Increasing awareness about the influence of

Air Quality & Noise

on WELL-BEING

GRADUATION THESIS OF JOZET AERTS
MSC INTEGRATED PRODUCT DESIGN

TU Delft

INCREASING AWARENESS ABOUT THE INFLUENCE OF AIR QUALITY AND NOISE ON WELL-BEING.

Master Thesis

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SUMMARY

Introduction

About 6% of the total burden of disease can be accounted to influences of the natural environment on well-being. Part of the problem is the unawareness of people about these influences. Health can be defined as "a state of complete physical, mental and social well-being and not merely as the absence of disease or infirmity". In order to improve well-being, people first have to reflect on the current situation and therefore become aware. Therefore, the goal of the product is to increase awareness and give people the knowledge to make different or better decisions. Studio Überdutch saw potential in measuring, interpreting, processing and adjusting the quality of the living environment. As a result, this project was initiated.

Analysis

A definition of a healthy living environment was established and can be seen as "an environment that is experienced as pleasant, invites to healthy behavior and where health pressure is as low as possible". This environment consists of many variables that together determine the quality. Different variables were chosen to explore, that could be measured with the use of sensors. It was seen that many variables can have negative influence on well-being, but besides physical effects, there were also many psychological effects. One of the psychological effects is stress, causing the need to measure subjectively on the experience of variables as well. Not all variables can be directly noticed, which makes it more difficult to be aware about them. Five categories in contexts were distinguished: recreation space, working space, private space, public transport and public spaces. Besides these, there was also a difference between indoor and outdoor contexts. It was seen that as an individual little influence can be exerted on variables in public and recreational spaces, both indoor and outdoor.

In the trend analysis it was seen that there is a big focus on data gathering and making this data "smart". Turning the quantified self in the quantified us provides valuable data about groups of people. In the end of the existing products analysis, it was seen that there are many products that measure objective variables and only little that measure subjectively. Furthermore it was seen that most products have a very technical appearance and provide feedback in numbers or with colors. It was concluded that there is an opportunity in exploring the area of measuring subjective input in combination with objective measurements.

Project Scope

It was found that the variables that have most impact on human health are air pollution and noise. Based on the outcomes of the influence of the different variables, a look was taken at the influence of stress on well-being. Being able to cope with environmental stressors can only be done when being aware of the interpretation of the stressor. At this point it was decided to measure air pollution and noise for the rest of the project, both objectively and subjectively. The context for which the product will be made will be the city center and specifically the influence that outdoor variables have on the indoor quality of the living environment. This led to the following design vision:

"I want to design a product-service system that measures the quality of the air and the level of noise to provide feedback to the citizens of a city (in this case The Hague) to make them aware of the quality of their living environment and its impact on their well-being in order to increase making well-informed decisions."

Conceptualization

During the project scope phase, a concept direction was chosen, being a product connected inside and outside the home environment to measure air quality and noise. This means the products will consist of two parts, Part A for indoor and Part B for outdoor. Possible positions for attachment were considered, as well as different types of windows. Inspiration for a way to provide feedback was found in other products. With this inspiration, two improved concepts were created: AirPort and VisionAir. Both were analysed and scored based on stated requirements and it was decided to continue with VisionAir. This concept was mainly further developed on giving feedback and collecting input. The final concept consists of two parts attached on opposite sides of the window. Feedback will be given by indicators in a transparent ring and

input will be collected by touch. This concept was validated by a user test. From the user test it was concluded that the product can increase awareness on the level of air quality and noise, but that the experienced need for providing input is missing.

Embodiment

The product was further detailed and consists of six main components: measurement of air quality, measurement of noise, subjective input, communication, power supply and the housing with attachment. An optimization was done on the air quality and noise level indicator to reduce the amount of space taken. The use of the product was considered in the amount of times the product is active per day which provided the opportunity to calculate current use. From this, a power source was determined, being batteries in combination with a solar panel for the outdoor part and rechargeable batteries for the indoor part.
All of the components were modeled and brought together in a final model, that was optimized for its size.

Final design

With the use of the validation outcome, a final design was created. Changed aspects were: the feedback on air quality and noise is supported by colored lights, improved mechanism to drive the indicators and a new location to provide input. Besides the physical product, there should be a coexisting app in order to take full advantage of the product and get more insights. The product cost for the total product will be €161,33. It is recommended to do more tests on the feasibility of the product and the user interaction.

It is concluded that the product can contribute to the awareness of air quality and noise and that a municipality can learn from the subjective input given by the user.

Evaluation

The final design provides a valuable tool in becoming aware of air quality and noise. However, the value for providing subjective input is not clearly seen by the users. The product could be sold business to business, with a strong support for the subjective input.

Two factors made this graduation assignment very challenging, the broad scope and getting a grip on the technical details of the sensors. Eventually all came together in the final product.

PREFACE

This thesis is the result of my graduation assignment fot the master Integrated Product Design at the faculty Industrial Design Engineering at Delft University of Technology. The goal of the project was to find out what natural variables have an influence on human well-being and how these can be measured and communicated to an intended user.

The project was formulated by Studio Überdutch as they saw an opportunity in sensing technologies and wanted to explore this. It was a challenging project, but I hope there are valuable insights that can be taken away from this.

Doing the project on my own was my biggest challenge, but luckily I had a great supervisory team, company and friends & family who supported me.

First of all, I would like to thank my supervisory team of the TU Delft, Henk Kuipers and Natalia Romero Herrera for their help and patience throughout the project. Sometimes I would come to the meetings a little bit lost or frustrated, but you always made me leave with a good feeling.

I would like to thank Studio Überdutch for providing me the opportunity to do my graduation assignment for their company. Besides learning a lot about my own project, I have also learned a lot about the projects they work on.

Furthermore, I would like to thank all of my friends and family, who have supported me through this project. For cheering me up, listening to my frustrations and excitements, helping me find my structure and ofcourse the coffee breaks.

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1. INTRODUCTION

The first chapter presents the nature of this project, namely the influence of the natural environments on human well-being. The problem definition will be stated, after which the assignment will be explained. The assignment was initiated by Studio Überdutch, who will be introduced in chapter 1.3. Finally, the approach for the project will be explained.

1.1 PROBLEM DEFINITION

The conditions on the planet are changing, with as a result a rise of temperature and more extreme weather conditions. Besides this, cities continue to grow because more and more people are moving to the cities. As a result, these growing cities have changing environmental variables. Air composition, level of noise, the amount of green surroundings, local hotspots and so on, are all changing. Because of this change, every human being is affected by the living environment. However, not every living environment and every variable has the same level of impact.

In the living environment there are many variables that determine the quality of an environment. All together they influence people's well-being. This influence can be either negative or positive effects on human health. In the Netherlands, almost 6% of the burden of disease is due to environmental factors with in particular air quality and noise (see **Figure 1**). Out of this 6%, the biggest factor is particulate matter (PM2.5) with 77.1%, after which traffic noise has a second place with 7.2% and third place is for second hand smoke with 6,9% (Hänninen & Knol, 2011). Accounting for almost 6% of the total burden of disease, puts the environment in the top three of main causes of the total burden of disease (RIVM, 2014; Hänninen & Knol, 2011).

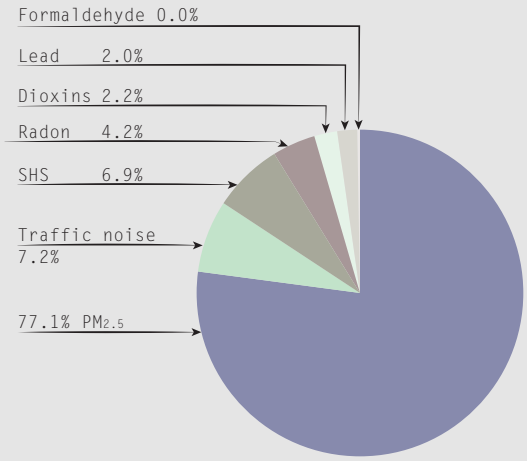


Figure 1 | *DALY's per million in the Netherlands (Hänninen & Knol, 2011)*

On top of the influence of the environment on people's health, there is also the issue that most of the time people are not even aware of the possible negative impact. One of the reasons for this is that people do not experience the variables consciously, although it is clear that there are real consequences for the impact on people's health.

One way to improve the well-being of human beings, is to make them aware of the influences of their surroundings on their well-being. People have already strived to obtain self-knowledge for a very long time (Li, I., Dey, A., & Forlizzi, J., 2010). Especially regarding health, collecting data is increasingly being done, for instance with the help of activity trackers such as Fitbit or apps to track eating habits. By making people aware that they are doing something that might harm their well-being, they can make different or better decisions. This can be seen as a trend called Quantified Self and is all about collecting, interpreting and acting upon data gathered. According to Li (2010), people first have to reflect on the current situation before they can act upon it. However, data can be difficult to interpret, resulting in people becoming afraid or lose their interest. People can start feeling loss of control in case they are aware that their surroundings are bad but they cannot influence this.

Measuring the variables provides objective data, however the problem is that every individual has its own subjective perception, preferences and vulnerabilities to the variables in an environment.

Therefore, it is also important to find out how these variables are perceived by the occupants, resulting in subjective data. Since every individual has its own subjective perception conflicts can be caused in shared spaces, making it a challenge to please everyone. Besides the difference in perception there is also a difference in the level of influence one can have on each variable. Influencing variables indoor is easier than outdoor, since it is an enclosed space. In case influencing a variable is not possible, opportunities can be found in providing insights in possibilities to respond to the environment.

1.2 ASSIGNMENT

"Design a product that collects data from the living environment and its occupants in order to provide informative feedback to the occupant in order to make well-informed decisions on how to improve their well-being."

The main question that arises from this assignment is to find out how people are being influenced by their environment. Therefore a research question was stated as follows:

"What is the impact of the environment's quality on people's well-being and what are the variables that have an impact?"

First of all, in order to understand how the environment influences human well-being, it has to be understood how well-being can be defined. There are many different definitions for defining health and well-being, however the definition by the World Health Organization (WHO) defines health as follows: ""health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". Also, according to Dodge, R. et. al (2012), stable well-being can be seen as a balance between faced challenges and available resources including psychological, social and physical resources to meet a particular psychological, social and/or physical challenge, this can be seen in **Figure 2**.

Most of the variables have an effect on either the psychological or the physical well-being of people. Besides, the psychological effects can cause physical effects and the other way around. During this project it is chosen not to include the social effects of the environment.

The different variables have a different impact regarding long or short term exposure. For some variables short term exposure with a high intensity can be very damaging while for others longterm exposure with a low intensity can be just as bad. To find out what effect each variable has on well-being, what is already done to measure these and how this is currently being communicated, the following questions will be asked:

- Which variables determine a living environment's quality?
- What are the effects of these variables on human well-being?
- Which variables can be influenced by the user?
- Which variables are already being measured and in which environments?
- How are these outcomes communicated to the user?
- What insights does the user want that they don't get now?

In the end, the goal of the product is increase awareness on the influence of the environment on people's health to make sure they will make different or better decisions. That way, the desired consequence is that their well-being will increase.

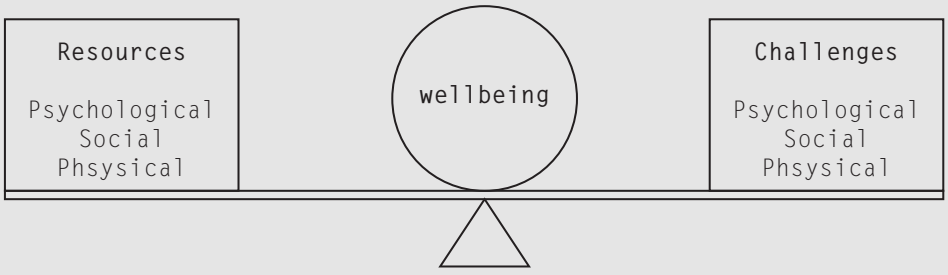


Figure 2 | *Definition of well-being (Dodge, R., et. al, 2012)*

1.3 STUDIO ÜBERDUTCH

This graduation assignment was initiated by Studio Überdutch, an interior and product design studio situated in The Hague. As a design studio they work on assignments for other companies, as well as on their own products. While working on a project they saw a great potential in measuring, interpreting, processing and adjusting the quality of a living environment. Therefore they initiated this assignment to create a product that contributes in this area. Studio Überdutch is a small company existing of three employees. Since they are a rather small company they have experience in outsourcing the production of components for their products or projects.

Interior design

In the past they have designed interiors for office, retail and leisure environments, see **Figure 3**. They translate Brand Identity into spaces and products. Their aim is to bring products to a next level.

Product design

They have created products for different brands and clients. At the moment they are working on their own insect hotel, created to contribute in saving the bees. Most of their products are created for the business to business market. They mostly use existing technology, but manage to use this in an innovative way.

The goal for them is to get informed on what variables are most important for an environment's quality and how to measure this.

One of the potentials of the product is to be combined with existing products of Studio Überdutch or to be implemented in one of their interior designs. The interior designs they create can be distinguished in retail, leisure and office spaces as can be seen in **Figure 4**. The products they have created are mostly for public spaces either indoor or outdoor.

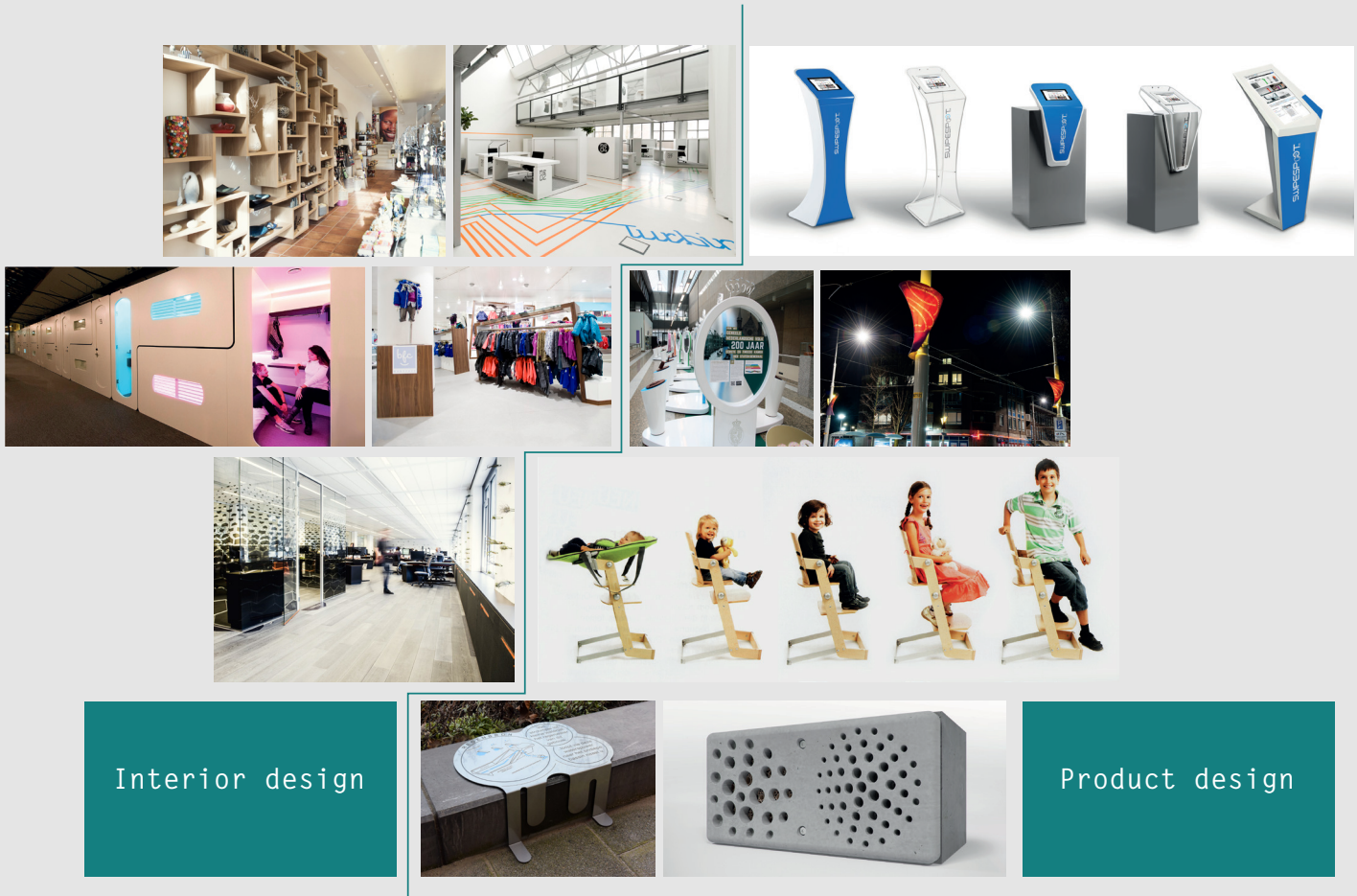


Figure 3 | *Studio Überdutch design portfolio*

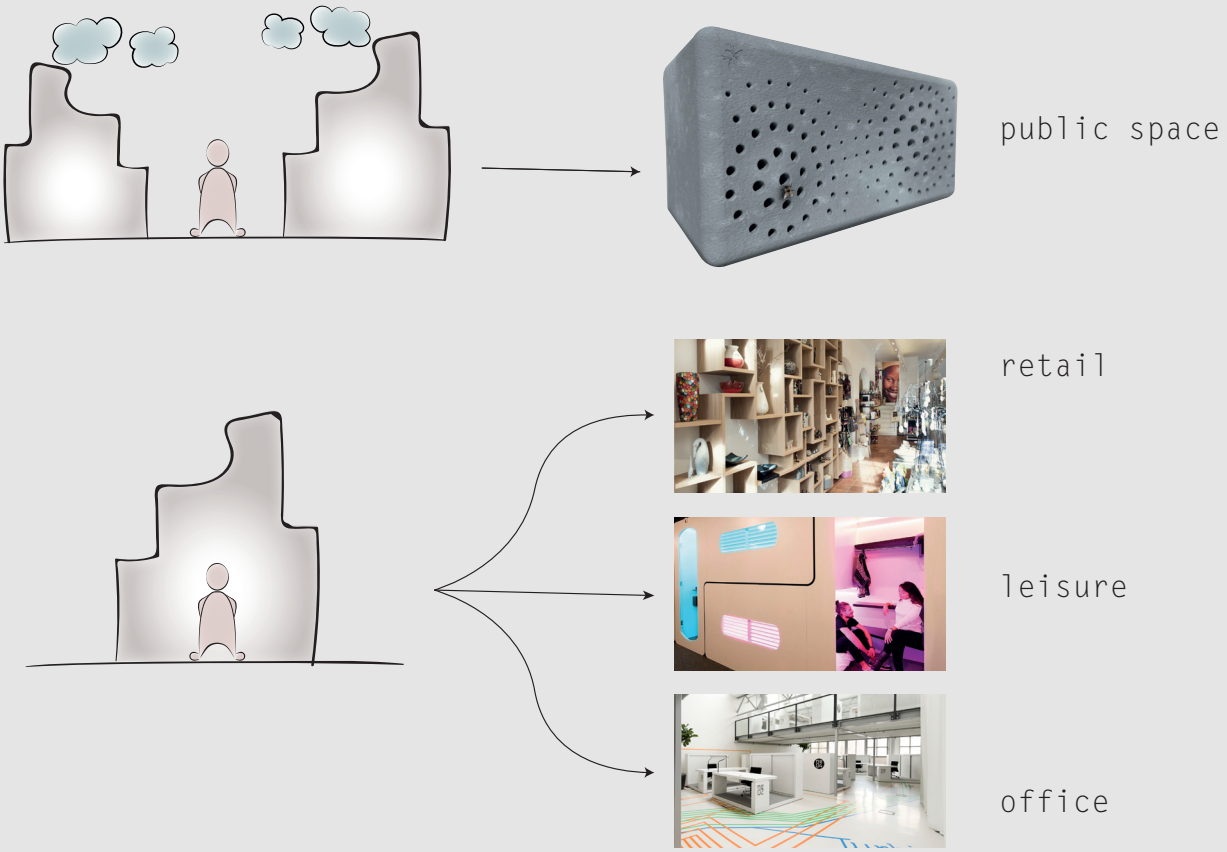
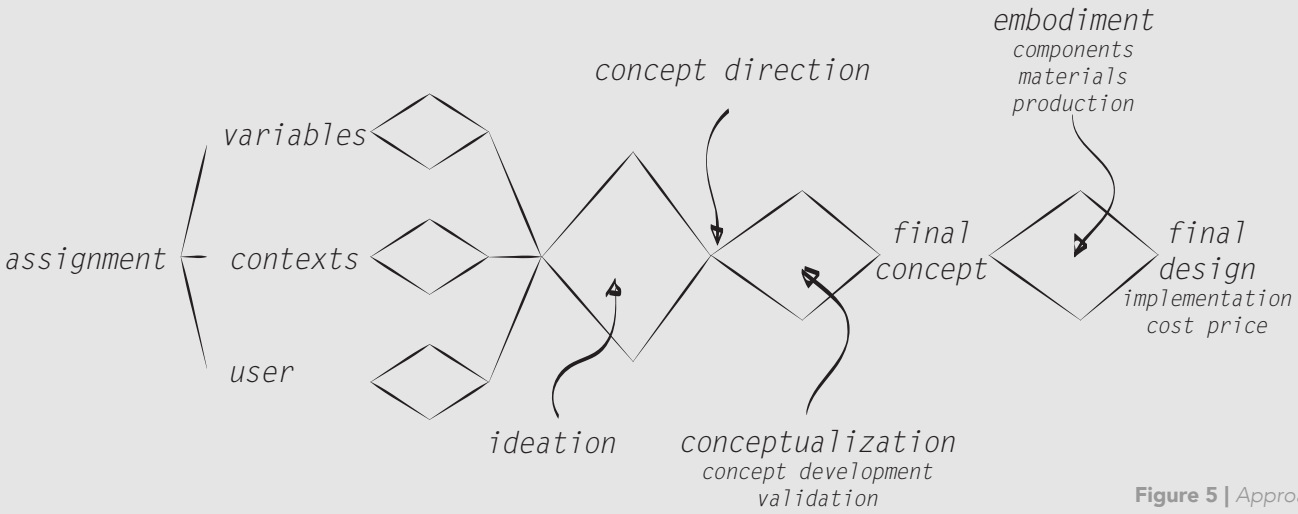


Figure 4 | *Studio Uberdutch's work divided into contexts*

1.4 APPROACH & REPORT STRUCTURE

During this project, the following approach was followed of which a visualization can be seen in **Figure 5**. The project started with an assignment that was very broad, in order to make it more concrete, variables, context and user were analysed. For each a choise was made on which to continue.

From here, a first ideation phase was done followed by a concept direction. This concept direction was then further developed into the final concept. In the embodiment, the needed components were determined together with the materials and production method. Finally, the final product is presented together with a cost calculation.



2. ANALYSIS OF THE HEALTHY LIVING ENVIRONMENT

During the analysis phase, the main research question and subquestions as stated before were answered. In the beginning of each paragraph it is stated which question will be answered in that part.

Before finding out which variables influence the living environment, a definition of a healthy living environment has to be established. A healthy living environment is "an environment that is experienced as pleasant, invites to healthy behavior and where health pressure is as low as possible" (RIVM, 2017). Besides providing a clean environment, it should be designed to invite people to exercise, play and move, use public transport and get around by bike and foot. It should facilitate the possibility to socially interact with other people and provide a satisfying amount of green, nature and water, all of these can be seen in **Figure 6**. Besides this there should be attention for climate adaption, especially with the changing climate nowadays. The RIVM stresses the importance of combining the objective measurements with subjective feedback of inhabitants, such as noise annoyance and the level of satisfaction on the amount of green. The reason for this is that it can often differ from the situation sketched with the use of objective measurements. A healthy environment relates to both the physical and the social environment (RIVM, 2017). In this project the focus will be on the physical environment.

As stated before, the physical environment has an influence on people's well-being. A distinction can be made between direct influences like air quality, the amount of sunlight or dangerous traffic situations and indirect influences, like stress because of annoyance of noise or dissatisfaction of the neighbourhood. Also, the duration of exposure plays an important part. A very clear example of this can be found in the influence of the sun on the skin. A high level of exposure can do much damage in a short amount of time (like a sunburn), while a long exposure to a lower level can still cause damage to the skin resulting in skin cancer. An estimation for air pollution and noise has been done resulting in **Figure 7**.

Besides having a direct or indirect influence, there is also the question whether people are able to notice the impact or not and if people are aware of the impact. Getting back to the burning sun, most people are aware that being in the sun for too long is bad for your health and besides this, you can feel the impact of the radiation on your skin. Nevertheless, sometimes this is still too late and the damage has already been done.

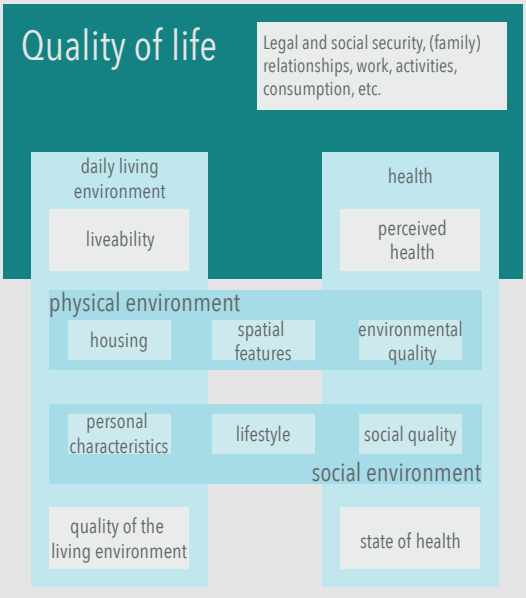


Figure 6 | *Quality of life according to the RIVM (2011)*

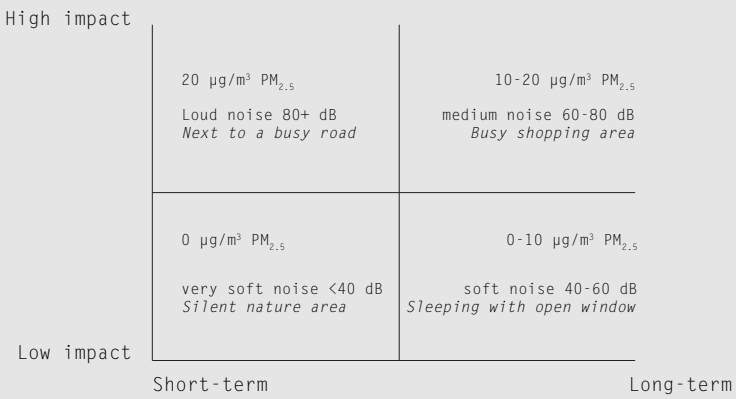


Figure 7 | *Impact versus time of exposure*

2.1 VARIABLES

Which variables determine a living environment's quality?

The living environment consists of many variables that together determine the quality. The air people breathe, the water they drink and the sun that reaches their skin are essentials in the existence of human beings. Besides these, there are also variables that determine the level of comfort that is experienced by people. Thermal comfort is dependent on the level of humidity and people can experience the same level of sound either as noise or as pleasant depending on the situation. The initial approach of this project is to find out which variables are most interesting for measuring and why.

Many different variables were distinguished, which can be seen in **Figure 8**. All of the variables that are included in this project can be measured with the use of sensors, besides green surroundings and spatial planning. These were included to find out in what way they can have a negative or positive impact on human well-being and whether they can potentially be used in the new product.

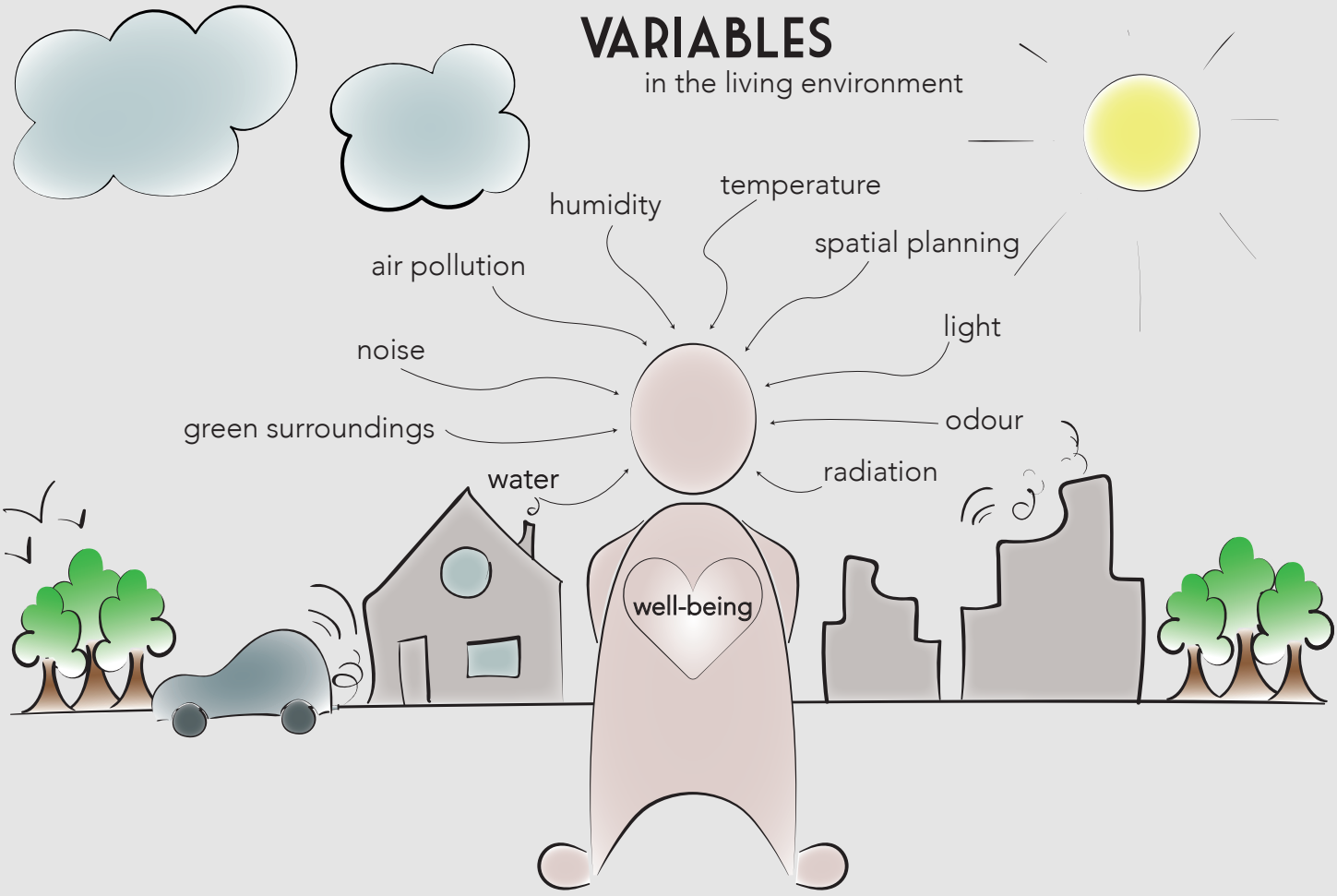


Figure 8 | *Variables of the living environment*

For each for the stated variables, the effects on well-being regarding physically and psychologically were determined. A look was also taken at the perceptibility of the variables. Overall, the findings were brought together in **Table 1**.

Air pollution

Physical
Indoor and outdoor air pollution can cause health risks including higher chances on asthma, COPD, lung cancer and cardiovascular diseases. Yearly, bad air quality is the cause of 4500 early deaths and 16.000 emergency admissions in the Netherlands alone (Gezonde Lucht, 2016). The average life expectancy of Dutch citizens is lowered with nine months. Air pollution consists of different components, among which are particulate matter, ozone, carbon oxides, nitrogen dioxide and sulfur dioxide (WHO, 2016).

People spend about 90% of their time indoors (NHAPS, 2001). Besides containing particulate matter and other components, the level of CO_2 is very important for job and study performance. High levels of CO_2 can cause feelings of fatigue.

Psychological
Bad air quality can cause depression and anxiety, mainly when the opportunity is missing to cope with physical stress, for example when someone is not able to open a window for fresh air.

Perceptability
Air pollution is very difficult to detect. Bad smell can be an indicator for dirty air, but this is not always the case. In severe cases of air pollution, the formation of black dust on physical objects can occur.

Humidity

Physical
The amount of water in the air plays an important role in thermal comfort. Besides this, dry air can cause respiratory problems, skin and eye irritation. Through the air, infectious diseases can be spread. It depends on the temperature and the humidity of the air whether these biological pollutants can survive. Also, a high level of humidity can cause molds to grow in homes, which is damaging for people's health and can cause allergies.

Psychological
Comparable to temperature, the feeling of control is very important. Lacking this feeling of control can cause stress.

Perceptibility
Since humidity is part of thermal comfort, it is easy to notice when one is not fealing comfortable. However, most of the time people mainly link this to the temperature and in a lesser degree to the level of humidity. In homes, the level of humidity is more difficult to notice and is sometimes only noticed when damage like growth of molds is already done.

Temperature

Physical
Direct health effects can occur when the temperature is above 25°C, causing dehydration and health problems like headaches, exhaustion, dizziness and heart problems. However, mostly these effects occur in case the high temperature is combined with not consuming enough fluids. In this, the highest risk is for the elderly. This problem can increase because of the aging population. Besides being too hot, the temperature can also be too cold, causing hypothermia and frostbite, however in the Netherlands this is more exceptional (RIVM, 2011).

Next to the direct health effects, temperature is an important aspect for being comfortable in an environment.

The relationship of a person with ones thermal environment is called thermal comfort and mainly describes whether a person is too hot or too cold. However, thermal comfort is dependant on many different factors and therefore hard to define. Air temperature, mean radiant temperature, relative humidity and air movements together have an effect on human thermal comfort. Besides these factors, age, gender, human metabolic rate, activity

level and thermal insulation of clothing also play a role. There is a clear relation between temperature and relative humidity that together determine the experienced temperature by the occupant of an environment.

Rise of the global temperature makes outdoor thermal comfort more urgent. In urban spaces, outdoor comfort is important for pedestrian's health (Taleghani, M., Kleerekoper, L., Tenpierik, M., & Van Den Dobbelsteen, A., 2015). The changing cities and increasing temperature can cause urban heat islands, in which temperature is significantly higher than its surrounding areas due to human activities. Mainly this is caused by the higher amount of asphalt, stone and steel and the lesser amount of green. Primarily, among sensitive groups like elderly and chronically ill people, this can lead to additional mortality. Especially during the evening, differences up to 7 degrees between the city center and surrounding areas can occur, mostly because the ability to cool down is higher at the countryside since there is more green (NRC, 2017).

Psychological
An important aspect in thermal comfort is the feeling of control by an occupant. Since many buildings are controlled automatically, people can miss a feeling of controll, causing stress.

Perceptibility
The influence of temperature is direct noticeable and can directly be acted upon in case people have this possibility.

Light

Physical
The right amount and color of light is very important for how humans function. Especially the color of light contributes to the human circadian rhythm. When this rhythm is disturbed, this can cause long-term health problems. By adjusting the color of the

	Psychological	*Physical*	*Perceptibility*
Air pollution	Depression, anxiety	Fatigue, respiratory disease, cancer	Low
Humidity	Part of thermal comfort, control, stress	Respiratory disease, asthma, allergies (because of mold)	High
Temperature	Perceived level of control, stress	Thermal stress, dehydration, hyperthermia	High
Light	Seasonal depression, influence mood	Visual discomfort, eyestrain, disturbance of circadian rhythm	Medium
Noise	Annoyance, stress, tiredness	Hearing loss, tinnitus, alterations in blood pressure, cardiovascular disease, sleep disturbance, hormonal response	Medium
Odor	Annoyance, stress	Irritation in nose and eyes, allergic response	High
Radiation		Lung cancer (radon), skin cancer (UV), UV light for production Vitamin D	Low
Water		Infection disease, poisoning	Low
Spatial planning	Crowding, distress	Spread of infectious diseases	High
Green surroundings	Positive effect on subjective feeling, less anxiety, perform better on tasks	Less fatigue	Medium

Table 1 | *Overview of the found effects of the variables on well-being and their level of perceptibility*

light to the natural colors the circadian rhythm can be restored. Bright light can cause visual discomfort through glare and distraction and eyestrain.

