matrix

The three concepts with potential were graded against each other in a series of weighted criteria that reflect the priority list conducted in the previous phases. The weight of the criterion was in form of a percentage. Each concept was thereafter given a score of 1-5 for each criterion. When all cells had been filled, the final score was calculated by multiplying the score in a criterion with its respective weight. An average score was then calculated for each concept and allowed for inter-concept comparison of which concept handled all the criteria best.

3.4.4 Concept refinement

When a final concept setup was chosen the concept was further refined, this was done both on individual sub concept level and on entire system level. This was done to improve both the performance of each of the separate components but also to improve the interaction between all the components.

3.4.5 CAD modelling

The final concept was made into a single digital CAD model in the program Creo Parametric sustained by the company. The model was built in a single file, making different parts of the products as 'bodies' rather than separate CAD-parts. CAD consisted of both surface and solid parts modeling. This method of modelling benefitted this project as it facilitated shared referencing and visualized the entire concept without assembly.

3.4.6 Prototyping

From the CAD model, a full-size printed prototype was made. This was done to demonstrate size, aesthetics and functions. Electronic parts were added to visualize their layout and size but were not connected to any functioning wires and or devices. In the prototype, strobe and speaker were connected to ethernet to provide demonstration of the products use-cases and user interaction.

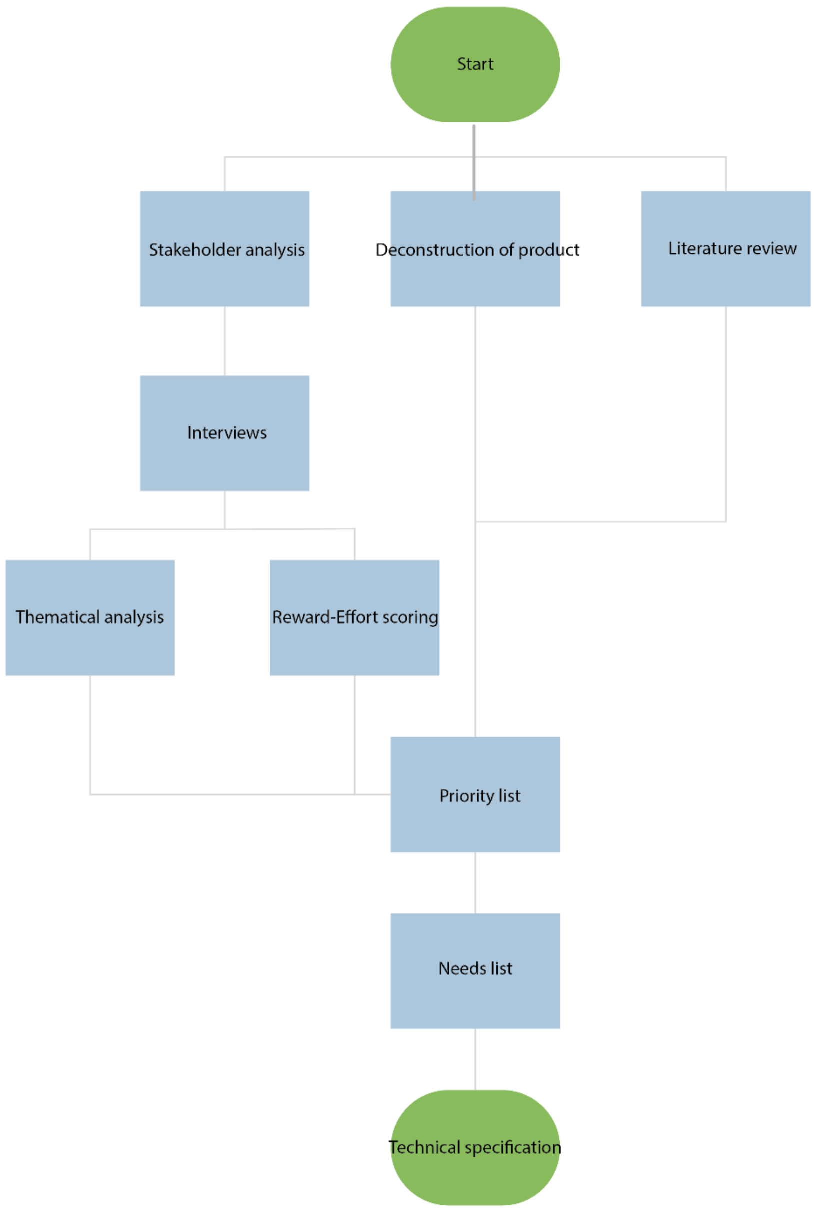

Figure 7 Flowchart of two first phases Discover and Define.

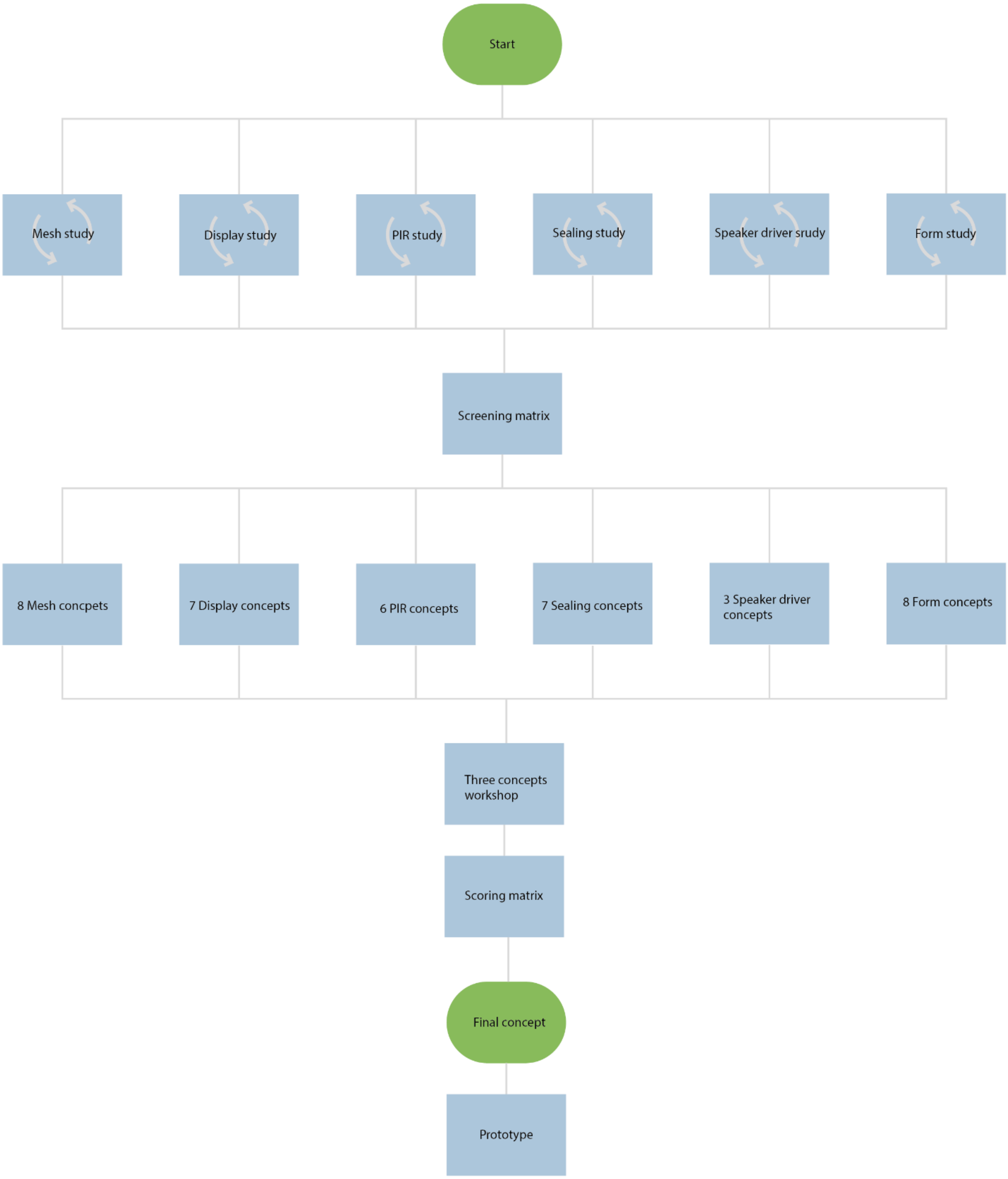

Figure 8 Flowchart of last two phases Develop and Deliver.

4 Development steps

This chapter covers the development steps through the entire project.

4.1 Discover

4.1.1 Stakeholder analysis

The full stakeholder table can be seen below in Table 3. Areas explored were Development of the current product, Experts, Production and Life of the product. These fields included relevant engineers, project managers, designers, various experts, people around testing and assembly of the product, sales, repairs and customers/users.

4.1.1.1 Engineers involved in the current products development

Engineers who were involved in the development of the current product were deemed to be important stakeholders as they have insight into the previously conducted development process. This could be insights into areas already explored, challenges already tackled and areas where exploration was limited due to time constraints. These stakeholders could also provide insight into the outcome of the development process and identify potential areas of improvement.

4.1.1.2 Field experts

When analyzing and improving the current product various separate fields of study were relevant. To gain more knowledge into these different fields, experts in for example audio, signal conditioning and sensors were identified as relevant. This was needed for a complete understanding of the product and to gain knowledge of how to improve the product in these areas.

4.1.1.3 Users

Users were identified as an important stakeholder to the development of the product since input from them was central to understanding what needed to be improved in the product for the next generation. Users were in this case both identified as customers and as installers since they handle the product during installation.

Table 3 Identified relevant stakeholders.

Stakeholders		
Product expert	Sales engineer	User experience (UX) designer
Mechanical engineer	Test engineer	Design for production (DFP) engineer
Electrical engineer	Quality Assurance (QA) engineer	Product owner
Product Specialist	Customer	Sensor specialist
Project Lead	Audio Specialist	Data engineer
Acoustics Engineer	Microphone Specialist	Industrial Designer
Filtering Expert	Installer	

4.1.2 Interviews

In total, 15 people were interviewed in accordance with section 3.1.2. The interviewees were asked to share their general thoughts and opinions on the current product and/or other relevant projects. When needed, the prepared questions were extended to include their area of expertise in the interview. A full version of the original interview questions is found in Appendix A. In Table 4, a complete list of people interviewed is presented. For anonymity of the interviewees, each participant was given a letter as reference.

Table 4 Interviewees with given reference letter, area of expertise and belonging notes.

ID	*Expertise / Title*	*Note*
A	Experienced Mechanical engineer	Audio engineer during development
B	Specialist engineer	Filtering
C	Product Specialist	
D	Global Sales engineer	USA trip
E	Experienced engineer	USA trip
F	QA engineer	Proficient in plastics

G	Senior engineer	Currently responsible for project
H	Expert engineer	Electric engineer
I	Experienced UX designer	UX responsible
J	Experienced Product Test engineer	Testing
K	Experienced Mechanical Engineer	Gaskets and Audio
L	Industrial design manager	
M	Industrial designer	Head designer
N	Senior Project Manager	Project manager
O	Design for Production Engineer	

Several improvement areas were found during the interviews, some more discussed than others. All statements from the interviews were listed and given a reference number, see Table 5. To map out how much a topic was discussed, answers were quantitatively mapped out in accordance with section 3.2.1 see Table 6. Data over the quantitively response gave insights into how widespread the area was and its significance to resolve. Confidential information was censured.

Table 5 List of problems mentioned during interviews and their respective given reference number.

Problem	*No*
Weight of the product [redacted]	1
[redacted]	2
Too many [redacted]	3
Microphones [redacted]	4
Microphones [redacted]	5
There is an extra [redacted]	6
The sound [redacted] too much	7
[redacted]	8
Too small [redacted]	9

[redacted] the display	10
[redacted] can be [redacted] slightly off, [redacted] mesh	11
[redacted] removed in assembly	12
[redacted] the display	13
The strobe [redacted] [redacted]	14
The strobe has [redacted]	15
[redacted] cables are [redacted]	16
[redacted] cables are [redacted]	17
It is difficult to align [redacted]	18
[redacted] can be mixed up in assembly	19
Status [redacted] to the speaker	20
Seal is [redacted]	21
Difficulty in [redacted]	22
[redacted]	23
Backpiece have [redacted]	24
[redacted] backpiece with connections	25
[redacted] backpiece with [redacted]	26
[redacted] back volume	27
There exists [redacted] driver	28
[redacted] around the speaker could [redacted]	29
[redacted] difference between [redacted]	30
[redacted] is difficult without [redacted]	31
Mesh is [redacted]	32
Mesh is [redacted]	33
[redacted] sealed	34
[redacted] easily reached	35
The product has [redacted] capabilities	36
The product has [redacted]	37
There is [redacted]	38
[redacted] sensor and status [redacted]	39
Cables are [redacted]	40
[redacted]	41

Difficulty with [redacted] because of [redacted]	42
Cables are [redacted]	43
The PIR sensor [redacted]	44
There is [redacted] connecting a PoE [redacted]	45
The product [redacted]	46
[redacted] heat [redacted]	47
[redacted] holding up the unit [redacted]	48
[redacted] during installation	49
The display [redacted]	50
The universal serial bus (USB) port [redacted]	51
There is no [redacted]	52
Ability to [redacted]	53
Ability to [redacted]	54
[redacted] transportation	55
Ability to [redacted]	56
The product does [redacted]	57
There are [redacted] on the product	58

Table 6 Problems found during the interviews with quantitative data.

No	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*Tot*
1	x	x						x			x				x	5
2	x	x														2
3	x							x		x					x	4
4	x	x						x							x	4
5															x	1
6	x	x														2
7		x						x								2
8									x							1
9	x		x	x	x		x	x	x							7
10												x	x			2
11															x	1
12															x	1
13	x						x				x				x	4

14									x							1
15				x	x											2
16	x															1
17															x	1
18															x	1
19															x	1
20															x	1
21															x	1
22	x									x	x				x	4
23	x															1
24	x						x				x					3
25	x															1
26	x						x									2
27	x	x														2
28		x														1
29		x														1
30		x														1
31	x			x	x		x			x	x				x	7
32	x					x	x			x	x					5
33	x			x	x			x			x					5
34	x															1
35	x															1
36			x	x	x	x										4
37			x	x	x											3
38			x	x	x			x								4
39										x						1
40										x						1
41										x						1
42										x						1
43										x						1
44	x			x	x	x		x			x	x	x		x	9
45			x	x	x			x								4
46			x	x	x											3
47								x								1
48	x							x				x	x			4
49				x	x											2
50				x	x									x		3
51				x	x											2

52	x	x		2
53	x	x	x	3
54	x	x	x	3
55	x	x	x	3
56	x	x	x	3
57	x	x		2
58	x	x		2

In contrast to the problems found, several positive insights, lessons learned and design guidelines were mentioned as well. These findings were compiled into two lists presented below in section 4.1.2.1 and 4.1.2.2, to keep track of features that should not be altered with and/or taken into consideration during the next phase of the thesis work. Confidential information was censured.

4.1.2.1 Useful guidelines

- Don't use [redacted] displays
- [redacted] are usually better, the company has [redacted]
- Make room for [redacted]
- [redacted] are expensive, so it is better to [redacted]
- [redacted] shapes tend to [redacted]
- [redacted] products feel [redacted]
- Use as low [redacted] as possible
- Sustain a big [redacted]
- Let PCB holder [redacted]
- Avoid metal [redacted]
- Avoid common [redacted]
- Avoid [redacted]
- Avoid [redacted]
- Incapsulate [redacted]
- Avoid [redacted]
- Aim for few [redacted]
- [redacted] are appreciated
- Keep microphone [redacted]
- Interference occurs [redacted]

4.1.2.2 Positive findings

- The product is stable [redacted]
- The [redacted] is appreciated by the customers
- The [redacted] has received high praise
- The product has received good feedback [redacted]

- The [redacted] is appreciated
- The [redacted] audible even in noisy environment
- The [redacted] functions well
- The [redacted] gives a sense of quality
- The product works well in its [redacted]
- It can show all [redacted]
- Good [redacted] in more than one way
- There are separate [redacted]
- The contact from [redacted] correct way.
- Easy to [redacted]
- [redacted] is powerful
- Easy to [redacted]

4.1.3 Deconstruction of product

Deconstructing the product was done in a systematic way and gave insight into its parts and assembly as well as how the company tackled previous problems. Seeing how the components were assembled and what they consisted of helped the comprehension of loudspeakers in general as well as audio devices specifically at the company.

Moreover, an overview of wires, PCB layout, screws and screw pillars, outports, size of components and sealing solutions were found during the deconstruction. This information was kept in mind moving forward and defined further considerations regarding the hardware design previously unknown for the team.

4.2 Define

4.2.1 Reward Effort Scoring

To analyze the data gathered from the previous phase, a reward effort scoring was performed in accordance with the description presented in 3.2.2. The result is found in Table 7 together with what quadrant it belonged to.

Table 7 Listed problems and their respective reward and effort, as well as their combined score and in which quadrant it landed.

Problem No.	*Reward*	*Effort*	*Score*	*Quadrant*
6	5	1	4,20	4
45	5	1	4,20	4
56	5	1	4,20	4
4	5	2	3,40	4
53	4	1	3,20	4
54	4	1	3,20	4
3	5	3	2,60	4
8	5	3	2,60	4
9	5	3	2,60	4
14	5	3	2,60	4
5	4	2	2,40	4
16	4	2	2,40	4
17	4	2	2,40	4
39	4	2	2,40	4
43	3	1	2,20	4
51	3	1	2,20	4
57	3	1	2,20	4
1	4	3	1,60	4
10	4	3	1,60	4
52	2	1	1,20	3
22	5	5	1,00	1
31	5	5	1,00	1
36	5	5	1,00	1
42	5	5	1,00	1
44	5	5	1,00	1

13	4	4	0,80	1
15	4	4	0,80	1
21	4	4	0,80	1
24	4	4	0,80	1
26	4	4	0,80	1
48	4	4	0,80	1
49	4	4	0,80	1
27	3	3	0,60	4
40	3	3	0,60	4
50	3	3	0,60	4
58	3	3	0,60	4
18	2	2	0,40	3
20	2	2	0,40	3
47	2	2	0,40	3
7	1	1	0,20	3
32	4	5	0,00	1
33	4	5	0,00	1
37	4	5	0,00	1
46	4	5	0,00	1
19	3	4	-0,20	2
25	3	4	-0,20	2
28	3	4	-0,20	2
38	3	4	-0,20	2
11	2	3	-0,40	3
23	2	3	-0,40	3
29	2	3	-0,40	3
35	2	3	-0,40	3
55	3	5	-1,00	2
2	2	4	-1,20	2
12	2	4	-1,20	2
34	1	3	-1,40	3
41	1	3	-1,40	3
30	2	5	-2,00	2

4.2.2 Priority list

Based on the benchmark of competitors as well as what each interviewee said and reward-effort scoring, a finalized priority list of all statements was established. Each statement was given priority by 1-10, where 10 is the most critical to solve and 1 the least. If a statement was deemed important but either outside the scope of the thesis or had a trivial solution not requiring a development process, it was labeled as 'To Be Implemented' (TBI). They were not given a development process but rather mentioned as part of the final concept. Results can be found in Table 8.

Table 8 Final list of problems sorted by their priority of solve.

No.	*Priority (1-10)*	*No.*	*Priority (1-10)*
6	TBI	33	7
45	TBI	39	7
46	TBI	40	7
50	TBI	43	7
53	TBI	48	7
54	TBI	8	6
56	TBI	26	6
9	10	30	6
4	9	49	6
22	9	51	6
44	9	52	6
1	8	11	5
3	8	23	5
15	8	57	5
16	8	58	5
17	8	10	4
24	8	20	4
31	8	35	4
36	8	47	4
37	8	25	3
42	8	55	3
2	7	18	2

5	7	19	2
13	7	28	2
14	7	34	2
21	7	41	2
27	7	7	1
29	7	12	1
32	7	38	1

4.2.3 Thematical analysis

With a defined priority list, it was decided that statements above a priority of 5 would be the main areas focused on. To identify what categories these statements represented, a thematical analysis was performed in accordance with section 3.2.4. The found themes were Form and Layout, PIR lens, Mesh attachment, Display attachment, Speaker driver and Sealing see Figure 9 A Venn diagram of the different problems and what categories they fell into. The numbers each represent a problem statement from in priority list with a priority of 6 or higher.Figure 9. These would come to be the six main studies in the next phase.

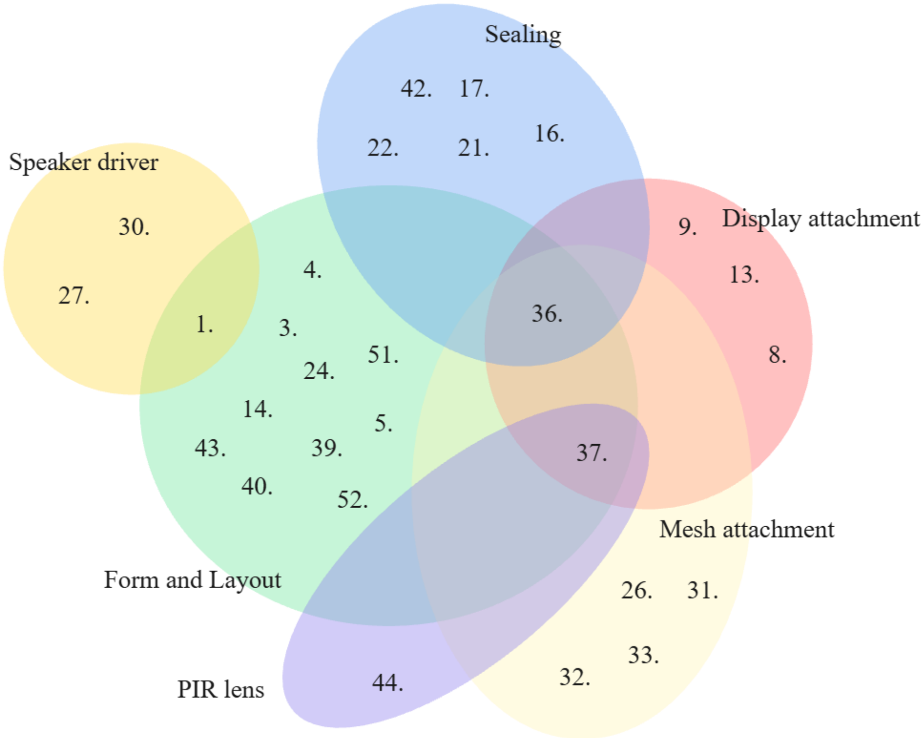

Figure 9 A Venn diagram of the different problems and what categories they fell into. The numbers each represent a problem statement from in priority list with a priority of 6 or higher.

4.2.4 Needs

For better overview of the prioritized problems, a table of needs was compiled where each statement was transformed into a need statement and weighed accordingly on a scale from 1-5, see Table 9. In this table, thoughts from the *Useful guidelines* and *Positive findings* were considered.

Table 9 List of needs with respective scoring 1-5 based on priority list. A higher score implies a higher priority.

No	*Need*	*Score*
1	The display is compatible with strobe	3
2	The display is large enough to see from 12 meters	5
3	The display is matt	2
4	The parts in the product are placed strategically	5

5	The product aligns with ADA requirements	3
6	The product disperses heat	2
7	The product doesn't contain unnecessary parts	3
8	The product handles 110 dB	5
9	The product has an analog clock	1
10	The product is aesthetically pleasing	4
11	The product is cheap to manufacture	3
12	The product is compatible with outdoor environment	4
13	The product is compatible with other devices	2
14	The product is customizable	3
15	The product is easily assembled	4
16	The product is easily disassembled	4
17	The product is easily installed	2
18	The product is energy efficient	2
19	The product is inclusive	4
20	The product is lightweight	4
21	The product is resistant to tolerances	3
22	The product is resistant to violence	4
23	The product is transported effectively	2
24	The products act in favor of audio quality	5
25	The strobe is homogenous	4
26	The wiring is secure	4
27	The product manages current specifications equally or better	4

4.2.5 Technical specification / Requirements

To define requirements the product would have to meet, a technical specification was made in form of a metric table, stating what requirement would be needed and its respective value, see Table 10. For instance, as stated in the introduction, the product will have to uphold the same standard or better as the current product. This means, for example, that sound pressure still must be at 110 dB. The technical specification was kept in mind together with the priority list, needs and reward-effort scoring when moving on to the next phase.

Table 10 Metric table based on need statements

Metric No	*Need No*	*Metric*	*Unit*	*Marginal Value*
1	8	Sound Pressure	dB	> 110
2	24, 27	Frequency Response	Hz	20-20 000
3	2	Motion detection range	m	12
4	27	Sound dispersion	°	120
5	17, 20	Weight	g	< 6400
6	11, 15, 16, 26	Manufacturability	Subj.	Good
7	1, 9, 12, 13	Compatibility	Subj.	Good
8	14	Customizability	Boolean	Yes
9	3, 10	Aesthetically pleasing	Subj.	Good
10	22	IK rating	-	> IK05
11	24	IP rating	-	> IP55
12	18, 23, 27	Sustainability	Subj.	Good
13	7, 9, 27	Number of parts	No	< today
14	4, 6, 7, 15, 16, 2, 24, 25, 26, 27	Strategic placement	Subj.	Good
15	5, 9, 17, 19, 27	Inclusive design	Subj.	Neutral

4.3 Develop

From previous phase, six main problem areas were identified: mesh attachment, display attachment, PIR lens, sealing, form and layout and speaker drivers. Each category was examined separately and came to be referred to as ‘studies’ in this project. Moreover, a strobe test was also conducted in this stage as well as an initial brainstorming activity SCAMPER.

4.3.1 SCAMPER

The develop phase started with performing SCAMPER activity around the current product in accordance with method 3.3.1.3. The exercise gave an overview of how problems should be approached, if they should be eliminated, added, changed, modified etc. More specifically, it yielded findings such as integrating horn speaker with the product, making the display act as the strobe, changing aluminum to plastic and fastening the mesh in a protective skeleton to aid impact protection. All findings were visualized in form of a mind map see Figure 10.

Figure 10 Findings from SCAMPER exercise in form of sticky notes / mind map. Created with miro.com.

4.3.2 Strobe test

From the interviews, one statement mentioned that viewing the display was difficult with active strobe. To test how severe this problem was, a short experiment was conducted where the strobe was set to its maximum power and placed at different distances from the display. The display was at each distance observed and the difficulty of reading the display was judged by the team.

It was found that the light from the strobe greatly reduced the readability of text on the display if placed within an 8 cm radius from the display. This concludes that the strobe should ideally be placed at least 8 cm away from the display to ensure readability while signaling with the strobe. Images from the study are presented below in Figure 11 and in Figure 12.