Psychological
Light can change the mood of occupants of a room, mostly because of expectations and preferences (Mills et al., 2017). Since winters are more dark, this can cause seasonal affective disorder (Boyce, P., Hunter, C., & Howlett, O., 2003). Besides, the amount of light is very important for work and school performance.

Perceptibility
It is quite difficult to notice whether the light you are in is the right color and therefore important for your circadian rhythm. However, people can tell whether the level of light is comfortable.

Noise

Physical
A high level of sound can cause damage to the ears with as a result hearing loss or tinnitus. As a result of stress that is caused by the psychological effects of noise, alterations in blood pressure and hormonal response can occur. Besides this, people can be disturbed while sleeping, causing the body not being able to restore during the night.

Psychological
Especially in the growing cities there are almost constantly sounds everywhere. People need quietness in order for restoration. Quietness does not mean there can be no sound at all, it only means the absence of sound that is experienced as disturbing (van den Bosch, K. A., & Andringa, T. C., 2014). Being surrounded by noise all day can cause stress. Even when people think they get used to sounds it is proven that this is not true. Mainly during the night, noise can cause sleep disturbance without people knowing, resulting in a less good sleep and fatigue during the day. On the other hand noise can cause annoyance and is named as one of the biggest problems on the office floor.

Perceptibility
There are two parts in noticing the effect of noise. The first one is the direct effect, when you directly experience high levels of noise or when you are directly annoyed. The second one is the noise you "get used to", but is still influencing your well-being.

Odor

Physical
Odor means there are particles in the air that are causing a certain smell. These particles can cause irritations in nose and eyes and allergic responses.

Psychological
Besides negative effects of odor, smells can also be used to seduce people to buy certain products. In case people experience a certain odor as a bad smell repeatedly, annoyance an occur, resulting in stress. Again, important here is the feeling of control that is missing.

Perceptibility
Odor is a variable that is immediately noticed, but is also very subjective. Nevertheless, there is Hedonic Tone, which is a measure of how pleasant or unpleasant an odor is perceived.

Radiation

Physical
There are different types of radiation, in this case two will be considered; radon and UV-light.

Radon is a radioactive noble gas which originates from radium and is naturally present in nearly every type of soil, among which stone-like building materials like concrete. When radon decays, a series of decay products are produced which are no longer gasses but solids. These particles can attach to particulate matter and be inhaled. When inhaled, it can cause lung cancer because of the radiation caused by the decay. Main exposure to radon occurs indoors, both because people spend more time inside and because of the significantly higher level of concentration of radon indoors than outdoors (RIVM, 2011).

UV-light as radiation can cause sunburn with as a result damage of the skin. When the skin is repeatedly exposed to the sun, a protective

response in the skin is triggered, causing the skin to darken due to pigment migration to the surface of the skin. When the sun passes through glass, the effect of the radiation is drastically reduced. UV-light can influence health positively as well as negatively. In order for people to produce Vitamin D, UV is needed. Too much UV however, can cause skin cancer. The number of skin cancer patients is still rising.

Perceptibility
Also in this case, there are two parts in the level of perceptibility. Where the direct damage of the sun can be noticed quite well, the influence of Radon is not noticeable at all.

Water

Physical
Water quality is very important for human well-being. Both drinking water as well as natural waters. However, in the Netherlands the quality of the water is good (RIVM, 2016). Bad water can cause infectious diseases and legionella or other poisining. One of the future risks is the level of medicine in the drinking water.

Perceptibility
Water quality is very difficult to notice, besides from tasting bad.

Spatial planning

Physical
Spatial planning is important in urban planning. The area should invite people to exercise in order to retain good physical health. In a crowded city, infectious diseases are more likely to spread.

Psychological
The amount of available space for relaxation, or how people feel in an area are important for their psychological well-being. Crowding means there are too many people in one space. This can casue distress and anxiety.

Perceptibility
This part is very subjective and therefore very person related. The result of spatial planning can be directly noticed when a person is not feeling comfortable.

Green surroundings

Physical
More and more evidence is being found that green environments can have a positive effect on health. Because plants create oxigen and reduce the level of CO_2 they can reduce fatigue.

Psychological
Plants can have a positive effect on subjective well-being, reduce anxiety and result in better performance on tasks. It is found that view on a natural environment can reduce recovery time in hospital environments.

Perceptibility
Although not always consciously, people feel subjectively better in an environment with higher level of green surroundings. Nevertheless, it is difficult to directly see the effect on their well-being.

Vulnerable people

People who are already experiencing health problems like cardiovascular or repiratory diseases are more vulnerable for environmental factors than healthy people. Also, elderly, young children and babies are more vulnerable. Besides these groups, essentially healthy people are also extra vulnerable during intense exercise in polluted air. In addition, some people are more sensitive to certain variables such as noise, however, this is subjectively and therefore they are likely to experience more stress.

Conclusion

It can be seen that many variables that directly have an effect are part of human comfort. Since they are directly noticed they can cause annoyance and stress. The variables that are not directly noticed can have a bigger impact on well-being since no measures can be taken when people are not aware of the influence. For the variables that influence comfort, measuring objective data is not adequate, since not everyone perceives and responds in the same way.

2.2 CONTEXT

Who has influence in which environment?

The living environment of human beings consists of many different smaller contexts. Each of this contexts has a different influence on the well-being of people. In order to find out in which environment it would be most interesting to measure the variables, a look had to be taken at which variables have influence in which environment and to what extend people can have influence on these variables.

As a start, all different kind of environments were clustered into five categories: recreation space, working space, private space, public transport and public spaces (**Figure 9**). These are the main environments people visit daily. Besides the five categories, a distinction can also be made between environments indoor and outdoor. This is mainly due to the level of influence that can be exercised on the variables by the person who is responsible for the quality of the environment.

For each of these environments, a look was taken at those who are able to have influence on (some of) the variables, which can be seen in **Figure 10**. It can be seen that an individual user has influence on their own private spaces. An operator or building manager have influence in the environments they manage, but mostly these are automated systems, meaning their influence is limited. However, the influence of these environment's occupants is even smaller. Municipality, government and EU mostly have influence on the outside environments. This is because of regulations regarding some of the variables, such as air- and noise pollution. The person responsible for the quality of the living environment will be called the problem owner. In outdoor spaces, the problem owner will be the municipality.

As a result of this, a framework for the influence in different living environments was made, shown in **Figure 11**.

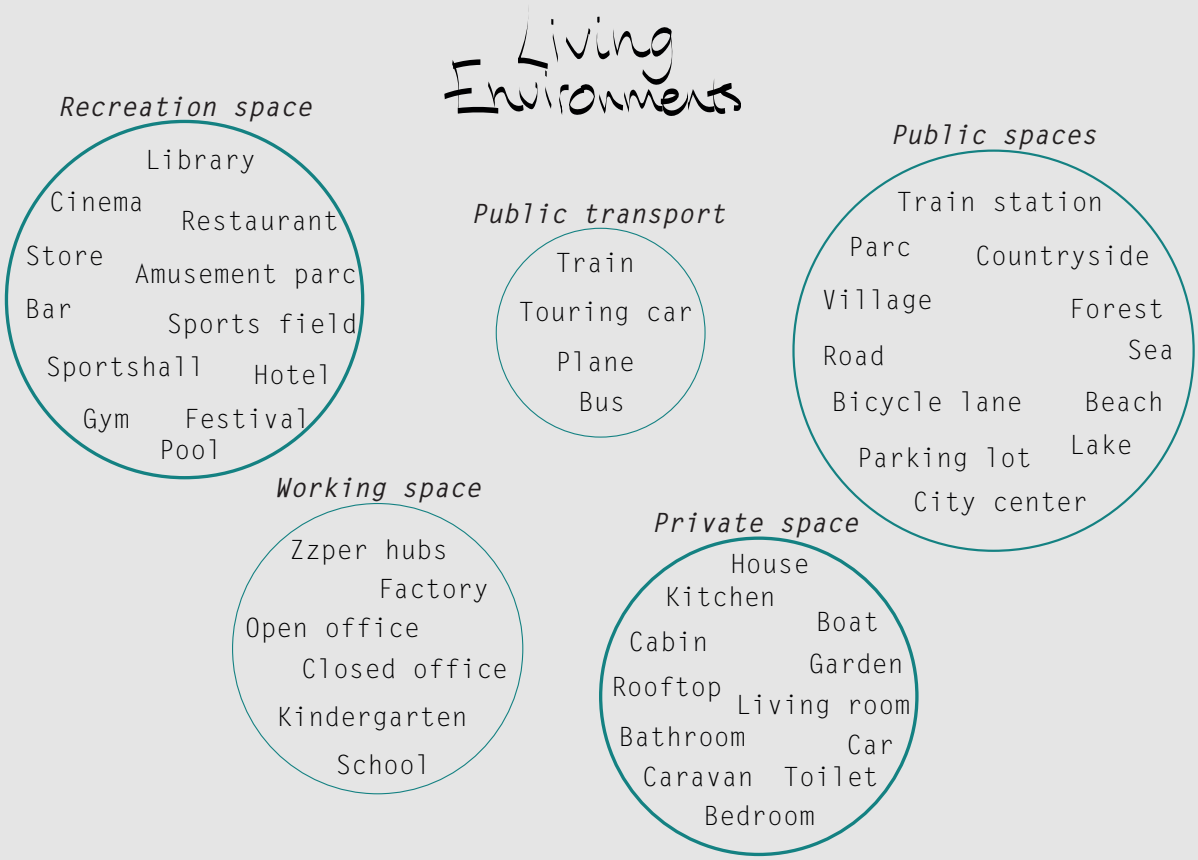


Figure 9 | *Living environments in catagories*

Individual user	Operator	Building manager	Municipality	Government	EU
House	Train	Cinema	Parc	Beach	Sea
Kitchen	Bus	Store	City center	Road	
Toilet	Plane	Restaurant	Sportsfield	Countryside	
Bathroom	Touring car	Bar	Forest	Sewer system	
Living room		Sportshall	Lake		
Bedroom		Gym	Bicycle lane		
Boat		Train station	Parking lot		
Trailer		Library	Village		
Cabin		Pool	Amusement parc		
Car		Factory	Festival		
		Prison	Garden		
		Zzper hubs	Rooftop		
		Open office			
		Closed office			
		Hotel			
		Kindergarten			
		School			

Figure 10 | *Who has influence?*

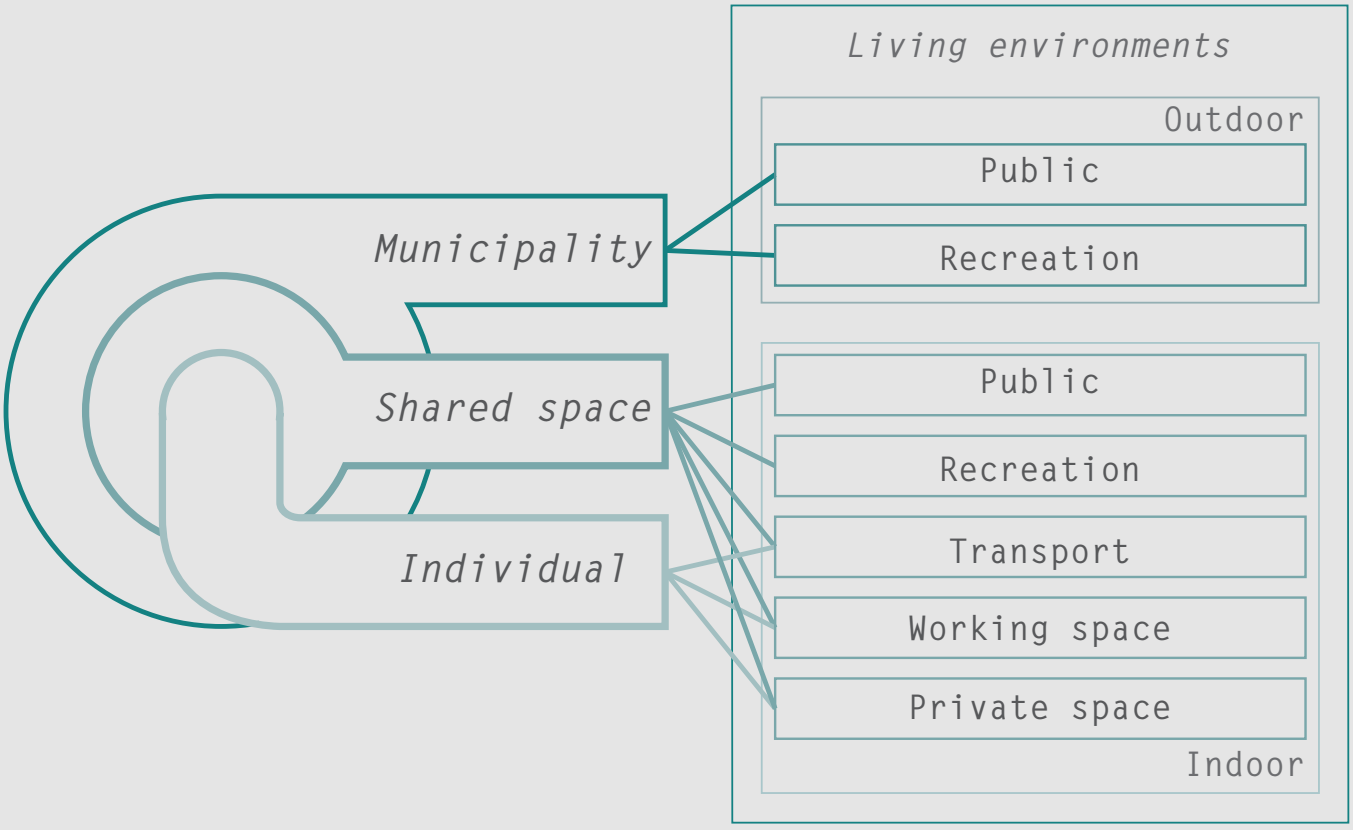


Figure 11 | *Who has influence in which environment?*

2.3 POSSIBLE CONTEXTS

Which variables can be influenced by the user?

Besides adjusting the variable itself, it is also possible to respond to the variable. Instead of changing the temperature in a room, you can put on a sweater and instead of changing the quality of the air in one street you can choose to use the street parallel with less traffic.

By changing rules, regulations or spatial planning, a municipality can change variables in open air up to a certain point. Heat stress can be reduced by implementing more green and less stone and air pollution can be reduced by creating car-free zones or providing more green. Even though it seems logical that planting more trees will increase air quality, in case they are planted wrong they can cause the opposite effect when the polluted air gets trapped under the trees. Therefore spatial planning is very important to make sure air circulation can continue.

In a shared space, many processes are automated, like air circulation and temperature regulation. In offices this can cause big problems regarding thermal comfort. Being warm or cold is very personal and people not having influence on the temperature can cause them to lose their feeling of control.

Mainly in personal spaces people have a bigger feeling of control, while in the shared environments temperature is mostly centrally controlled.

From this, **Figure 12** was created showing the one who can have influence on (some) of the variables.

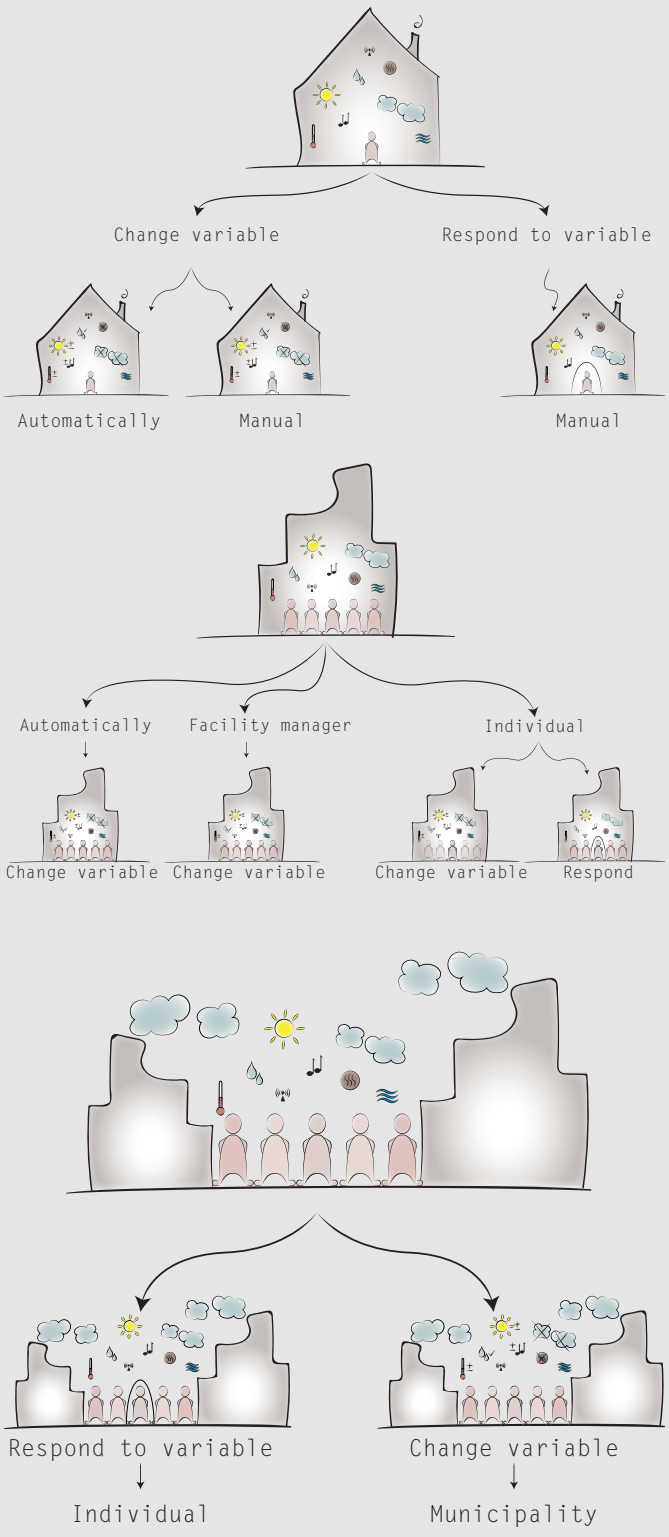


Figure 12 | *Possibilities to influence or respond to variables*

City center

The city center is a place where all five kinds of living environments come together. There are recreational and public spaces, outdoor as well as indoor, there is public transport and there are many working spaces. There are plenty private spaces, mostly as apartments where many people are living in somewhat smaller environments. In this case, the city center is considered as the public and recreational outdoor environment.

Current situation

In the city, the biggest source of air pollution is traffic. This is already well known and measurements are being taken. As a result cars are becoming cleaner. At first, the focus of measuring air pollution was on nitrogen dioxide (NO_2), which is part of the vehicle's exhaust, and particulates. Part of these particulates is black carbon, which is the most damaging part. Since cars are becoming cleaner, it is thought that this will result in a decline in the level of air pollution. However, a big unknown fact is that wood burning is a great part of air pollution. At the moment, the city of The Hague is working on a campaign to make the residents aware of the effects of wood burning (personal communication, actieplan Den Haag, 2015). Odor can be caused by many different sources, from industrial to waste, but also because of wood burning. This can cause annoyance among citizen.

An increasing problem in urban areas in the formation of local hotspots. In these areas the temperature can be up to 7 degrees higher than surrounding areas. People living in these areas can have difficulties finding coolness (Atlas, 2011). Because of the global warming, the level of humidity in the air can also increase. Together with temperature and wind speed, humidity has an influence on the level of thermal comfort of people. Besides this, in outdoor spaces there should be enough areas with protection from radiation of the sun. Other types of radiation are more likely to cause problems indoor. In order to offer a healthy environment, spatial planning should be optimal, with a high level of green surroundings and water.

Office Environments

In office environments, employees are working for eight hours, which means it is probably the environment where most time is spent after the home environment. Employers want the best work and productivity of their employees, therefore they should make sure the circumstances in the work environment are optimal. A lot of research has already been done in this area. It is clear that a healthy office environment has to meet many different requirements to meet the standards. Besides that, every person in the office receives, perceives and responds in a different way, generating many different opinions on the temperature, level of noise and light quality (Bluyssen, P. M., Oostra, M. A. R., & Meertins, D., 2013).

Current situation

In closed indoor environments, air quality is a big issue because of the lack of possibilities to ventilate the space. Therefore, automated systems are created. However, the effects of these systems on the air quality could be higher than thought when not correctly maintained, this can cause sick building syndrome. Influence on the temperature and humidity by room occupants is very little, but is starting to get more important. New office plans with open structure can cause much more noise annoyance, which is one of the major irritations in the office. Furthermore, the level of light is very important for job performance and receiving natural light is good for the circadian rhythm. Odor can be controlled by fragrances or ventilation of the space. The spatial planning of office environments has to be optimal to make sure people can work most productively and are not bothered by each other. Finally, more research is being done about natural and green environment in the workplace and it is concluded that this has beneficial effects on employees health.

Home environments

In the home environment there can still be many different compositions of the residents and the type of home. A difference between the home environment and the shared and public environments is that in the home the resident has more influence on the variables. As stated before, people spend about 90% of their time indoors, of which about 8 hours in their bedroom. Since the human body is restored during the night, it is very important that the quality of the bedroom is good

as well.

Current situation
It is said that the air quality in the house is up to five times as bad as outside. Therefore, the home should be ventilated or the air should be cleaned with an air purifier. Also, inside the home there can be many allergens and children or adults with asthma can benefit from air purifiers that remove these pollutants from the air. On top of this, the stove in the kitchen is a great source of air pollution when cooking. Temperature can be regulated with a regular thermostat or can be regulated with newer systems like Nest. This product will get to know everyone from the family who has access to the product and will achieve a comfortable temperature for all. Humidity problems can occur in the bathroom as well as other spaces around the home when there is not enough ventilation, as a result mould can grow, causing health problems. A less known fact is that the wrong color of light can disturb the human circadian rhythm. Also watching tv late at night, or reading a book in the wrong color of light can make you more awake than sleepy. People might have trouble sleeping but don't know whether this is because of noise annoyance, bad air quality or something else. Integrating plants into the home is very beneficial for air quality.

Environments for vulnerable people

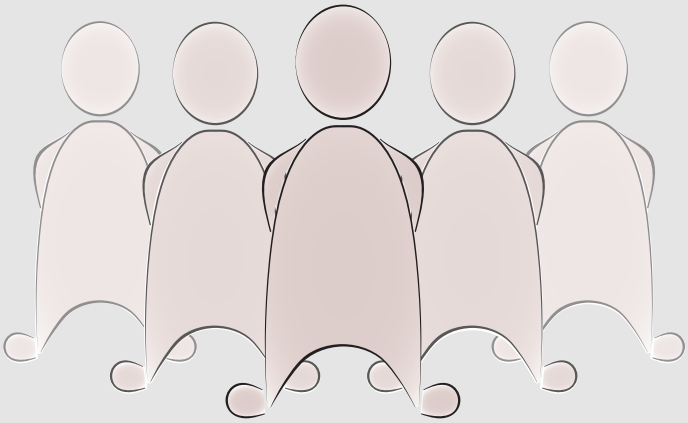
Groups of people that are more vulnerable for environmental influences are elderly, babies and children and people with allergies, respiratory or cardiovascular diseases. These groups are brought together in environments which means these environments should even have a better quality. Environments like these are hospitals, elderly homes, daycares and schools. Another aspect of these environments is that a lot of time is spent indoors, especially in hospitals and elderly homes. Therefore, ventilating the spaces is very important.

Current situation
In most of these environments, temperature, humidity and light are centrally controlled. Therefore, there is little influence of occupants. Good indoor climate has a positive effect on healing (van den Berg, A.E., 2005). Also the influence of a view on a natural environment can have positive effects. Bad quality of the air can have negative influence on the study performance of children. Insufficient ventilation can cause bad odor, eye irritation, headaches and a higher level of fatigue than usual.

2.4 TRENDS

Individualisation

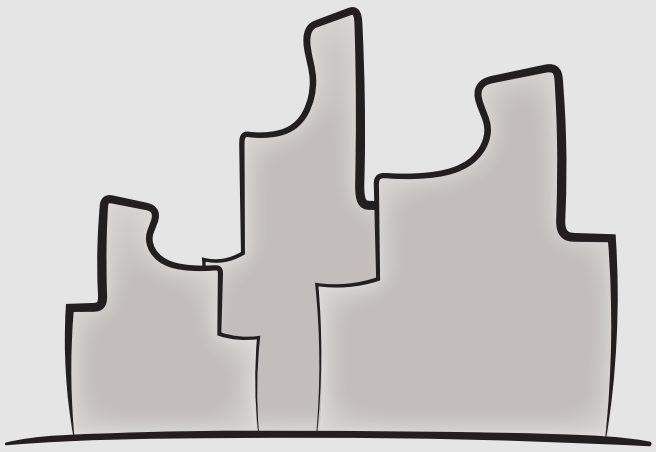
Companies benefit by creating strong relationships with their customer by using low boundaries, unprecedented ease of use, the absence of hassle and a high level of personalisation. People want to be unique and stand out from the crowd, therefore there is a high level of personalisation in consumer products and services. The increase of digital butlers like Siri, Alexa and Google Assistant provide personal help in making your home smart and connected or provide help in your daily life. With the help of self-learning software, products and services get to know their owner and can provide interesting insights in habits and needs.



INDIVIDUALIZATION

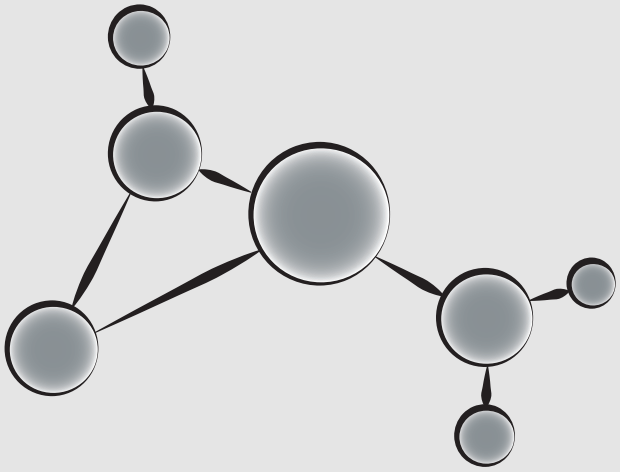
Urbanization

More and more people are moving into the city, causing them to grow. As a result there is a need for new living concepts. One of these concepts is the trend small space living. People realize they don't need as much space and they are able to share common rooms. The realization is growing that green space is needed, especially in the city, resulting in Eco Cities. For this, green space will be incorporated in buildings, as well as the use of the rooftops to create green areas and food will be grown in the city. Another benefit of increasing the amount of green space is the resilience of the city which is needed with the changing weather becoming more extreme, cooling down the city in the summer and keeping it warm in the winter.
Besides this, inhabitants are encouraged to participate in shaping the urban environment and maintaining this and to come up with initiatives to improve their neighbourhood participate in their community. With the help of sensors and smart cities, this will result in collaborative cities, where people are willing to share their data in order to improve the city and therefore become smart citizen.



URBANIZATION

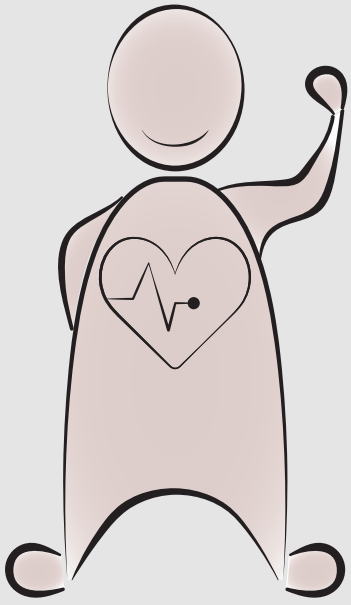
Figure 13 | *Trends*



CONNECTED WORLD

Connected world

Mainly due to the internet, people all around the world are now connected. Being able to share everything through social media makes people feel connected, as well as the opportunity to achieve common goals. These crowd actions can include crowdfunding for new startups or petitions for or against certain situations. People feel the need to share their experiences and value other people's input. There is a big focus on customer feedback on products and services in order to make decision-making for other people easier. The connected world also makes it possible for employees to work from a distant, while still being able to communicate digitally and do teamwork online. Besides people being connected, connecting products to the internet makes it possible for them to become smart, being able to influence them or gather data about them without being around.



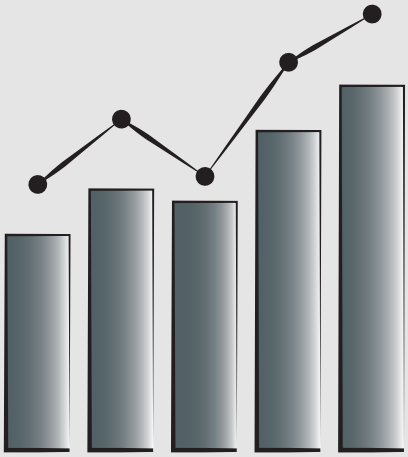
HEALTHSTYLE

Healthstyle

People are getting more aware about their own health thanks to the increasing amount of apps and wearables. Because of the developments in the area of wearables, possibilities on measuring health are increasing, resulting in the quantified self. Fitness trackers, smartwatches and smart clothes are mainly sold for health benefits and results are often shared through social media or other platforms. Many possibilities for healthcare are rising, people start to do their own analysis and track their own health. In case something is wrong, their doctor can be notified. Also patients with chronic diseases could do their own health checks saving time and money. Not only individuals see the benefits in health tracking, also companies acknowledge the importance of a good health of their employees taking quantified self to quantified enterprise or quantified us. This can give companies insights in the fitness and stress levels of their employees and the reason why some are more productive than others.

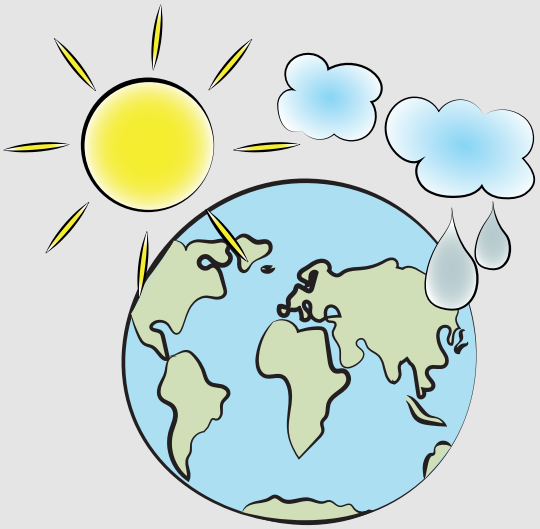
Data era

More and more data is created and gathered everyday of which valuable information can be extracted. From Big Data that analysed the past, the shift is now made to Smart Data in which useful data will be distinguished from the pile of data and used to predict future scenarios. By tracking user data, personalised suggestions can be done. Instead of using data from a single person, shared data sets can be used to understand and learn about whole groups of people. Where data was previously collected without the person being aware it is now shifting towards the person becoming the data owner and forwarding data transparently.



Environmental change

The temperature is rising because of the climate change, making sure the water level rises and the weather becomes more extreme. The temperature in the cities will rise, causing more hot spots to grow and the opportunities to find coolness within the city to reduce. The climate change caused the need for an agreement between as many countries as possible to put effort in reducing emissions. As a result, the climate agreement was adopted by 195 countries in 2015. The goal of the agreement is to limit the increase of global average temperature to 1.5°C. In order to reach this goal, the government has set limits to new buildings which have to be nearly energy neutral when build after 1 January 2021. This results in totally automated buildings with little input from occupants.



Shy Tech

Products are becoming more and more complicated, raising the need to get to intuitive interactions between user and product. Therefore, high tech is replaced by shy tech that is integrated in objects. Voice, gesture and thought control will enhance the intuitive way in which products will be used. These interactions are made possible by increasingly smaller technical components and new developments in sensors. Many of the household products can be controlled by the smartphone, which means the analogue and digital world get integrated in smart network systems. Energy

Figure 14 | *Trends*

management is done by smart thermostats with the goal to reduce energy costs and as a result energy use. These thermostats get to know the home's resident and already respond to their preferences even before they are home.

Conclusion

In the trends it can be seen that there is a big focus on data gathering and turning this data into smart data in order to learn about the user, its health and habits. Besides learning from one person, it is also interesting to learn about groups of people, forming quantified self into quantified us. People use other people's opinion to ease decision making, but want to remain unique. In the future, the cities will become smart, to achieve this, citizen have to become smart. This can be achieved by community participation in which citizen contribute to the improvement of the urban environment.

Interesting points for the rest of the project are:

Smart citizen
Smart Data
Self learning
Social learning
Crowd Sourcing
Quantified self & us
Intuitive interactions
Collaborative city
Personalization
Green space

2.5 EXISTING PRODUCTS

Which variables are already being measured and in which environments?
How are these outcomes communicated to the user?

In order to find out which variables are already being meausured and in which environments and to find out in what way the outcomes are communicated to the user, existing products were analyzed.

It can be said that for every variable, there are already products that measure the objective value. For some variables there are more consumer products and for other variables there are more business products on the market.

Air Pollution

B2C

People are starting to become aware that air pollution is a big problem. Therefore, a lot of new air pollution products can be find among kickstarters. Among these are products that only measure air quality and give the objective values, like TZOA, but also products that measure air quality and immidiately start cleaning the air, like Wynd. Besides this, there are many purifiers on the market, some with and some without sensors, that just clean the air within a closed environment. Furthermore, there is an increase in Do-it-yourself products with Arduino and low boundary products like the Smart Citizen Kit.

TZOA[1]


Wynd[2]


Smart Citizen Kit[3]

B2B

Highly accurate measurement tools are available for measuring air pollution or individual components. These tools are often used in factories for quality control or to detect pollutants in sterile environments. Besides this, there are the stationary measuring stations from the RIVM that are spread throughout the country. These are very large and can cost about €200.000,-. Furthermore, since many cities want to become "Smart Cities", companies are starting to create measuring stations, such as Airbox from Aireas that is measuring air quality in Eindhoven and Libelium Smart City Pro, a measuring tool which measures about 20 different variables.


RIVM station[4]

Airbox[6]

Libelium Smart City Pro[5]

Humidity

B2C

In order to measure humidity, there are more extensive thermostats, but also weather stations to be placed outside. Also, there are many humidifiers on the market to make sure your house has the right level of humidity.

Eve[7]

B2B

In large buildings, building management systems are commonly used to regulate, among others, HVAC systems. HVAC is heating, ventilation and air-conditioning, but is also for the level of humidity.


Symaro (Siemens)[8]

Temperature

B2C

Since temperature regulation is a big part of energy use, companies are using this to make people aware of their usage. With the help of Nest, people can regulate the heating in their houses, based on their preferences and at the same time can see how they are saving energy and therefore money.

Nest[9]

B2B

For temperature the same accounts as for humidity. In bigger buildings

this is mostly automatically controlled by HVAC systems. However, since people lose their feeling of control in case they cannot change anything about their environment, new systems are being developed like the app Comfy. With this app, room occupants can send their heating or cooling request directly to the climate system.

Comfy app[10]

Light

B2C

Natural daylight is the best light for people and it has different colors throughout the day. Since we mobile phones and other devices are used, they can disturb the circadian rhythm because they don't produce the right color of light. One of the solutions for having the right color of light was the Hue light by Philips. The color of this light can change throughout the day. However, it does not measure the light level. Here, the LYS can tell what kind of light people are exposed to and show this in an app.

LYS[11]

Philips Hue[12]

B2B

In the office building The Edge, Philips included many sensors from which one is to measure and regulate the level of light. Also, occupants of spaces can regulate the level of light with the use of an app. Furthermore, Philips has created connected lighting systems that make city lighting smart.

Philips[13]

Philips Connected Light System[14]

UV-radiation

B2C

People nowadays are aware that too much UV-light is very unhealthy. There is a kickstarter product, named UVI that can be connected into the headphone jack of a mobile phone and can measure the amount of UV-radiation.

B2B

The power of the sun is being measured at the measuring station in Bilthoven in the Netherlands. From here, warnings can be issued if the levels get high and people have to be extra aware of the high intensity of the sun.