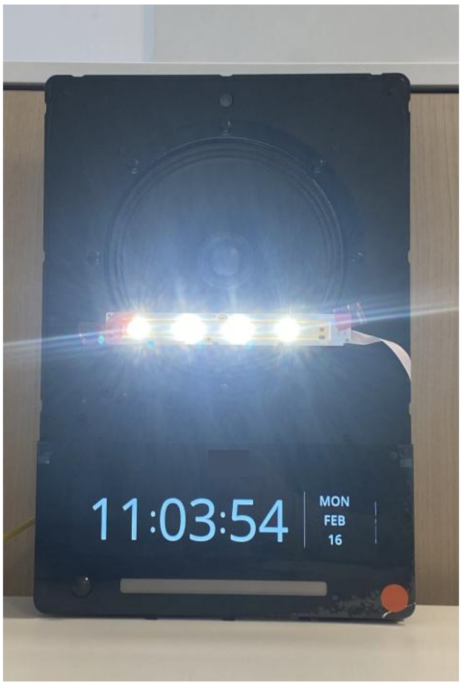

Figure 11 Image from strobe test, 8 cm distance to display

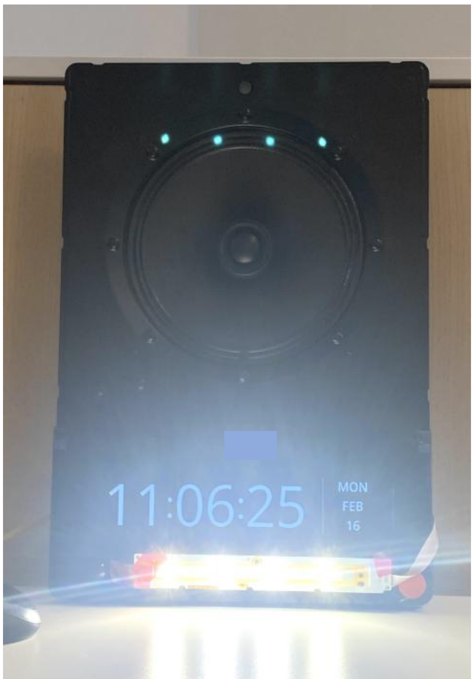

Figure 12 Image from strobe test, 2 cm distance to display

4.3.3 Mesh study

Through rapid ideation and mindmapping described in 3.3.1.1 and 3.3.1.2, 15 solutions of attaching the mesh onto the speaker were discovered. The solutions were drawn on a whiteboard and 5 were selected for further investigation, and brought up as mockups. In Figure 13, sketches of the five concepts are presented. The other 9 concepts were postponed or directly eliminated due to lack of potential after a team discussion.

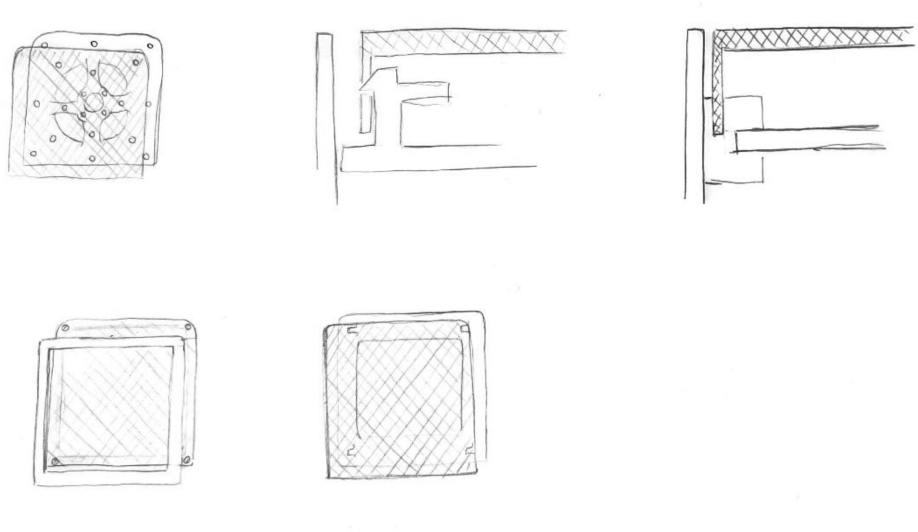

Figure 13 Sketches from mesh study. From left to right, a) Magnets b) Snap fit c) Seal d) Screws with plastic cover and e) Plastic plugs

The solutions in which potential was shown were namely use of magnets, a snapfit mechanism, use of a silicone seal, regular screws and dampening plugs. The concepts were sketched, 3D-modelled and printed over one weeks time. Refinement of the initial mockup was considered when needed, for example in the snapfit mechanism where the design was iterated four times.

After all mockups were tested, the concepts were evaluated using screening matrix described in 3.4.1.1 findings. From this, it was clear that magnets, screws and making use of the seal was beneficial for the needs of the product since they all provided more pros than cons in line with the identified problems.

4.3.4 PIR study

The PIR study began with brainstorming potential solutions wich were drawn up on a whiteboard. Some solutions were in regards to the placement of the sensor, while some were about changing the sensor entirely.

The most discussed concept was to lower the sensor and its lens into the front plate, stopping it from sticking out. When lowering the sensor, its cover range of 105° needed to be accounted for, adjusting the profile of the front plate in a way that it did not block any of the its view.

For aesthetic reasons, the lowered sensor and lens could also be covered by a sheet of IR compatible plastic. After discussing the matter with employees at the company, it was found that a high denisty polyethylene (HDPE) would be most suitable, as it is commonly used for PIR lenses already.

The third most discussed concept was changing the lens to a flat surfaced one. Changing the lens came with a few uncertanties regarding its performance, as the shape of the fresnel lens had high requirements such as a 10 m range of detection and a dispersion of at least 105°.

Three lenses was ordered and tested by connecting to the device and reading the sensor output with a script together with the lowered concept with and without two plastic sheets with different thickness. The script was based off a previously conducted test several years ago with necessary additions. From the unit, the raw sensor value was read aswell as the detection state of the sensor ie. if the descision logic deemed the input to be a detected signal or not. A program which made the device blink with red lights while having an active PIR detection was also used, visualising the detection state.

With this new test in place, three new sensors and two other concepts described above was tested. The lenses that were tested can be seen in Figure 14. The test was conducted with one person walking past the device at different distances from the sensor and standing in different places around it. By placing a piece of tape on the floor where the PIR sensor was triggered, its range was found and measured. If the range was above 10 m and its coverage over 105°, it passed. In Table 11, all PIR concepts result are found along with their performance during the test. The same results are visually represented in Figure 15.

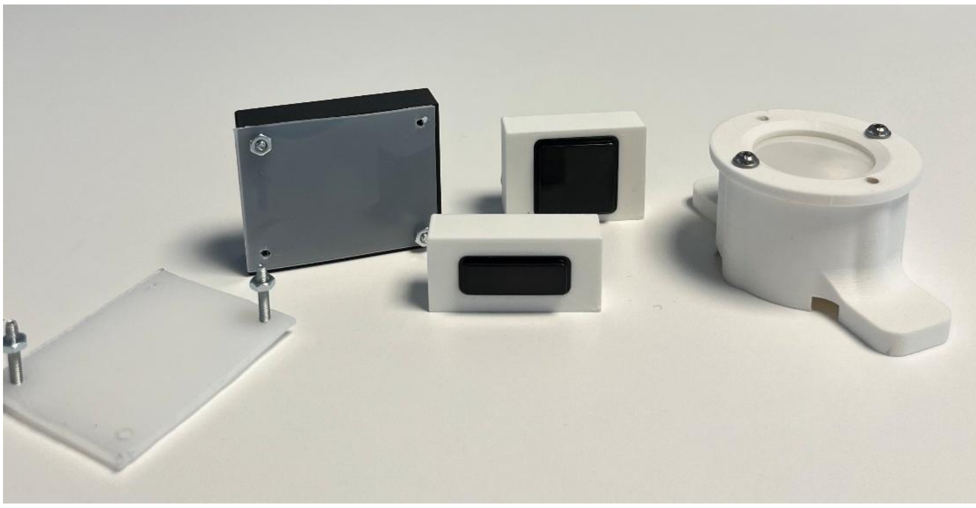

Figure 14 Lenses used in the PIR test. From left to right, HDPE (thick), HDPE (thin), rectangle, square and circle.

Table 11 Results of range and width of different PIR sensor lenses.

PIR lens	*Range [m]*	*Width [°]*	*Pass*
Regular	12	105	yes
Lowered	12	105	yes
HDPE sheet (thick)	5	94	no
HDPE sheet (thin)	9	86	no
Flat lens 1 (square)	12	88	no*
Flat lens 2 (rectangle)	10	73	no*
Flat lens 3 (circle)	12	14	no

*Close to passing

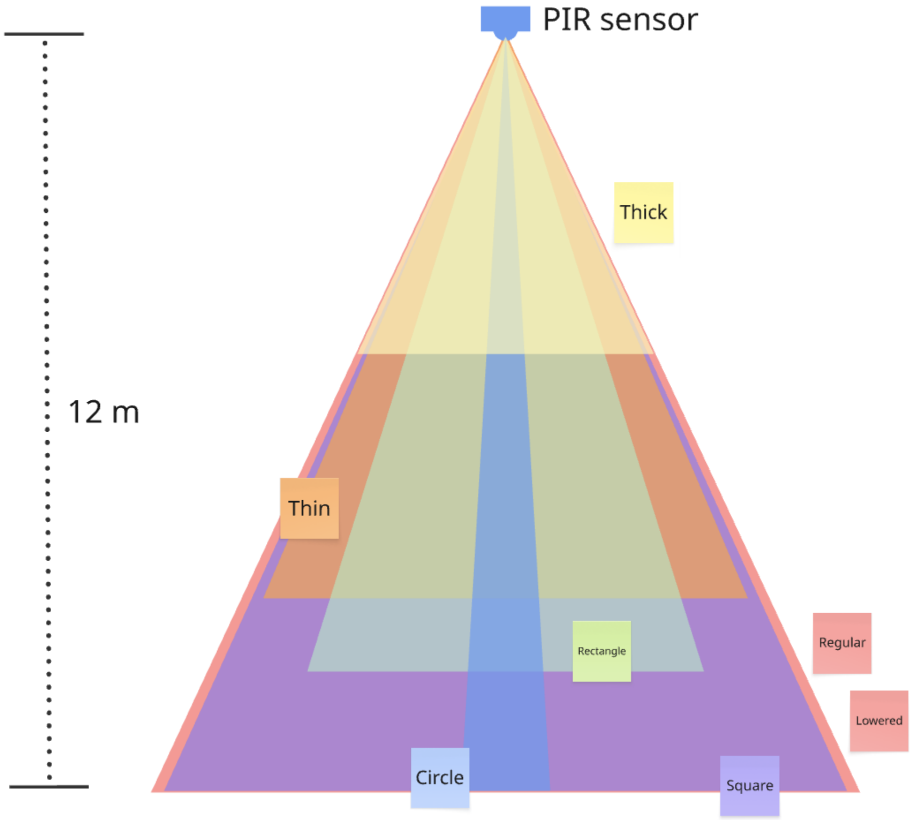

Figure 15 Visual representation of the results from the PIR test. Each color represents one lens. Viewed from above. Created on miro.com.

Before the test, the current lens setup was assessed that it performed according to specification. It passed its own range but the width was found to be lower. With this in mind the test proceded as planned.

The first test was of the lowered lens, this setup performed identically to the regular lens in both the aspect of width and range and therefore passed the test. The next was for the thick HDPE sheet, where the read sensor values were much lower, it had a detection rate at about 5 meter, about half of the passing value. When testing the thin HDPE sheet, the range was longer than that of the thick HDPE sheet but still shorter than the regular lens. The width angle was similar to that of the thick HDPE.

When testing the flat square lens, the measured detection range was identical to the current setup but the angle was narrower. The rectangular flat lens performed worse than the regular lens in both metrics. During the tests of the the flat circular lens, the maximum detection range was observed to be equal or better than that of the current lens, but came at the expense of a much narrower angle.

After the tests were performed they were evaluated using the previously described sub concept selection method from chapter 3.4.1. This resulted in the square PIR sensor being determined to have the highest potential followed by the lowered and the lowered with a thin HDPE sheet on top.

4.3.5 Sealing study

Like the previous studies, 19 solutions were found via brainstorming, rapid iteration and research. When these were sketched on a whiteboard some of the concepts were discarded and the rest were evaluated using the sub concept selection method from 3.4.1.

Three ideas stood out the most, see sketches presented in Figure 16. They all utilized a radial seal, as it would save material, require less applied force and protect the device more effectively. The difference between the three was how the PCBs and output ports would be sealed from the sound pressure. The ideas of interest were a separate box covering them, a wall integrated into main body with two separate front plates and lastly no wall at all, meaning the ports would be sealed and all components would be exposed to sound pressure. The concepts were not complete and needed further refinement, meaning several versions of each of the three concepts were brought up.

In addition to the three major concepts of sealing chambers, solutions of sealing cables were also explored, see sketches presented in Figure 17. The problem area was located at the barrier between sound chamber and PCB chamber. If not properly sealed, air could slip between the cables and create unwanted noise. The exact form and usage of these ideas depended on what main way of sealing the chambers would use and were therefore not fully investigated in this stage.

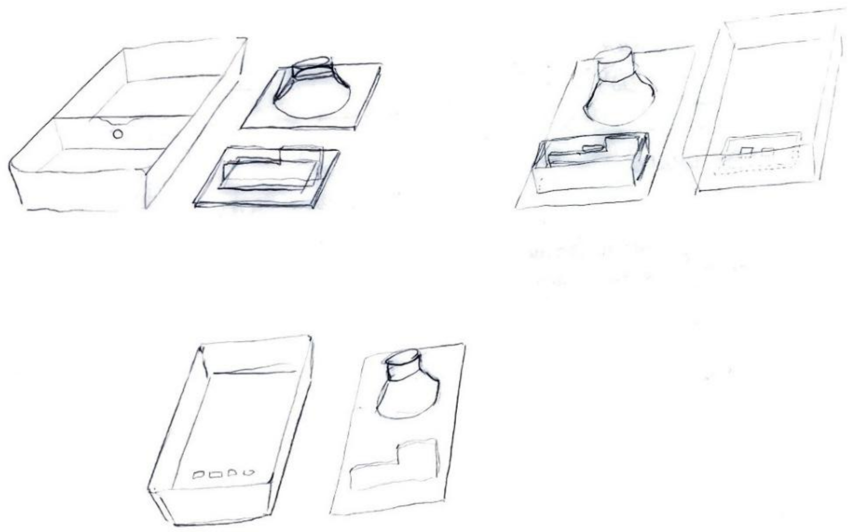

Figure 16 Sketches of chamber sealing solutions. From left to right, a) Two front plates b) Box concept and c) Open chamber

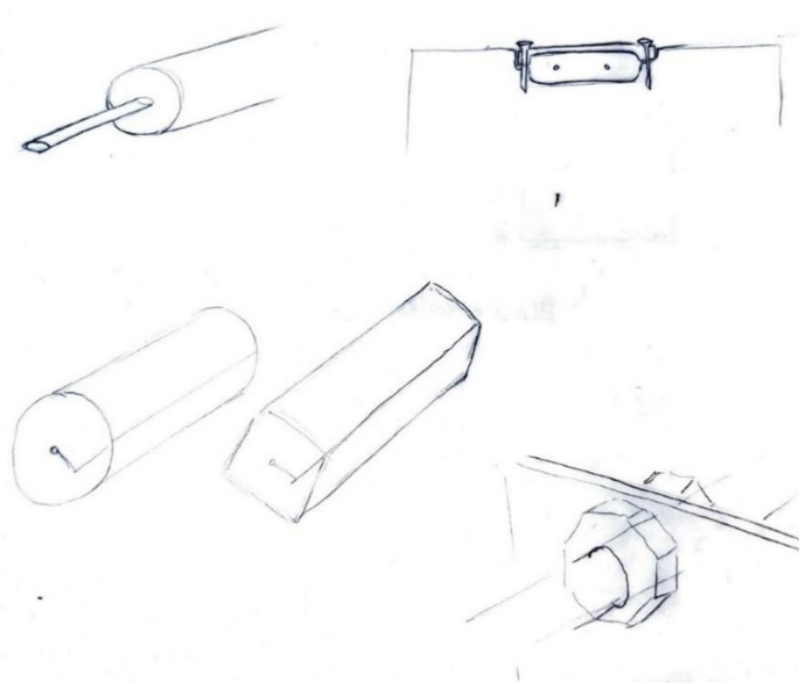

Figure 17 Sketches of cable seals from sealing study. From left to right, a) Oval cables b) Screws c) V-slit and d) Standardized cable gland

4.3.6 Display study

The study started with research and idea generation, these ideas were compiled on a whiteboard, resulting in 17 drawings of alternative solutions for mounting displays optically bonded to acrylic sheet. After a team discussion, 10 ideas were eliminated or changed until 6 were left for further evaluation see Figure 18. The solutions were evaluated using the sub concept selection method described in 3.4.1, this resulted in a list of solutions categorized into glue based, snap fits and screw versions. The highest ranked solutions were screw based and snap-fit based solutions, thereafter adhesive solutions ranked.

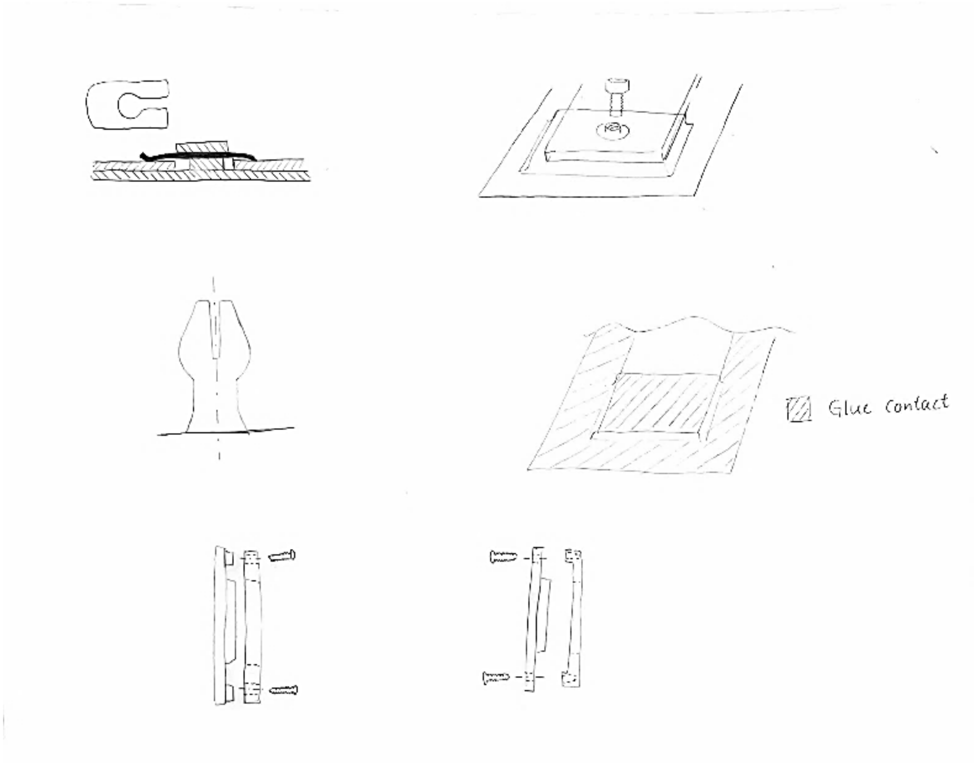

Figure 18 Sketches from display attachment study. From left to right, up to down, a) Metalplate b) Solvent bonded adhesive nut plate c) Plastic plug d) Larger glue area e) Screws from backside and f) Screws from frontside.

4.3.7 Driver study

In the driver study, firstly an interview with a speaker expert was conducted, where limitations and possibilities regarding the current speaker driver were discussed. Insights into frequency range, sound pressure and use cases were found. This discussion opened for more ideas, where an integrated siren could replace the demand of high sound pressure currently put on the driver, and that maybe the next product should not be an upgrade of the current one, but a smaller slimmer version of it. That would mean the next speaker might focus on other aspects such as IK and IP rating rather than producing the highest sound pressure with the smallest power budget.

Moreover, some requirements were set for the driver to be used depending on the use case that would be focused on. By putting these parameters into a database of loudspeakers, available options in response to those demands surfaced, see Table 12.

Table 12 Data for drivers from [30].

Use case	Sensitivity (SPL) (dB)	Frequency range (Hz)	Impedance (Ω)	Diameter (inches)	Available speakers
Current (background music, emergency, speech, two way communication)	95	100 - 20 000	4	<8	7
Speech only	95	100 - 8000	4	<8	5

Three concepts of driver designs are presented in Figure 19. The first was having the tweeter separated from the woofer, as it enables easier IP classification and less interference with each other. The second was having a single driver optimized for speech frequencies and then a siren for emergencies that is louder and meets the demand of 110 dB. The midrange driver would not be as powerful as combining a woofer and tweeter but came with other advantages such as being easily IP classified and more lightweight. The last one was the same solutions as the current product, but with the tweeter pushed back into the woofer.

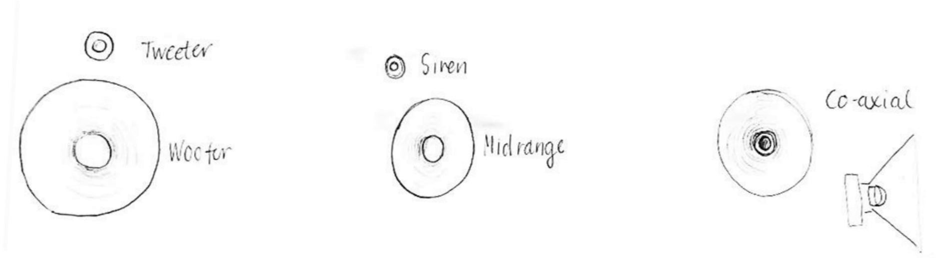

Figure 19 Sketches of speaker driver concepts from driver study. From left to right, a) Separate drivers b) Midrange driver with siren c) Co-axial driver.

4.3.8 Form study

Throughout the entire development phase, several ideas regarding the speaker shape and industrial design were considered in terms of both small and more significant changes. Several pros and cons in changing the exterior design of the product were found during this time.

For example, a larger radius of the die-casted enclosure could prevent warpage and reduce material, two highly valued needs. In changing its flat surface, one could avoid sharp corners which could benefit the motion of the sound waves, possibly improving the sound quality. Moreover, a slightly rounded or bent mesh could bring it better structural integrity, making it more resistant to rattling, ringing and general damage. On the other hand, changing too much might cause confusion regarding the product, as it should still be in the company's style and show a belonging to the product family. Colors, materials, logos, branding etc. should be left as it is, to ensure unity.

A few variations of the shape of the speaker were created. One test tried having different radiuses in the corners. 8 alternatives were 3D-printed in miniature form to visualize the general shape, with radiuses up to 120 mm see Figure 20. In addition to this, several different shapes were considered as well. These concepts deviated more from the original design, to explore different shapes and sizes, see Figure 21.

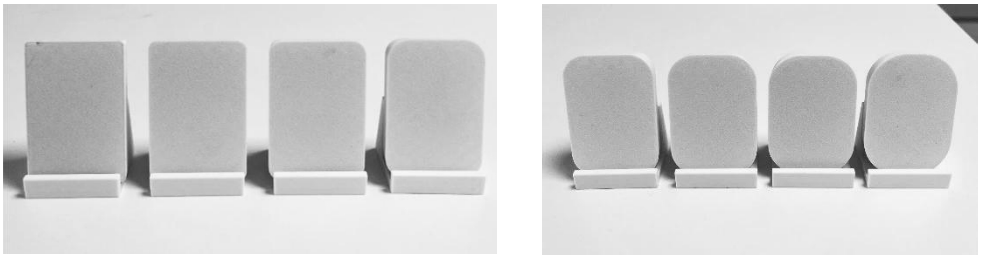

Figure 20 Picture of 3D-pirnted miniature shapes of the product with ranging radiuses from 14 mm to 120 mm going from left to right.

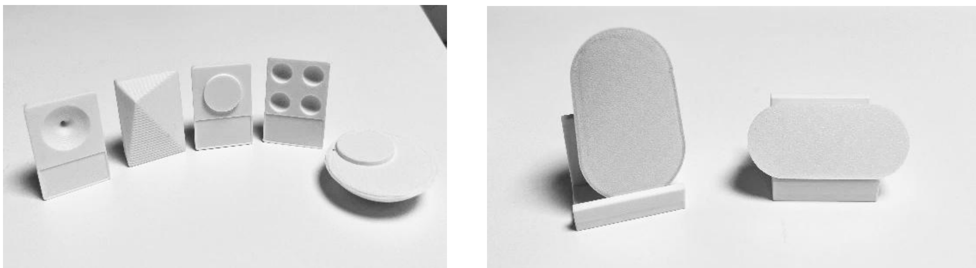

Figure 21 Picture of 3D-pirnted miniature shapes of the product with alternative form and- or layout.

4.4 Deliver

4.4.1 Sub concept selection

As previously mentioned, screening-matrixes were performed on the categories Display, Mesh, PIR, Chamber and Seal according to method described in 3.4.1.1. For full overview of each screening matrix, see Appendix B. This provided a ranking of each sub concept and- or if the sub concept should be discarded entirely or not, which aided the final concept selection. Each sub concept was labeled with a reference number, which is presented in Final concept selection

4.4.1.1 Combination table

All sub concepts from each study were summarized into a combination table see Figure 22. During a workshop, subconcepts were combined into three complete concepts, with one solution from each category in accordance with method described in 3.4.2. The decision behind each choice of concept was based on compatibility with each other, ranking from previous performed screening matrixes and input from supervisor. A reference number was given to each concept and are further explained below.

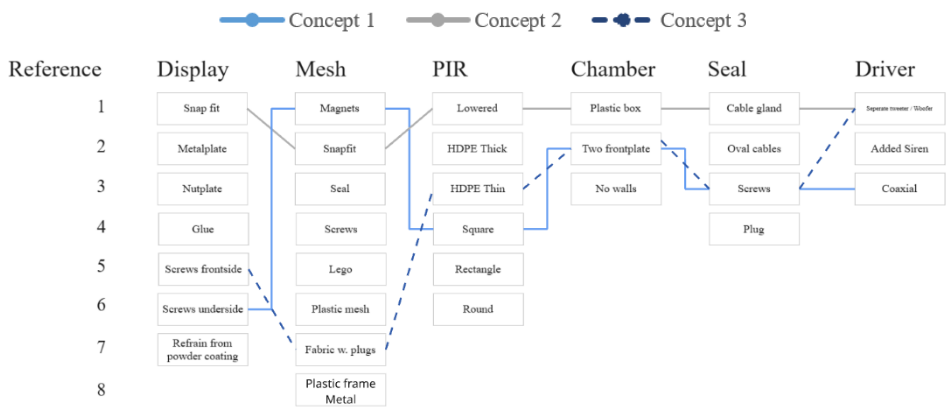

Figure 22 Concept combination table with marked results for three concepts.