UVI[15]

Odor

B2C

There are limited products that measure odors for consumers. NeOse by Aryballe is a personal product that is able to recognize different odors. Febreze home has a product that detects if the air is fresh and otherwise automatically spread a fresh fragrance.

NeOse (Aryballe)[16]

B2B

In indstrial applications very precise and expensive sensors are used to detect certain scents and detect gas leaks. In Barcelona, sensors are used to detect odors nearby waste bins. Rotterdam has placed E-noses throughout the harbour for smell enforcement.

Febreze Home[17]

E-nose[18]

Radiation

B2C

For consumers there are radon detectors that can be placed inside the home just as a smoke detector, the Wave Smart Radon Detector.

B2B

In buildings, radon is controlled by ventilation of the environment.

Wave Smart Radon Detector[19]

Water

B2C

On the market, many water filtering tools are available, but also products to measure the pH of water. Ecomo has a smart water filter and a water bottle with water sensors.

Ecomo[20]

B2B

Just like for components in the air, there are many high tech products to measure the quality of the water. Both drinking water that is controlled in the drinking water treatment facilities and the open waters that are controlled by the municipalities.

PASCO Advanced Water Quality Sensor[21]

Conlusion

Most of the products measure variables objectively and do not combine objective measurements with subjective feedback of an environments occupant. It is questioned whether there is a reason for this. Furthermore, it can be said that most products look very complicated and high tech, besides the consumer products that focus on air quality. These products also seem to be in the majority.
The professional products give feedback to the user in numbers while consumer products give either feedback in numbers in an app or on the product itself and otherwise with colored lights.

2.6 SEARCH AREA

To be able to find an interesting area to create a new product, a combination between the measurable variables, the interesting trends, the characteristics of Studio Überdutch and the existing products will be made.

What was said about the variables is that most of them are only measured objectively, while for some of them, like thermal comfort and noise, the subjective part is important as well.

The most interesting trends were based on collecting information about the environment by Smart Citizen and Smart Data, in order to get a Smart and Collaborative City. Products are created that are self-learning in order to tell something about the quantified self and the quantified us (all citizen together). Important about the product is that it needs to have intuitive interactions, a level of personalization and that it could have a link to a green environment.

What can be said about Studio Überdutch is that they create interiors for shared spaces and products for B2B markets. Therefore it would be interesting to see how a new product could be integrated in these shared spaces and what B2B market would be interesting for them to enter or in which they could expand.

To find the interesting area, a perceptual map is shown in **Figure 15** with products divided on a scale from objective to subjective and from use in individual to shared environments. Here it can be seen that there are many individual products that measure objective data. Also the products for the shared environment also mostly measure objective data. Then a newer product like Comfy, which is an app, does consider the subjective input from occupants of a space, as well as Nest and Philips connected lighting.

It is concluded that there is an interesting area in the shared environment with a focus on a combination between objective and subjective measurements.

2.7 CONCLUSION

The goal of this chapter was to gain insight in the influence of the living environment on human well-being. Therefore, the following research question was answered:

"What is the impact of the environment's quality on people's well-being and what are the variables that have an impact?"

Human well-being is influenced by variables both conscious and unconscious. Furthermore, every individual experiences a variable differently.
It was concluded that there is an opportunity in exploring the area of measuring subjective input in combination with objective measurements.

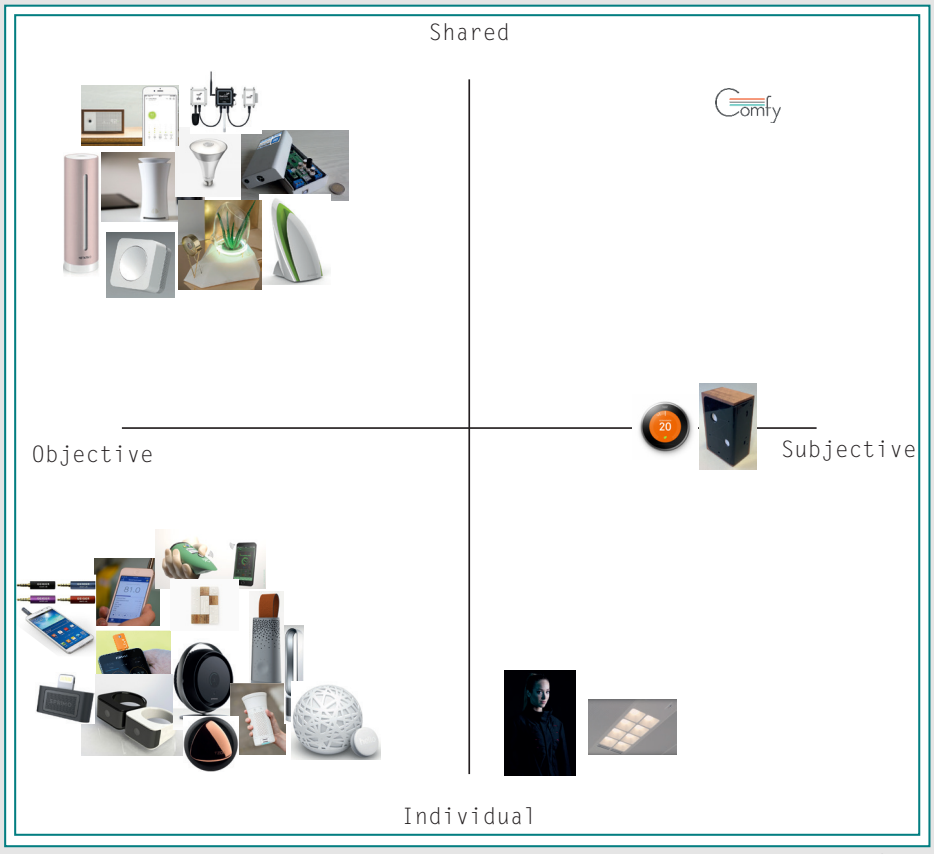


Figure 15 | *Perceptual map*

3. PROJECT SCOPE

As a result of the analysis, possible variables and contexts were determined. In order to create a valuable product, the context has to be further determined as well as the variables that will be measured. In addition, the user of the product will be defined.

From the context analysis, 7 different contexts were distinguished based on who is able to have influence on the variables in the environment. These contexts were: outdoor public and recreation, indoor public, recreation, transport, working and private. Every environment has occupants with different needs. Environments such as hospitals and daycare have vulnerable groups making the need for a healthy environment even bigger.

A literature research was done in order to find out which variables have the biggest impact on human well-being. According to Hänninen & Knol, Particulate air pollution, second hand smoke and traffic noise have the highest public health impact, see **Figure 16**. These results are also used by the RIVM. The Ministry of Infrastructure and the Environment has created a programme called "Slimme en Gezonde stad" (Smart and Healthy City), in which air quality and noise pollution are important aspects. This is a programme with six pilot cities that use different tools, solutions and projects with the aim to improve the quality of the living environment. To verify the outcome, an interview was conducted with an expert on noise pollution from TNO and with two employees of the departments of air quality and sound from the municipality of The Hague, a summary of these interviews can be found in Appendix A.
As a result of the analysis of variables and the opinion of the TNO expert, it was determined that air quality and noise have the biggest impact on human well-being. Also, lately the focus on these two variables has gained more attention in the news. The court has recently determined that the Dutch state has to make efforts to reduce air pollution and make sure to meet the European standards for particulate matter and nitrogen dioxide (van Bokkum, M., 2017). Air quality in the Netherlands is still often above European standards, nevertheless, regulations like increasing the speed limit to 130 km/h have been implemented while the effects for worsening the air quality were well known. Noise pollution has been in the news as well and even named as a potential number one environmental cause of death (Kennisvannu, 2017). However, the difference between these two variables is in their perceptibility. Air pollution is very difficult to notice, while noise is much easier perceived. A certain level of noise is damaging for everyone, but it can also be perceived differently by everyone.

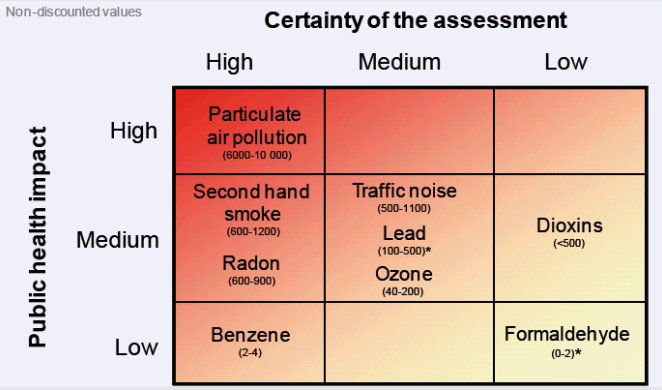


Figure 16 | *Relative public health impact of selected environmental stressors (Hänninen & Knol, 2011)*

In determining the effects of the environmental variables on well-being, it was seen that many of the variables can cause stress. Therefore, a short research was done on what causes stress.
There is a higher level of annoyance when a person does not depend on the noise source and in case the use of the transportation that causes the noise is low. Households of two have a higher level of annoyance than household of other sizes. (Miedema, H. M. E., & Vos, H., 1999)
Noise annoyance can cause stress, besides this also fatigue associated with ineffective attempts

to cope with noise. For coping with stress, Richard Lazarus created a model in which can be seen how a person is affected by stressors from the environment. This model can be seen in **Figure 17**. Appraisal means the evaluation by a person on how something affects their well-being. A distinction is made between primary and secondary appraisal, in which primary is concerned with the motivational relevance of what is happening and how stressors are interpreted. In case they are either interpreted as positive or irrelevant, no stress is caused. However, in case they are interpreted as dangerous (challenge, threat or harm) an analysis of available resources will be made. If the situation is relevant to the person's goals, the quality and intensity of the emotion will vary with what and how much is at stake.
Secondary appraisal is the estimation of the level of control we think we can exert.

In case it is thought that not enough control can be exerted on the situation, this can be experienced as stress.
Once stress is experienced, one can find ways to cope with this. There are two types of coping, one of them is problem-focused, in which a person can alter the troubled person-environment relationship and the other one is emotion-focused, in which a person has to manage emotional distress.

Finally, there is reappraisal, in which a person revisits the emotional response to the situation. In order to do this, the negative response first has to be recognized. Then a reinterpretation of the situation can take place. As a result, the severity of the negative response can reduce, or the negative attitude can be exchanged for a more positive attitude (Lazarus, R. S., & Folkman, S., 1987).

In order to cope with the situation without changing the circumstances, one must become aware of the negative response and then the negative attitude can be exchanged for a more positive attitude.

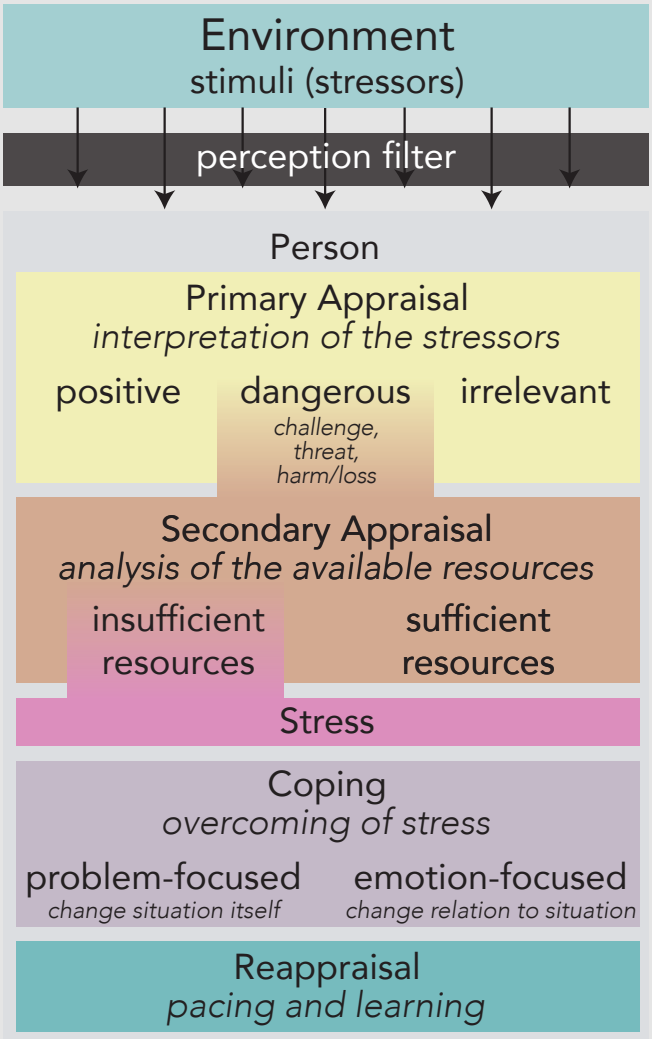


Figure 17 | *Transational model of stress by R. Lazarus (1991)*

3.1 CHOSEN VARIABLES

The two chosen variables air pollution and noise will be further elaborated.

Air pollution

Besides oxygen, there are other components in the air, of which many can be described as pollutants. These can be NO_X, CO, CO_2, O_3, SO_2, VOC's (volatile organic compounds), biological pollutants and particulate matter.
Particulate matter is a mixture of small particles and can be divided in different levels of impact depending on their size. The smaller the particles, the further they can penetrate into the body and the more health effects they can cause.They are categorized in the following sizes: PM_{10}, $PM_{2.5}$, $PM_{0.1}$. The numbers behind PM represent the size of the particle, respectively 10 µm (dust, pollen, mold, etc.), 2.5 µm (combustion particles, organic compounds, metals, etc.) and 0.1 µm (wood smoke (Riddle, S. G., Robert, M. A., Jakober, C. A., Fine, P. M., Hays, M. D., Schauer, J. J., & Hannigan, M. P. (2009)). In comparison, a human hair has a thickness of 50-70 µm (micrometer).
There is a difference in pollutants indoor and outdoor. CO_2 has a bigger influence in a closed environment than outdoor, as well as CO. CO is very dangerous, since it is odorless and colorless, but it can be lethal in higher concentrations. CO_2 can cause feelings of fatigue, which can have a great impact on study prestation in schools and job performance in offices and is therefore important to measure indoor. A big source of particulate matter indoor is the stove. In a recent study of TNO, it was seen that the level of particulate matter was very high during cooking. Because of the excellent isolation of the houses nowadays, it takes much longer for the air to be clean again (TNO, 2017).

In the outdoor, most important pollutants are NO_2, which is caused by traffic emissions, and PM_x, among which is also black carbon. Black carbon is stated to be the most damaging part in particulate matter.

As stated before, people spent about 90% of their time indoor. Even though air quality inside the home can be very bad, many products are already developed to take care of this. Therefore it was decided to create a product for the outdoor enviroment. While looking for an interesting context to specify the outdoor environment, poor air quality in the city of The Hague was a very actual topic:

From the citizen of The Hague, the need for another air quality measurement station arose. This was received by Mr. Gerwin van Vulpen, councilor in the city council of The Hague. He is committed to persuade the municipality to purchase another measuring station, which costs about 200.000 euros. This would result in measuring at one location which made the question arise whether it would be feasible to create a network of sensors for a cheaper price in order to give a good estimation of the air quality.

Noise pollution

Research on noise has already been done for a very long time, nevertheless little measurements are taken. Where air pollution is being measured and calculated across the Netherlands, noise pollution is only calculated with models. However, these models do not correspond to reality. They don't go into enough detail, are only based on ideal weather conditions, assume traffic does not exceed maximum speed and they don't include scooters and motorcycles. As a result, calculations can differ with measurements by 2-6 dB (Erik Roelofsen, Kennis van NU (2017).

An important aspect about noise is that it is very subjective whether people are annoyed or not. There is a distinction between desired and undesired sounds. These undesired sounds can be experienced as noise (Janssen, S., 2017).

In Sweden, they have created the Sound Environment Laboratory in which they research the effects of noise on sleep (55+dB). Here it is shown that eventhough people are asleep, they can be disturbed by noise, resulting in a lighter sleep, increased heart rate and movements. This means that even when people are not aware about it, they can still be disturbed by noise, resulting in fatigue during the day (Kennis van Nu, 2017).

RIVM started a research to the effect of traffic noise

on children's development after a research was published by Wuppertal University that stated that five year old children who are exposed to traffic noise of at least 10 dB more than the average 44 dB, have a chance to be behind in their development up to three months (Parool, 2017).

Expectations, relations to the source (neighbours, loitering youth) and circumstances influence the way in which sounds are experienced. In case a high level of sound is expected and the sound is perceived as pleasureable, such as in a concert, there will be no annoyance, however if the same music and level of sound is experienced indoor because of the neighbour's music then it can be very annoying. This makes noise annoyance both interesting and complicated.

Besides negative effects of noise, there are also researches that show the positive effect sounds, or the absence of noise can have. Natural sounds can help in restoration. In the Netherlands there are silence areas throughout the country. These are areas in which no unnatural sounds can be experienced. It is estimated that in 2030, 30% of these areas will have disappeared.

The way in which soundenvironments are experienced by people is called 'soundscapes'. These soundscapes can be implemented in for example public areas or office environments. In the past, sounds were merely a by-product of other products, now there is a recognition that sounds have to be designed as well, being soundscapes.

The challenge in measuring noise pollution is identifying the source and every source (airplane, train, vehicle) has a different impact on health. When the total level of all of these and other sounds is gathered, nothing can be said about the direct health effects (Janssen, S., 2017). Maximum values have been set for road traffic (53 - 68 dB(A)), railway (68 dB(A)) and industry (55 - 60 dB(A)) on the facade of buildings (IenM, 2017). Facade insulation can reduce this up to 30 dB. However, there are many people that leave windows open during the night which decreases this reduction up to 15 dB (WHO, 2009).

The World Health Organisation (WHO) has created Night Noise Guidelines for Europe. In this, it is stated that sound levels during the night (23:00 till 07:00) without substantial biological effects is 30 dB. Between 30 and 40 dB effects on sleep like body movements, awakening, self-reported sleep disturbance and arousals can occur. Higher values, between 40 and 55 dB can cause adverse health effects and above 55 dB these are caused frequently and evidence is found for increased risk for cardiovascular disease. Above this, the effects are likely to be less dependent on the nature of the noise (WHO, 2009).

Conclusion

For the rest of the project, air pollution and noise are the two variabels that are being measured. Since it was stated that the subjective part is very important as well, input from the environment's occupant will also be gathered, see **Figure 18**. As a case study, the city of The Hague was chosen to analyse, since Studio Uberdutch is situated in The Hague it can serve as a pilot city for the product.

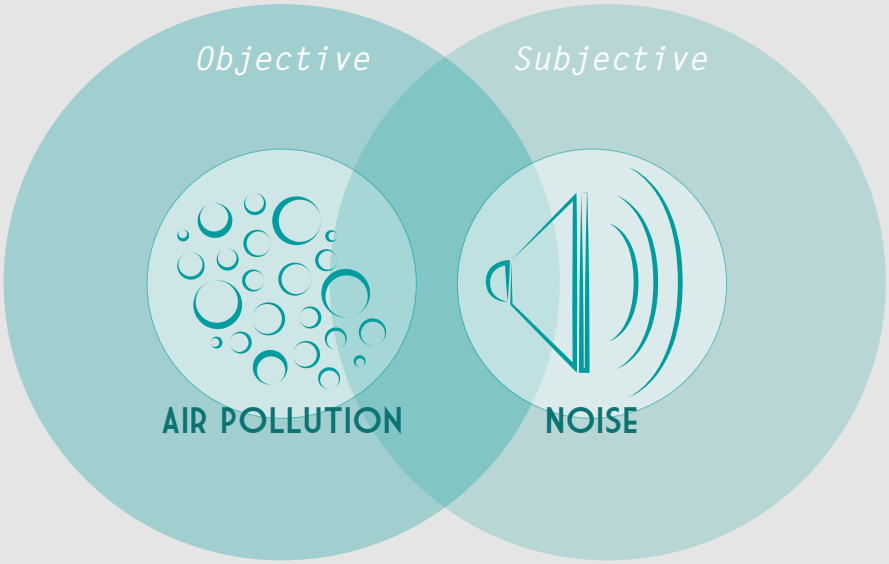


Figure 18 | *Visual of air pollution and noise being objective and subjective*

3.2 CHOSEN CONTEXT

Outdoor environment of the city

(Case study The Hague)

The Hague has 526.439 inhabitants (30 april, 2017) and is after Amsterdam and Rotterdam the biggest municipality of the Netherlands. In 2014 the fifth Gezondheidsmonitor was issued providing information about a number of subjects regarding health. This issue was used to determine how inhabitants of The Hague experience the quality of their city. The city is divided in neighborhoods, of which a number can be classified as deprived neighbourhoods, which are areas with problems. These are the neighbourhoods in the center of the city, which can be seen in **Figure 19**. The blue area is the most deprived, then purple and then orange.

Aspects discussed about the living environment are the level of satisfaction regarding housing and residential environment, including the level of satisfaction regarding the amount of green in the area and the experience of summer conditions. Besides this, air quality, noise pollution, odor and light pollution are discussed. For this project, air quality and noise pollution were interesting.

Of all inhabitants of The Hague, 63% is annoyed by noise and 23% is seriously annoyed by noise. Most of the causes are mopeds/scooters, road traffic and sound from neighbors, this can be seen in Figure 17. Sound levels on the facade of buildings are calculated with the use of model calculations and traffic counts from 2011. The reason only calculations are done is that not everything that produces sound is included in the calculations, therefore it is difficult to measure because the sounds cannot be seperated. The calculations resulted in 23% of the citizens of The Hague being exposed to sound levels of 60dB or higher, causing 11% (57.000 people) to be seriously annoyed.

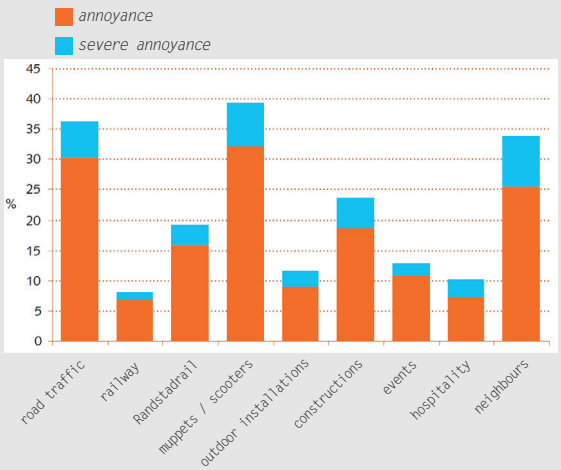


Figure 19 | *Annoyance and severe annoyance*

The biggest source of odor annoyance is wood burn which is also a source for damaging health. Of the citizen 9% states being annoyed by a fireplace or burner. Another source of annoyance is incoming light into the house, which can disturb the circadian rhythm. 56% states being able to observe light from road traffic, street lanterns or bill boards, of which 11% is annoyed by this.

During Meeting The Market, an initiative of the city of The Hague to connect entrepreneurs with employees of the municipality, answers to relevant issues were seeked. One of these was the question how to create an oasis in the bustling city. This shows the relevance of the issue.

Status of the air quality

In the city of The Hague there are one hundred points at which the level of NO_2 is being measured. This is done with the use of palmes tubes, which are small plastic tubes with a chemically active substance that responds to NO_2, resulting in a monthly average (RIVM, 2016). Besides this, there are four air measuring stations, measuring the substances that can be seen in **Figure 20**.
Measurements are being done in four locations in The Hague:

- Amsterdamse Veerkade
- Bleriotlaan
- Constant Rebecquestraat
- Vaillantlaan

These are marked with the red dots on the map (**Figure 21**). The station at Constant Rebecquestraat is a location to measure background concentrations, which means that no peak values in this area are being measured. On the map is also shown the typical traffic (green, orange red)(Google maps).
To improve the air quality in the city an action plan was made (Actieplan Den Haag 2015-2018). One of these measures is to have a demolition regulation for scooters. When inhabitants have their scooters demolished, they receive a credit to either buy a bike or to use the public transportation. The World Health Organization advises even lower levels of

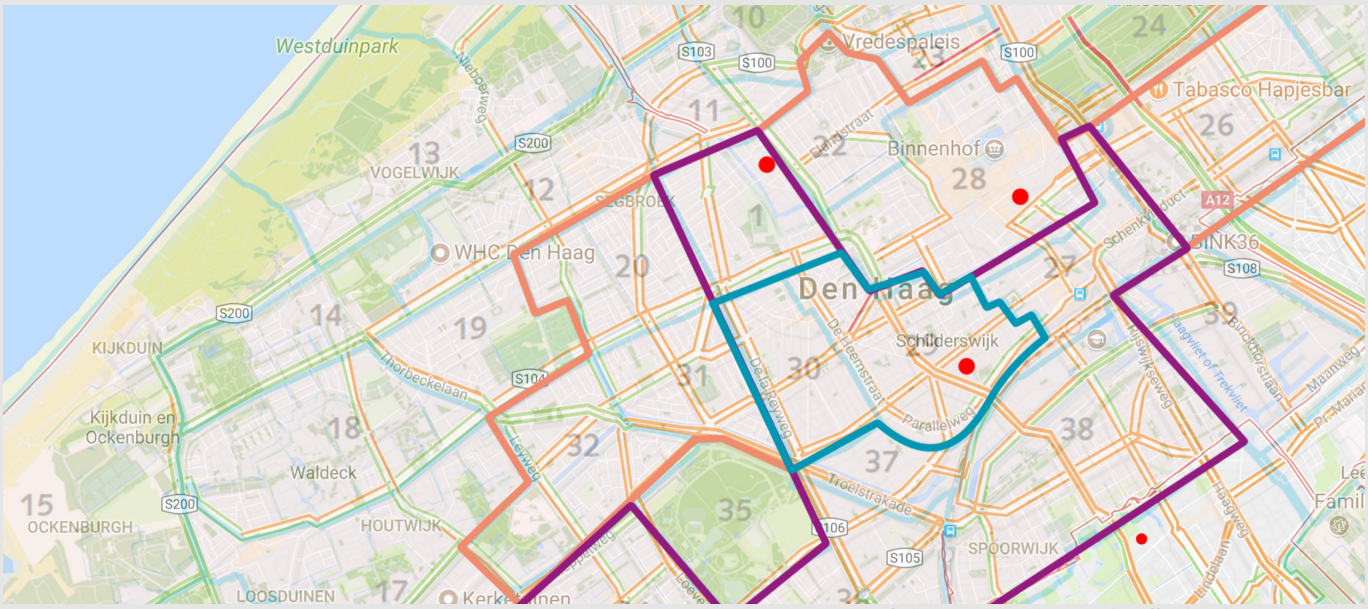


Figure 21 | *City of The Hague with typical traffic, levels depreviation and four measuring stations*

air pollution than the European standards, in order to achieve this, more measures have to be taken (Dossier Fijnstof, 2013).

Status of noise pollution

In the city of The Hague, noise is not being measured, only calculated. These calculations are translated into noise maps. This is in order to monitor noise pollution and see whether there are exceedances of allowed values. Every 5 years, these maps are created. Between 2007 and 2012 they were more or less the same. It is shown that in the area of The Hague, road traffic is the most important source of noise pollution, also because there is very little industry. Road traffic including trams is responsible for about 97% of the noise annoyance among inhabitants. Even though cars become more silent, when their speed is above 50 km/h the most dominant source of noise pollution is the contact between the tire and the road. One of the measures taken is changing the road surface to silent asphalt (Actieplan geluid, 2012). The only time measurements are being taken is when people complain about noise, however mostly this is about horeca or neighbours and not about traffic. In case this happens, there are extensive protocols that have to be followed. People should become more aware of the effects of noise pollution, therefore the municipality of The Hague would like to use the new noise pollution maps to educate people (municipality of The Hague, 2017).

Conclusion

It is shown that the air quality is improving in The Hague and that the level of air pollution is being measured and calculated. However, these measurements are limited and the calculations do not show peak values. Therefore it could be interesting for the municipality to place multiple measuring points to get a better view on the actual situation. Regarding noise, not very much is done besides noise mapping. This is partially because of difficulties in measuring and defining sources of noise. Furthermore, the subjective opinion of people is also not involved yet and people are not aware of the consequences yet.

Therefore a solution could be searched into making people aware of the situation regarding air and noise pollution in the city in order to give them insights and give them the possibility to make different decisions.

	NO_2	NO	O_3	PM_{10}	$PM_{2.5}$	Carbon black
Amsterdamse Veerkade						
Bleriotlaan						
Constant Rebecquestraat						
Vaillantlaan						

Figure 20 | *Measuring stations in The Hague with measured pollutants*

3.3 SCENARIOS

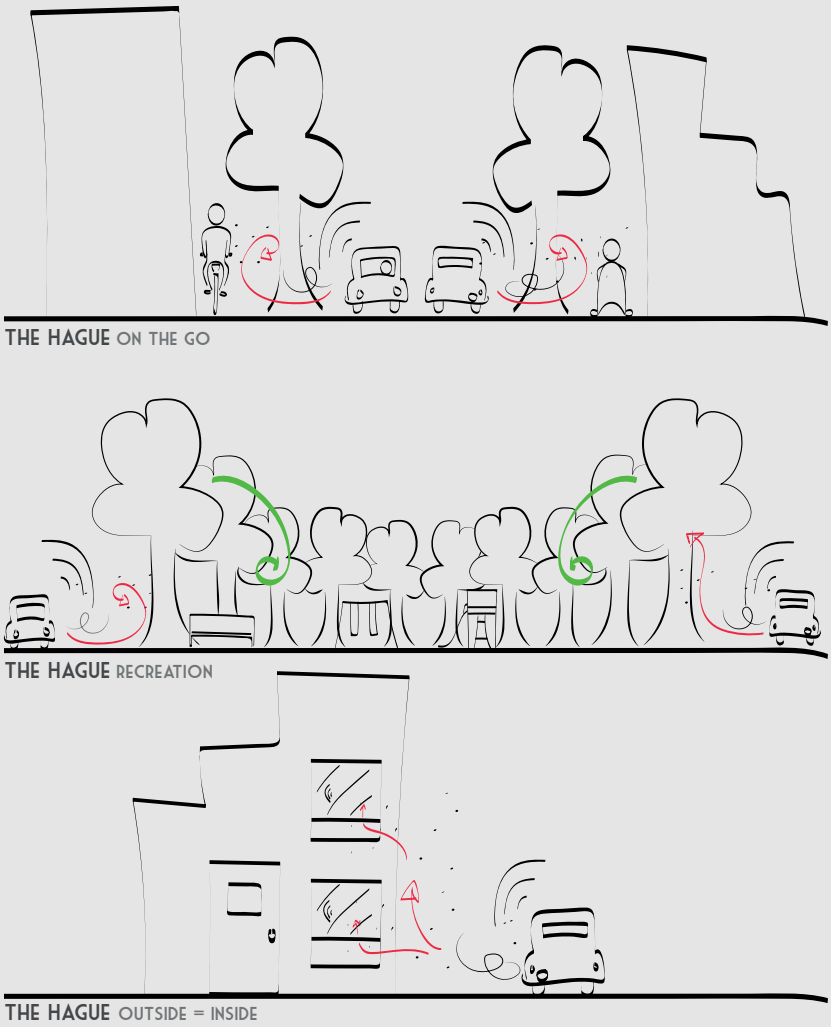


Figure 22 | *Three different contexts within a city*

Within the city of The Hague, multiple contexts can be distinguished, which can be seen in **Figure 22**. Three of them will be elaborated with an eye on air quality and sound levels.

On the go

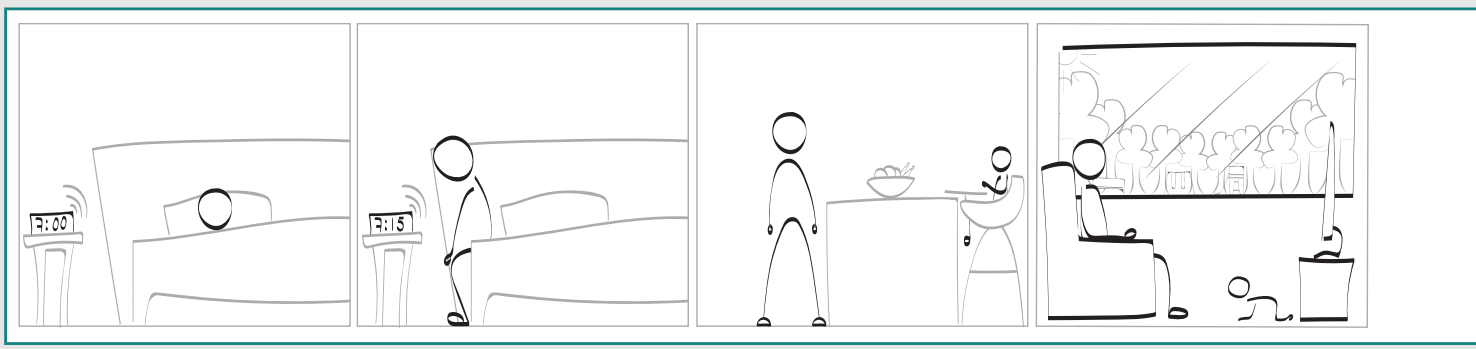
People have to navigate through the city everyday in order to get to their work/school/sports or they are waiting for the bus/tram or at the traffic light. It would be valuable for people to know the quality of the air and the level of noise in order to find a better route to get to their destination.

Recreation

People are seeking for relaxation around the city, going to parks, playgrounds and other recreational areas. Since people need quiet time, it can be a contribution for people to be able to find out where the quieter places are, or the places perceived by other people as quiet and comfortable.

Outside = inside

Many people live close to busy streets which results in higher levels of air- and noise pollution. Monitoring this on the outside of the house can give people an idea on the quality of the air when opening a window or it can give insight in the influence of sound on their sleeping quality.



3.4 STORYBOARD

A storyboard has been created to show in what ways there are opportunities to create a new product and in which situations awareness of the environment is needed. These situations are visualized in **Figure 23**.

1. On the go

In the first scenario it can be seen that a parent living in the city center is taking his child to daycare. In case people go around the city during rush hour it would be wise to choose a different route, especially when traveling with children. In case a product will measure the quality of the environment, an alternative route can be provided to reach the destination. This way the child and parent will breathe cleaner air and as a result their wellbein will benefit.

2. Recreation

The second scenario is based on the limited amount of greenery and recreation space in the city. Some parks are very close to high speed roads, resulting in an area not even beneficial for your restoration. When the quality of the recreation areas are monitored, people can see which park would be best to visit on that day. Also, when other people who already visited the park provide their feedback on how they experienced this environment other people can take this feedback with them in their decisions.

3. Outside = inside

The final scenerio focusses on the impact of the outdoor quality on the indoor quality. One of the most important things in the house is to ventilate the house with fresh outdoor air. However, in case the outdoor air is not fresh it would be nice to get a warning. Besides this, traffic noise and other sounds from outside can interrupt people while sleeping. When measuring the noise from outside and perhaps comparing them to a sleep tracker it can be seen whether people are affected by this or not.

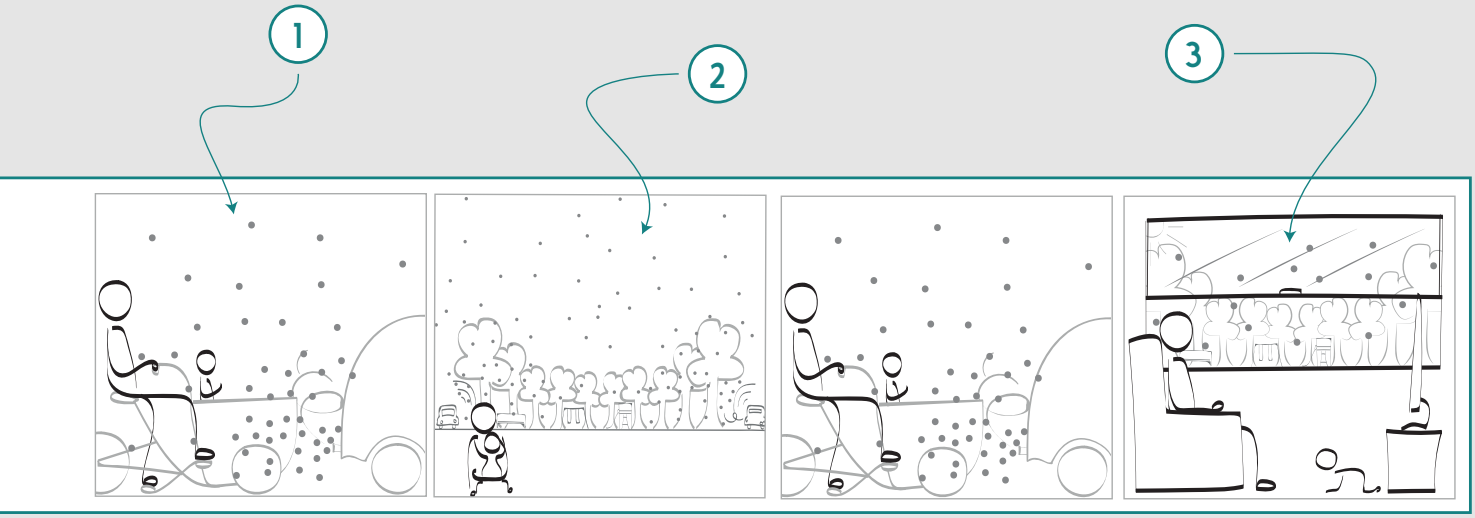


Figure 23 | *Story board based on the three contexts*

3.4 USER

Because it was still unclear who is going to use the product, a brainstorm was done in order to define the user.

A distinction can be seen between the problem owner and the user. In this case, the citizen of The Hague will be the user of the product, however most of the time they are not the problem owner. This will be the municipality of The Hague since they are responsible for the air quality and the level of noise in order to make sure these are below certain levels.

User

For every context the user can be differently defined which can be seen in **Figure 24**. However, in the end they all want to breathe clean air and not experience noise annoyance.

Citizen living in the city center or next to busy streets were chosen as the user since they are the ones that have to become aware of the quality of their living environment and they are the ones that have to provide the subjective feedback. Therefore, the use of the product has to be clear in order for them to see the benefit in using it. Eventually, the problem owner, in this case the municipality, can use the data of the objective measurements and the subjective input of the citizen to create a healthy city.

Problem Owner

Since the municipality needs to make sure air quality and noise pollution are below certain levels, it will be usefull for them to get more insights in the levels throughout the city besides the measuring stations and calculations which don't show peak loads. At the moment it is very actual to talk about "The Smart & Healthy City". In the Netherlands there are six cities are pilot cities in which they try to improve the quality of the living environment (Slimme & Gezonde Stad, 2017).

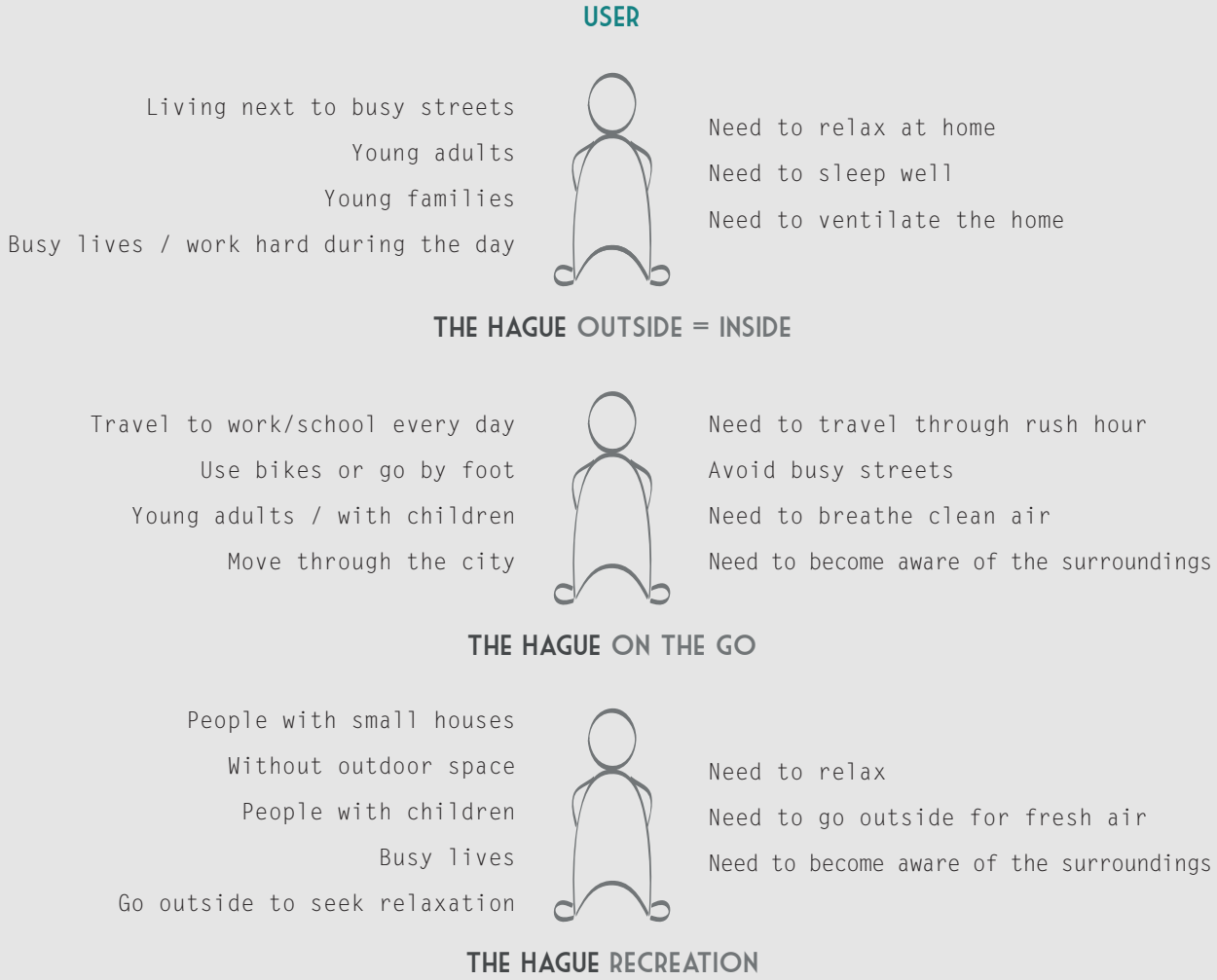


Figure 24 | *User characteristics with user's needs*

A questionnaire was carried out to find out what people find most interesting to measure, how much time they spend in which environment, and whether they live next to a busy road.

82 respondents were asked how much need they felt to gain information about the quality of the air and the level of noise in their living environment. They were asked to score each of the tree contexts stated before. Most need was expressed for quality of the air and the level of noise for the context outside = inside (**Figure 25**).

In order to find out in which environment measuring air quality and noise would be most interesting, respondents were asked to score each of the three contexts on how much they valued air quality and quietness. Most respondents valued both air quality and quietness in the context outside = inside most (**Figure 26**).

Furthermore, respondents were asked in what way they would like to receive feedback on air quality and noise. 43.9% stated they wanted to make a request on their own to receive information and 41.5% stated they wanted information automatically in case circumstances change (**Figure 27**).

Respondents preferably want to spend less than 2 minutes when providing input (63.4%), this can be seen in **Figure 28**.

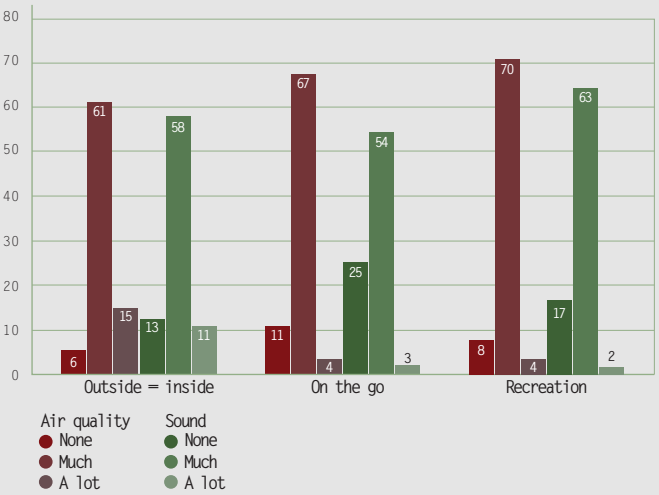


Figure 25 | *How much do people feel the need to get information on the air quality and level of noise in the three different contexts*

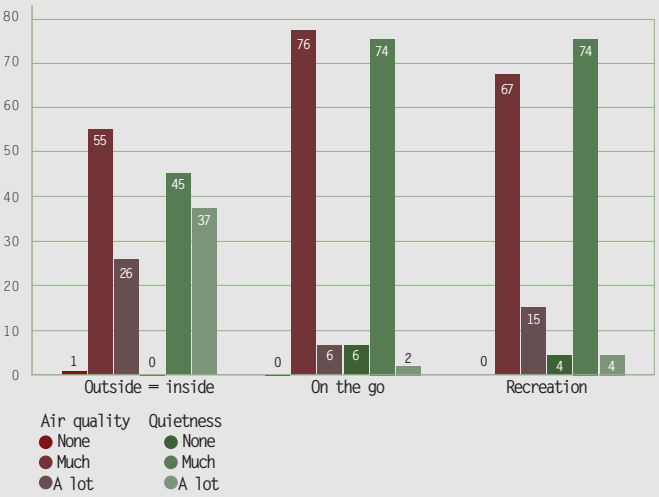


Figure 26 | *How much do people value air quality and quietness in the three different contexts*

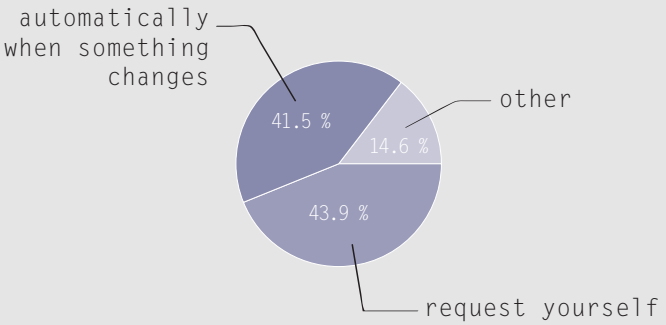


Figure 27 | *The way in which respondents want to receive information on air quality and level of noise.*

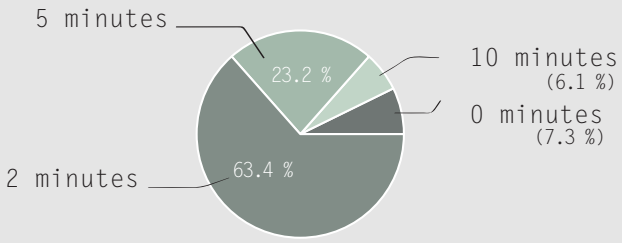


Figure 28 | *The amount of time respondents want to spend on providing input about the environment*

3.5 DESIGN DIRECTION

In order to choose a design direction, a creative phase was needed to get insight in the context and the possible directions. This creative phase led to several ideas suitable for the three stated scenarios. These ideas can be found in Appendix B.

Based on these insights and on the outcomes of the questionnaire of chapter 3.3, it was decided to continue with the context "outside=inside"(**Figure 29**). As stated before, it was found that most people saw the need to get information on air quality and noise in this area. Besides this, an opportunity was seen to create a business to business product in this area, since the gathered data can be highly valuable for other companies, instances or municipalities. Because municipalities measure air quality with expensive equipment, a measuring network of less costly products could be created by spreading the product throughout cities. This is already being done in cities like Eindhoven with the use of Airboxes by Aireas. These boxes measure air quality throughout the city. However, they don't include the inhabitants of the city and their experiences, but measure pure objective data. It is exactly on that point that an improvement can be made.

Product functions
In order to achieve gathering data on both objective and subjective input, the product needs to gather data on the air quality, the level of noise and the experiences of the inhabitants regarding these aspects. In **Figure 30**, the functions of the product are visualized. The product should measure the air quality and level of noise both inside and outside. After these are measured, feedback has to be given to the user. The user can provide input on how the variables are experienced.

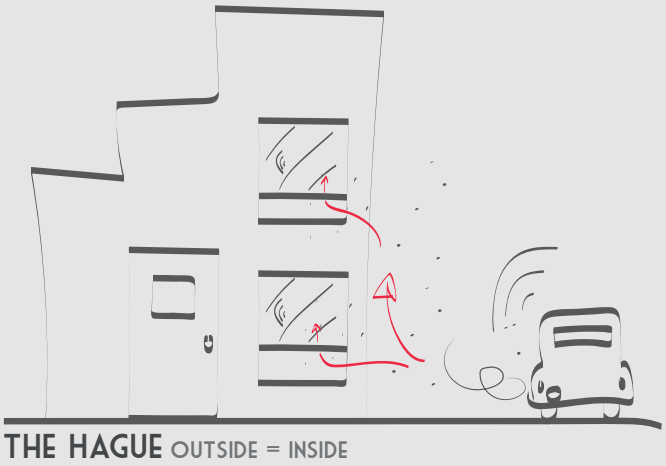


Figure 29 | *Product functions*

Benefits for the user
Because people have very little influence in changing the circumstances in the city, it is important for them to become aware of the situation in order to be able to make well-informed decidisons. Furthermore, the user has to become aware of their primary appraisal on the variables, how they respond to air pollution and noise.

Benefits for the problem owner
As stated before, the user of the product in this case is not the problem owner since the user has little influence on the circumstances outdoor. The municipality can be seen as the problem owner with as a problem unhealthy inhabitants as a result of air and noise pollution. The benefit for the problem owner here is to get more insights in the problem areas regarding air- and noise pollution and to gain insights in the opinions of their citizen.

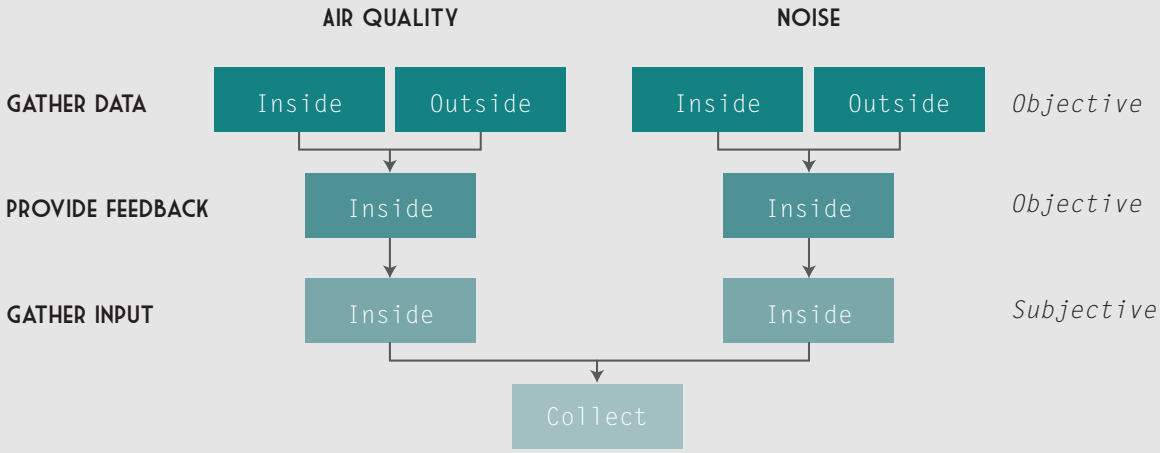


Figure 30 | *Product functions*

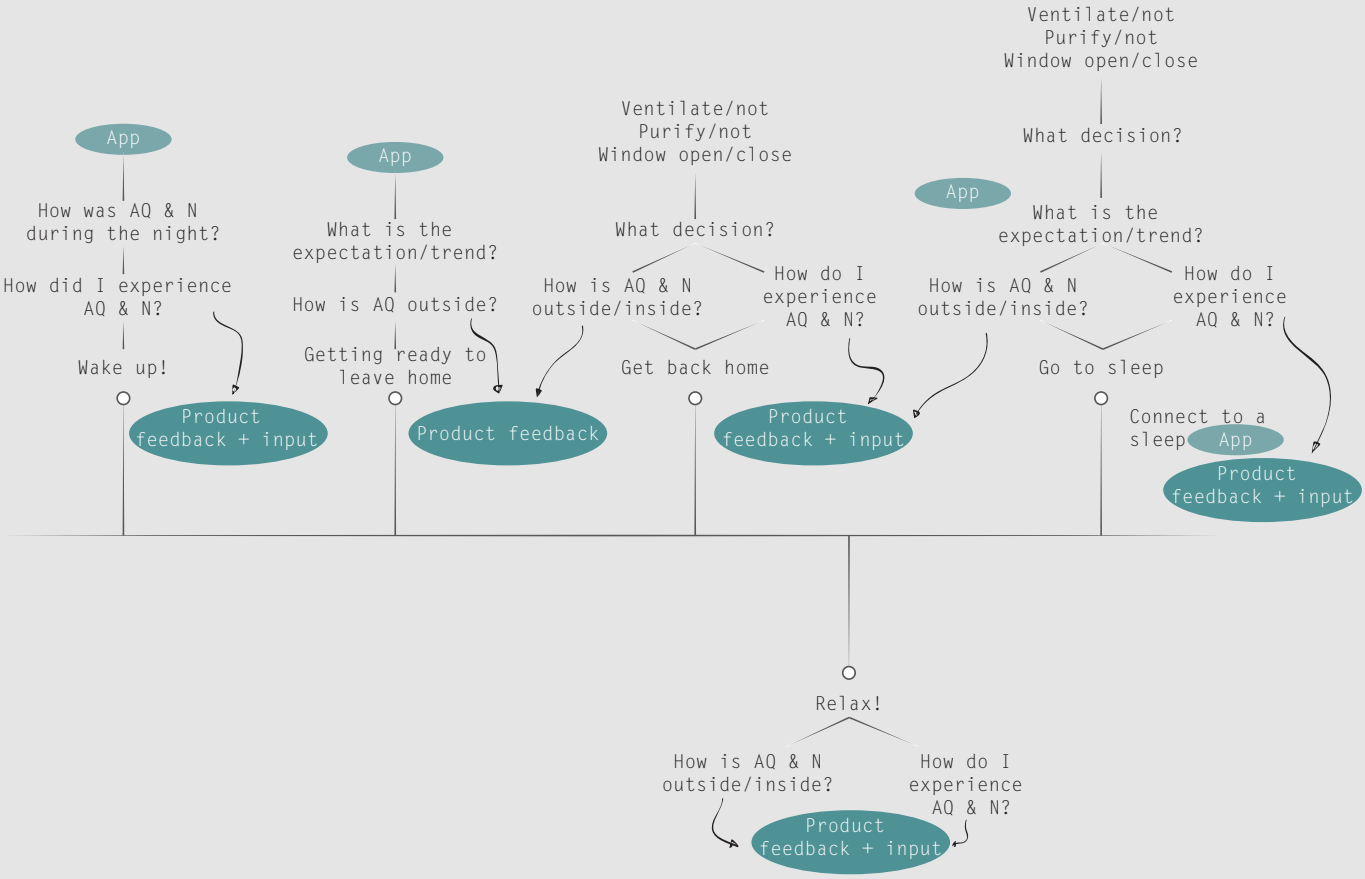


Figure 31 | *Schematic timeline of product use*

Use of the product

In **Figure 31** it can be seen when the product can be used.

With the help of this product, people will become aware of the quality of the air and the influence of the level of noise on their well-being.

When waking up, the user can see the air quality and level of noise in- and outdoors and can state how air quality and noise were experienced during the night. In case more detailed information is desired, like average data, the user can refer to an app, in which the data gathered will be visualized. From this, the user becomes aware of the circumstances during the night and whether he/she is affected by it or not.

While preparing to leave the home, the user can take a look at the product to see outdoor air quality. With this information, the user can deside to leave the home being informed about the circumstances, or choose another time to leave the home when circumstances are better.

Being at home, the product can act upon changing circumstances. When air quality or level of noise are changing, the user will get notified and can act upon the situation. Examples for this regarding air quality can be found in people cooking, vacuum cleaning or when it is rush hour. The air quality changes and the product will show which air is better, inside or outside.

All in all, the product will help the user in making well-informed decisions, such as those stated in **Figure 32**.

	AIR POLLUTION	NOISE POLLUTION
SHORT-TERM	Do nothing Open window Close window Start purifier Go/don't go outside	Do nothing Close window Turn volume down Mask noise with other sound
LONG-TERM	Start neighbourhood initiative to improve air Change times to leave the house Move Cope/reappraisal	Start neighbourhood initiative to reduce noise Solve issues with neighbours Identify source Cope/reappraisal

Figure 32 | *Possible desicions that can be made with the use of the feedback from the product*

3.6 CRITERIA & DESIGN VISION

To establish a design that is fitting the needs and wishes of the user and the company, a design vision was formulated based on the design direction.

Design vision:

I want to design a product-service system that measures the quality of the air and the level of noise to provide feedback to the citizens of a city (in this case The Hague) to make them aware of the quality of their living environment and its impact on their well-being in order to increase making well-informed decisions.

In order to achieve this design vision, requirements for the product have been set. These are stated as follows:

- The product should measure the most important air pollutants, NO_2, CO_2, and PM and the level of noise both indoor and outdoor
- The product should be attached both on the outside of the home as well as on the inside of the home, (preferably) on a place/location where air and noise enter the home

Besides the requirements, there are also wishes that have to be fulfilled as good as possible. These will be used as the criteria to choose from different concepts in a later stage:

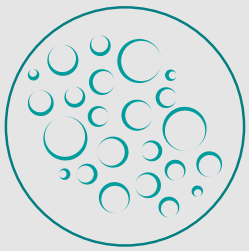
- The product should provide feedback on the quality of the air and the level of noise on the right level, from "good to bad" in order to make it understandable for the user
- The product should require intuitive interaction when the user is providing input
- The product should provide feedback in an intuitive way (to follow the current trend "Shy Tech") in order for it to be easily understandable
- The product should fit Studio Überdutch's vision to sell the product business to business
- Require little effort to provide input (preferably less than 2 minutes)

3.7 CONCLUSION

The product-service system will be used by people living in the city to make them more aware of the air quality in their living environment and the level of noise. They can provide subjective input on the level of noise and the quality of the air. Because of the data gathering, useful analyzing can be done regarding the level of noise in combination with air quality and location. Important for the product is that little effort is needed for occupants of an environment to provide input, the feedback given to the citizen should be easily understandable, the product should require intuitive interaction and finally it should fit Studio Überdutch.

In order to fulfill the design vision, the product-service system will contain at least the functions that are shown in **Figure 33**. These functions are needed to make the user aware of the quality of their living environment.

Subjective input on the experience of noise and air quality



Objective measurements of air quility

Objective measurements of noise

Figure 33 | *Product functions*

4. CONCEPTUALIZATION

After a first creative phase, an idea direction was chosen that fits within the chosen context of "inside=outside". Ideas were generated with the idea that one part of the product would be attached on the outside of the window while the other one was attached on the inside of the window. From this, the most promising idea direction was chosen to be further developed.

4.1 CONCEPT DIRECTION

The chosen concept direction contains a product that consists of two parts, which are part A and part B, attached to each other on the window with strong magnets. This method can be seen in window cleaners designed for cleaning the outside of windows from the inside (**Figure 37**).

In **Figure 34**, the initial idea can be seen. Part A will be attached on the outside of the window, while part B will be attached on the inside. Both parts will contain sensors, measuring air quality and the level of noise. Besides this, both parts will contain a light ring for feedback on the objective measurements. Input can be given with the turnable button on part B.

As it can be seen in **Figure 35**, a small plant was included in the product. This was done to refer to the power of nature to improve air quality. Bringing more plants into the home will decrease the level of CO_2 and pollutants.

After the first idea generation, this idea direction was chosen, this can be seen in **Appendix B**. However, several aspects still had to be improved and further elaborated.
Such as the following:

- The manner in which feedback is given regarding the level of air quality, both indoor and outdoor.
- The manner in which input is collected from the user on the level of air quality and noise.
- The manner in which the product is attached to the window.

This idea is used as a starting point for concept development.

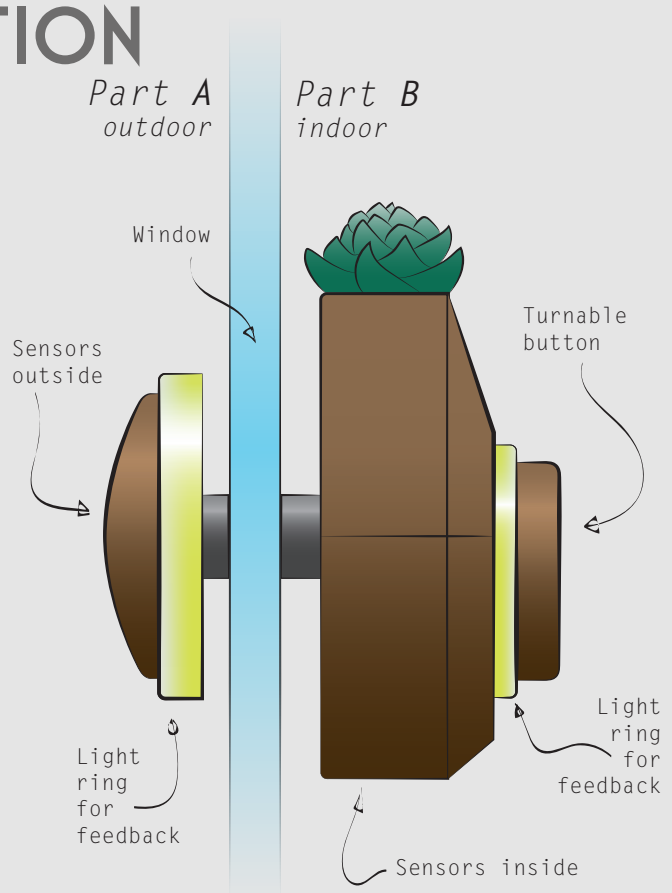


Figure 34 | *Window magnet*

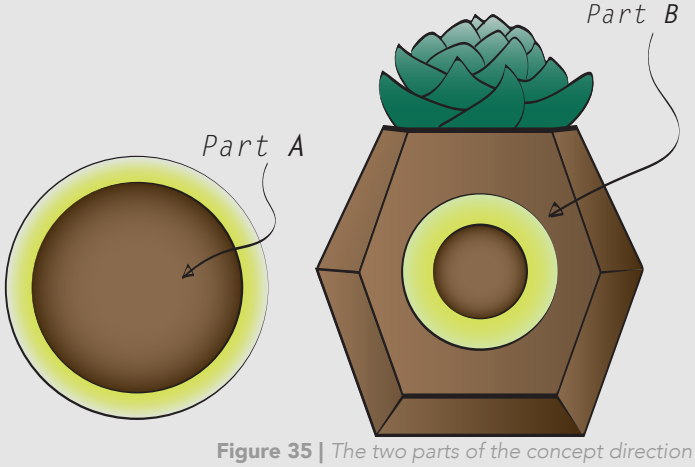


Figure 35 | *The two parts of the concept direction*

4.2 IDEATION

After choosing the idea direction, an iteration was made to the initial idea. In order to do this, How To's were created.

As stated before, the product will consist of two parts. In the initial idea, the method of attachment to the window was by using magnets. In order to generate more ideas, it was decided that it was not necessary for the two parts to be on the same location on the window if no magnets would be used. This opened up more space for generating ideas. Therefore, the two parts were taken apart during the idea generation. Thus, there is part A which is attached somewhere outside on the facade and part B that is placed somewhere in the home. This led to the following "How to's":

Part A (outdoor)
How to attach the product to the window?

Part B (indoor)
How to collect subjective input?
How to give feedback on the level of pollution?
How to give feedback on the level of noise?

In this paragraph, the outcomes of the How To's will be discussed. Starting with the part that is attached on the outside of the home.

Part A (outdoor)

As it was decided to attach the product to the window or facade, different types of windows were analysed. These different types can be seen in **Figure 36**. One of the requirements of the window is that it has to be a non-fixed window, unless the window is situated on the ground floor or balcony. In case the window cannot be opened, the product cannot be attached to the window by the user itself. In that case, attaching the product should be done as a service by a mechanic.

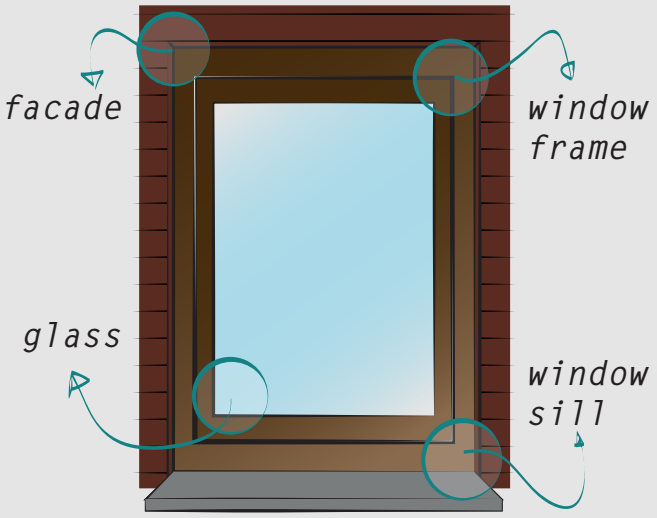


Figure 38 | *Possible positions for attachment*

Besides the different types of windows, a window itself with possible places for attachment has been analysed. Possibilities are: the facade, the window frame, the window sill and the glass. Besides this, it would also be possible to integrate the product in the window frame or window sill, these can be seen in **Figure 38**.

A possible risk to take into account is that there is a possibility for the product to be detached from the window in case of misuse or because of weather conditions if not attached properly.

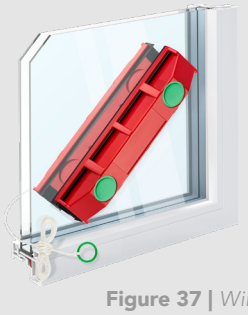


Figure 37 | *Window cleaner with magnets*

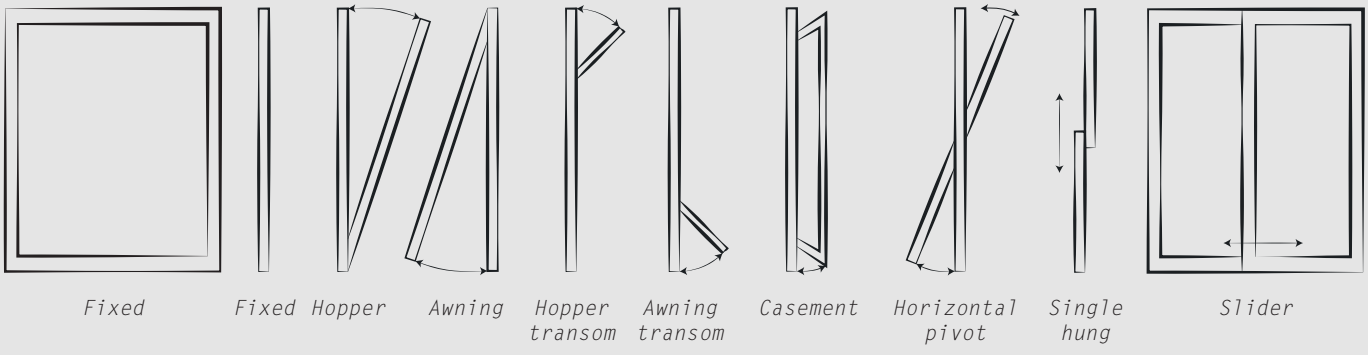


Figure 36 | *Different types of windows*

Part B (indoor)

During the analysis phase it was seen that most of the products that provide feedback to the user either do this with different colors of light or by displaying numbers. In the trend analysis in chapter 2.4 it was seen that it is desired that technology is more or less dissappearing, making the products minimalistic with little technical details.

For the indoor part that provides the feedback on air quality and sound, inspiration was sought in other products (**Figure 39**). One of these products were clocks, which were especially valuable. This is because they have to show time in a glance and be easily understandable. There are many clocks that show the time in a different way than just with a pointer and numbers as it can be seen in **Figure 40**.

Inspiration was also found in Ripple[22], a product for deaf people with which they can feel music, the wirling particles of a snow globe[23] and changing opacity.

Inspiration was searched regarding the visual appearance of the product. A collage was created to capture the desired aesthetics which can be seen in **Figure 41**. The visual appearance of the product can be stated as minimalistic, with natural materials, geometrical shapes and minimal components.

Since the user will be providing input on the experienced level of air quality and noise, ideas were created on how to collect this input.

The How To's were created during a brainstorm session at Studio Überdutch. After creating the How To's, they were collected in a morphological chart that can be seen in **Appendix C**. From this, combinations were made to create different ideas.

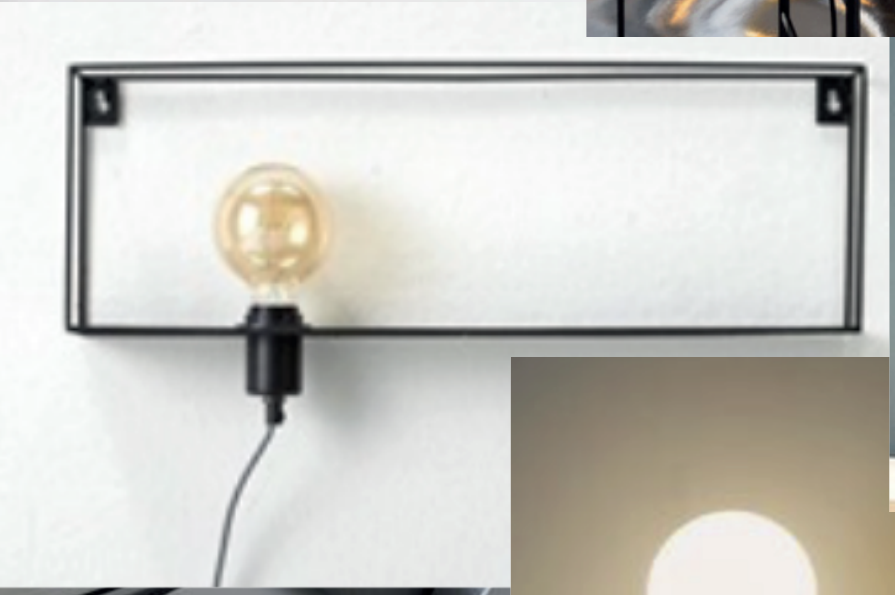
Out of these different ideas, two ideas were chosen and further developed into concept directions. For both ideas, there is also a part that is placed outdoor to measure those variables. These ideas will be described in the next paragraph.