4.4.1.2 Concept 1

Table 13 Concept 1 Architecture

Display	Screws, underside

Mesh	Magnets
PIR	Square
Seal	Two front plates
Small seals	Screws
Driver	Coaxial

The first concept had the display attached with screws mounted from the underside of the display. The acrylic screw pillars were attached using solvent bonding on the back side of the LCD screen's acrylic front glass. The display could thereby be attached with the aluminum front plate with screws going through the back side of the front plate into the screw pillars. The mesh was fastened with magnets mounted into the front plate and secured with adhesive. The contact points between the mesh and the magnets were covered with vibration damping tape. A square PIR lens and a coaxial driver was chosen for this concept.

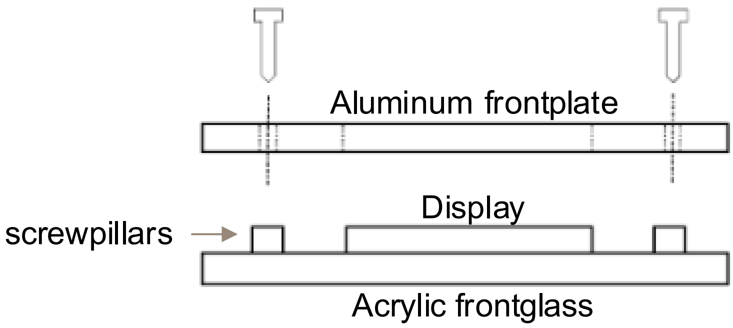

Figure 23 Display attachment "Screws, underside" – side view

The main sealing concept chosen was a solution with two front plates and a separating wall between, thus creating two separate volumes. The lower volume was where the main electrical components were housed such as the main PCB and the microphone, while the upper compartment was the audio chamber where the driver was mounted. Both front plates had a radial seal around their respective edges that sealed against the back aluminum cover.

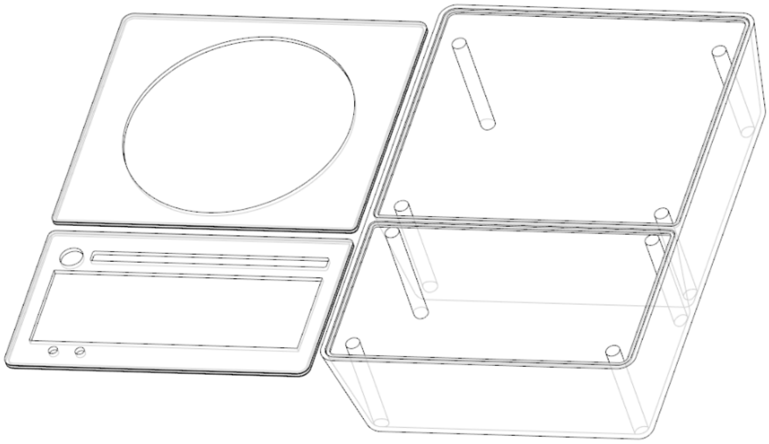

Figure 24 Chamber concept “Two front plates” – Exploded view

To route cables between these two compartments, for example from the main PCB to the driver a solution named ”screws” was selected. The solution screws consisted of a cutout in the walls between the chambers. In this cutout a slightly oversized silicone plug was sat, clamped in place by another cast part in the shape of a block. In between the wall and the block was a thin silicone sheet, attached to the silicone plug as “wings”. The whole assembly could be screwed together from the top. Images of the assembly can be seen below in Figure 25 and Figure 26.

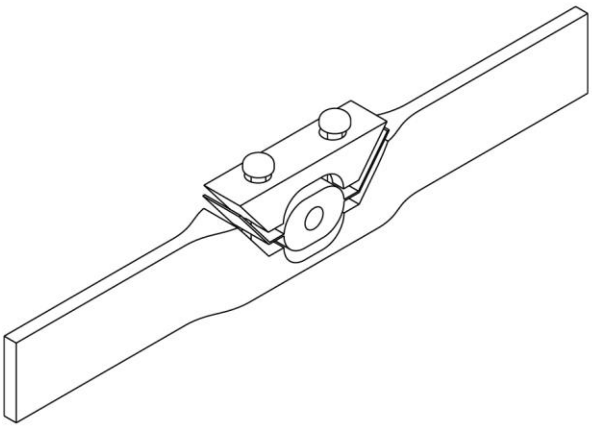

Figure 25 “Screws” concept for small seals – Exploded view.

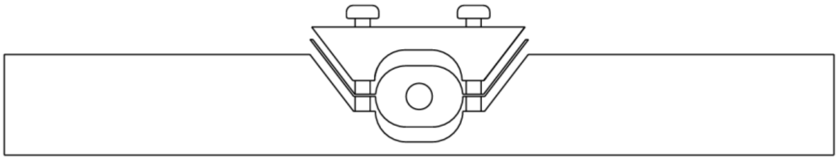

Figure 26 “Screws” concept for small seals – Exploded front view.

4.4.1.3 Concept 2

Table 14 Concept 2 Architecture

Display	Snap fit
Mesh	Snap fit
PIR	HDPE Thin
Seal	Box
Small seals	Cable gland
Driver	Separate

For the second concept, the display was attached with round snap fit plugs as well a layer of adhesive to improve the sealing capacity of the mount. The snap fit plugs were fastened through solvent bonding to the back side of the LCD screens front glass. By pushing the plugs through matching holes in the aluminum front plate the screen snapped into place. The mesh was also attached with snap fit plugs, to be inserted into the front plate. For the PIR sensor, the concept of lowering it into the product was chosen, with a thin HDPE sheet in front of it. Separate drivers were used in this concept, meaning a tweeter and a woofer were mounted separately from each other. The woofer would have a diameter of 6 inches or 15 cm and the tweeter 1,5 inch or 3,8 cm.

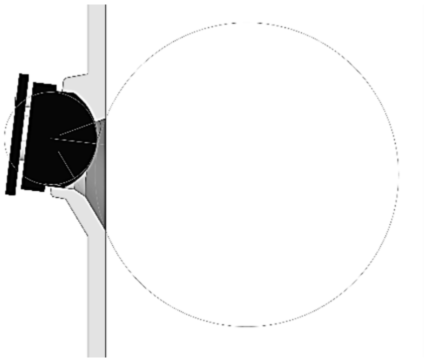

Figure 28 PIR sensor concept “Lowered” – side view

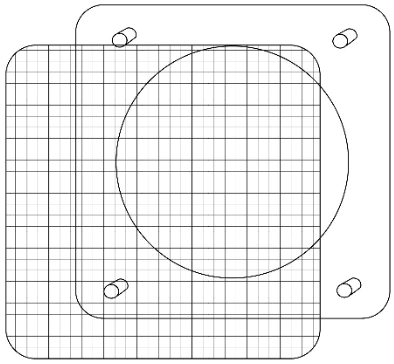

Figure 27 Mesh attachment “Plugs” – Exploded view

The chosen main seal was the box solution, which consisted of a plastic box inside the unit that sealed the electrical components from the audio chamber. This meant that the inside volumes divided the internal volume of the product into an audio volume and an electrical volume. The internal box had no plastic top or bottom, instead it was sealed through a radial seal against a rim on the inside of the top plate and a rim on the inside of the aluminum casing. This concept utilized a single front plate with a radial seal around its edges that sealed against the aluminum case see Figure 29 and Figure 30 for images of assembly.

For cable sealing, a cable gland was chosen. It was mounted in the plastic box separating the audio chamber from the electronic components.

Figure 29 Chamber concept “Box” – side view

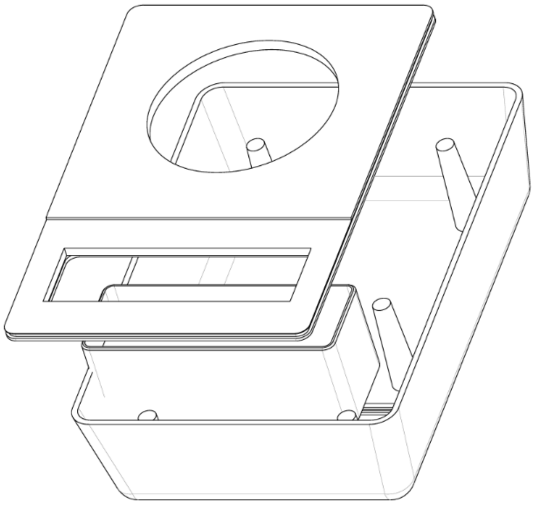

Figure 30 Chamber concept "Box" – Exploded view

4.4.1.4 Concept 3

Table 15 Concept 3 Architecture

Display	Screws, underside
Mesh	Plugs
PIR	Lowered
Seal	Two front plates
Small seals	Screws
Driver	Separate

The last concept utilized screws for mounting the display, the screws were attached from the back side as described above in concept 1. The mesh was attached with plugs and the PIR sensor lowered without any cover. Two font plates were chosen for this concept, with the screw solution for the cable seal. The selected driver for this concept was separate drivers.

4.4.1.5 Scoring matrix

To aid in the decision of which concept to move forward with, a scoring matrix was conducted in accordance with section 3.4.3.1, see Table 16.

Table 16 Scoring matrix of three concepts.

Criteria	*Weight %*	*Concepts & Score (1-5)*		
		1	2	3
Reduced weight	17	3	4	3
Aesthetic fit	13	5	4	4
IK	17	2	1	4
IP	17	2	4	4
Manufacturing	11	3	3	3
Cost	11	3	3	3
Repairability	14	5	4	5
Total score		24	26	26
Weighted score		3,37	3,72	3,75

Weight, IK and IP were the criteria with the highest weight with 17 percent each. Aesthetic fit referred to how well the concepts design fitted the already established visual identity and design language of the company. Weight distribution was based on the most discussed focus areas of this project as well as the priority list conducted in the first phase.

To visualize the scores for each of the concepts in each of the criteria, a spider diagram was created which can be seen in Figure 31. It visualizes how each of the concepts compare to each other in terms of points. No weight was considered in this diagram. For example, concept 2 performed slightly better in terms of weight but slightly worse in the aspect of repairability.

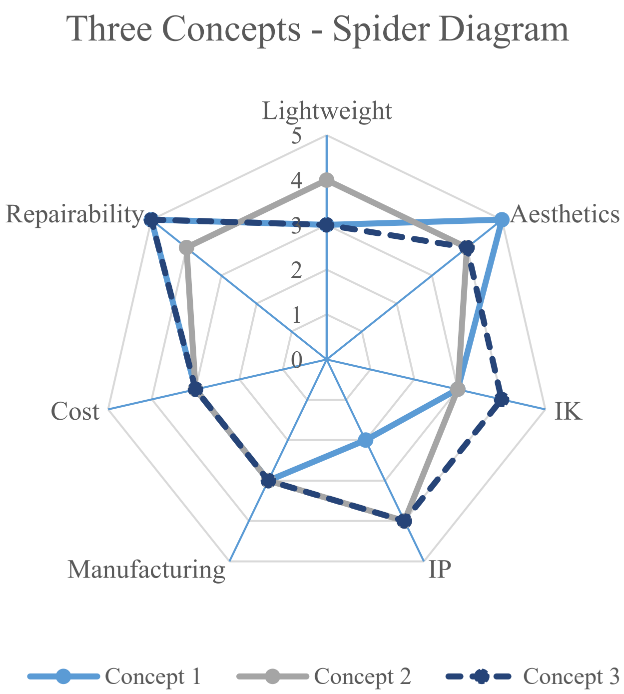

Figure 31 Spider diagram displaying the scores for each of the three concepts

From the scoring matrix and spider diagram, concept 3 was selected to be the final concept as it yielded the highest score. Concept 3 was therefore moved on for further refinement and finalization in terms of layout, CAD model and prototype.

4.5 Final Concept

4.5.1 PIR refinement

Once the PIR solution had been chosen, the solution was further refined to increase the IK classification possibilities of the sensor. In the selected iteration of the solution the lens sat recessed into the front plate of the product. However, this recess still allowed the lens to be dented by smaller objects including the 5 cm ball used in standardized IK testing. To improve the protection of the lens, while still providing an adequate field of view (FOV), the sensor and lens unit were angled slightly downwards. This was done as the sensor performs better the closer to the middle of its field of view a subject is located. According to the product specification the unit is mounted in such a way that the PIR would be located 2 meters above the ground. The product specification also determines the maximum horizontal distance to a person reading the display to be 12 meters. The center of the FOV should therefore be placed at half that distance, 6 meters.

To determine the angle α which is the angle that the PIR should be mounted in, the height for the center point of the FOV had to be decided. This was set to be 0,7 meters below the PIR as this corresponds to 1.30 meters above the ground which in turn approximately coincides with the upper body of most people. Below in Figure 32 a schematic image of the dimensions can be seen.

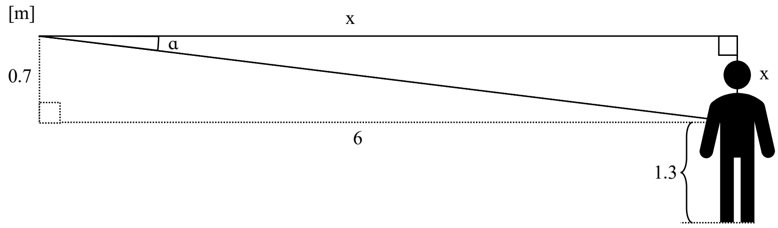

Figure 32 Dimensions to determine PIR angle

Once the angle had been determined, the front plate, PIR lens with FOV angles and IK test sphere were sketched up. The mounting angle of the pir was set to the determined angle α and the front plate was refined in CAD and physical prototypes to protrude in such a way that the IK test sphere could not contact the lens. To achieve this, some of the sensor FOV had to be obstructed. The obstructed area was chosen at the top of the FOV which at mounting height would be pointed into the roof. Attention was also given to the manufacturability of the solution since overhang existed. However, it was determined that it could be cast through the hole by adjusting the release angle. A cross section of the PIR mounted into the front plate with IK test sphere can be seen below in Figure 34. In Figure 35, the full view of the PIR and the FOV blocked by the front plate can be seen. Prototype for the lens refinement can be seen in Figure 33.