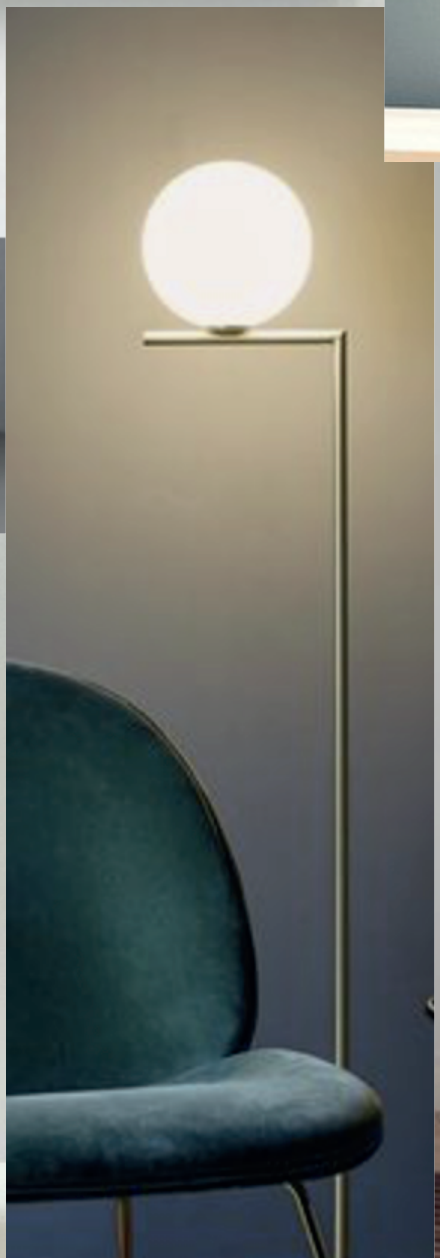
Figure 39 | *Inspiration (from left to right: Ripple, Snow globe, Clock)*

Figure 40 | *Inspirational clocks*

Collage with inspiration for the aesthetics of the product) **| Figure 41**



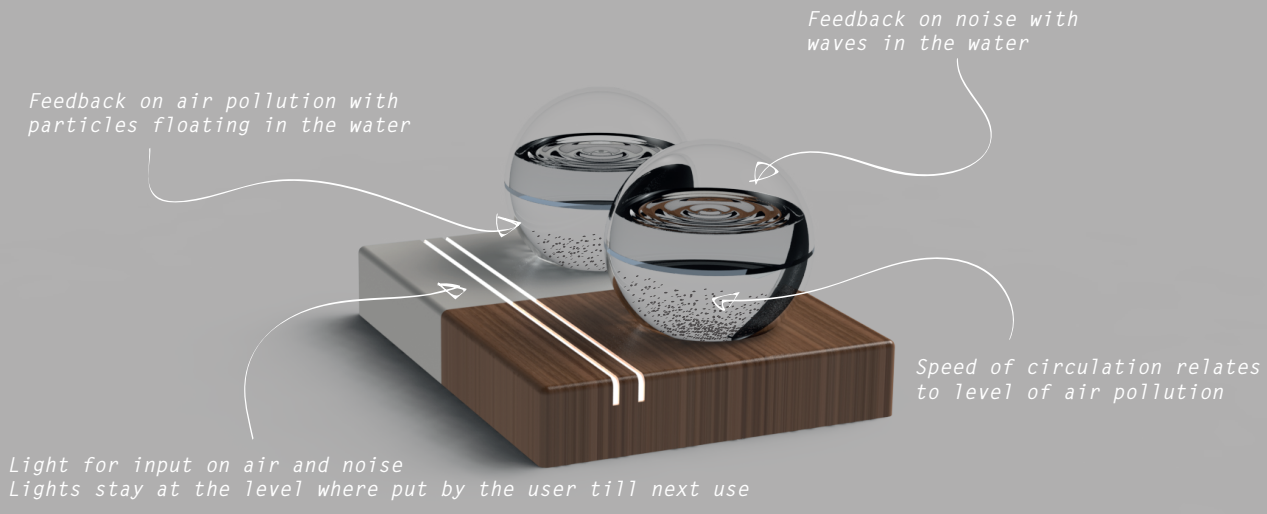



4.3 CONCEPT DIRECTIONS

CONCEPT A: AIRPORT

The first idea was based on snow globes and the rippling of the water by soundwaves.

The AirPort is placed somewhere around the house, preferably in the living room. Images of the concept can be seen in **Figure 42**. In the globes, two types of feedback are given, the upper part provides feedback on the level of noise and the lower part provides feedback on the air quality. The feedback on noise is given by generating vibrations in the water level, the more noise, the more vibrations. The feedback on the air quality is given by circulating particles that are in the water in the lower part. The faster the water is circulated, the more movement in the particles is observed. This represents more air pollution. Input can be given by simply using the light bars that responds to touch. Swiping to the right means that more air pollution/ noise is experienced and swiping to the left means less is experienced. Also, the color of the light will change from green to yellow to red.
This input will remain visible at the set level until next use. In case the user experiences the sound or air quality as less severe, the product will calm down and the water and particles will slow down. On the otherhand, if it is experienced as more severe, the product will become more active. This will only last for a short while before it goes back to its normal state.

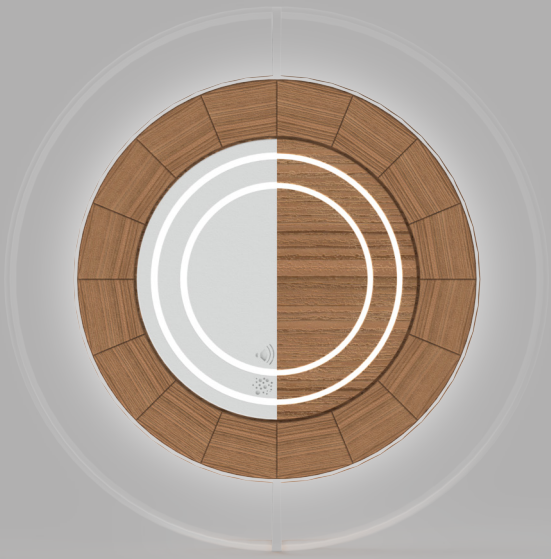


Above: Top view of AirPort; Bottom: AirPort and its functions | **Figure 42**

CONCEPT B: VISIONAIR

The second idea was based on the inspiration from Ripple in which the movement of the metal rods show the sounds.

The VisionAir is placed on the window, see **Figure 43**. Feedback on air pollution is given by blowing air into the transparent part that is filled with particles, which will start flying around. Much movement is a high level of air pollution, little movement means clean air. The product is divided in two halves, so one half represents the inside air and noise and the other one the outside. The circle with blocks will pop out on the level of noise. The user can provide input by touching the light circles. The outer circle is for air quality and the inner circle is for the level of noise. Immediate feedback to the user on the given input is quieting down of the product, in case the variables are experienced as less severe. In case the variables are experienced as more severe it will become more active. This will only last for about a minute before it goes back to the objective state.



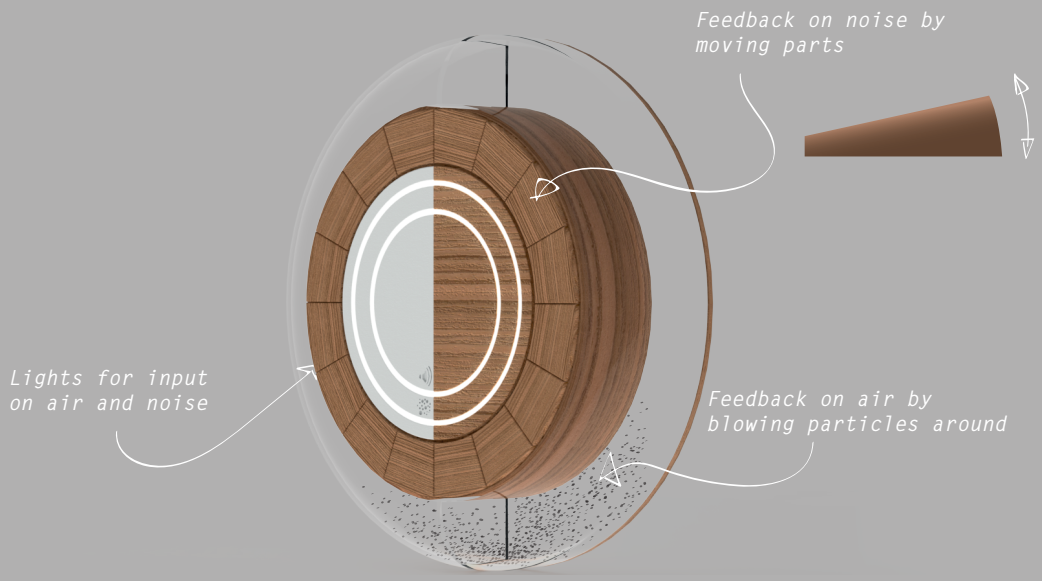


Figure 43 | *Above: Top view of VisionAir; Bottom: VisionAir and its functions*

4.4 CONCEPT DECISION

After the two concepts were created, a decision had to be made. Therefore, the two concepts had to be analyzed on their strengths and weaknesses. This was done by scoring the stated criteria.

The design criteria are as follows:

- The product should provide feedback on the quality of the air and the level of noise on the right level, from "good to bad" in order to make it understandable for the user
- The product should require intuitive interaction when the user is providing input
- The product should provide feedback in an intuitive way (to follow the current trend "Shy Tech")
- The product should have a minimalistic design.
- The product should fit Studio Überdutch's vision to sell the product business to business

AirPort

The first concept uses movement and vibrations to visualize the objective data, the scoring of the Harris Profile can be seen in **Figure 44**.

Level of feedback
The feedback given by the AirPort is lacking a scale. A distinction can be made between no air pollution and a lot of air pollution, but in between it would be difficult to identify how good or bad the air quality is. A positive point is that the product makes it possible to compare indoor and outdoor by simply looking at the product. However, small differences can still not be noticed.

Intuitive input
Since input can be given by touching the light, it can be seen as very intuitive because the color will change when touching it. Therefore you also get direct feedback on the provided input.

Intuitive feedback
The way in which feedback is given in the AirPort resembles air and noise in a quite natural way. Therefore it is easy to understand what is meant by the product.

Minimalistic design
Because of the limited use of materials and the geometrical shapes, the design can be seen as minimalistic. The need for distinction between the indoor and outdoor measurements make the product less minimalistic.

B2B feasible
In case the product will be sold B2B, the AirPort is less feasible because the product is rather aesthetical than functional.

VisionAir

The second concept uses movement and air circulation to visualize the objective data. The scoring of the Harris Profile can be seen in **Figure 45**.

Level of feedback
In the VisionAir, the level of feedback is more concrete than in the AirPort. The outcomes from both indoor and outdoor can be compared by looking at the product. However, there is still not a scale on which the user can see whether it is harmfull or not.

Intuitive input
The input is collected in the same way as it is in the AirPort. However, here the LED lights are in a circle, which means the movement of touch will be more like turning a button. This resembles for example the volume button of an Ipod that also uses touch to set the volume louder or softer. Just like on the AirPort, the lights will change color when providing input in order to give feedback on what is stated by the user.

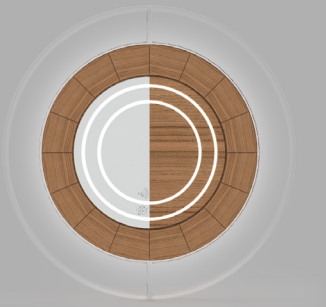
Intuitive feedback
By blowing small particles around in the air, the air pollution is visualized. Therefore, it is very easy to understand it represents air quality. The noise is represented by the movement of the blocks, which means you can see the movement and directly link it to the sounds you hear.

Minimalistic design
Because of all the seperately moving blocks and the half colored part, the product become less minimalistic.

B2B feasible
Because this product can be rather small and

AIRPORT	--	-	+	++
LEVEL OF FEEDBACK				
INTUITIVE INPUT				
INTUITIVE FEEDBACK				
MINIMALISTIC DESIGN				
B2B FEASIBLE				

Figure 44 | *Harris profile of AirPort*



VISIONAIR	--	-	+	++
LEVEL OF FEEDBACK				
INTUITIVE INPUT				
INTUITIVE FEEDBACK				
MINIMALISTIC DESIGN				
B2B FEASIBLE				

Figure 45 | *Harris profile of VisionAir*

flexible on where to put it, the VisionAir seems more feasible for a B2B vision

.

Concept choice

After analysing both concepts and seeing their strenghts and weaknesses, the two concepts were consulted with Studio Überdutch. Eventhough the aesthetics of the AirPort is stronger, the VisionAir scores better on the other criteria. Also the preferance of Studio Überdutch is going to the VisionAir, since this is more feasible for B2B purposes.

It is decided to continue with the VisionAir. Nevertheless, this concept still needs some improvement as it was seen that the level feedback was too abstract and the design could be more minimal. This results in another iteration on the concept as described in Chapter 4.5.

4.5 DEVELOPMENT OF VISIONAIR

From the concept decision arised the need for another iteration on the concept. Another look was taken at the way the feedback is given by the product and how to make the feedback more concrete without making it technical with numbers.

One of the obstacles was how to visualize measurements of both indoor and outdoor while remaining the minimalistisch aesthetics of the product.

In order to resolve the issue of having to show both outdoor and indoor objective measurements on one product, the idea arose to make the product transparent and show the outdoor variables on the outdoor part.

Final concept

As a result, the VisionAir now exists of two parts, both attached on another side of the window. As it can be seen in **Figure 46** and **Figure 47** the small balls represent the level of air quality, while the small metal rods represent the level of noise.

Because of the transparent enclosure, you can see both measurements from the outside and the inside at one glance. This situation can be seen in **Figure 48**. Here both parts are attached to the window. Next to that, it is shown how the two products look from the side view when attached to the window (**Figure 49**).

As it can be seen in **Figure 46**, the part that is inside also provides the opportunity to provide input on how the variables are experienced. The part that is attached outside on the window contains a solar panel to ensure the energy supply for the product without the need to connect it to the grid by wires, see **Figure 47**.

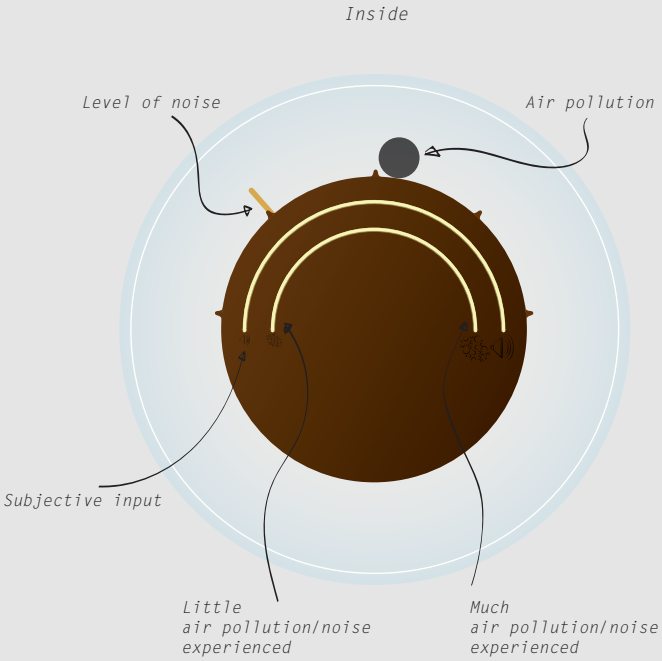


Figure 46 | *VisionAir inside part*

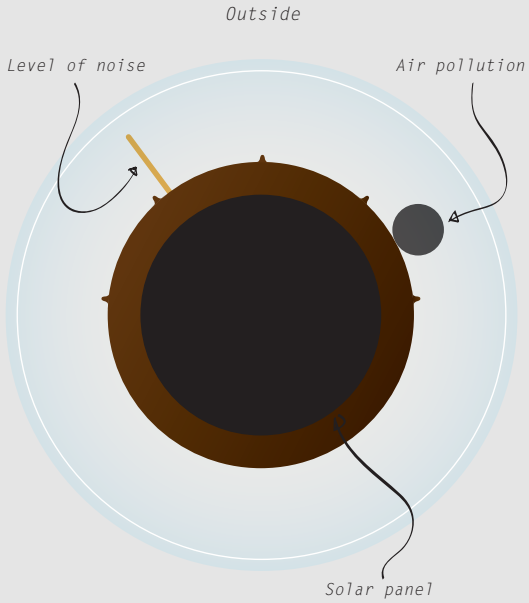


Figure 47 | *VisionAir outside part*

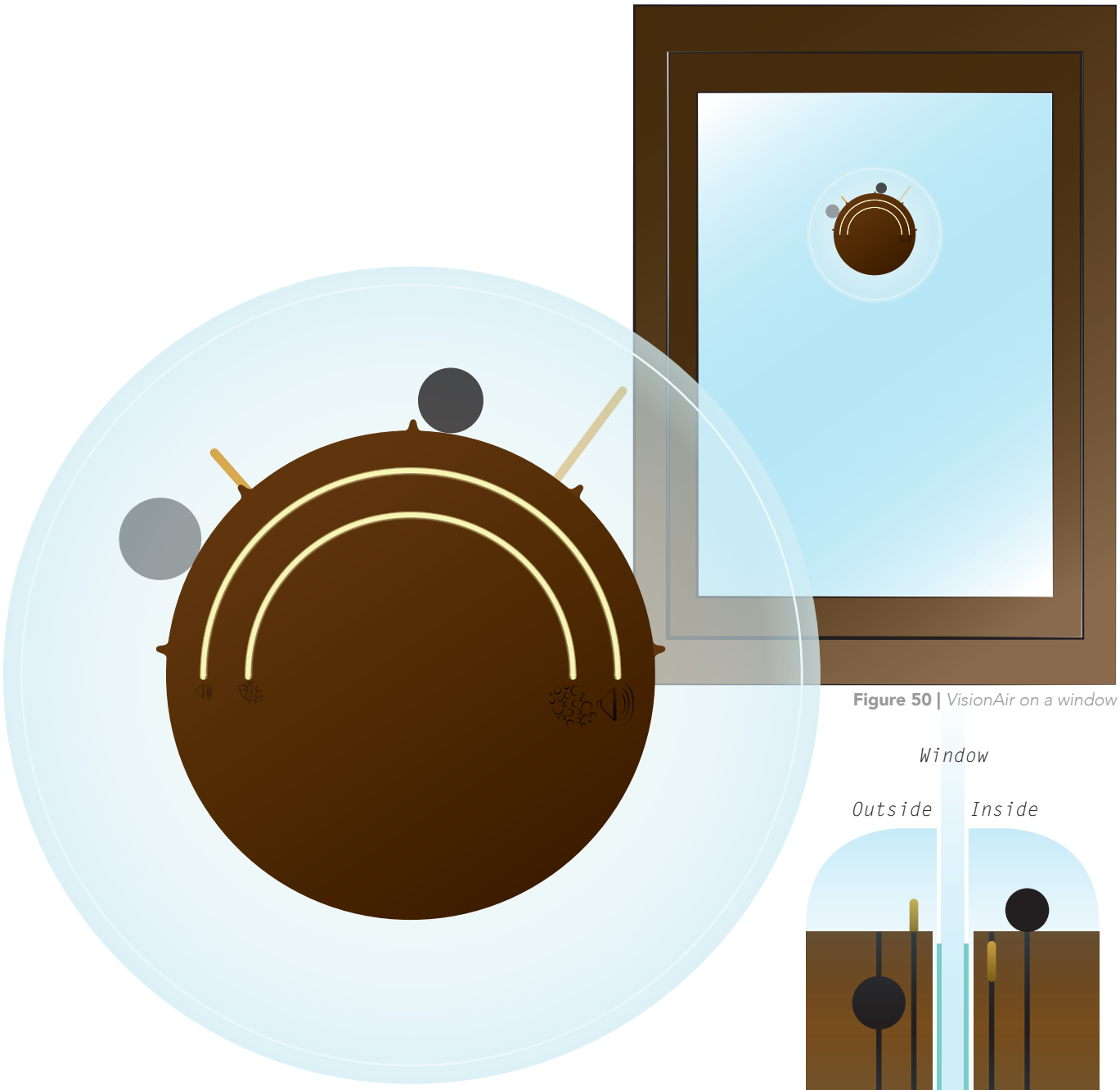
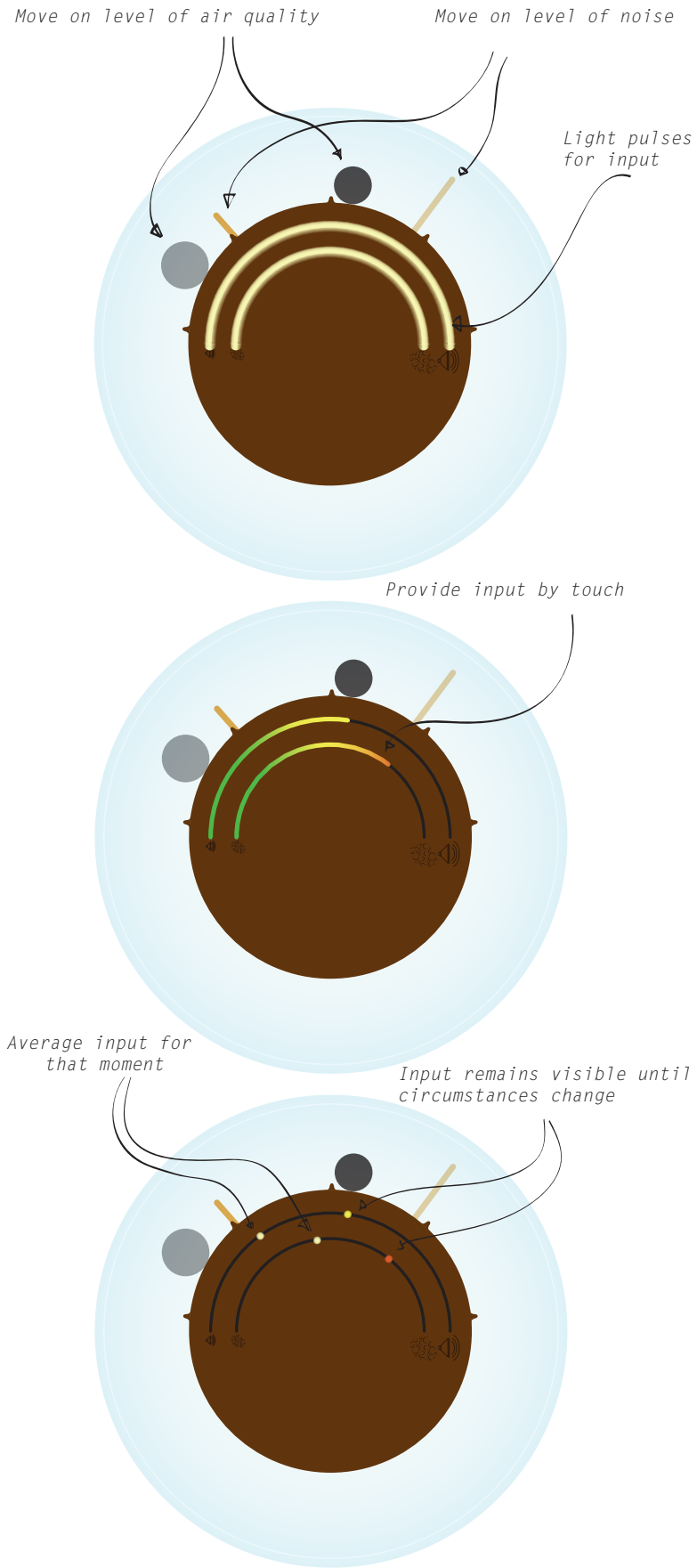


Figure 48 | *VisionAir both part together seen from inside*

Figure 50 | *VisionAir on a window*

Figure 49 | *Side view from both parts of VisionAir*



Use of the VisionAir

As stated before, the product will be used inside the home in order to measure air quality and noise inside and outside the home environment. The objective values are programmed based on set values for air quality and noise. Next, the use of the product will be explained with references to **Figure 51**.

1. A variable changes

In case the product measures a different level of air pollution or noise, the dependent sphere or rod will start moving towards the designated position. This can be seen by the user in the event that the user is near the product. In case there is a change in the variable and the user is at home, the lights will start pulsing for input.

2. User can provide input

When the user is near the product and decides to provide input, he or she can swipe over the lights in order to reach the desired value.

3. User receives feedback on provided input

To achieve a moment of awareness, the user receives feedback on the provided input. The average input that is provided by the user on that moment on the day is exposed on the product. Seeing a substantial difference between the average input and the current input can provide a learning moment to the user.

4. Input remains visible for the user

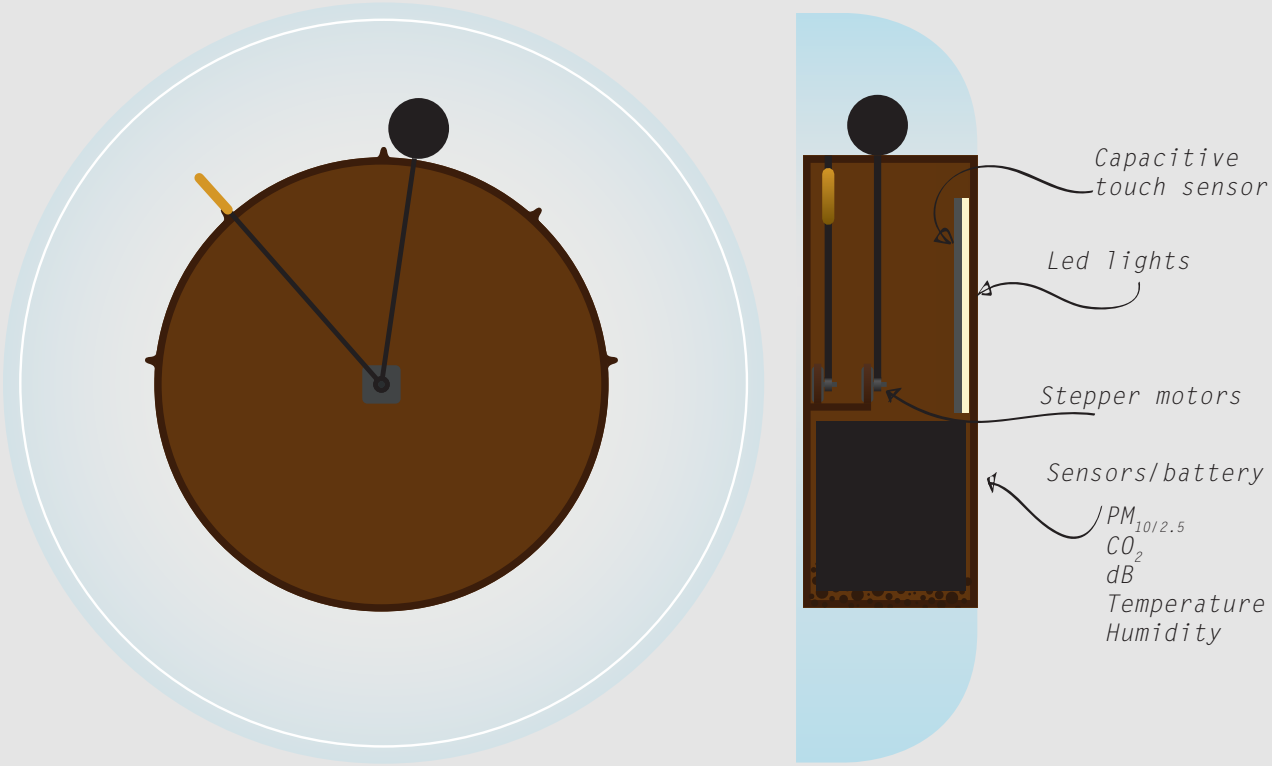
Untill the moment the product requests for another input, the input will remain visible. This way the user can also provide input in case he or she experiences the circumstances differently than before.

Working principle

The feedback on the variables is provided by rotating indicators that are powered by small stepper motors. The input is collected by touch sensors and the feedback on the input is given by LEDs. The data on the variables is collected by sensors. The basics of the product can be seen on the right in Figure X.

Figure 51 | *The use of VisionAir*

Part A *Indoor*



Part B *Outdoor*

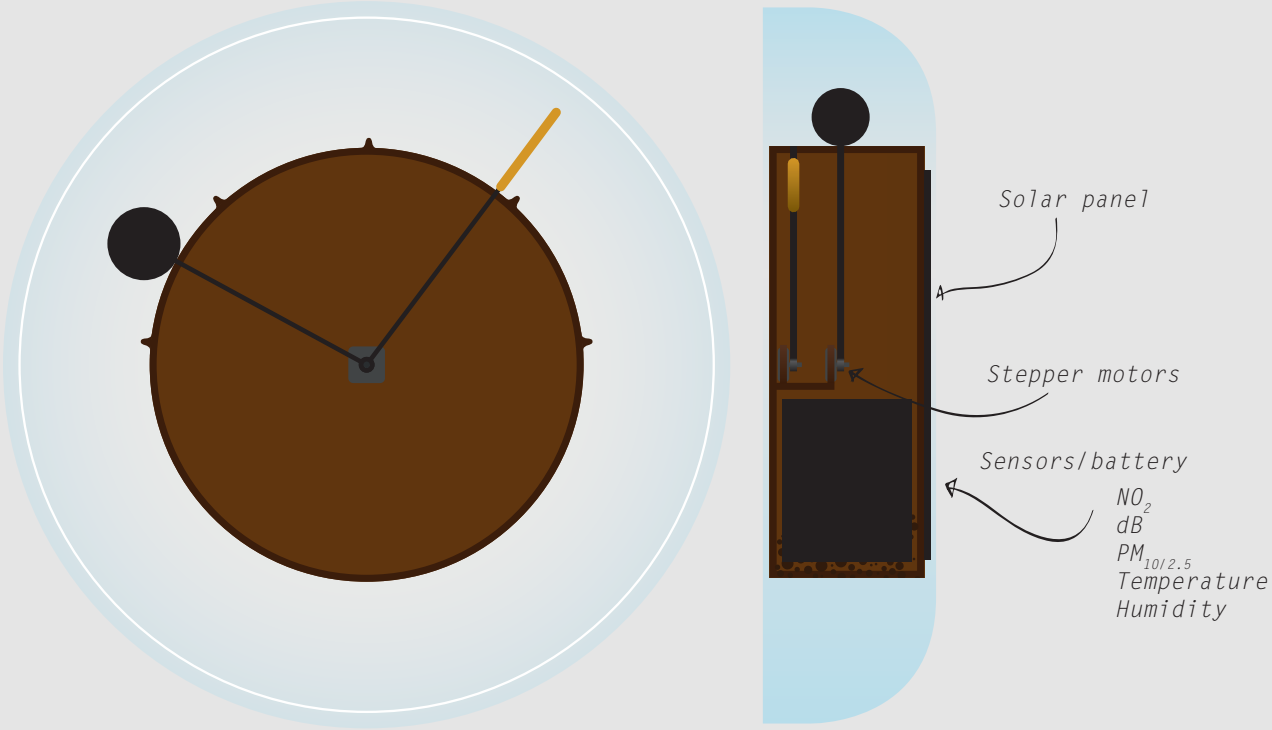


Figure 52 | *Side view from both parts of VisionAir and their components*

4.6 VALIDATION

The goal of the VisionAir is to increase awareness on air quality and noise inside and outside the home environment and its impact on well-being. In order to validate the VisionAir, a user test was executed by combining an interview with testing the use of the product.

Approach
Five people participated in the test, of which two male and three female ranging in the age from 23 to 28. The user test had two goals, firstly to explore the use of the product in the context and secondly the use of the mountig system from the product on the window. In order to test the product and whether it achieves its goal, images of the product were used to show to the participant. Also, images of the imagined interaction were shown to give an idea of the working of the product. To test the attachment to the window, a test model was created with a mounting system. This model can be seen in **Figure 53**. The duration of the test was about 30 to 45 minutes and took place in a home environment with a window.

The user test started with a small introduction and an opening question about the user's experience of air quality and noise in their home. From this, the basics of the product were explained with an image, after which they were asked to describe the image and to try finding out what the icons indicator represented.

After establishing the base of the product, it was further explained on its functions with more images. Participants were asked how the resemblance of the Figures was to the variable it represented. Finally, they were asked to attach the product to the window. Here for, a model was made with an attachment.

Outcomes
The participants are aware that bad air quality is bad for their health, however, three of them a were not aware that the indoor air quality can also be bad. One participant questioned how he would be able to notice that. Another participant was aware of the fact that burning scented candles influences air quality negatively. She noticed the difference in the air from the lighting of the candle till after some time, when the air became stuffy. Two other participants stated they know that their extractor hood in the kitchen does not properly function, one of them does not have one at all. They feel they do have influence on this, by opening doors and windows.

Regarding the influence on noise on well-being, four participants know too loud music can be damaging for their hearing. Two participants stated they think noise also has an influence on your psychological health, while another participant stated to have no idea that there can be negative effects on well-being. Only one of the participants sometimes feels annoyed by noise at home. Another one only experienced annoyance during construction of a new building next door.

It was seen that the icons represent air quality

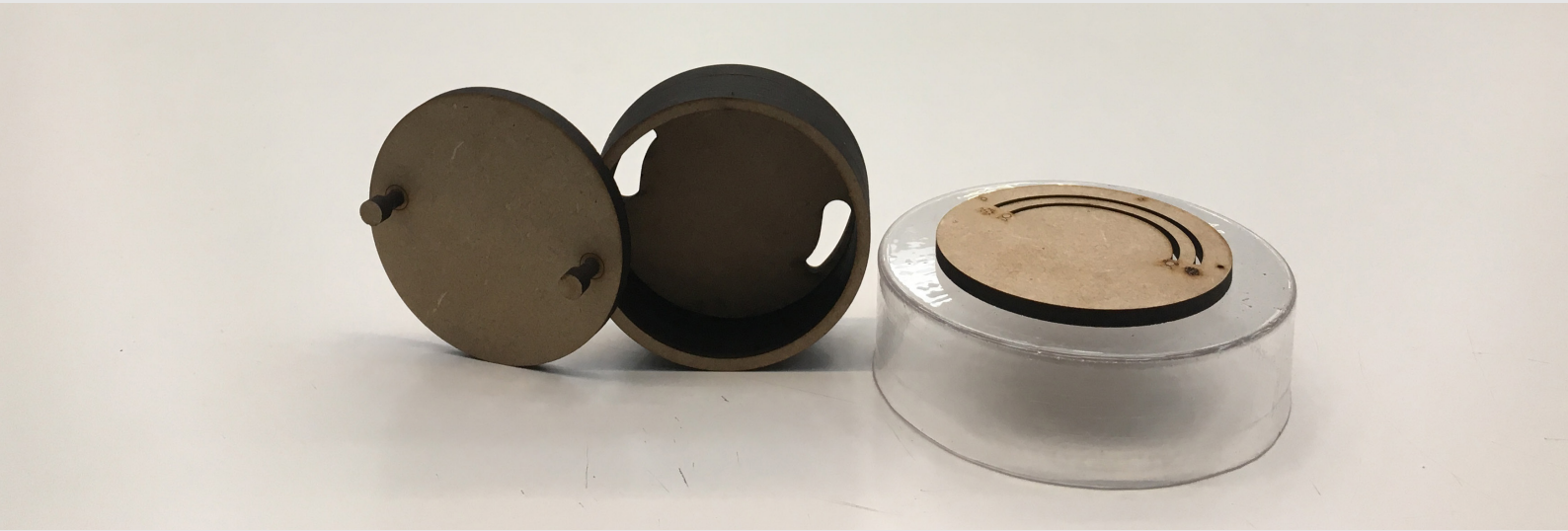


Figure 53 | *Model with attachment used for user test*

and noise well, however no one understood there was a possibility to provide personal input. The distribution of scale from little to a lot was clear to all respondents. It was not clear which indicator represented which variable. Three of the participants thought the indicators were actually the sensors measuring the variables.

According to the respondents, the product can make them more aware of the variables and can incite to action. According to one participant it would be useful if the user can set certain values at which to receive an alarm. The participants did see the value of giving personal input, however they did not feel like they would take the effort to do this. One participant stated she would probably feel differently about this in case it was in relation to the health of her children, in that case she would be willing to take the time. Another participant stated it would only be valuable in case useful things happen to the gathered data. He saw most relevance in providing input in the morning, but did not really see people doing this even though in his opinion this could possibly be the most useful data with the biggest impact on long term changes. The participants mostly saw the benefit in providing input either before going to bed or when being at home.

Finally, the participants were asked what they would expect to find in an app that would be connected to the product. They all stated graphs or overviews of the day/week/month. One participant mentioned advice, small facts or inspiring quotes regarding the measurements. Other options mentioned were an alarm for certain values, the set values of what is good or not and the option to personalize the setting of the number of notifications.

Attachment of the VisionAir to the window

After the first part of the test, the participants were asked to attach the product to the window. For this, they were given the two components, the VisionAir and the mounting plate. The intended method of attachment was to first attach the mounting plate to the window and secondly attach the VisionAir on the mounting plate.

All of the participants succeeded in attaching the product to the window, however two of them first attached the mounting plate to the product before attaching them to the window in one piece (**Figure 57**). The other participants had some trouble with finding the right orientation of the mounting plate and connecting the device to the mounting plate since they could not really see where the connection points were (**Figure 56**).

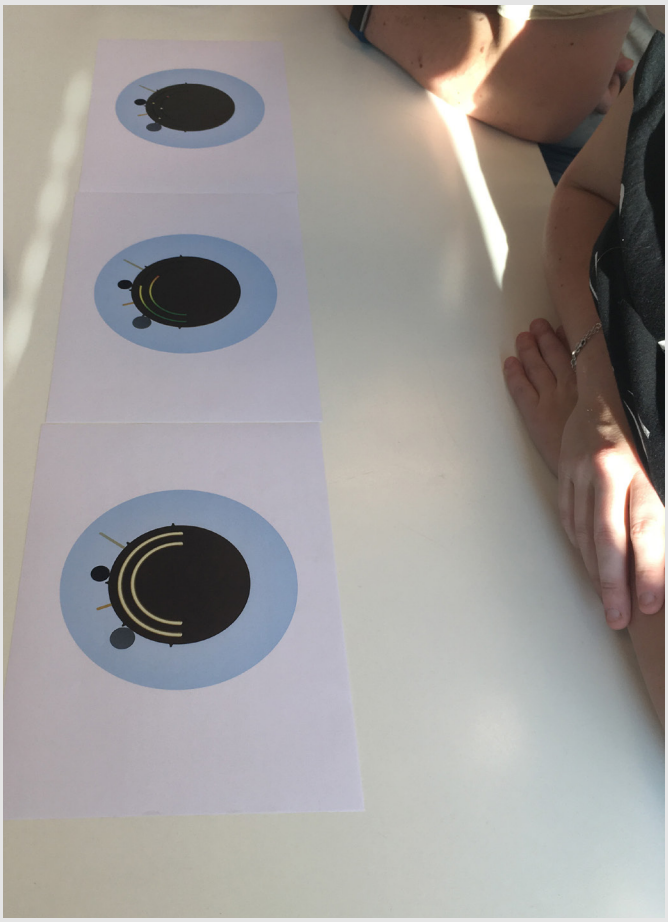


Figure 54 | *Explaination of the interaction with the product*

Figure 55 | *Test setup*

Once the product is attached to the window, some final questions were asked about the way in which the level of air quality and noise is visualized. One of the participants stated it might be better to make a more detailed scale for the indicators and another one asked to add colors to the indicators as well, just as to the subjective input. The changing color of the input was very clear.

Conclusions from the user test
Several conclusions can be drawn as a result from the user test. These findings can be included to create the final product.

- The participants see that the product can increase awareness on the level of air quality.
- The participants see the value in providing subjective input on air quality and noise, however only when there is a clear goal on what will be done with the input.
- The resemblance of the indicators to air quality and noise is not intuitively understood. However, it is understood that one pair resembles the indoor values and the other one the outdoor values.
- The icons that visualize air quality and noise are well understood, only instead of making the icons bigger, there could also be a change in the icon (less waves or mute for noise).
- In order to encourage the user to provide subjective input, the goal of doing this should be clear. This could be done with the use of the app.

Figure 56 | *Attachment of VisionAir in the intended way*

Figure 57 | *Attachment of the VisionAir in another way*

4.7 CONCLUSION

In this chapter, the initial concept of a product attached on the window was developed into the VisionAir. The goal of this product-service system is to provide the user with the information needed to become more aware of their environment and make well-informed choices.

In chapter 3, the importance of subjective input was shown in the model of Lazarus. In **Figure 58**, the model of Lazarus can be seen after altering the model to show the connections between the model and the product.
In order to find out if the product contributes to the making of well-informed decisions, a user test was done.

It can be concluded that the concept at this point provides the right amount of information to create awareness about the air quality and level of noise by providing objective feedback to the user. However, the goal of providing input is not clear enough. Therefore, the reason to create awareness about the users personal response should become more clear. explicit. Also, the distinction between the objective feedback and the subjective feedback could be made more intuitive.

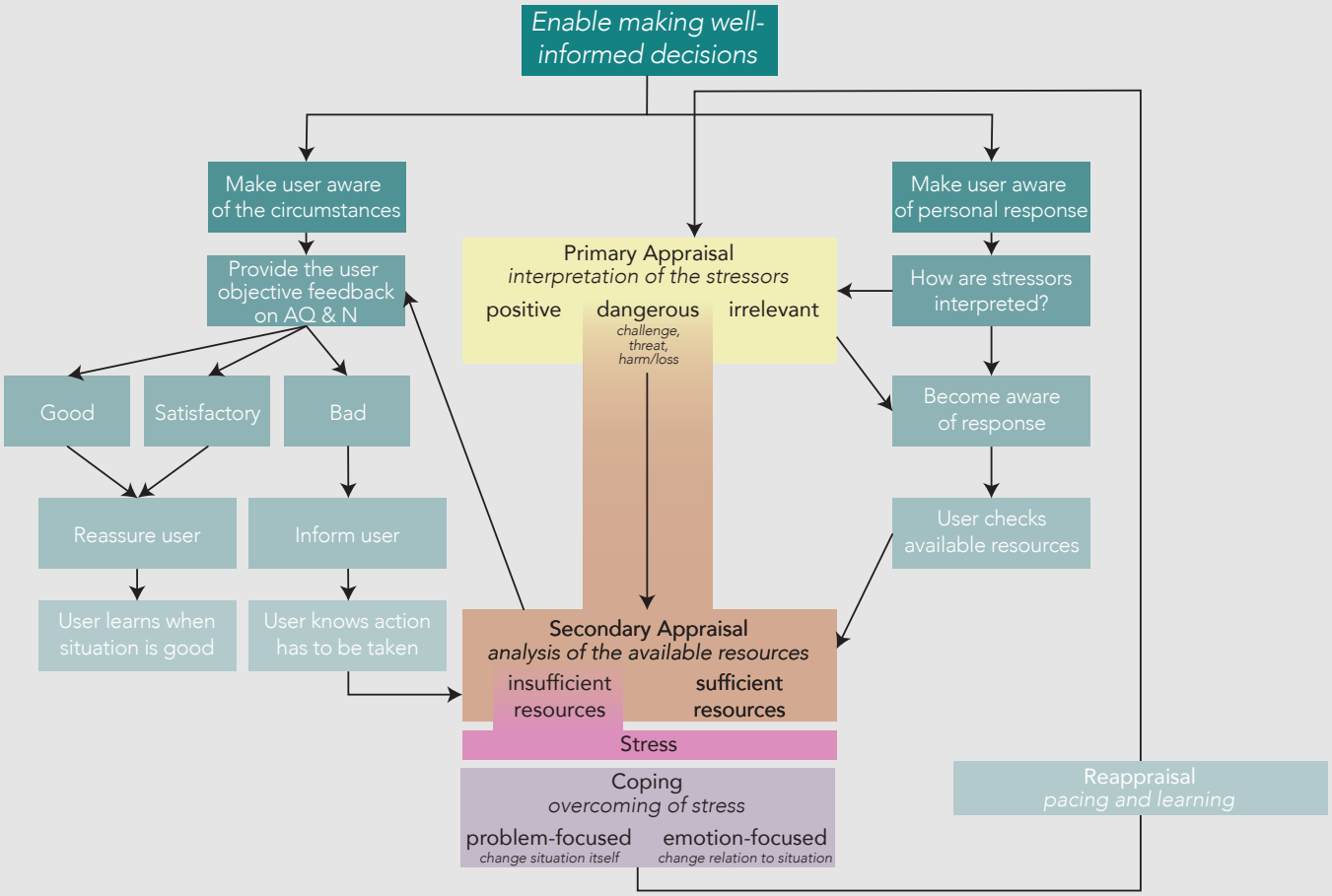


Figure 58 | *Adjusted transitional model of Lazarus (1991)*

5. EMBODIMENT

During the embodiment phase, the product was detailed on different aspects. These components can be seen in **Figure 60**. In order to measure noise and air quality, the best suitable sensors had to be found. In order to collect this data, the product has to be able to communicate, both to eachother, as well as to an application. Since one part will be attached on the outside of the window, it had to be seen whether solar power was sufficient to power the product or whether more battery would be needed. Also the indoor part has to be powered. Finally everything came together in the housing.

Figure 59 | *Visualization of the final concept VisionAir*

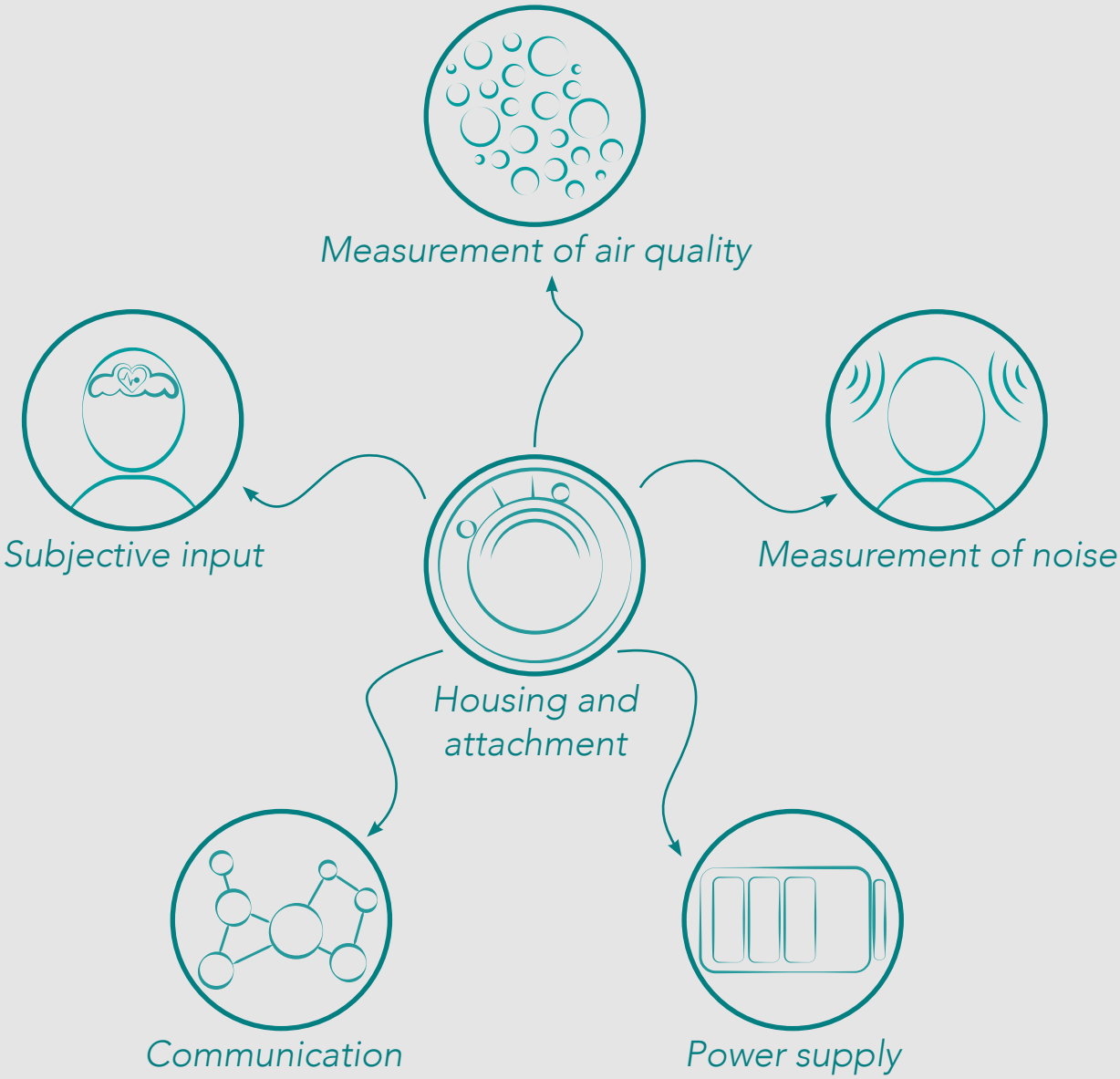
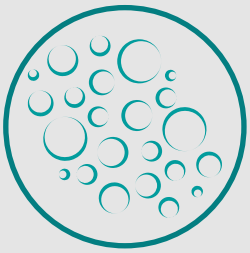


Figure 60 | *Components of the VisionAir*

5.1 MEASURING AIR QUALITY & NOISE

The core of the product is the measurement of the environmental variables air quality and noise. In this paragraph, the right sensors are searched to measure these variables. An overview of the chosen components can be seen in **Figure 62**.

Air quality



Air quality consists of different variables as stated before in the analysis chapter. In the analysis it was found that the most important pollutants in the air are $PM_{2.5/10}$(outdoor+indoor), NO_2(outdoor). Indoor, CO_2 is a very good indicator of the air quality. This means these are the variables that will be measured. In order to do so, sensors were compared by cost, accuracy, measuring range, current consumption and size. For each sensor another measuring range is important. There is a difference between the limit values for air pollutants of the European Union and the limit values adviced by the WHO (World Health Organization). The values stated by the WHO are lower, but will probably become the leading values in the future. Therefore, these values will be used to determine air quality[24].

According to the World Health Organization (WHO[25]) the norm values are as follows:

	Maximum tolerated values
$PM_{2.5}$	10 µg/m3 annual mean 25 µg/m3 24-hour mean
PM_{10}	20 µg/m3 annual mean 50 µg/m3 24-hour mean
NO_2	40 µg/m3 annual mean 200 µg/m3 1-hour mean

Figure 61 | *Maximum adviced values by the WHO*

CO_2 has an adviced value of 800 ppm and a maximum of 1200 ppm for healthy environments

NO_2

Before a selection of a sensor could be made, it was necessary to determine the needed range and accuracy. Therefore it was calculated how much the adviced maximum 1-hour mean is converted in parts per million (ppm). This is because the measuring range of NO_2 sensors is given in ppm and not µg/m^3. The calculation can be seen in **Appendix E**. The 1-hour mean of NO_2 is 0.1 ppm. Three sensors were found that fit the measuring range, however one seemed most suited, from Spec Sensor. The reason is that it has a good level of accuracy, with a good size and price.

CO_2

Many of the CO_2 sensors are very expensive and large. After searching and personal communication with an expert at TU Delft (R. Bekking, 2017), it was decided to choose the Telaire sensor. This sensor has a measuring range of 0-2000 ppm and a good accuracy. Since it is advised to keep the level of CO_2 under 1200 ppm, the measuring range is sufficient. Other sensors that were considered can be found in **Appendix E**.

Particulate matter ($PM_{2.5/10}$)

Particulate matter sensors work by detecting reflected light of dust particles in the air.
Sharp has the lowest current consumption while having a sufficient measuring range and accuracy.

Temperature and humidity

Besides the pollution in the air, the humidity and temperature also influence the air quality. Besides, small sensors can be found that use very little current which makes it a good addition in order to determine the air quality.

Noise

A way to measure noise is simply using an app on a mobile phone. This leads to accurate measurements. In mobile phones, MEMS microphones are used. Another possibility is to use an electret microphone. However, an important aspect for a microphone is the signal to noise ratio (SNR[26]). The SNR is a value for the noise the microphone produces itself. A higher value means a quieter microphone. At the moment, MEMS caught up to electrets, reaching higher SNR values in a smaller shape. Therefore, it was decided to use a MEMS microphone to measure the level of noise.

5.2 SUBJECTIVE INPUT

Providing input

Collecting subjective input will be done by using touch sensors, see **Figure 63**. These will be placed under the front of the housing. A touch sensor that could be used is the 12-channel sensor by Silicon Labs[27]. This sensor costs €1,16. The distance between the sensor and the surface can be up to 6 mm.

Figure 63 | *Lay-out of touch sensors in the product*

Requesting input and providing feedback

LED lights will provide the light source of the VisionAir. For this, the WS2812b LEDs are chosen. These can be bought for €5.82/100 pieces[28]. As it can be seen in **Figure 64**, there will be 12 LEDs used. This is because of the placement of the touch sensors and that each LED will be corresponding to a touch point in order to give the right feedback to the user.

Figure 64 | *Lay-out of LED lights in the product*

Sensor	*Cost*	*Measuring range*	*Accuracy*	*Supply Voltage*	*Current consumption*	*Size (mm)*
NO_2  Spec Sensor	€16,96	0-5 ppm	0.02 ppm	2,7-3,3 V	5-15 µA	21x21x3,5
CO_2  Telaire	€62,99	0-2.000 ppm	±30 ppm ±3% of reading	4,5-5,5 V	25mA average 200mA peak	30x15,6x8,6
$PM_{10/2.5}$  Sharp	€9,63	0-500 µg/m³	0,5V/0,1mg/m³	5 V	20 mA peak	46x30x17,6
Temperature + Humidity  Texas Instruments	€2,18	0-100% RH -40-85 °C	±2% RH ±0.2°C	1,6-3,6 V	0,55 µA	1,5x1,5x0,675
Sound  Knowles	€1,95	20Hz-20kHz	65 SNR	0-3,6 V	10 µA average 600 µA peak	3,5x2,65x0,98

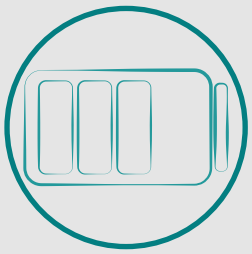
Figure 62 | *Overview of chosen sensors*

5.3 COMMUNICATION & POWER SUPPLY

Communication

The product exists of two seperate parts which means they have to be able to communicate together. Also, the product will be supported by an app, for which it is necessary to also connect to the product. Through the app, the user can also communicate back to the product by personalizing its own settings. In order for the products to communicate to eachother, Bluetooth Low Energy (BLE) will be used. Besides bluetooth, the indoor part will also have a Wi-Fi module to be able to communicate to the cloud. There are bluetooth modules available that offer both bluetooth as well as Wi-Fi. A BLE module form STMicroelectronics will be used for the outdoor part and a combined BLE and Wi-Fi module from Pycom[29] will be used indoor.

Power supply



Making it possible to calculate the battery needed, it had to be decided what frequency the product would use to take measurements of the variables. Since the outdoor part will work on a battery, it was desired to use as little power as possible. However, to remain having a clear overview of the date it was decided to use a 5-minute interval. This means the product will take a measurement every 5 minutes, collect this data, control the indicators to the right pose and send the data to the cloud. The moving of the indicators and the activation of the lights will only be working in case the user is at home and whithin set hours.

By using this information an estimation of the needed power can be made. There is a difference between the indoor and outdoor products, since the indoor product also contains the touch sensor and the LED lights. These do not have to be active in case the user is not around. This also accounts for the stepper motors driving the indicators. An estimation of the time at which the user is at home will be made so a calculation can be made regarding the energy use of the product. During the analysis phase a questionnaire was executed. In this questionnaire the respondents were asked how much time they spend indoor without counting sleep. More than half of the respondents (58,5%) states to be indoor more than 4 hours a day (**Figure 65**). It is estimated that a user of the product spends about six hours in the living environment. Furthermore, it is estimated that the user will provide feedback for three times a day.

The product will be active every 5 minutes for 5 seconds. During this time, the sensors will measure the variables and the data will be communicated from part A (indoor) to part B (outdoor) and to the cloud. In **Figure 66** the total amount of time in which the product is active can be seen. With all the information on the current consumption, the total current was calculated for both the indoor product as well as the outdoor product. This calculation can be seen in **Appendix F**.

For both parts of the product, it was decided what kind of power supply to use. Power sources considered were batteries, solar power and wireless charging. In case of the wireless charging, the maximum distance between the two coils was 6 mm, which is not achievable through the glass. Probably this will be possible in the future.

Part A (indoor)

In total, the indoor device will require 41.9 mA per day. When using 4 AA batteries with a capacity of 2300 mAh, the product can last for 9 days. Most of this energy is required by the CO_2 sensor. There is another possible sensor, that requires much less energy, however it is much more expensive. Powering the device with a permanent power source was also considered, since this is not aesthetically pleasing, the preference is given to the rechargeable batteries.

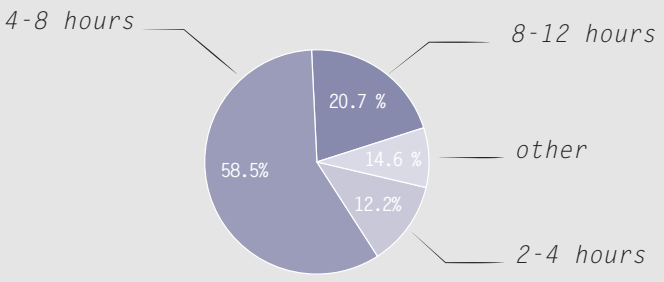


Figure 65 | *Overview of chosen sensors*

Part B (outdoor)
It was calculated that the outdoor product requires a current of 11.7 mA. Using the same 4 AA batteries, the product can last for 32 days. However, on the outdoor product a solar panel will be used. To find a fitting solar panel, the maximum size was calculated with the help of the housing. This housing will have a diameter of 100 mm, which makes the maximum size of the solar panel is 70x70 mm. A panel this size was found providing 0,65W.

With the calculated current use, the needed power for the product can be calculated. The overall product will use 5V and together with a current of 11.7 mA, the needed power is 1.4W/day. In the Netherlands, the average hours of sun ranges from 1.2 hours/day in December to 6.8 hours/day in June[30].
This means that a solar panel of 0.65 W, can provide 0.78W on an average day in December. This is not enough to fully power the product, however, it can increase the battery life. In the summer, the solar panel can provide 4.42 W, which makes it possible to charge the battery and provide enough energy to the product at the same time.

	Indoor	Hrs	Times /day	Outdoor	Hrs	Times /day
LEDs	12 x per hour	6	72	12 x per hour	0	72
Touch sensor	3 x per day	0	3	3 x per day	0	3
Stepper motor	12 x per hour	6	72	12 x per hour	6	72
PM sensor	12 x per hour	24	288	12 x per hour	24	288
Temperature & Humidity	12 x per hour	24	288	12 x per hour	24	288
Microphone	12 x per hour	24	288	12 x per hour	24	288
NO_2		0	0	12 x per hour	24	288
CO_2	12 x per hour	24	288		0	0
Bluetooth & Wi-Fi	12 x per hour	24	288	12 x per hour	24	288

Figure 66 | *Overview of chosen sensors*

5.4 HOUSING AND ATTACHMENT

All components have now been discussed, besides from the housing and the attachment of the product. In this paragraph, these will be detailed, as well as the indicators and their driving mechanism.

Indicators

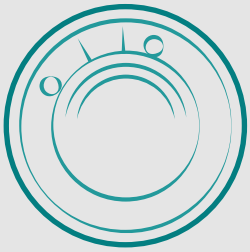
The feedback on the level of air quality and noise will be given by indicators as stated before. Both indicators will be connected to seperate internal spur gears that in their turn will be linked to the gear attached to the stepper motor.

Shape

Both indicators will have different shapes in order to be able to resemble air pollution and noise. The indicater that resembles air pollution will be a circular disc with small cavities, symbolizing particles of dust. Regarding noise, the indicator will be a narrow rod, symbolizing an analog decibel meter. Images of the indicators can be seen in **Figure 67**

Material and production

Trying to keep the product minimalistic, it was chosen to use a transparant plastic for the air indicator and a metal rod for the noise indicator.
Since the air indicator is such a small piece, it was decided to use laser cutting as a production method. Based on the production method, it was decided to use Acrylic (plexiglass). This material is extremely suitable for laser cutting, even with very small details[31]. Creating the metal rod will be done by processing a brass rod into shorter pieces[32].

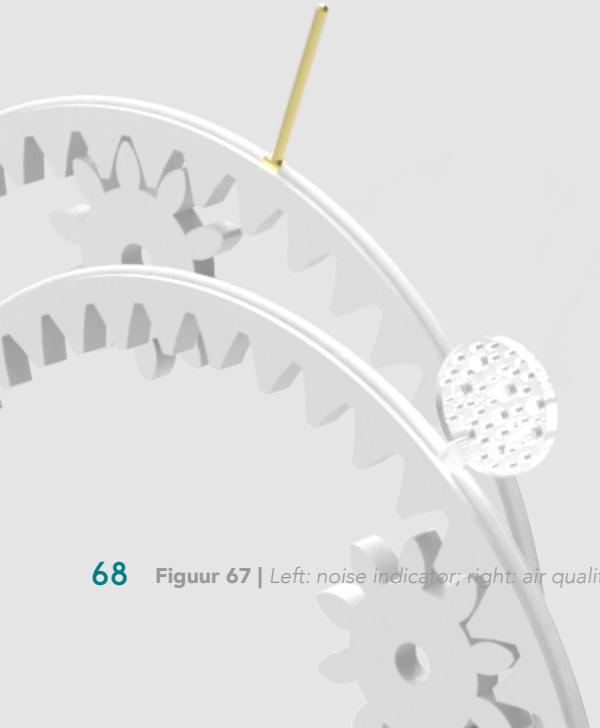


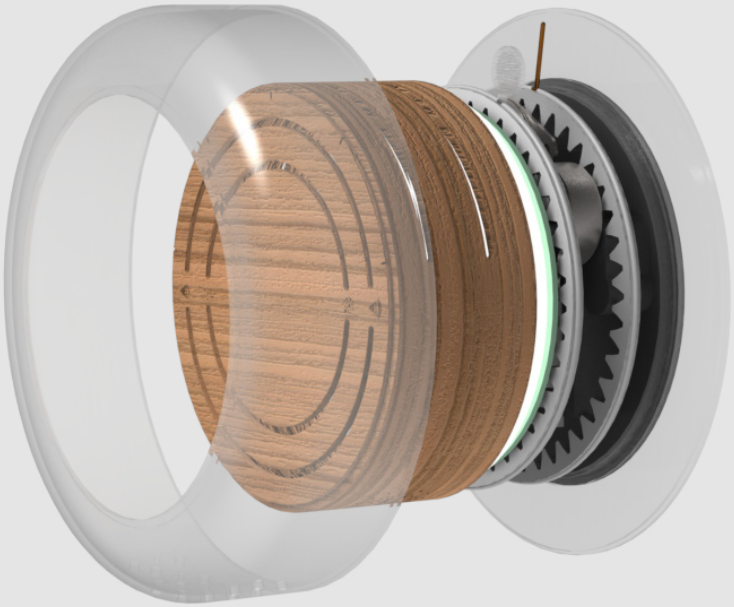
Once the indicaters are made, they will be attached to the internal spur gear. These will be made by cnc milling, since they have a recess for the connection with the indicators. The material used for the spur gear and for the other two gears will be POM[33]. This is a tough and durable plastic which has a low friction coefficient. Another option would have been nylon since this is often used as a material for gears. A drawback of this material is however, the high level of moisture absorption. Since the product is not 100% water tight, this might cause troubles in the rotation of the gears.

Finally, the parts will be glued together to make one piece.

Stepper

To drive the indicators back and forth, a stepper motor will be used. These motors make tiny steps which provides the opportunity to control them very accurately. They can be programmed to respond to the changes of the variables. Steppers come in different sizes, of which the more well-known are the NEMA steppers. However, these are still too large to be integrated in the product. Therefore, a smaller stepper was found and chosen.





Figuur 67 | *Left: noise indicator; right: air quality indicator*

Figuur 68 | *Exploded view of VisionAir*

Housing

Finally, all of these components have to be brought together in the housing. Because the two parts are not totally equal, different parts have to be created.
There are eight different parts, of which six have to be injection moulded.

Shape

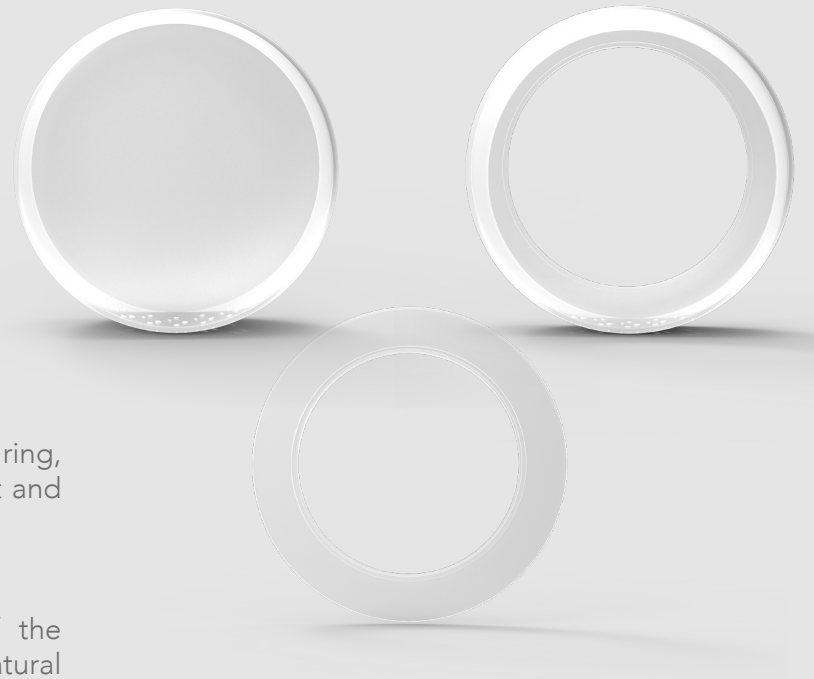
The shape of the product can be in seen in **Figure 68**. A circular base is surrounded by a transparent ring (**Figure 69**). On the back, the product is closed with a transparent ring, an insert containing the battery compartment and the cover.

Material and production

Getting back to the desired aesthetics of the product, it was stated that the use of natural materials was preferred. Therefore, the base of the product will be made from wood. The base will be CNC milled with two points of connection for the back part of the product. Since air has to be able to reach the sensors, small holes are created in the bottom of the base. A model of the base can be seen in **Figure 70**. By also adding small holes in the transparent ring, but on a different location, air will be able to circulate and the risk of water reaching the inside of the product will be limited with normal use.

The transparent parts will be made from PMMA (polymethyl metacrylate). Characteristics of this material are: high level of transparency, scratch resistance, excellent resistance to sunlight and aging due to weather circumstances[34].
The transparent part that will enclose the outdoor product will be produced in the same injection mold as the indoor part. However when producing the indoor part, an insert will be placed so that there will be an opening withing the ring. This saves an extra mold.

The remaining parts will be made of PP (polypropylene), a commonly used material well resistant against uv influenced and weather conditions[35].



Figuur 69 | *Top left: Outdoor transparent ring; top right: indoor transparent ring; middle: transparent closure*

Figuur 70 | *Base of VisionAir with air inlets and connection points*

Attachment

Different methods of attachment were considered. Magnets, sucking cups and double sided tape were opted.

Shape

It was decided to create a disconnectable attachment, since the product has to be taken down from the window in case the batteries have to be charged. Therefore, a method of attachment was created as can be seen in **Figure 71**. A mounting plate will be connected to the window, on which the product can be mounted by twisting and locking.

Material

The material and production of the mounting plate is equal to the other injection moulded parts, being PP. To attach the product to the window, VHB (Very High Bond) double sided tape from 3M is used[36]. This tape is UV-resistant, resistant to harsh weather conditions and very strong.

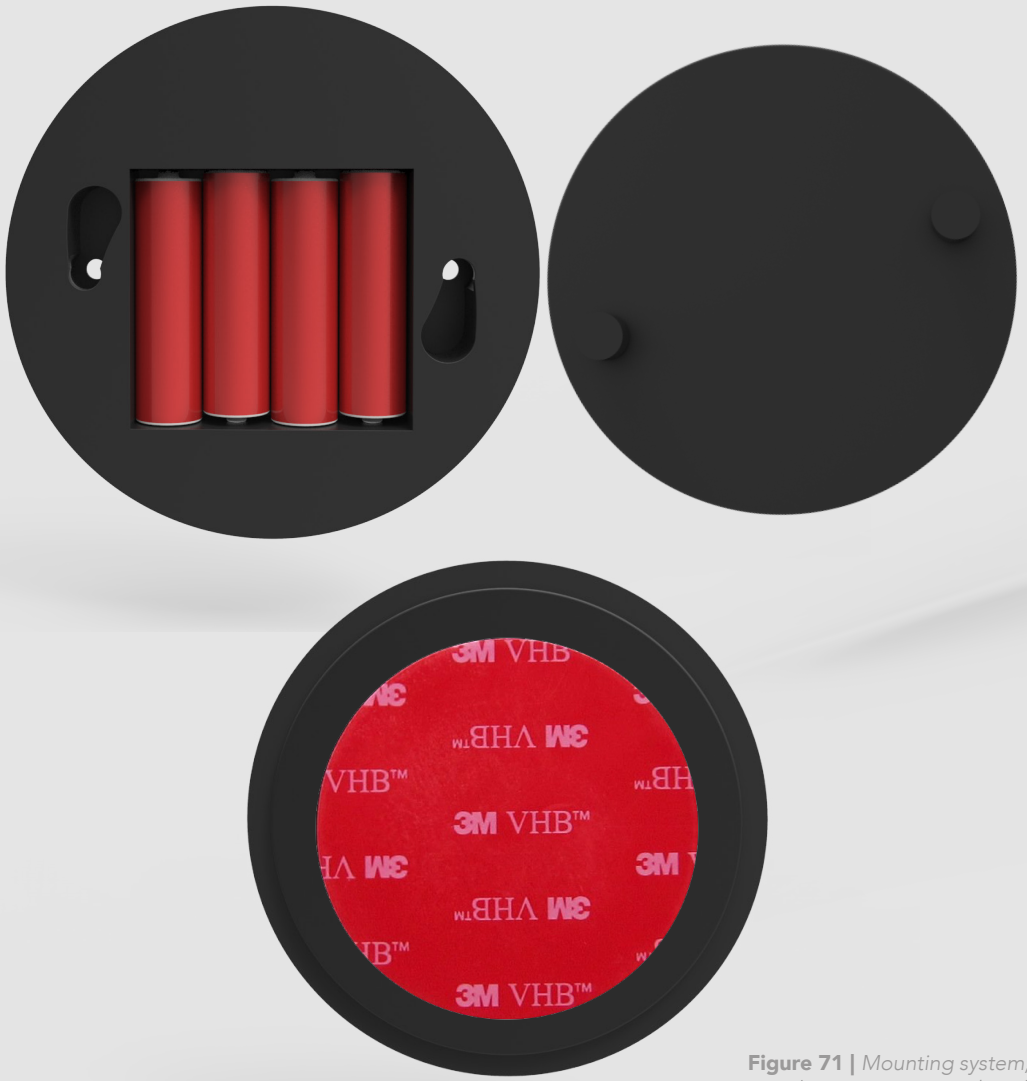


Figure 71 | *Mounting system; Left top: battery compartment; right top: mounting plate; bottom: adhesive on the back of the mounting plate*

5.5 ASSEMBLY

In **Figure 72**, an exploded view of the product is shown. All compenents will come together in the base. The electronics will be mounted on a PCB, that after a LED diffusion plate will be placed in the base. Afterwards, the pre-assembled indicators will be placed in their dedicated rail. The stepper motors will be alligned with the internal spur gears. At this moment, all compartments are integrated in the product. The product will be closed by firstly placing the transparent closing ring and subsequently the closure with battery compartment will be connencted by inserting two screws. At this point, the closure for the battery compartment can be attached an the mounting plate can be attached while shipping the product.