Figure 33 Picture of lowered PIR sensor concept.

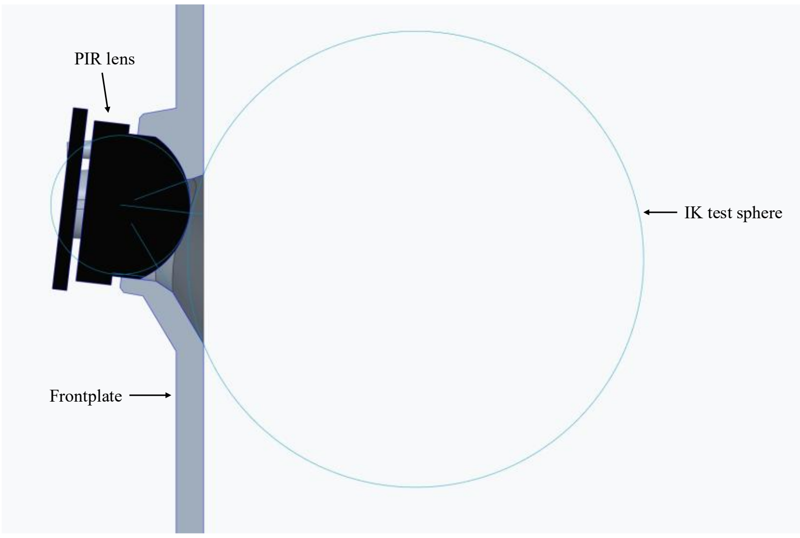

Figure 34 Cross section of PIR-solution with lens

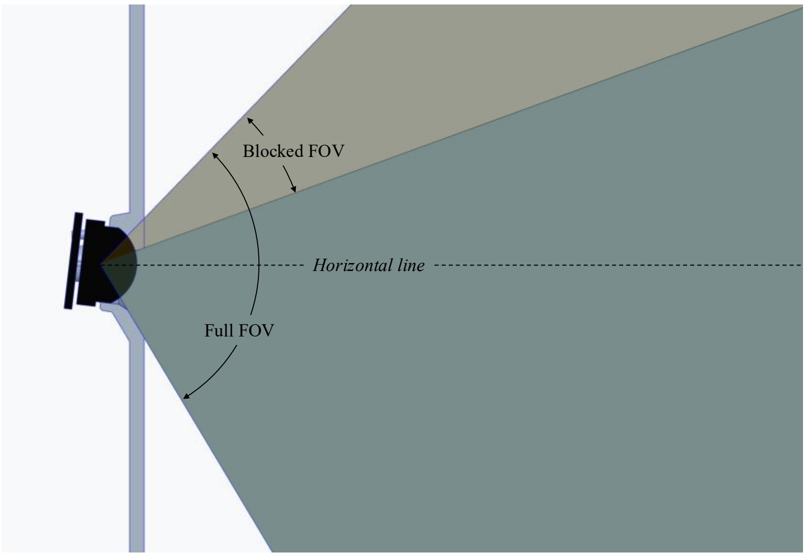

Figure 35 Cross section of PIR-solution displaying full and blocked FOV

4.5.2 PoE out

It was decided that the product should support a PoE out port, however, the power budget for the product when powered in the lower supported PoE classes such as 3 and 4 was very constrained. For example, the maximum strobe and screen brightness was throttled down in class 4 and the amplifier power was also reduced to conserve power and allow all systems to be powered simultaneously. Adding support for PoE was therefore not an option here. The options were therefore limited to only offer PoE out support when the unit is powered by PoE 6. As the power budget here was almost fully assigned, the power to the amplifier had to be throttled down when the PoE out port is in use.

When determining what PoE class to offer, class 3 was chosen as most of the peripheral devices that could be used here have support for PoE Class 3. This was also the largest PoE class that could be added without breaking the power budget of the unit.

4.5.3 Internal battery

To handle the strained power budget and cut the highest power peaks that limit the product in the lower PoE classes, an internal battery was added to the unit. Since the power budget was constructed to handle worst case situations where all components are activated at maximum allowed power at the same time, the unit was rarely under maximum load. Consequently, there was often available power and the new product was designed to use this available power to charge an internal battery that later could be used when the power available from the PoE connection was a limiting factor. For example, today if the unit is powered over PoE class 4 the power to the strobe is limited to 50% power, with the available battery power, the strobe can for a limited time be used at 100% power. Since the strobes are only used for shorter durations of time to call attention to the unit, the available battery power would be enough.

In PoE class 3 the original unit only had enough power for installation and updating the unit. However, when the unit was not under maximum load there was available power for charging a battery which could be used to power the strobe and display at the PoE class 4 level for a shorter duration of time to display messages in emergencies.

4.5.4 Material reduction

After deciding to continue with the two front plates, material usage in the back cover could be reduced. With the radial seal, the heel on which the previous front plate rested on could be removed, which resulted in thinner walls. The wall thickness decreased to 2.5 mm, resulting in a 25 % decrease in aluminum material. The measurements were performed with the CAD volume measurement tool. To ensure unity in the back cover piece, the model was reviewed and altered when needed, to eliminate drastic changes in wall thickness and- or unnecessary parts. Volume comparison is found in Table 17 in section 5.2.

4.5.5 Layout

To determine the final layout of all components in the product, miniature cutouts of all parts of the product were made. By arranging the components in different spots, several iterations of the products layout could be reviewed quickly. It was established that the PIR sensor should be located at the bottom of the product near the display, as it does not cooperate as well with the mesh as with the acrylic screen. Moreover, the strobe was to be at the top corners of the mesh, as it should be at least 8 cm from the display but also not block the LED indicator in the top middle. The microphone was placed in the electronics chamber in the middle, making it possible for the mesh to cover the port out. The speaker drivers should, from audio quality perspective, be irregular and close together, which was considered when determining the cutouts for the drivers in the front plate.

The overall shape of the product was decided to stay rectangular with portrait orientation, but with a larger radius in the corners because it would benefit the die-cast process and give the product a more unique look compared to competitors.

PCB placement was considered when deciding the layout, as it comes with restrictions as planar surfaces and weak points. However, most alterations regarding the PCB positioning came after final decision regarding components layout. The considerations resulted in a larger flat PCB located above the display, attached to the back cover via screw pillars. By having a flat PCB, the number of PCBs was able to be reduced to 3. For example, the microphone was previously set on its own PCB but now added to the main PCB. The area of the main PCB was set to be the exact value as that of today, to ensure all electrical components and circuits would fit.

4.5.6 CAD model

The CAD model was created in the computer program CREO parametric see Figure 36 and Figure 37. It followed the layout decided in the prevoius section. As the model was built, many alterations occurred due to lack space, draft requirements, tolerances and more. For example, the hanging bracket was originally meant to be borrowed from the current product, but with changes in radiuses, speaker driver placements, PoE ports etc, it had to be redesigned to fit the new form and layout.

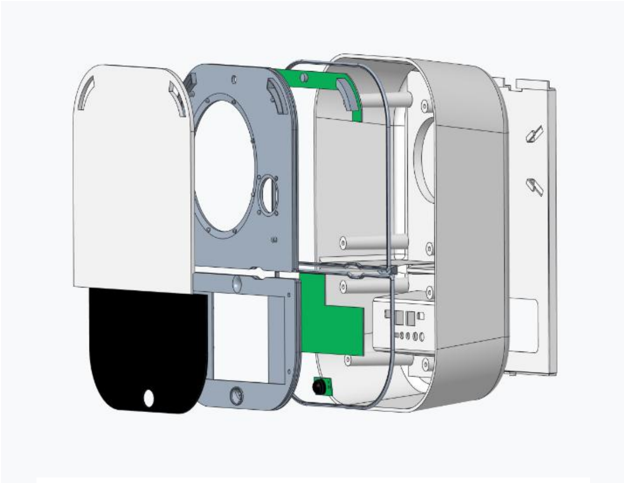

Figure 36 Final concept CAD model – Exploded view

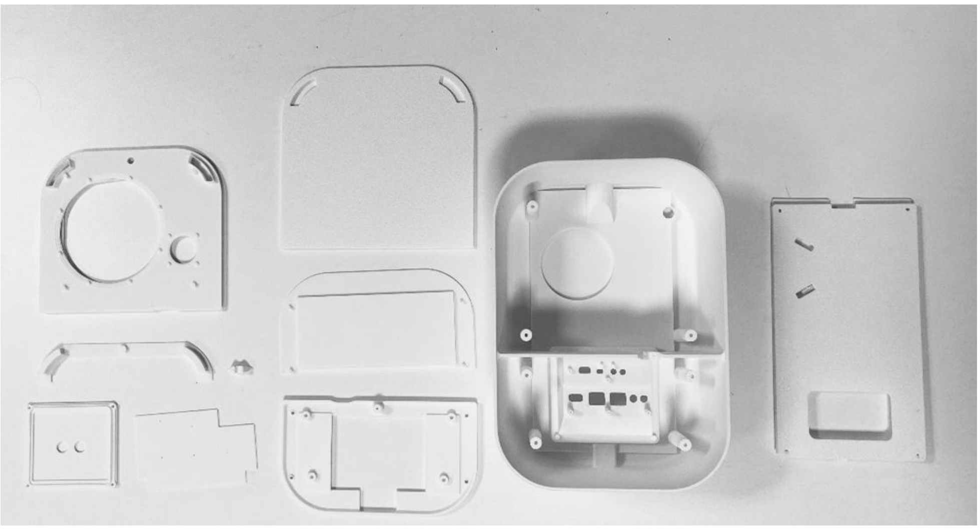

Figure 37 All CAD parts printed and arranged.

The model consisted of 9 bodies inside one part. The bodies were; Mesh, Display, Upper front plate, Lower front plate, PCB, Back cover, Port cover, Sealing bracket and Hanging bracket. In preparation for the prototype, a splitbody operation was conducted in the middle of the back cover, splitting the body into two see Figure 38. This was done in order to fit the piece inside the 3D-printer.

Figure 38 Split body operation results in 3D-printed model

4.5.7 Assembly tests

To fully understand and refine the assembly of the product, mock assembly tests were performed with 3D printed miniatures of all the components. During these tests the product was assembled in many different orders to fully understand the limitations and benefits of the different layouts. This gave valuable insight into overall component layout and allowed for a higher understanding of the manufacturing process, resulting in a product better designed for assembly.

4.5.8 Prototype

The prototype consisted of 3D-printed parts reflected in the CAD model, two speaker drivers taken from another speaker with their corresponding PCB, cables and electronics, a laser cut acrylic glass display spraypainted black, a grey synthetic fabric mesh and lastly silicone moulded seals. Parts were joined by either screws or glue. To show the display use case, a 3D-printed screen with clock example was added behind the acrylic sheet.

The prototype was powered via an ethernet cable and router, drawn behind the product via the outports and into the borrowed PCB from previously mentioned speaker. The prototype is showcased in the figures below.

a) Front view

b) Back view

c) Front view without mesh and screen

d) Closeup of strobe

e) Spraypainting the screen

Figure 39 Pictures of the prototype and process.

5 Final Concept

This chapter goes through the finalized concept.

5.1 The Concept

5.1.1 Body

The product consists of a main body cast from recycled aluminum in the shape of a rectangle 40,5 cm tall and 28,5 cm wide with a slight draft angle towards the wall and rounded corners with 8 cm corner radius. The unit is 11 cm deep from back to front with a wall thickness of around 2,5mm.

The internal structure consists of two main volumes, in the top volume the audio chamber is located, and the bottom volume houses the majority of the electronics.

Each of the chambers has a front plate covering its opening of constructed from machined die cast aluminum. Around the perimeter of each of the front plates a radial real is located which seals the chambers from penetration of water or dust, this is also the main seal of the audio chamber. Between the two front plates a wall is located, cable routing through this wall is done through a silicone seal that gets compressed by a cast aluminum block.

The front plates are attached to the main body using screws through screws towers from the back of the unit.

5.1.2 Speakers

The unit has two speakers, one 6-inch woofer and one 1.5-inch tweeter, these are IP certified and mounted using screws and a gasket. The two separate speakers can together deliver a SPL of 110 dB and have their main response around the 20 – 20000 Hz frequency range

5.1.3 Mesh

The mesh consists of a synthetic weaved fabric glued to a plastic plate with small holes in it corresponding to where the speaker drivers are located. The mesh covers the upper front plate, the separating wall between chambers and 2 cm of the lower front plate. The plastic plate is attached by inserting plugs cast in the aluminum front plate into marked holes in the mesh. A cross section of the mesh plug can be seen in Figure 40. Two holes are in the top corners of the mesh to enable strobe light guides to pass through. The mesh features a slight notch at the top of the product that is used for gaining leverage for removal of the mesh.

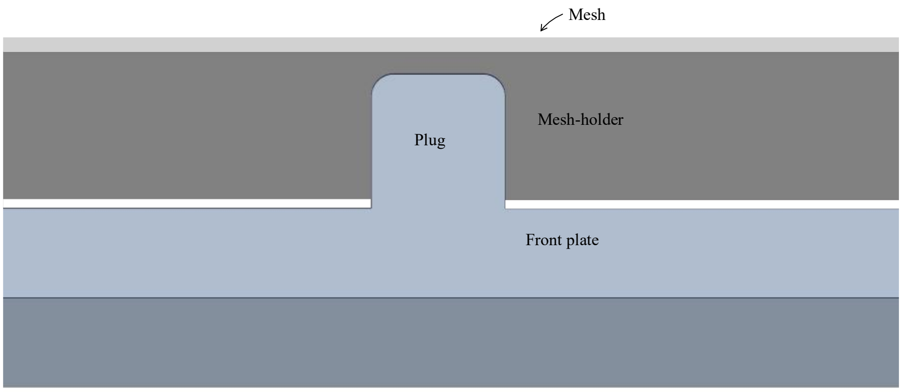

Figure 40 Cross section through mesh plug

5.1.4 Strobes

In each of the two top corners, a strobe is located. Each strobe consists of two multicolor led diodes mounted behind a lightguide that diffuses the light slightly, the lightguide seals against the front plate with the help of an axial seal. The strobe is curved offset to the corner radius and the distance to the screen allows for reading the display while strobes are activated at full power.

5.1.5 Screen

The display is an LCD screen with a size of 21,6 x 9,7 cm. It is attached by an adhesive as well as screws from the backside of the lower front plate that goes through the front plate and into solvent bonded acrylic screw pillars on the backside of the displays acrylic screen cover.

The screen background is customizable to any color or image, the screen can display either an analog or digital clock, date, weekday or other chosen information as well as rolling text messages.

5.1.6 Microphone

A microphone is located above the display in the bottom chamber and covered behind the mesh. The microphone enables full duplex two-way talkback functionality.

5.1.7 PIR sensor

The PIR sensor has a range of 12 m and a FOV of 105° to the sides. It is covered by a Fresnel lens in HDPE plastic material and mounted into the products bottom front plate under the screen.

5.1.8 Ports

On the back side of the unit the ports are located, these consist of 1x 3,5mm audio input port, RCA line out, 1x USB C port (for integration with an Auracast broadcasting device), 4x in and out (I/O) ports, 1x micro-SD card reader, 1x RJ45 PoE in, 1x RJ45 PoE class 3 out.

5.1.9 Classifications

The unit is designed to be IK07 and IP67 certified.

5.1.10 Internals

Inside the unit there are 3 PCBs, one main PCB that houses most of all components as well as the mic and the ports. At the top of the product one PCB is located, it houses the audio LED and ambient light sensor as well as two flashers. At the bottom of the unit one PCB is located which houses the PIR sensor. The three PCBs can be seen in green in Figure 41 below.

A small battery is located next to the main PCB. The battery is charged whenever there is available power and is used to boost functions for a short time when power demand is high.

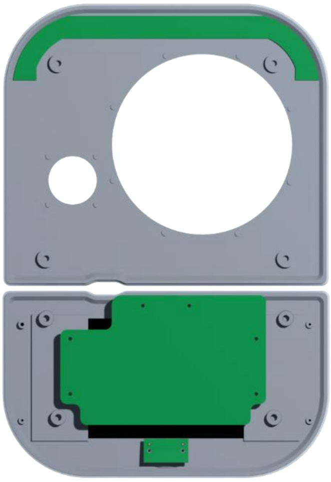

Figure 41 Front plates and PCB's

5.1.11 PoE Classes

The supported PoE Classes are 3, 4 and 6.

PoE 3, for class 3 the unit has support for installation and setup. The class also supports flashing the strobes and displaying a short message on screen.

PoE 4 (Standard mode), with class 4 the unit can play up to 100 dB SPL, continuously power the strobes, and continuously display messages on the screen. PoE 6 (Power mode), when powered by PoE class 6 the unit enters power mode and can play sound up to 110 dB SPL, the strobe is now twice as powerful and the screen is brighter. In PoE 6 the PoE out port is enabled and when in use the unit enters Standard mode however maximum display brightness remains the same as in power mode.

5.2 Comparison

Down below in Table 17 follows a comparison between the final concept and the current product. Most significant changes are the volume of back cover material, lowered PIR sensor, speaker and mesh type.

Table 17 Comparison table between current product and final concept.

	Current Product	Final concept
Volume Back cover material [mm³]	1070152	807282
Back Material	Aluminum	Recycled aluminum
Front Material	Aluminum	Recycled aluminum
Max sound pressure level [dB]	110	110
Frequency response	85 Hz - 20 kHz	<= 20 kHz
Display size (B x H) [mm]	219 x 55	216 x 97
Motion sensor	PIR sensor	Lowered PIR sensor
- Max Range	10 m	12 m
- FOV	105°	105°
Microphone	Yes	Yes
- Range	28 Hz -20 kHz	28 Hz -20 kHz
Streaming	Two Way, Full Duplex	Two Way, Full Duplex
Led Indicator	Yes	Yes
Signaling LED (Strobe)	Yes	Yes
Shape	Square	Rounded Square
Orientation	Portrait	Portrait
Drivers	Coaxial	Single
- No.	1	2
Speaker Size	8 in	6 in / 1,5 in
Mesh Material	Steel	Synthetic fabric / plastic
- Fastening	Snap fit	Plugs
Color	White	White
Sound Dispersion	120°	120°

6 Discussion

Here, the paper goes over a thorough analysis of a few selected activities.

6.1.1 Development process

The development process was based on the double diamond design process, with a few alterations. Generally, design processes are iterative, meaning it is unique for each project. For this thesis, it was decided that the iterative processes would be applied to different problem areas separately. This was to get a defined structure of the work but also to eliminate risk of the findings being dependent on each other. If the solutions generated in the development phase were unconnected, they could act alone and possibly be implemented elsewhere. It also benefitted the concept selection part of the thesis work, as they could freely be combined with each other.

Suitable amount of time was given to the different phases, with the development phase being the largest of them. However, this project would have benefitted from testing and validation of the concepts, as it could have provided concrete feedback on the functionality. This could have been incorporated into the development and delivery phase, or as an entirely separate phase at the end.

6.1.2 Market analysis

In the benchmark, one could see that the current product matches or exceeds most features regarding its competitors. A conclusion drawn from this was that no new version of the product could ever perform worse than that of the current product, as it must show improvement as its successor. It is also worth noting that the weight might be a problem, as it is almost twice as heavy as the other ones. Even though it is found from the interviews that the weight of the product is appreciated, from a sustainability perspective it is not to be preferred. It confirms that the product contains excess material and a heavy magnet for the driver to meet the requirement of 110 dB sound pressure. Higher weight also means heavier transportation, more demanding installation in both screws, mounting bracket but also human ergonomics, trying to hold it place.

Because the product already exceeds sound pressure, dispersion, frequency response etc. a second version might not focus on those areas but rather on other aspects such as IK, IP and reduced weight.

6.1.3 Analyzing interviews

Many different approaches were used for analyzing the data generated by the interviews. This was done to get an impartial conclusion from the different opinions brought up in the interviews. This project did not fulfill this need, because many decisions were based on subjective discussions between the team members. Because the team members were new to designing audio products in general, validation of content from the interviews was somewhat difficult to complete. Especially since matters discussed in the interviews often referred to subjective opinions like where a certain component should be located. These types of suggestions have no right or wrong answer, meaning a fully objective evaluation was impossible.

Furthermore, some interviewees were counted twice, as their interviews were conducted in groups. This means that a statement could be counted as mentioned twice, even though it only surfaced in one interview. This gave a false picture of how many times a statement was mentioned, affecting the statistics of the quantitively basis for the priority list. With this said, the team kept this in mind when comparing the different problems against each other, to compensate for the unfairness of this advantage.

6.1.4 PIR study

During the test of potential new PIR lenses it was observed how the unit detected the same person at different distances depending on which lens was used. The lenses which performed the worst regarding detection range were the thick and the thin HDPE sheets where the thick had the shortest detection range. This could stem from the fact that for these lenses the IR radiation had to travel through two layers of HDPE, first the flat sheet, then the currently used Fresnel lens. Since a portion of the light is lost every time it travels through the HDPE, this would result in a reduced amount of light reaching the sensor.

This hypothesis is further backed by the fact that when observing the raw sensor output, which later is used as input into the decision logic, the reading was overall lower for the HDPE sheets than for the rest of the lenses. Since the decision logic is tuned to the regular, higher, output that is reasonably the source of the shorter detection range. That would also mean that with software tuning and/or signal conditioning with amplification the detection range could be extended. However, this could also increase the sensitivity and impact noise levels. On the other hand, potential consequences would be a false positive detection resulting in the screen activating while the impact could be regarded as low. To verify the theories about software tuning and/or signal conditioning further testing would be needed.

For higher accuracy further testing of the lenses should also be done in a larger room to observe the true maximum range. The room in which the test was conducted was limited to 12 m long, and some lenses showed detection at the very end of it. This suggests that lenses could have longer detection range than 12 m. To get better accuracy in the observations of the width of the detection area a wider room should also be used. Further testing should also include multiple different people of different sizes as in our tests the same person was used to test all lenses.

6.1.5 Driver study

Worth noting is that the data in Table 12 originates from one website alone and for drivers that handle the requirements all on their own, meaning the same effect could be fulfilled by having multiple drivers, as to handle different frequencies. Furthermore, the specifications for the drivers did not take back-volume, type of system, power available or other environmental aspects that could affect their performance into consideration. Therefore, these results should not be evaluated after performance, but rather as confirmation that options for the current driver exist.

Setting the woofer to 6 inches in the separate driver concept came with both advantages and drawbacks. A smaller driver could yield more space in the audio chamber, better tolerances of the cutouts in the front plate, and a lower weight. However, a smaller magnet will also limit the audio quality or sound pressure. To meet the requirement of 110 dB, the speaker would have to compensate with the frequency response. This would mean that lower frequencies would probably be affected negatively and not be accounted for in the frequency response. This project prioritized sound pressure over qualitative base sounds, but if one were to need both, a larger magnet and diameter of woofer would be needed.

6.1.6 Prototyping

From the prototyping stages, a lot of lessons could be learned regarding the finalized design. Firstly, tolerances were small and more times than not, parts did not fit together satisfactory. This could be because of the 3D-printing, as printers do not create perfect replicas of CAD models. However, it does show that tolerances might be a problem in the future if this were to move into real production, since die-casted parts does not produce perfect tolerances either. Because of this, all critical dimensions were reviewed in the CAD model and altered to be more resistant to mistakes in production.

Moreover, it was clear during assembly of the prototype that many screw pillars were missing. This caused the prototype to be either re-printed or glued. Re-printing parts is not to prefer as it contributes to wasteful prototyping, and glue is not as strong as screwing the part together, making it more fragile. This project leaned more towards gluing the parts together, leaving the prototype somewhat unstable. However, since it was primarily used for demonstration, it was considered acceptable.

Further mistakes in the CAD part were bodies overlapping each other, primarily the speaker driver and front plate, creating faulty differences in height between the two plates, hindering a flush top surface. The PCB part in the CAD model was also not large enough to cover all outports. Mistakes were reviewed and altered.

Besides missed aspects in the CAD model, the moulding of the silicone parts did not turn out optimally. Because of the wide area the silicone sealing covered, an open mould was used. This caused the silicone to flow in the wrong direction, causing the part to lose volume. Lost volume in the silicone seal meant it was too small to seal the front plate on its own and had to be glued in place. Therefore, a second attempt at the silicone seal was made, with some alterations in the mould part which resulted in a much smoother and fuller part not in need of glue.

6.1.7 Material reduction

While working on the design of the back cover attention was given to reduce the amount of material used whilst keeping the structural integrity of the unit. It was found that the material in the back piece decreased with 25 %, a significant amount considering it was kept the same size as the current product. Reducing material in the back piece greatly improves the environmental impact of unit, as one could now get 5 units for the same amount of material as 4.

The reduced material also provides a lighter weight, especially with the smaller magnet in the 6-inch driver. A lighter product is beneficial for the aspect of transport both environmentally as less energy is required but also in terms of cost, since a lighter product is cheaper to transport.

For further development and reduction of material a topology optimisation should be conducted which could reveal additional areas where material could be reduced. This should be conducted in conjunction with a structural simulation to verify the structural integrity of the product.

Further, resonance and modal simulations should be conducted to analyse whether the audio chamber needs additional stiffening.

6.1.8 Adding internal battery

An internal battery was added to the unit with the purpose of shaving off the highest power peaks and allowing for extended function during high power demands. The development of the exact battery system was outside the scope of this thesis and was therefore not developed beyond concept phase.

When developing the battery circuit, considerations must be made about what type of battery should be used, or whether alternatives such as supercapacitors should be used instead. Factors such as physical space, battery capacity and price should be taken into consideration.

Other considerations that must be made is how the charging circuitry should be constructed, which of course depends on the chosen battery solution. Another circuit should also be able to determine when to charge the battery and when to use the battery power.

Possible problems that could be encountered when adding an internal battery is certification of the product as adding a battery could come with the need for further certification. Other affected factors, depending on chosen battery, could be transport of the product since an added battery could impact the available possibilities with transport.

Furthermore, the factor of total battery life such as total number of charge cycles must be taken into consideration as this could be a limiting factor for the total length of the entire products lifecycle. This is of course highly dependent on the projected charge-discharge cycles of the battery during its life.

6.1.9 Adding PoE out

PoE out was a feature that was mentioned multiple times during the interviews and was deemed important in the exploration phase of the process. As the power budget for the unit in the lower PoE classes was rather constrained, adding PoE out was not an option. When the unit is powered by PoE class 6 however, an option to add support for a PoE out port of class 3 was seen. The development of this PoE port was outside the scope of the thesis and therefore left to future work.

Considerations to make when developing this solution further is among other things; how to handle the produced extra heat, how to detect when the port is in use and how to handle the data sent to and from the powered device.

6.1.10 Contribution

From this thesis, several contributions were found in terms of design choices, added features and innovative solutions.