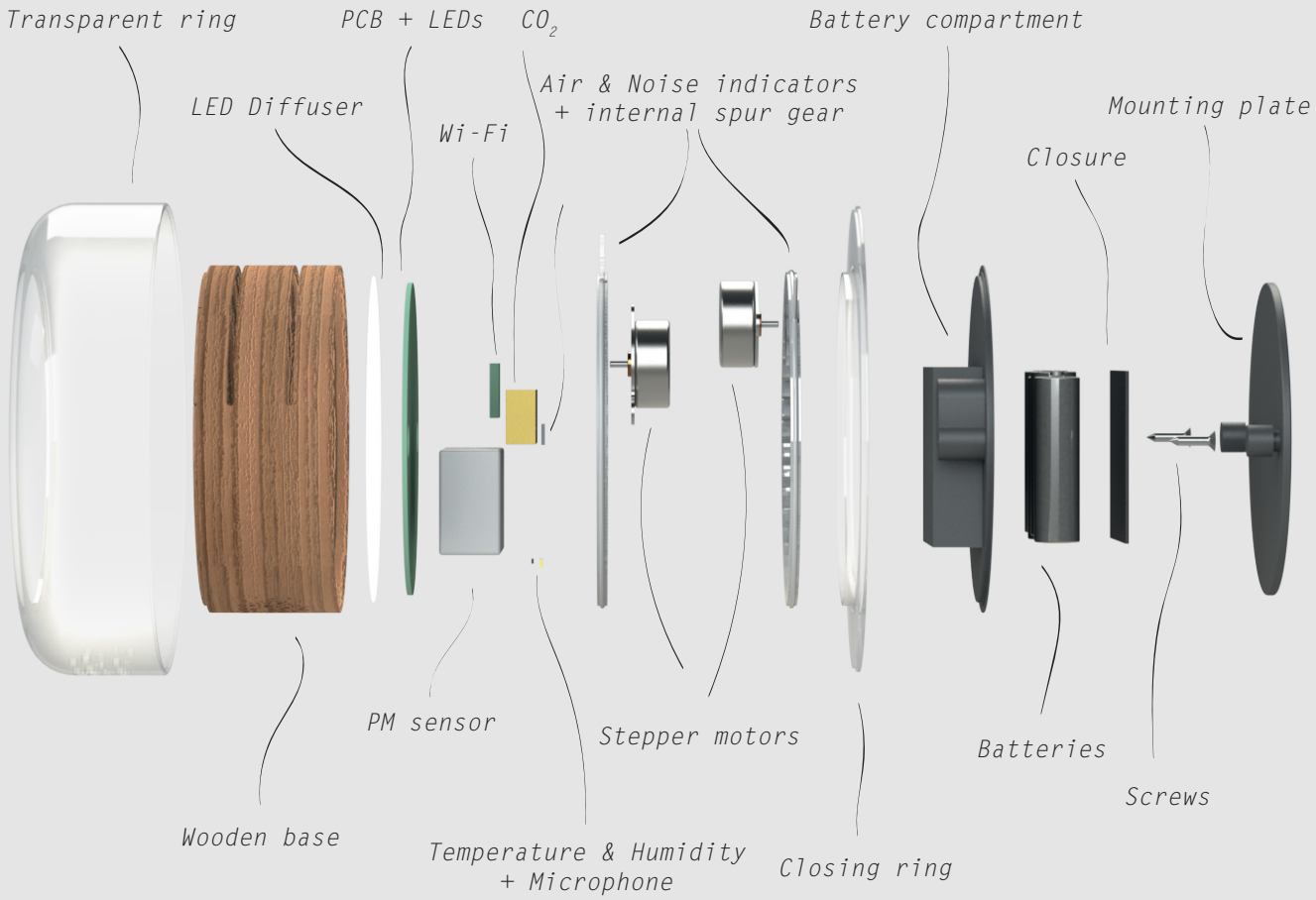


Figure 72 | *Exploded view of the VisionAir*

5.6 CONCLUSION

In the embodiment phase, the concept was further developed into a detailed concept. It can be concluded that all components have been determined

The result of the embodiment phase was a detailed concept. From this concept, the final design will be shown in the next chapter. In the embodiment phase, only the physical product has been detailed while before it was stated that there will also be an app involved. This will also be shown in the next chapter.

 Figure 73 | *Sideview*

Figure 74 | *Inside of the VisionAir*

6. FINAL DESIGN

A final design was created, as a result of the outcome of the validation and the chosen components in the embodiment phase and can be seen in **Figure 75**. The improvements made in the final design are stated in **Figure 76**. After creating the final model of the product that contains all needed components, an estimation of the cost and a possible implementation plan were created. These will be elaborated in this chapter. Finally, recommendations for further development will be given.

Figure 75 | *Image of the final design of the VisionAir*

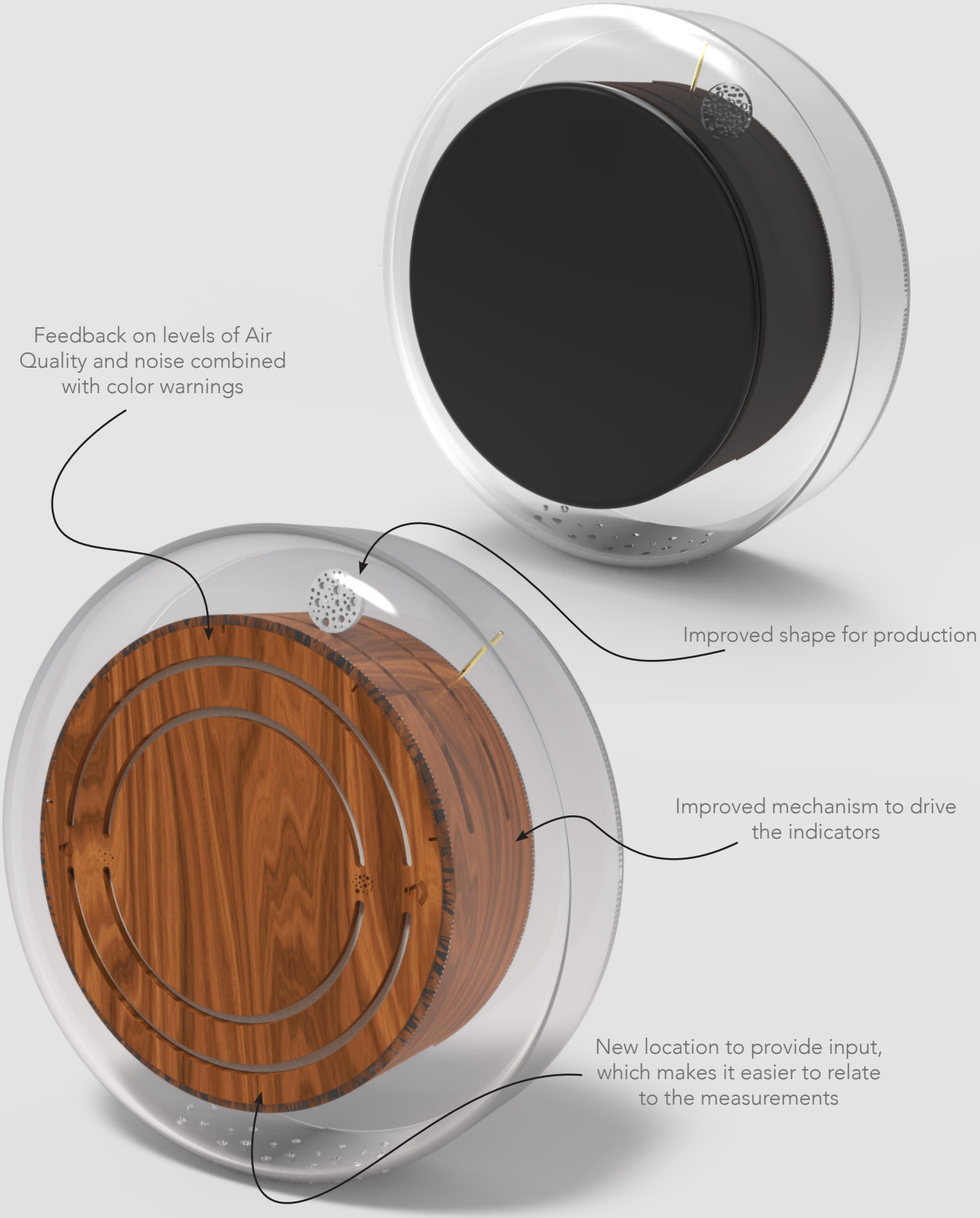


Figure 76 | *Impression of the Visionair from outdoor (top) and indoor (bottom)*

6.1 IMPLEMENTATION

As stated before it was the wish of Studio Überdutch to create a business to business product. Therefore, the business model will be focused on selling the product to municipalities or other instances focused on air quality or human well-being.

The product will be offered in coexistence with an app. In this app, multiple features will be available, however in essence, the following features should be included:

Objective
- Current levels of air pollution and noise, both indoor and outdoor.
- Overview of the average level of air pollution and noise on that moment of the day.
- Overview of the average level of air pollution and noise during the day/week/month.
- Overview of measured levels by other products in the street/city.
- Measured levels and average levels in the city.
- Tips on how to improve the air quality or level of noise.

Subjective
- Last input provided by the user.
- Average input provided by the user around that moment of the day.
- Overview of input given by neighbours/fellow citizen.

Furthermore people should be able to determine how active the product is. They can set levels at which they would like to receive a warning, besides the set levels at which it is unhealthy. Another possibility is to get rewarded for remaining clean air and low levels of noise in the home environment.

In order to achieve this, the product has to be financially feasible. Therefore, a cost calculation was executed. The complete calculation can be found in **Appendix G**.

It is estimated that there will be a batch size of 25.000. In **Table 2**, an overview can be seen of the price per component.

Part	Amount	Total
T+H	2	2.16
PM sensor	2	11.5
CO_2	1	57.02
Sound	2	2.34
NO_2	1	17.2
Stepper	4	10.04
LEDs	18	1.02
Touch sens	1	0.88
Bluetooth	1	1.84
Wi-Fi+BLE	1	8.65
PCB	2	2.46
Battery (4)	1	8.55
Solar panel	1	3.93
Air ind.	2	0.35
Noise ind.	2	0.21
3M tape	2	1.1
Plastic parts	1	10.08
Wood	2	20
Labour	1	2
Total		€161.33

Table 2 | *Cost calculation*

As it can be seen, the production price for one product is €161,33. The largest expense is by far the CO_2 sensor, which is almost a third of the product price. Besides the CO_2 sensor, the stepper motors, the NO2 and PM sensor, the communication modules and the housing are the biggest costs.

A comparable product can be found in Netatmo Weather Station (**Figure 77**). This product consists of two parts that measure the weather indoor and outdoor. Netatmo is sold for €159,00[37]. Eventhough the VisionAir has more features than the Netatmo, it would be more favorable to be able to sell the product in this range.

Figure 77 | *Netatmo wheather station*

6.2 RECOMMENDATIONS

Another user test on interaction
Being limited in time, the user test could have been more extensive. Therefore it is recommended to do another user test in which the interaction is tested with an interactive prototype. In that way it can be seen whether users do understand the intended interaction.

Durability test with 3M tape
Although it is stated that the tape is very strong, a test to see whether the tape is strong enough to hold the product can be done. Also, it could be tested whether the tape can be removed from the window after use.

Waterproofness
Since the product needs air inlets for the sensors to work, the product cannot be 100% watertight. It can be tested whether the other parts still function properly at certain humidity levels, even though they were selected to work up to 95% of humidity. In normal conditions water should not be able to enter the product from the bottom, but this could be tested.

Solar panel and batteries
Another test that could be done is seeing whether the solar panel provides enough energy to charge the battery in sunny days. Also the battery indoor should be tested for durability. In case it is even less than a week, it should be considered to create a permanent connection after all.

Size of the product
Because of the stepper motors and the batteries used, the product has a greather depth than desired. It could be considered using smaller steppers, like the ones used in cameras, however it should be tested how much force they can provide to drive the indicators.

Privacy regulation
Collecting and sharing data requires providing personal data. A look should be taken at the regulations in order to see all data is secured.

PCB design
An experienced electrotechnical should design the printed circuit board in order to make sure all components are connected accurately.

Mounting plate
The attachment of the product on the mounting plate should be tested to see if it is well secured, if not it should be optimized with something like a spring system that provides a force on the attachment. Another possibility could be including magnets, however it is not clear whether magnets influence the sensors.

6.3 CONCLUSION

In the master of Integrated Product design, there are three important pillars, user needs, technical feasibility and business. To conclude the project, these pillars will be discussed and concluded.

User needs
It was found that the awareness on the effects of air pollution are rising. However, the effect of noise is not that clear and used to be barely discussed. Nowadays, the media is starting to give more attention to the effects of noise and people are starting to notice that. During the validation it was seen that the need to provide input by the user was not there yet. Only when providing a greater cause than one's own well-being, for example by forwarding the data to the municipality, then the user would be willing to take the time to provide input. However, the use in measuring air quality was seen and liked. Therefore it can be said that the user needs would only be satisfied by the objective measurement of the air quality.

Technical feasibility
The technical principles of the product have not been tested yet, beside from experimenting with Arduino Grove and a stepper motor. Nevertheless, the technical aspects of the product should be feasible. In this project, a consideration has been done between showing the objective data on a screen, or by visualizing them. Using a screen would have been better for the feasibility than using the mechanical parts.

Business feasibility
Since Studio Überdutch wanted to create a business to business product, this was one of the wishes. Only during the questionnaire it was seen that the user was more interested in knowing about the variables in their homes. Therefore it was attempted to combine the two worlds for the user at home and outdoor. This made the problem owner and user less clear, but eventually it was seen that both could profit by this opportunity. It needs to be clear to the problem owner (municipality) why a product should be purchased for the user, or given in loan.

All in all, if the product would be used by a municipality, it could contribute to the awareness in the city, since air quality and noise maps can be made based on measurements and not only calculations. Furthermore, the municipality will get more insight in the way air quality and noise are experienced by its citizens.

7. EVALUATION

In this final chapter, a review will be done on the design process. At first, the project will be discussed on the different parts, after which a reflection will be done on the overall design. It will conclude with a reflection on the personal process during this project.

Assignment

The assignment was initiated by Studio Überdutch, who requested a product to measure the quality of the living environment. At this point, the project was still very broad and the possibilities had to be limited. In order to do this, research was done on natural variables and their impacts on health. During this research, a lot of possibly interesting opportunities were found.

Chosen variables

After the research, the influences on a number of variables were studied in different contexts. From this, it was concluded that air quality and noise are the two most influential variables on human well-being.

Chosen context

The amount of influence of the user on the circumstances was studied/was compared in different contexts. At this point, a competitors and trend analysis were done to get more insight in the existing products and future needs of people. Eventually, it was decided that there already existed a lot of consumer products that concern personal air quality and therefore, the product should be used in a shared space. To find an interesting shared space, an interview was conducted with a member of the local council of The Hague.

Chosen user

At the beginning of the project, the user of the product and the problem owner were in conflict since the solution was searched for a user that was not the problem owner. This caused a missing need for the product to be created. However, as the context became clear, so did both the user and the problem owner. Then it was the goal to create value for both.

First ideation phase

After the first choice of the context, initial ideas were created that led to another converging moment regarding the context. It was found that the ideas were still very broad and not comparable. This led to concept direction based on a combination of a context and an idea. This idea became the first concept.

Second ideation phase

During the second ideation phase, the concept was redesigned with the help of an ideation session with Studio Überdutch. From this, a morphological chart was made and resulted in two new concept directions.

Choice for concept

Both concepts fitted to the context "outside=inside" and were scored on criteria. From this, it was seen that the VisionAir concept had the most potential as a B2B product and was therefore chosen.

Detailing of the concept

During the detailing of the concept, another iteration was made regarding the way in which the user receives feedback. Eventually the VisionAir succeeded to show all the feedback in one location with a clear distinction between indoor and outdoor.

User test

Once the concept was detailed, it could be tested by users. This was done by five participants, which was not really a good representation of the user. The test was done with the help of images and a model.

Embodiment

In the embodiment phase, all components that had to be used were determined. Firstly, the definition of air quality had to be defined more specifically in

order to determine the components. This was done by additional research after which all components were selected by criteria such as current use, size and costs. Also the housing and other parts of the product were detailed and a 3d model was created.

Reflection on the final design

Technology
The technology in the product is not new, neither is the measuring of these variables. Nevertheless, bringing together objective feedback on air quality and noise and providing subjective input was new.

User
The system provides the user with the opportunity to interact with the product. This interaction had not been used previously. However, the need for this interaction was later questioned. Possibly the interaction with the product in this particular setting was not implemented for a reason. Nevertheless, it was interesting enough to see how much value the user sees in providing input on experience of air quality and noise. It can be stated that there was only little value seen by the users that tested the product. Overall, the product satisfies the user regarding the objective measurements of noise but less on the other aspects.

Business
In regards to the product being a B2B product it can be stated that there should be a strong support for the subjective input in order to sell the product to a company or instance. However, by distributing this product valuable data can be collected which can also be a business model on its own.

Personal reflection
From the beginning of the project I knew it was going to be very challenging. Nevertheless, it was also very interesting. One of the challenges of the assignment was its broadness, which of course could also be seen as a challenging opportunity. It was very interesting to learn about all the different variables that have influence on human well-being. One of the downsides is that there is so much information that can be found that it was difficult to indicate a moment to stop and make a decision.

Furthermore, I found embodiment phase more difficult than expected. This was among other things because of the difficulty for me to understand the datasheets of the sensors. Luckily I had some help from a sensor expert at IO. Not being able to get a grip on these sensors also influenced the development of the rest of the concept. I felt retained since I did not have all of the right components yet. Eventually I am really happy that I have managed to figure out most of it.

During the project I was really happy with the possibility to work at Studio Überdutch, since this was most of the time better for my concentration. I have also noticed that an individual project is really hard for me because of the lack of feedback from group members. In the end I think I could have taken more advantage of the knowledge of Studio Überdutch.

Looking back on the project, there are several aspects that I wish I would have done differently. Here are some examples:

- Set clear goals and deadlines for each part of the project, this will also help in decision making
- Make assumptions on aspects I'm not really sure about instead of keeping to try to find all of the answers.
- Include the user earlier in the process. Now doing the user test was really difficult
- Communicate better with Studio Überdutch about what I was doing.

To conclude, I'm really thankful that I was able to do my graduation assignment for Studio Überdutch and I really hope they can take something useful out of this.

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APPENDICES

APPENDIX A INTERVIEW

In interview was done with Sabine Janssen, expert in the area of noise pollution at TNO.

Gaat over de stad/ urbane leefomgeving, het ontwerp en de inrichting van de stad

Er moet een balans zijn tussen bereikbaarheid en het niet schaden van de leefomgeving. De neiging is soms bereikbaarheid voor te laten gaan vanwege economische redenen, milieu zit dan in de weg.
Leefomgeving en geluid -> verschillende niveaus
Focus op de rol van geluid vanuit psychologische kant.
Verschil tussen gewenste geluiden en niet gewenste geluiden, niet tussen wel geluid en geen geluid. Natuurlijke geluiden zijn wel gewenst.
Het meten is lastig voor het modelleren van de stad
In de slaapkamer meten en buiten meten

In parken geluid gemeten, al het geluid wordt gemeten, je ziet niet terug op de meting welke piek welk geluid was, onderzoeker scoorde de omgeving op wat er gebeurde (bv. Veel vogels)

Mensen hebben restoration nodig, als er geen rustige plekken zijn kunnen zij niet herstellen. Mensen kunnen dan parken zelfs gaan mijden, wat slecht is voor beweging en andere gezondheidseffecten
Hinder wordt bepaald over een periode van 12 maanden (achteraf)
Vragen worden gesteld aan mensen of zij geluidshinder hebben ondervonden in de afgelopen tijd. Mensen moeten dan inschatten hoeveel inder zij hebben ondervonden.
Het gaat hierbij over langere tijd in de woonsituatie.
Tijdens onderzoek in park ook gevraagd of mensen hinder hadden van geluid, echter pas achteraf. Ook hartslagmeting en vragenlijst invullen over omgeving.
Luchtkwaliteit en geluid zijn de meest relevante factoren
4 categorieën in de platform gezond ontwerp (zie folder):
Basis op orde
Inrichting vd stad: beweegvriendelijk, mogelijk maken en stimuleren van beweging.
Lucht en geluid krijgen veel aandacht, maar laatste tijd ook meer aandacht voor andere invloeden als groen en warmte.
Bedenk waarom je wil meten en wat je ermee wilt doen.
In de parken waren bijvoorbeeld de metingen hoog, maar evengoed kunnen mensen het waarderen, het kan relatief stil zijn ten opzichte van de rest van de stad. Dan is het alsnog gezond, ook al zijn de waarde hoger.
Het geeft evengoed mensen nog de mogelijkheid te herstellen.
Geluidsniveau is mede bepalend hoe mensen een ruimte ervaren (erg interessant)
In de parken zag je wel dat mensen de omgeving ervaren als positiever wanneer er minder geluid is.
De fysiologische waarden (hartslag en bloeddruk) zijn lager in het park.
Er was echter geen verschil tussen deel met lawaai en het stille deel (qua fysiologische waarden)

Interessante vraag: Bepaalt de aantrekkelijkheid van een park of mensen gaan of niet?

Geluid is mede bepalend hoe graag mensen een park bezoeken.
Zoek naar een praktische/pragmatische oplossing
Elk geluid in elke mate heeft andere effect (verkeer/ trein/vliegtuig) ook nog andere bronnen

Als je het totale geluid neemt kan je niks zeggen over de gezondheidsgevolgen

Er is ook nog onderscheid tussen verschillende omstandigheden. Verwacht geluid tegenover onverwacht geluid.
Kies je ervoor geluid te meten en lak te hebben aan wat je nou precies meet kan je wel onderscheid maken in verschillende situaties. Ondervragen in die situatie.

Slaapverstoring:
Mensen denken dat ze wennen aan geluid tijdens slaap, aangetoond dat ze toch worden gestoord in hun slaap.
Sommige mensen klaagde wel over het geluid, kan zijn dat zij gevoeliger zijn.
Minder gevoelige mensen ervaren minder hinder.

Sommige mensen ontkende dat ze werden gestoord, maar werden toch wakker/gestoord
Ze hebben een test gedaan met het koppelen van een slaapapp, was lastig. Metingen werden gedaan van geluid binnen. Vraag achteraf was of mensen wakker werden van het geluid, of dat mensen geluid maakten omdat ze wakker waren.
Je kan buiten een meting doen van verkeersgeluid, en binnen meten, dan pieken pakken, deze combineren en kijken wat de isolatiefactor is van de gevel/raam.
Dan voor de rest neem je de buitenwaarde en dan haal je de isolatiefactor eraf voor het binnengeluid
De gevel kan tot 30 dB isoleren (?)
Vraag of er dan nog huizen zijn met minder goede isolatie, maar uiteraard zijn er ook mensen die slapen met het raam open.

Met parken wordt nog weinig gedaan.
Onderzoeknaaraantrekkelijkheid,bezoekfrequentie en bereidwillendheid voor het bezoeken van een bepaald park en de invloed van geluid hierop
Luchtkwaliteit kan je van tevoren communiceren
Achteraf zou je kunnen vragen naar de ervaring van lucht/geluid
Lucht is moeilijk, dat merken mensen niet zo goed
Vraag: Welke richting is het meest interessant?
Slapen is erg interessant maar lastig.
Parken ook interessant gezond voor mensen, moeten bewegen
Geluidsniveau in parken is belangrijk voor de beleving
Vraag die opkomt is hoe het zit met straatsituaties?
Hoe worden straten ervaren? Stil/niet stil?
Deel van de tijd brengen mensen thuis door, dan moeten ze juist rusten/slapen, maar ze zijn ook een deel van de tijd onderweg of buiten
Wat gebeurt er outdoor?

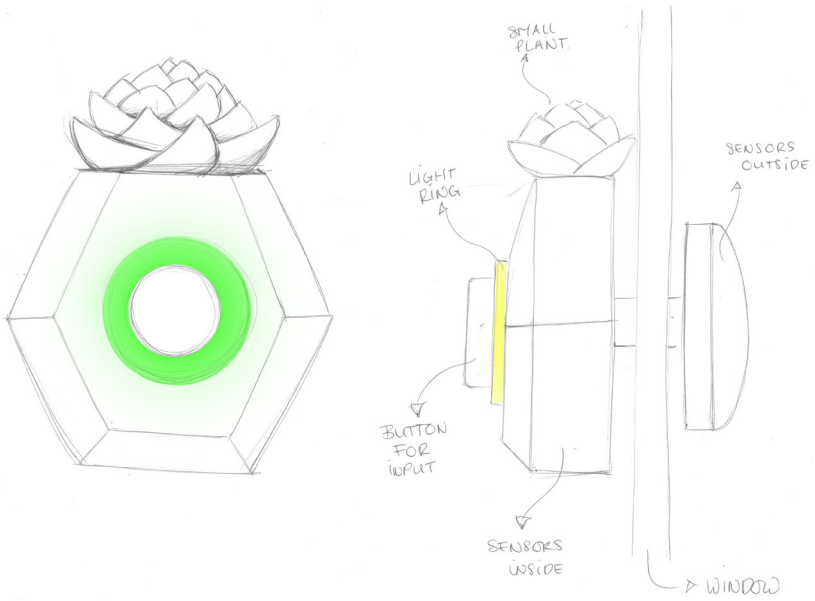
Parken zijn belangrijk, maar hoe zit het met het geheel?
Zijn voetgangers comfortabel als ze onderweg zijn?
Vergelijking straten en park met dezelfde aanpak?
Hoe beleven mensen dat?
Bij het input vragen van mensen kan ook feedback gegeven worden, ze kunnen informatie vragen over geluid.
TNO heeft een Tool : Urban Strategy
verkeers/lucht/geluidsmodellen
Door middel van aanpassingen in het model kunnen nieuwe situaties berekend worden.
Wat zijn de effecten op de mensen die er wonen.
Doel is om nog meer factoren te koppelen : groen, hittestress
Modellen geven gemiddelden, maar kan live worden aangepast en dan kunnen ook live feedback gegeven worden.
Verkeersituaties kunnen veranderen gedurende de dag.
Effecten op hinder en slaapverstoring kunnen gemodelleerd worden.
Het is niet mogelijk dit te koppelen aan metingen, hoe druk is het/ realtime aanpassingen.

Behalve mensen vragen hoe het is kan je ze ook informeren over veranderingen.
Door middel van visualisatie en geluid

APPENDIX B

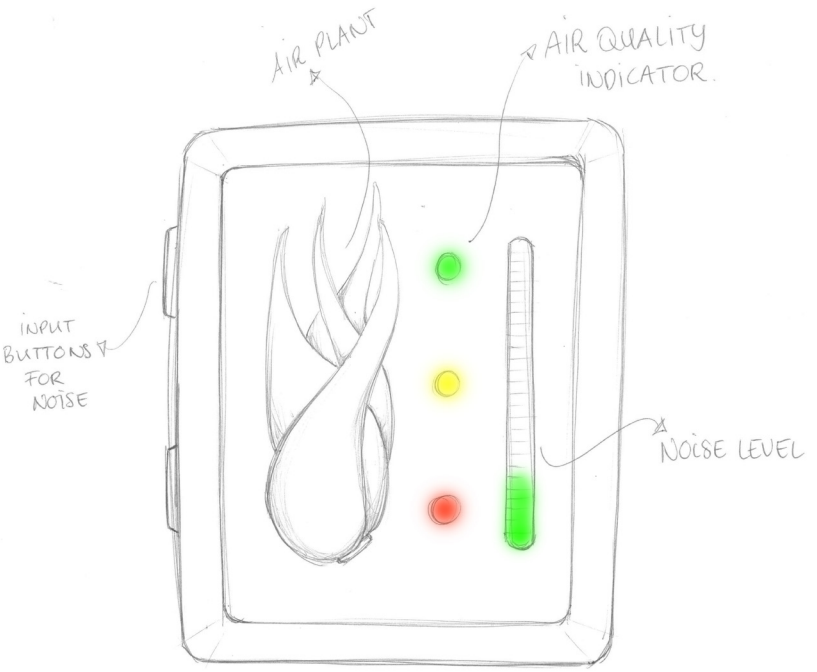
Concept A
Window magnet

The first idea consists of two parts, one is placed on the outside of the window and the other one is placed on the inside. Feedback on the level of air quality and noise is given both on the inside and outside. Input by the user can be given by turning the butten on the inside. An air plant is included to make a connection to the purifying qualities plants have.



Concept B
Wearable

The second concept is a wearable that measures air quality and the level of noise. The benefit in this is that the user can track the amount of sound they receive and how they respond to it. The product can analyse this and find possible connections between place, level of sound, experienced annoyance from the noise and air quality. Eventially it could give suggestions on which areas to avoid or visit at different times.



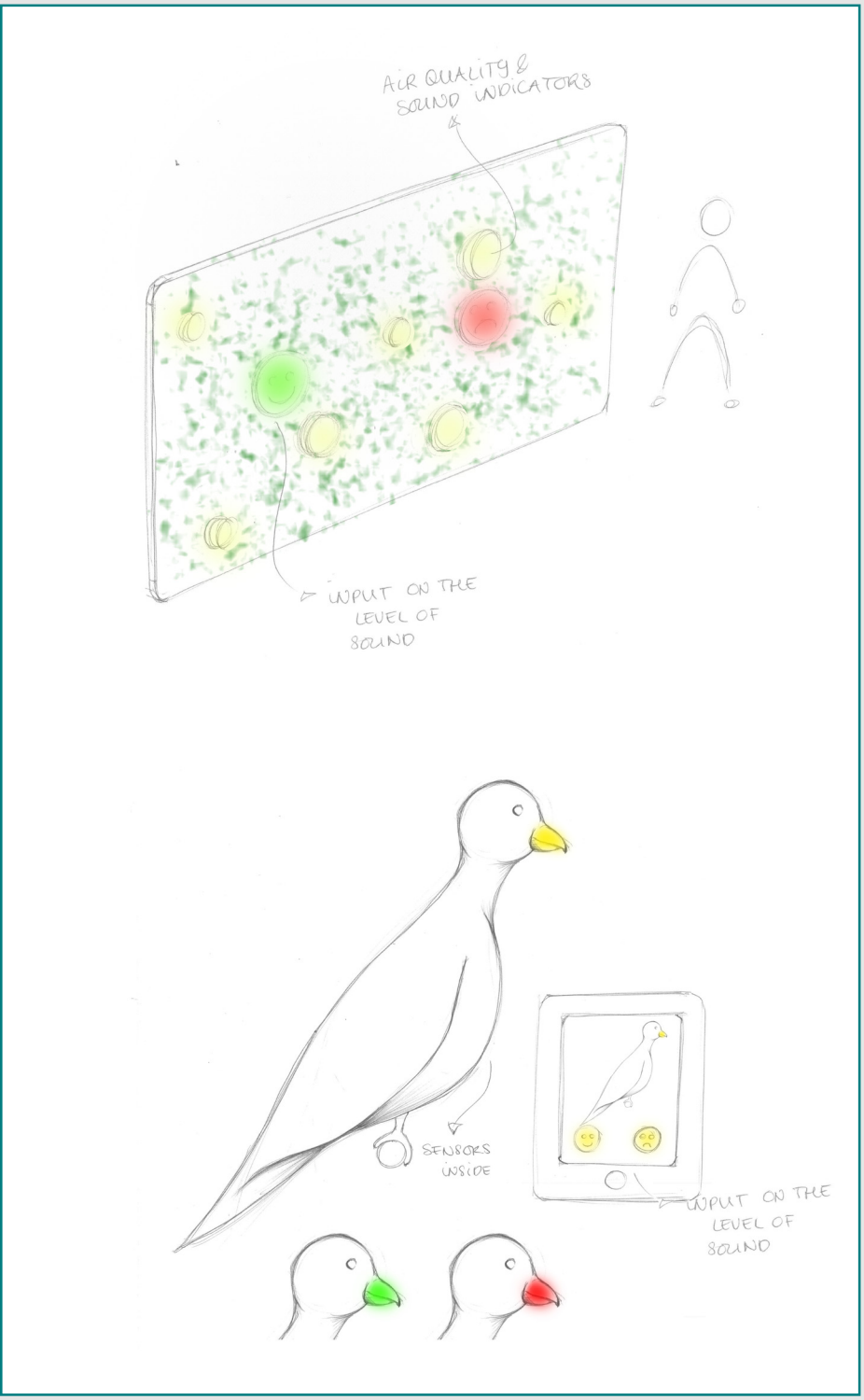
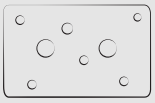


Figure 25 | *Four chosen concepts*



Concept C Green wall

This concept was created for the shared environment. Here, the occupant of the space can see how the air quality and level of noise are. Also, they can give input by interacting with the green wall. This creates data that other people can see online, as a result they can see which area is experienced as most pleasant regarding sound and where is the least air pollution. This way they can make a well-informed decision on what area to visit.

Concept D Bird watching

The final concept was based on the canary mine workers used to take with them into the mines to indicate air quality.

In this case, the beak indicates air quality and with the use of an augmented reality app more information can be obtained about level of noise. Input can be given through this app about the experienced sounds.

In order to evaluate the created concepts and make a decision on which one to further develop, a Harris Profile was used. Also, Studio Überdutch was consulted on their opinion. The criteria used to score the ideas were as follows:

- Minimal effort to provide input
- Optimal integration of objective and subjective input
- Understandable feedback on air quality & noise
- Engage user to interact
- Fit Studio Überdutch (UD)

A

	--	-	+	++
MINIMAL EFFORT			■	■
INTEGRATE O&S			■	
FEEDBACK			■	
ENGAGEMENT			■	
STUDIO UD			■	■

C

	--	-	+	++
MINIMAL EFFORT			■	■
INTEGRATE O&S			■	
FEEDBACK			■	
ENGAGEMENT		■		
STUDIO UD		■		

B

	--	-	+	++
MINIMAL EFFORT			■	■
INTEGRATE O&S			■	■
FEEDBACK			■	
ENGAGEMENT			■	
STUDIO UD			■	■

D

	--	-	+	++
MINIMAL EFFORT			■	
INTEGRATE O&S			■	
FEEDBACK			■	
ENGAGEMENT			■	
STUDIO UD		■		

Figure 26 | *Four chosen concepts scored by Harris Profile*

The four concepts were compared on the criteria stated before. Concept C and D scored less because they would fit the company the least. Besides this, concept C scored bad on engagement. These birds would be scattered throughout the city and would work with an app. It would be combined with an augmented reality app, this could be more attractive to people than a regular app.

Concept A and B had the best result based on the Harris Profile. Concept A scored less on the integration of objective and subjective, since the subjective input is based on the experience of the user indoor, while the noise is measured outdoor. It has to be seen whether people outdoor can also provide input and in what way.

Both A and B could score better on feedback and engagement. Now, the feedback is only given by lights.

After consulting with Studio Überdutch, it was decided to continue with concept A. This is a product that can be sold business to business to municipalities who can, for example, hand them out to new citizen of their cities.