The strobe test gave a confident result in where a strobe should ideally be placed regarding a screen. Depending on size and power of the strobe, results might differentiate. However, it is clear that the strobe is not compatible with displays at a short distance, as they impede readability. For this project, the strobe had to be at a minimum of 8 cm away from the screen.

In addition to this, the project has come up with a solution for protecting the PIR sensor. By sinking it into the front plate, the sphere in which they use for IK classification is now unable to reach the lens, hindering it from being damaged. This design blocked some of the FOV but since it was the top part of the view and the unit is hung on the wall, its functionality is preserved.

Continuing with the design alterations, this project investigated fastening the screen display mechanically with screws. It was found that it could be screwed in place if threaded acrylic screw pillars were attached to the display through solvent bonding. Although it adds steps to the manufacturing process, it yields multiple benefits like ability to rework and exchange the screens as well as more secure fastening.

Another design choice was to add a fabric mesh instead of a metal one. The fabric does not only reduce ringing and protect the driver from dust, but it also gives a warm and soft feel to the product, making it suitable for school environments.

The internal battery is another added feature that improves the concept, in the sense that it expands the power budget for a limited time. The team members see potential in this feature as it opens more future possibilities such as larger screens, higher sound pressure or even more added features.

7 Conclusion

This project developed a new concept for network display speakers in collaboration with a large global company. The concept consisted of two speaker drivers and a large display screen, modified and added features such as outside capabilities, PoE out ports, motion sensors and more.

The aim of the project was to develop a concept based on aspects like

- Sustainability
- Classification
- Ease of manufacturing
- Customer feedback
- Inclusive design
- New features

Some areas were given more attention than others. For example, ability to get the product an IK rating of IK06 or IK07 as well as an IP certification, were two of the leading forces behind choices made. From a sustainable perspective, the product was able to decrease its material usage and weight thanks to the radial seal and smaller driver. However, it could have been even less if a topology optimization were to take place, as it could further reduce aluminum usage.

Customer feedback was a prospect this project had trouble finding, as the current target market is the education system in the US. Moreover, the product has only been on the market for about a year, meaning the company has not received enough feedback from the customers yet. These two aspects made it difficult for the team to gather information on what the users wanted and needed.

Inclusive design can be seen in the larger display to increase letter size and the relocated strobe to ease visibility of the screen. The concept contains a USB-C port, making it possible to implement tools for assistive listening systems in the future.

Future work should include testing and validating the new features to confirm progress. It should ideally be tested for audio quality, IK rating and IP rating. A user test could also be favorable to observe how a user interacts with it. The results should be compared to the latest version for clear assessment.

Moreover, it should include the development of new concepts included in the solution such as the internal battery, combined circuit boards and PoE out support. This development process should also include testing, validation and certification.

Finally, this project followed a double diamond design process but modified it to be divided into smaller sup-projects, handling somewhat different problem areas. This benefitted this project well as it aids incorporation of the generated concepts to other products as well. Since they were developed separately and independent of each other, they are easier to adapt and be of use elsewhere as well. This thesis wants, as a final remark, to highlight the importance of this type of process, and encourage others to do the same.

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Appendix A

Intervjufrågor

Presentera oss och berätta att vi sitter med att ta fram ett nytt koncept för produktens mark 2. Just nu är vi i processen av att intervjua många som möjligt för att få bred kunskap om produkten. Ställ varför frågor! Intervjuerna är tänkta som kvalitativa och behöver därför inte se likadana ut beroende på vem man snackar med.

Datum:

Exempelfrågor

Vad heter du och vad är ditt huvudsakliga område som du jobbar med?

Vill du berätta mer om vad det innebär (dvs arbetsuppgifterna)?

Har du jobbat med produkten, om ja, vad jobbade du med i så fall?

Fanns det några intressanta spår som inte undersöktes/ som valdes bort?

Om du fick bidra med din expertis, vad hade du velat mecka med i produkten?

Vad är dina åsikter om produkten?

Tror du att produkten fungerar bra i dess uttänkta användarområde?

Vilka är produktens styrkor?

Saknas någonting med produkten i din mening?

Vad är överflödigt med produkten?

Om du skulle ge oss ett enda tips, vad hade du sagt?

Om vi skulle sätta ihop en design guidelines, vad tycker du är viktigt att ha med i en sådan?

Vilka fler personer skulle du rekommendera att vi pratar med?

Appendix B

Seals

Criteria	Reference	1	2	3	4	5	6	7	8
Separate chambers	0	+	+	0	0	0	0	0	0
Simple	0	0	0	0	0	+	+	0	+
No screws	0	+	0	0	0	0	0	0	0
Standardization	0	0	0	0	+	0	0	0	0
Easy manufacturing	0	0	0	+	0	+	0	+	+
Material	0	+	+	+	0	0	0	0	0
Backvolume	0	+	0	+	0	0	0	0	0
Few parts	0	0	-	0	0	0	0	-	0
Sturdy /strong	0	0	0	0	0	0	0	+	0
Easy rework	0	0	+	0	0	0	0	0	0
PCB space	0	-	0	+	0	0	0	0	0
Radial seal	0	+	+	0	0	-	-	0	-
Proven method	0	0	0	0	+	0	0	0	0
Compatability	0	0	0	0	0	0	0	+	0
All direction seal	0	0	0	0	0	0	0	+	+
Cheap	0	0	-	0	-	0	0	0	0
Small	0	0	0	0	-	0	0	0	0
Other risks	0	-	-	---	0	0	0	0	-
Audio quality	0	-	0	0	0	0	0	0	0
Sum +’s	0	5	4	3	2	2	1	4	3
Sum 0’s	19	11	12	13	15	16	17	14	14

Sum –‘s	0	3	3	3	2	1	1	1	2
Net score	0	2	1	0	0	1	0	3	1
Continue	Continue	yes	yes	no	no	yes	no	yes	yes

PIR

Criteria	Reference	1	2	3	4	5	6
Easy	0	+	0	0	+	+	0
Flush	0	0	+	+	+	+	+
Performance	0	+	-	-	+	0	0
No adhesive	0	0	-	-	0	0	-
Robust	0	0	0	+	+	0	-
Small	0	0	0	0	0	+	0
Aesthetic	0	0	+	+	+	+	+
Same components	0	+	0	0	0	0	0
Sum +’s	0	3	2	3	5	4	2
Sum 0’s	8	5	4	3	3	4	4
Sum –‘s	0	0	2	2	0	0	2
Net score	0	3	0	1	5	4	0
Continue	Continue	yes	no	no	yes	yes	no

Mesh

Criteria	Reference	1	2	3	4	5	6	7	8
Secure	0	-	+	-	+	0	0	-	0
Simple	0	0	0	0	0	0	+	0	0
No Noise	0	+	-	0	0	0	+	+	0
Standardization	0	0	0	0	0	0	0	0	+
Easy manufacturing	0	+	+	+	+	+	0	+	+
Compatibility	0	0	-	0	0	-	0	-	0
Clear feedback	0	0	+	-	0	0	0	0	0
Few parts	0	+	0	+	-	-	-	-	-

Sturdy /strong	0	+	-	0	+	0	-	-	0
Easy removal	0	+	-	+	+	+	-	+	+
Sustainable	0	-	0	0	0	0	0	0	0
Cheap	0	-	+	+	+	0	+	+	+
Proven method	0	0	0	0	+	0	0	0	+
Premium	0	+	0	0	0	0	-	0	0
Customizability	0	0	0	0	0	0	0	-	0
No Tape	0	-	-	+	+	0	0	+	-
Long lasting	0	+	0	+	+	0	-	+	0
Aesthetic	0	0	0	0	-	0	-	+	0
Dustproof	0	0	0	0	0	0	0	+	0
Sum +’s	0	7	4	6	8	2	3	8	5
Sum 0’s	9	8	10	11	9	15	10	6	12
Sum –‘s	0	4	5	2	2	2	6	5	2
Net score	0	3	-1	4	6	0	-3	3	3
Continue	Continue	yes	no	yes	yes	no	no	yes	yes

Display

Criteria	Reference	1	2	3	4	5	6	7
Material	0	0	0	0	-	0	0	0
Secure	0	-	0	-	0	+	+	-
Simple	0	+	+	0	+	+	+	+
No Noise	0	0	0	+	+	+	+	+
Standardization	0	0	0	+	0	+	+	0
Easy manufacturing	0	-	-	0	0	-	+	+
Space efficient	0	0	-	-	0	-	-	+
Solvent bonding	0	+	+	0	0	+	0	0
Compatibility	0	0	0	0	-	0	0	-
Clear feedback	0	+	+	0	0	0	0	0
Few parts	0	0	0	0	0	-	-	+

Sturdy	0	0	0	0	-	-	-	-
Same process	0	0	0	0	+	0	0	+
Sum +'s	0	3	3	2	3	5	5	6
Sum 0's	13	7	7	8	7	4	5	4
Sum –'s	0	2	2	2	3	4	3	3
Net score	0	1	1	0	0	0	2	3
Continue	Continue	Yes	Yes	No	No	No	Yes	yes

Appendix C

Work distrubution

Both members of this team have contributed significantly to all aspects of the project. The discussions held throughout this report have acted as the primarily basis for all choices, evaluations, developments and refinements. It is thereby safe to say that both Linus and Ella have set their mark in all parts of the thesis.

With this said, the responsibility of certain parts has been divided to the members, for an effective workflow. Linus had the primarily responsibility for testing of PIR lenses, researching new solutions, 3D-printing and refinement of the new features such as for example PIR and sealings, while Ella focused more on defining needs and the technical specification, CAD modelling, sketching and prototyping.

Appendix D

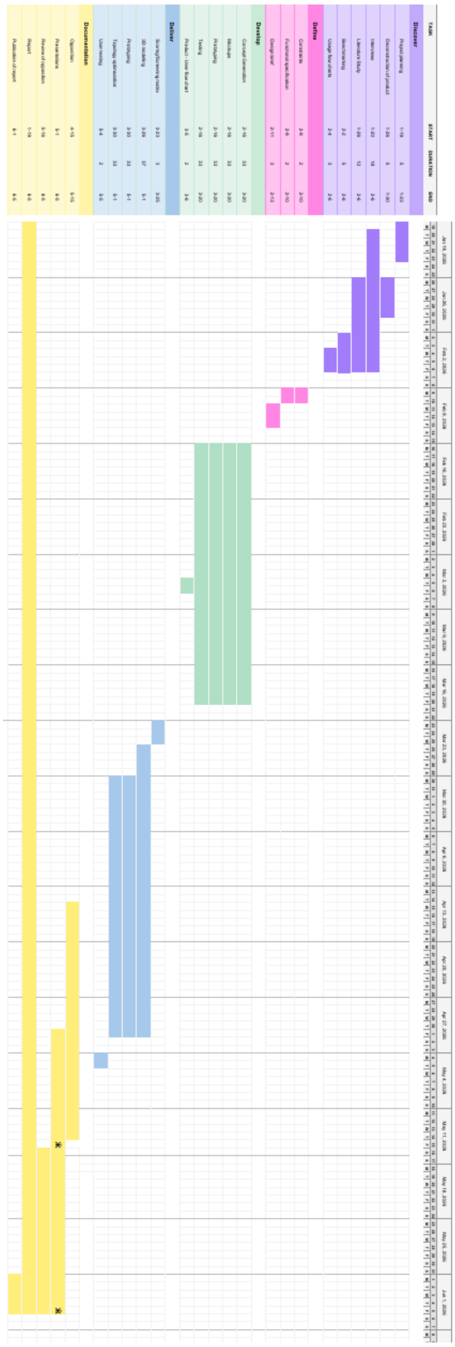

Figure 43 Initial Gantt project plan

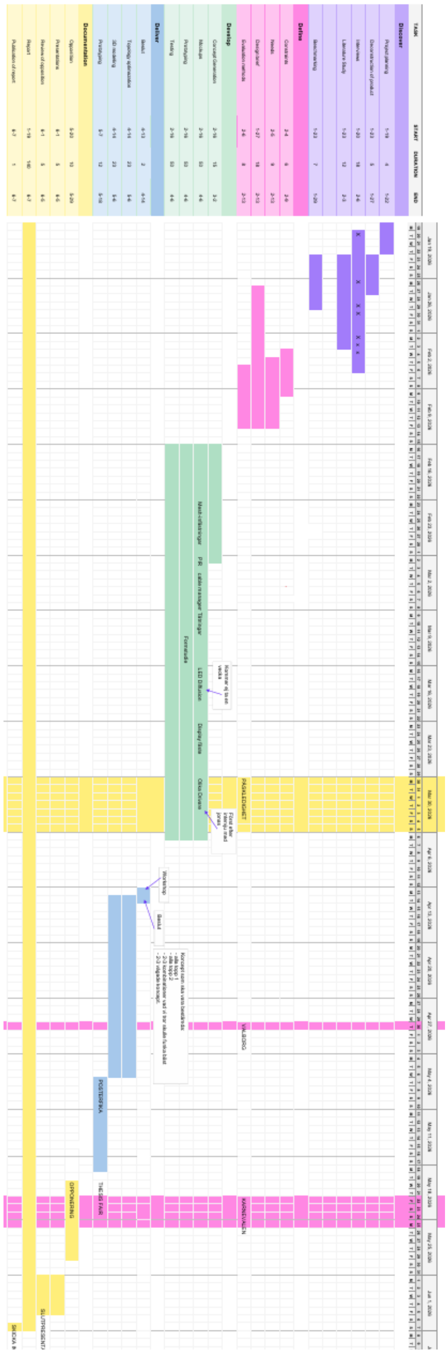

Figure 42 Actual Gannt project plan