APPENDIX C USER TEST

1.1 Wat weet je over slechte luchtkwaliteit en het effect hiervan op je gezondheid?
A: Afgelopen weken in het nieuws toch schadelijk voor gezondheid maar nog niet zodanig aantonen dat de overheid er iets aan moet doen
Overheid verantwoordelijkheid
Bij kinderen ook test, aantal weken pijpje, inademen en uitblazen om dat te testen
Denk ook dat het echt schadelijk kan zijn, fijnstof
W: Denk dat dat komt door industrie en uitlaatgassen en dat dat meer een rol speelt bij dichtbevolkte stedelijke gebieden en qua effect op gezondheid dat als je voortdurend in zo'n gebied leeft dat je verhoogde risico hebt op kanker en dat soort dingen longaandoeningen
M: Niks
R: als je slechte lucht inademt is het niet zo goed
1.2 Heb je wel eens last van slechte luchtkwaliteit in je huis?
A: Gebruik van geurkaarsen ook niet goed voor de kwaliteit van de lucht. Over het algemeen vaak de ramen open als we weg zijn dus dan kan het wel weer luchten.
W: Nee, hoe merk je dat dan?
M: Soms, omdat ik geen afzuigkap heb. Maar is dat echt slechte luchtkwaliteit? Voor mijn huis roken ze.
R: Ja, afzuigkap werkt niet zo goed. Zeker als er iets is aangebrand blijft dat lang hangen.
1.3 Wat ervaar je dan?
A: Lang geurkaars op de kamer, dan merk ik het. Eerst lekker ruiken, dan wordt het benauwd.
M: Het stinkt en niet prettig
R: Geurtjes zijn afleidend
1.4 Waar komt de luchtvervuiling vandaan?
A: Geurkaarsen
M: Rokers voor je huis, bij mijn raam
R: Fornuis, koken.
1.5 Heb je hier invloed op?
A: Ja. Maar er zijn vast ook mensen die buren hebben die ongezond leven, dan heb je er zelf geen invloed op. Ook via andere wegen komt het in je eigen huis.
M: Ik wilde naar buiten lopen en zeggen dat hij weg moest gaan maar toen was hij net weg. Sindsdien niet meer echt bij mijn raam maar wel op het pleintje.
R: Ramen en deuren open
2.1 Wat weet je over geluid en het effect hiervan op je gezondheid?
A: Ja, te harde muziek heeft effect. Ook gelezen dat het niet goed is om altijd muziek op te hebben want dat kan invloed hebben op je stemming. Aangetoond dat te hard geluid schadelijk is voor gehoor, vooral bij jonge kinderen. Doe altijd oordopjes in naar festivals.
W: Te hard geluid kan invloed hebben op je gehoor dat minder goed kan gaan functioneren, kan me voorstellen dat je op een plek woont dat veel geluidsoverlast heeft kan psychische effecten hebben zoals depressiviteit. Bijvoorbeeld als je lang een snelweg woont of langs een vliegveld.
M: Kan voor veel irritatie zorgen, over algemeen is stress en irritatie niet altijd goed voor je. Ook afhankelijk van hoeveelheid geluidsoverlast, extreme gevallen ook gehoor beschadiging
R: Geen idee dat geluid effect had op gezondheid, behalve op concentratie maar dat is niet echt gezondheid.
2.2 Heb je wel eens last geluid in je huis?
A: Ja, ik ben heel gevoelig voor geluid. Het huis leeft echt, als iemand beneden water pakt dan hoor je het door je hele huis.
W: Nee, wel eens bij te harde muziek maar dan op dat moment niet zo'n last.
M: Waren nog aan het bouwen met metalen platen die ze lieten vallen, dat was een hoge geluidspiek. Verder niet
R: Nooit
2.3 Wat ervaar je dan?
A: Wordt helemaal gek, probeer dan te mediteren want ik kan niet slapen als anderen nog bezig zijn in huis
M: Doordeweeks altijd overdag vanaf 7 uur 's ochtends. Soms werd ik er wakker van. Hing er vanaf wat ze aan het doen waren maar soms elke tien seconden lawaai maken. Dan liever ergens anders studeren dan thuis.
2.4 Waar komt het geluid vandaan?
A: Andere delen van het huis
2.5 Heb je hier invloed op?
A: Probeer het met een briefje op mijn deur, dan doen ze soms zachter.
M: Nee, maar toen ik er ging wonen wist ik dat ze er nog aan het werken waren.
Wel eraan geergerd. Dan niks aan te doen. TV harder.
Product
Luchtvervuiling en geluid hebben een grote invloed op je gezondheid. Daarom heb ik de VisionAir bedacht. Deze geeft inzicht in de luchtkwaliteit in

en rondom je huis en de hoeveelheid geluid in en rondom je huis. Om dit te bereiken meet hij de luchtvervuiling en het geluidsniveau.
3.1 Kan je mij proberen uit te leggen wat je ziet en hoe je denkt dat het product werkt?
A: Lijkt op een oog, een iris. Moet op een centraal punt anders kan het niet meten. Misschien ergens op de muur hangen. Misschien draait de cirkel rond en filtert het.
Binnenste bolletje voor lucht. Buitenste voor geluid omdat je het aan trillingen kan voelen.
W: Waarom ook een buiten?
Lucht van binnen vergelijken met de lucht van buiten
Gok dat sprietjes is om dingen te meten, net als bij een thermometer. Dat dat trillingen opneemt ofzo. Bolletjes niet echt verklaren. Streepjes ook geen idee. Ziet er een beetje uit als een wekker zonder pootjes.
R: HIer zo'n dingetje van laag naar hoog
M: Zie nu pas symbolen staan middelste is dus luchtkwaliteit, ik denk dat de bolletjes de sensoren zijn.
R: Ik denk dat het geluid aantal decibel meet. Een van de twee streepjes voor geluid, andere dingen voor luchtkwaliteit. Lijken op aanwijzers voor dingen ZOu niet weten wat de rondjes zijn. Grote rondje aan de buitenkant KLeine aan de binnenkant
3.2 Heb je enig idee waarvoor de halve cirkels zijn?
W: Binnenste vervuiling buitenste geluid
M: Geluid en lucht
R: Weinig vervuiling, Veel vervuiling, vier schalen van slechtheid, Links goed, rechts slecht
Verdere uitleg product
De VisionAir wordt zowel buiten als binnen op het raam bevestigd. Hierdoor zie je zowel de kwaliteit van de lucht buiten, als binnen en de hoeveelheid geluid zowel buiten als binnen.
3.3 Wat zou je kunnen doen met deze informatie?
A: Eerder ervan bewust, dus je kunt er eerder iets aan doen. Met name luchtkwaliteit, want geluid merk je vanzelf wel. Voorname lucht merk je niet snel dat het slecht is.
W: Conclusies of lucht in huis schoner is dan buiten/ vervuilder. Qua geluid je weet of er buiten meer geluid is.
R: Raam dicht, dat je er wel iets aan kunt doen dat het binnen stiller is
M: Als luchtkwaliteit binnen slechter is dan buiten dan kan je raam open zetten en andersom raam dichthouden.
Behalve het meten van objectieve data, meet hij ook subjectieve data. Dit betekent dat hij meet hoe jij de luchtkwaliteit en het geluidsniveau ervaart. Ik heb drie momenten op de dag gespecificeerd waarop je deze input zou kunnen leveren, namelijk na de nacht, bij het weggaan of thuiskomen en wanneer je thuis bent.
W: Hoe instellen?
Als hij boven bepaald niveau komt geeft signaal af, waardoor je weet pas op kan de verkeerde kant op gaan. Of de hele tijd zelf kijken maar praktischer als er een alarm op zit.
3.4 Zou je hiervoor de tijd willen nemen om dit in te geven?
A: Voor mezelf niet zo, maar als ik kinderen zou hebben misschien wel. Omdat zij nog moeten opgroeien voel ik me daar meer verantwoordelijk voor. Dan zou ik daar wel de tijd voor willen nemen.
R: Hoe kan je de luchtkwaliteit als je slaapt ervaren? Ik ben iemand die er mee begint maar dan na 2 weken klaar.
M: Ik zie het nut, maar ik ben zelf vrij lui. Neiging als notificatie op telefoon maar dan bleh weg. Ligt eraan of er nog iets mee gebeurd. Of de data nog ergens terecht komt bij mensen die er over nadenken.
3.5 Is er een situatie waarin je dit wel/niet zou willen doen?
W: Ja 1x nooit meer. Voor geluid misschien 's nachts lager
Inbrekers alarm
M: Als er opeens een piek of irritatie is die je niet had verwacht of niet aanhoudt, dan "klacht" . Die ochtend dingen weinig ingevuld, hoewel ze misschien wel het meest nuttig zijn omdat die feedback het meeste invloed kan hebben op lange termijn veranderingen
R: meest 's ochtends en 's avonds en als ik wegga of binnenkom minder boeiend. 'S ochtends wel want ik slaap echt heel vaak slecht. 'S avonds juist want dan ben je thuis dus dan ervaar je de "last".
De reden dat subjectieve data wordt gemeten is omdat mensen stress kunnen ondervinden wanneer zij zich in een situatie bevinden waarin zij niets kunnen doen aan dat wat ze minder comfortabel laat voelen. Echter, om je bewust te worden dat je stress ervaart moet je je hiervan eerst bewust zijn. Pas dan kan je op zoek gaan naar oplossingen of manieren om hiermee om te gaan.

3.6 Is er nu een situatie waarin je dit wel/niet zou willen doen?
A: Juist voordat je gaat slapen zodat je een goede nachtrust tegemoet gaat.
W: Als je thuis bent WEL. Als je weggaat is het misschien niet zo praktisch je raam open te laten. Stel je komt thuis kan je alsnog je raam open zetten. 'S nachts eerder voor het geluid dan voor luchtkwaliteit je kan hem niet checken als je ligt te slapen. Als je thuis bent toch meest mee bezig
Behalve het product zal er ook een app beschikbaar komen.
3.7 Wat verwacht je te kunnen zien in deze app?
A: Tips, niet zelf altijd weten wat je eraan kan doen. Weetjes, inspirerende quotes.
TImeline, begin van gebruik, over de dagen/weken. Geïmplementeerd in gezondheidsapp
Beloningssystemen, om het speels te maken. Stel week lang schone lucht in je huis, dan gefeliciteerd. Motiverends.
W: Op ieder moment de huidige stand van het ding
Soort overzicht van afgelopen week of maand/jaar
Grafieken op welke momenten iets te hoog/te laag.
Soort alarm functie in de app dat hij een notificatie stuurt als dat ding doorslaat boven een bepaald niveau
Batterij niveau
R: Grafieken met data, dat je de schommelingen kan zien in de kwaliteit van de lucht/geluid
M: Misschien ook de deviation van jouw gemeten data met de gemiddelde data in het land / de woonwijk
R: Misschien wat de uiterste grens van goed/slecht. Als je ziet dat er een piek ziet dat je er denkt ik moet er echt iets mee doen
M: Misschien ook instellingen bij bepaalde waarden voor waarschuwing. Ook fijn om dingen juist uit te zetten. Zelf bepalen hoeveel meldingen ed
Gebruik
4.1 Zou je het product aan de buitenkant van het raam willen hangen?
A: Eerder met zuignappen.
Hardop vertellen wat je denkt en doet. Observaties:
A: Haalt eerst de beschermlaag van de tape, dan plaatst ze de ophanging op het product, waarna ze het in zijn geheel op het raam plakt.
W: Haalt eerst de beschermlaag van de tape, dan plaatst ze de ophanging op het product, waarna ze het in zijn geheel op het raam plakt.
M: Kijkt eerst heel goed hoe de ophanging opgehangen moet worden alvorens de beschermlaag van de tape te verwijderen en de ophanging op het raam te bevestigen. Daarna wordt het product bevestigd.
R: Hangt eerst de ophanging op het raam, daarna het product erop.
*Het is niet heel gemakkelijk de juiste positie voor het product te vinden als de ophanging al op het raam hangt. *

4.2 Wat vertellen de icoontjes je?
M: Volume is duidelijker, ipv icoontje kleiner maken, balkjes verwijderen
R: zo'n mute tekenetje, weet niet wat die uitstulpinkjes zijn. Bij grensgeval, misschien nét slecht maar dan maakt het nog niet echt bewust. Net een extra stapje
M: 5 of 4 beter dan 2. Ook kleurcode tussen de streepjes
4.3 Wat vind je van de manier waarop de luchtkwaliteit wordt weergegeven?
A: Ja wel duidelijk
4.4 Wat vind je van de manier waarop geluid wordt weergegeven?
A: Doet me denken aan microfoontje
4.5 Wat vind je van de manier waarop je input kunt geven?
A: Vind ik een goede, ook heel duidelijk met die kleurtjes.
M: Het is pas nuttig als de input ook doorgaat naar mensen die er iets mee kunnen

APPENDIX D MORPHOLOGICAL CHART


3
4
5
6
7
ght
tensity
pins showing
sound waves
swinging
rod
pendulum
light
grid.
more
black
reen/
hysical
smell
filter
becomes
black
dying
plant
colour -
changing
flag.
grade
like/
dislike
app
face recog-
nition
drawing
hake
move
touch
stroke
clean
water plants.

APPENDIX E SENSOR SEARCH

Most of the measuring ranges of NO_2 sensors are stated in ppm or ppb (parts per million or parts per billion). This means the value has to be converted to ppm. For this it is needed to know the density of 1 part of NO_2.

1ppb NO2 = 1.88 µg/m^3 NO_2

The maximum NO2 per hour therefore is:

200/1.88 µg/m^3 = 106 ppb NO_2

NO2

Name	*Cost*	*Range*	*Accuracy*	*Supply Voltage*	*Current consumption*	*Size*
SGX Sensortech MICS-4514 	€13,58	0,05-10 ppm	N/A	5 V	32 mA	5,0x7,0x1,55
Spec Sensors 3SP_NO2_5F P package 110-507 	€16,96	0-5 ppm	0.02 ppm	2,7-3,3 V	5-15 µA	21,0x21,0x3,5
Alphasense NO2-B43F 	€72,00	0-20 ppm	0,015 ppm	3,6-6,4 V	N/A	32,3x16,5

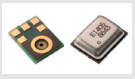
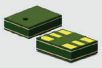
CO2

Name	*Cost*	*Range*	*Accuracy*	*Supply Voltage*	*Current consumption*	*Size*
GSS Cozir LP 	€91,99	0-5.000 ppm	±50 ppm ±3% of reading	3.3 or 5 V	33mA peak 1mA average	31x19,5
Senseair K30 	€71,99	0-5.000 ppm	±30 ppm ±3% of reading	4.5 to 14 V	300mA peak 40mA average	57x51x14
Telaire T6713 	€62,99	0-2.000 ppm	±30 ppm ±3% of reading	4.5 to 5.5 V	200mA peak 25mA average	30x15,6x8,6

$PM_{10/2.5}$

Name	*Cost*	*Range*	*Accuracy*	*Supply Voltage*	*Current consumption*	*Size*
Honeywell 785-HPMA115S0 -XXX 	€18,52	0-1000 µg/m³	± 15 µg/m³	5 V	80 mA peak 20 mA average	43x36x23,7 mm
Sharp GP2Y1010AU0F 	€9,63	0-500 µg/m³	0,5V/0.1 mg/m³	5 V	20 mA peak	46x30x17,6 mm
Amphenol AS SM-PWM-01C 	€14,22	N/A	N/A	5 V	90 mA	59x46x18 mm

Microphone

Name	*Cost*	*Range*	*SNR*	*Supply Voltage*	*Current consumption*	*Size*
Knowles SPH0645LM4HB 	€1,95	20Hz-20kHz	65	0-3,6 V	10 µA, 600 µA	3,5x2,65x0,98mm
STmicroelectronics MP23AB01DH 	€1,45	100Hz-10kHz	65	2,3-3,6 V	250 µA	3,35x2,5x0,98mm
TDK InvenSence ICS-40619 	€2,55	50Hz-20kHz	67	1,5-3,6 V	55 µA, 190 µA	3,5x2,65x0,98mm

Temperature + Humidity

Name	*Cost*	*Range*	*Accuracy*	*Supply Voltage*	*Current consumption*	*Size*
Texas Instruments HDC2010YPAR 	€2,18	0-100% RH -40-85 °C	2% RH, 0.2°C	1,6-3,6 V	0,55 µA	1,5x1,5x0,675mm
Sensirion 403-SHTW2 	€2,52	0-100% RH -40-125 °C	3% RH, 0.4°C	1,8 V	385 µA	1,3x0,7x0,5mm
Bosch (+pressure) 262-BME280 	€5,79	0-100% RH -40-85 °C 300-1100 hPa	3% RH, 1.0°C 1hPa	1,7-3,6 V	3,6 µA	2,5x2,5x0,93mm

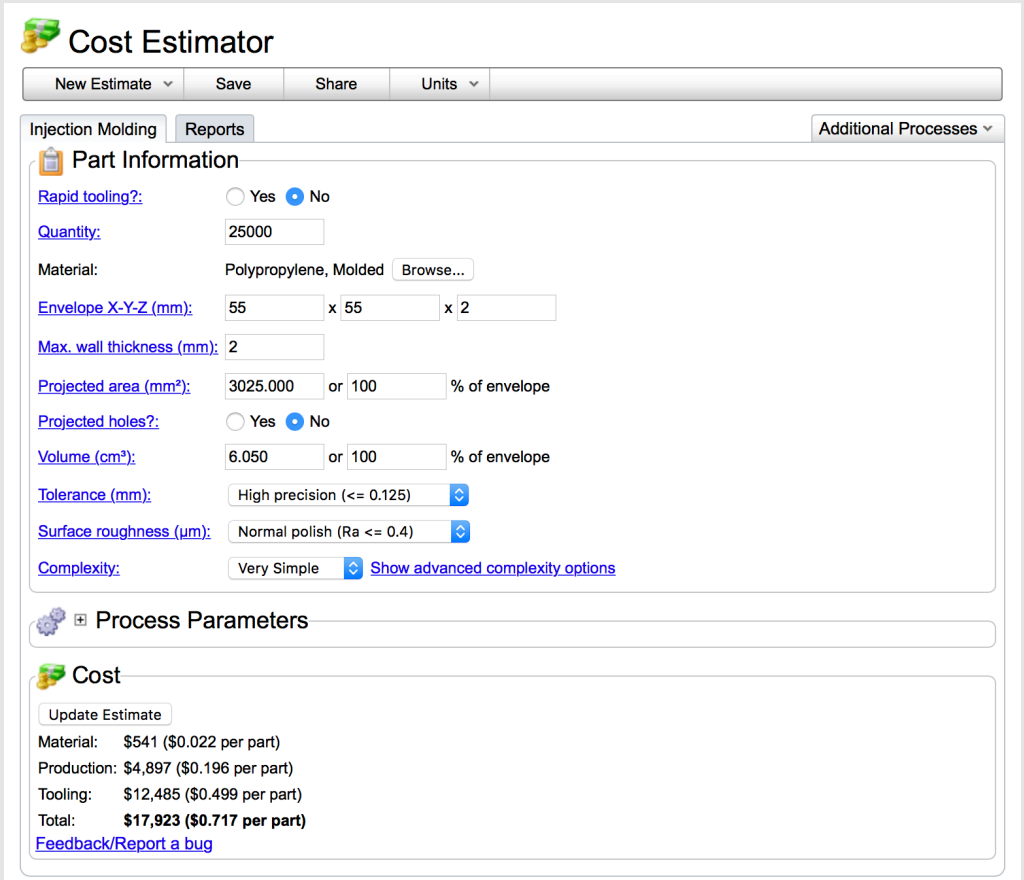
Bluetooth

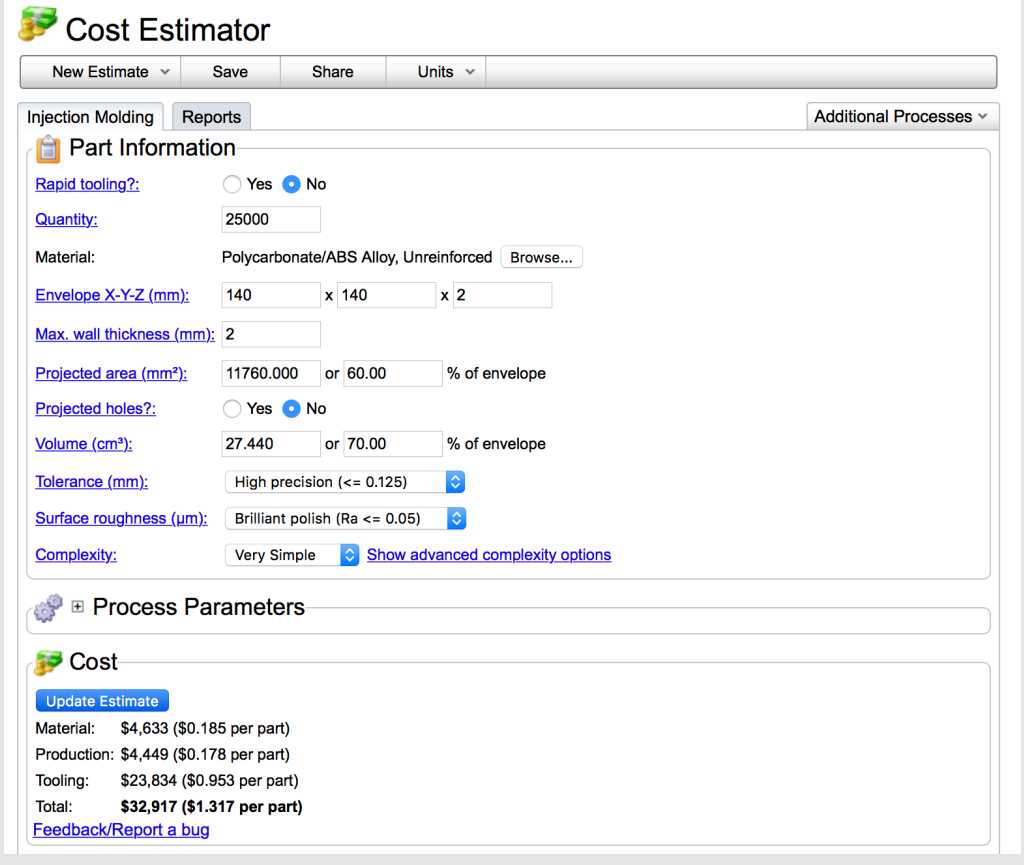
Name	*Cost*	*Memory*	*Speed*	*Supply Voltage*	*Current consumption*	*Size*
Nordic Semiconductor nRF51822-QFAC-R7 	€4,21	256 kb Flash 32 kb RAM	2 Mb/s	1,8-3,6 V	16 mA	6,0x6,0x0,9 mm
STMicroelectronics BLUENRG-232 	€3,49	256 kb Flash 24 kb RAM	1 Mb/s	1,7-3,6 V	15 mA	5,0x5,0x0,85 mm
Texas Instruments CC2541F256RHAR 	€3,69	256 kb Flash 8 kb RAM	2 Mb/s	2-3,6 V	18,2 mA	6,0x6,0x1,0 mm

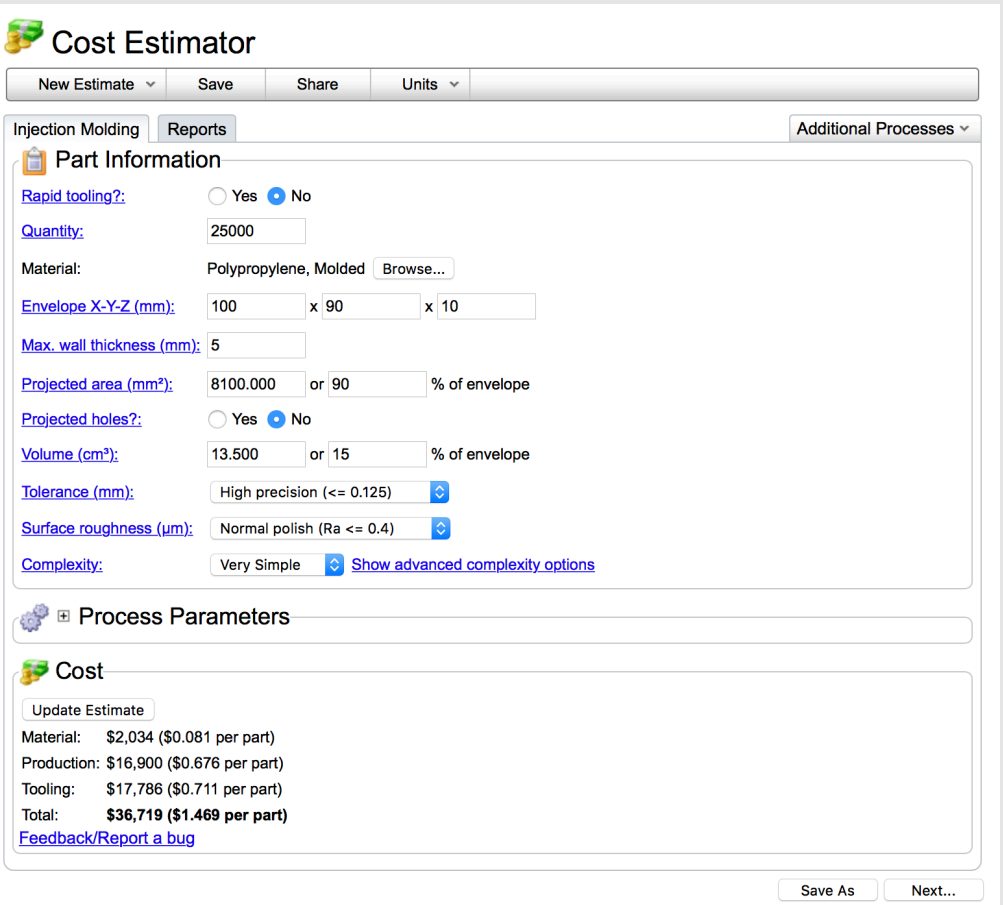
APPENDIX F CURRENT CALCULATION

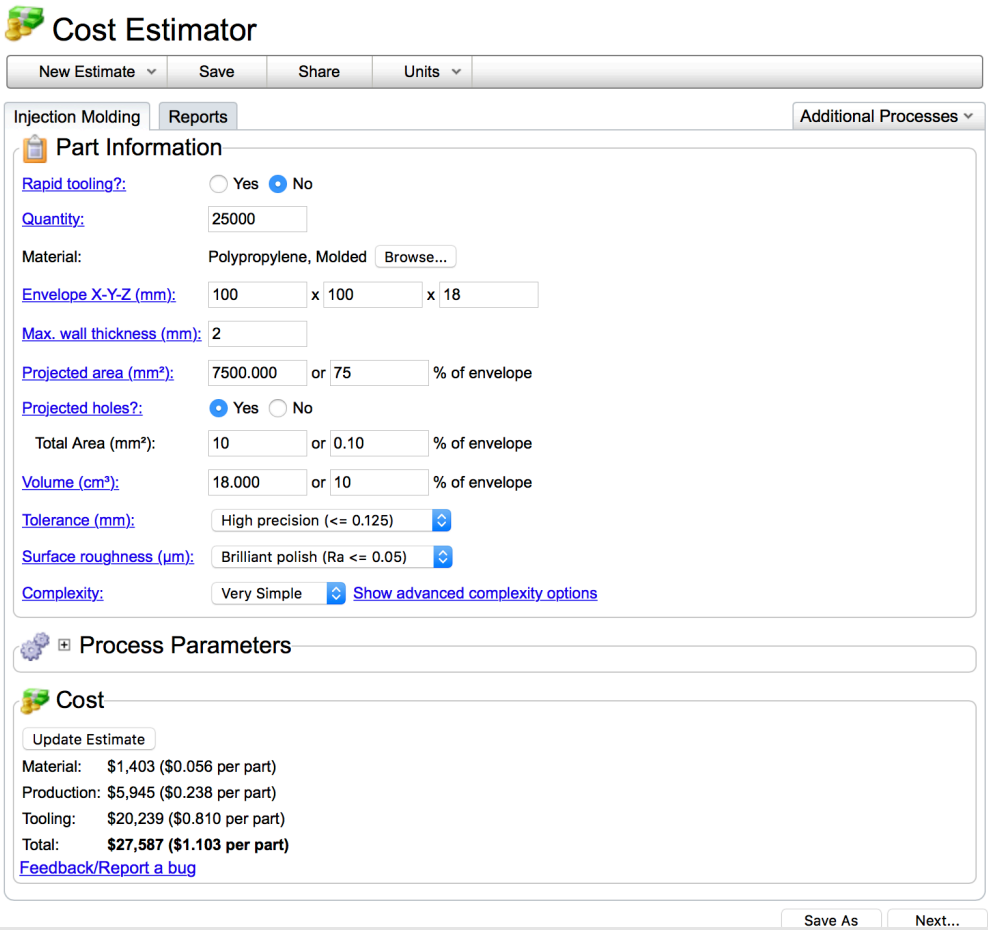
Inside		sleep (mA)	active (mA)	sleep	active	factor sleep	factor active	sleep av mA	active av mA	av mA				
sensors	T+H	0.00005	0.00055	84960	1440	0.9833	0.01667	0.000049	0.000009	0.000058				
	PM	10	20	84960	1440	0.9833	0.01667	9.833333	0.333333	10.166667				
	CO2	20	155	84960	1440	0.9833	0.01667	19.666667	2.583333	22.250000				
	Sound	0.01	0.6	84960	1440	0.9833	0.01667	0.009833	0.010000	0.019833				
other	Stepper (x2)	0	320	86040	360	0.9958	0.00417	0.000000	1.333333	1.333333				
	LED's (x18)	0	900	86040	360	0.9958	0.00417	0.000000	3.750000	3.750000				
	Touch sensors	0.000001	0.0002	86385	15	0.9998	0.00017	0.000001	0.000000	0.000001				
	Wi-Fi + BLE	0.000023	261	84960	1440	0.9833	0.01667	0.000023	4.350000	4.350023				
									total mA	41.869915		Power	0.2093495766	Watt
													5.024389838	Watt/day
Outside		sleep (mA)	active (mA)											
sensors	T+H	0.00005	0.00055	84960	1440	0.9833	0.01667	0.000049	0.000009	0.000058				
	PM	10	20	84960	1440	0.9833	0.01667	9.833333	0.333333	10.166667				
	NO2	0.005	0.015	84960	1440	0.9833	0.01667	0.004917	0.000250	0.005167				
	Sound	0.01	0.6	84960	1440	0.9833	0.01667	0.009833	0.010000	0.019833				
other	Stepper	0	320	86040	360	0.9958	0.00417	0.000000	1.333333	1.333333				
	Bluetooth	0.001	10.5	84960	1440	0.9833	0.01667	0.000983	0.175000	0.175983				
									total mA	11.701042		Power	0.05850520833	Watt
													1.404125	Watt/day
		outside			**Inside**									
		battery	9200	mAh	battery	9200	mAh							
		hours of power	786.254785		hours of power	219.7281731								
		number of days	32.76061604		number of days	9.155340545								
Battery	2300	mAh/piece	9200	mAh total										

APPENDIX G COST ESTIMATION


Cost Estimator
New Estimate
Save
Share
Units
Injection Molding
Reports
Additional Processes
Part Information
Rapid tooling?: Yes No
Quantity: 25000
Material: Polypropylene, Molded Browse...
Envelope X-Y-Z (mm): 55 x 55 x 2
Max. wall thickness (mm): 2
Projected area (mm²): 3025.000 or 100 % of envelope
Projected holes?: Yes No
Volume (cm³): 6.050 or 100 % of envelope
Tolerance (mm): High precision (<= 0.125)
Surface roughness (µm): Normal polish (Ra <= 0.4)
Complexity: Very Simple Show advanced complexity options
Process Parameters
Cost
Update Estimate
Material: $541 ($0.022 per part)
Production: $4,897 ($0.196 per part)
Tooling: $12,485 ($0.499 per part)
Total: $17,923 ($0.717 per part)
Feedback/Report a bug


Cost Estimator
New Estimate
Save
Share
Units
Injection Molding
Reports
Additional Processes
Part Information
Rapid tooling?: Yes No
Quantity: 25000
Material: Polycarbonate/ABS Alloy, Unreinforced Browse...
Envelope X-Y-Z (mm): 140 x 140 x 2
Max. wall thickness (mm): 2
Projected area (mm²): 11760.000 or 60.00 % of envelope
Projected holes?: Yes No
Volume (cm³): 27.440 or 70.00 % of envelope
Tolerance (mm): High precision (<= 0.125)
Surface roughness (µm): Brilliant polish (Ra <= 0.05)
Complexity: Very Simple Show advanced complexity options
Process Parameters
Cost
Update Estimate
Material: $4,633 ($0.185 per part)
Production: $4,449 ($0.178 per part)
Tooling: $23,834 ($0.953 per part)
Total: $32,917 ($1.317 per part)
Feedback/Report a bug


Cost Estimator
New Estimate
Save
Share
Units
Injection Molding
Reports
Additional Processes
Part Information
Rapid tooling?: Yes No
Quantity: 25000
Material: Polypropylene, Molded Browse...
Envelope X-Y-Z (mm): 100 x 90 x 10
Max. wall thickness (mm): 5
Projected area (mm²): 8100.000 or 90 % of envelope
Projected holes?: Yes No
Volume (cm³): 13.500 or 15 % of envelope
Tolerance (mm): High precision (<= 0.125)
Surface roughness (µm): Normal polish (Ra <= 0.4)
Complexity: Very Simple Show advanced complexity options
Process Parameters
Cost
Update Estimate
Material: $2,034 ($0.081 per part)
Production: $16,900 ($0.676 per part)
Tooling: $17,786 ($0.711 per part)
Total: $36,719 ($1.469 per part)
Feedback/Report a bug
Save As
Next...


Cost Estimator
New Estimate
Save
Share
Units
Injection Molding
Reports
Additional Processes
Part Information
Rapid tooling?: Yes No
Quantity: 25000
Material: Polypropylene, Molded Browse...
Envelope X-Y-Z (mm): 100 x 100 x 18
Max. wall thickness (mm): 2
Projected area (mm²): 7500.000 or 75 % of envelope
Projected holes?: Yes No
Total Area (mm²): 10 or 0.10 % of envelope
Volume (cm³): 18.000 or 10 % of envelope
Tolerance (mm): High precision (<= 0.125)
Surface roughness (µm): Brilliant polish (Ra <= 0.05)
Complexity: Very Simple Show advanced complexity options
Process Parameters
Cost
Update Estimate
Material: $1,403 ($0.056 per part)
Production: $5,945 ($0.238 per part)
Tooling: $20,239 ($0.810 per part)
Total: $27,587 ($1.103 per part)
Feedback/Report a bug
Save As
Next...

	amount	price/piece	total		amount	price/piece(1000	total	Source
T+H	2	2.18	4.36		2	1.08	2.16	https://nl.mouser.com/ProductDetail/Texas-Instruments/HDC2010YPAR/?qs=%2fha2pyFaduirC4l4MTLDdMvZ8xJLYO62tfhVgNlweY7IcqeYafgb5g%3d%3d
PM	2	10.25	20.5		2	5.75	11.5	https://www.digikey.nl/product-detail/en/sharp-socle-technology/GP2Y1010AU0F/1855-1012-ND/720164
CO2	1	62.99	62.99		1	57.02	57.02	https://www.digikey.nl/product-detail/en/amphenol-advanced-sensors/T6713/235-1373-ND/5027891
Sound	2	1.95	3.9		2	1.17	2.34	https://nl.mouser.com/ProductDetail/Knowles/SPH0645LM4H-B/?qs=%2fha2pyFaduibBwH2pjusts%252bG9k4AmBf1ol3iJP3Wl4CDyrzv3XH3rQ%3d%3d
NO2	1	17.2	17.2		1	17.2	17.2	https://www.digikey.com/product-detail/en/spec-sensors-llc/110-508/1684-1045-ND/7689226
Stepper	4	2.51	10.04		4	2.51	10.04	https://nl.aliexpress.com/item/NMB-25MM-Stepper-Motor-4-phase-5-wires-Thin-type-Stepper-Motor-with-Gear/32333720607.html
LED's	18	0.0582	1.0476		18	0.05678	1.02204	https://nl.aliexpress.com/item/100PCS-WS2812B-4pins-5050-SMD-WS2812-Individually-Addressable-Digital-RGB-LED-Chip-5V-WS2812B-ws2812b-2812/32597531881.html?src=google&albslr=220352482&isdl=y&aff_short_key=UneMJZVf&source=%7Bifdyn:dyn%7D%7Bifpla:pla%7D%7Bifdbm:DBM&albch=DID%7D&src=google&
Touch sensors	1	1.16	1.16		1	0.884	0.884	https://nl.mouser.com/productdetail/silicon-labs/cpt212b-a01-gm?qs=sGAEpiMZZMsVh0scArXy39%2FknOXIzeAtc4w8sh00SOE%3D
Bluetooth	1	3.49	3.49		1	1.84	1.84	https://nl.mouser.com/ProductDetail/STMicroelectronics/BLUENRG-232/?qs=%2fha2pyFaduiR6Cly9ul3%252bvD%2fTq85rbCpA6x1RKza8LfWdOlTgC2TlQ%3d%3d
Wifi+BLE	1	10.45	10.45		1	8.65	8.65	https://pycom.io/cart/
PCB	2	22.21	44.42		2	1.23	2.46	https://www.pcbcart.com/quote
Battery 4 pack	1	8.55	8.55		1	8.55	8.55	https://business.conrad.nl/nl/oplaadbare-aa-batterij-penlite-nimh-conrad-energy-endurance-hr06-2300-mah-12-v-4-stuks-251080.html
Solar panel	1	3.93	3.93		1	3.93	3.93	https://www.mrwatt.eu/en/shop/mini-solar-modules/mini-epoxy-solar-panel-monocrystalline-70x70-mm.html
			0				0	
Air indicator	2	4.8032	9.6064		2	0.1738	0.3476	https://snijlab.nl/nl/cart
Noise indicator	2	0.115	0.23		2	0.104	0.208	
3M Double tape	2	0.55	1.1		2	0.55	1.1	https://nl.aliexpress.com/store/product/Wholesale-100pcs-Lot-Original-5068A-Round-Double-Sided-3M-VHB-Sticker-Pad-Home-Kitchen-Office-Car/211153_32363603447.html
			0				0	
Plastic parts	1	10.08	10.08		1	10.08	10.08	http://www.custompartnet.com/estimate/injection-molding/?units=1
Wooden base	2	10	20		2	10	20	rough estimate
Labour	1	5	5		1	2	2	rough estimate
Transport			0				0	
			238.054				161.33164	
	dollar							
Transparent ring Indoor			1.51	1.51				
Transparent ring Outdoor			1.38	1.38				
Transparent closing ring	2	1.32	2.64					
Battery compartment	2	1.1	2.2					
Battery cover	2	0.72	1.44					
Mounting plate	2	1.49	2.98					
			7.52	12.15				

APPENDIX H REQUIREMENTS

Technical

The product-service system should be able to measure the following variables: Temperature; humidity, air quality (PM10/2.5, CO2, NO2); sound levels

The product-service system should be able to collect subjective input on the level of sound and the quality of the air from the occupant of the environment

The product should provide feedback on the quality of the air and the level of noise

The product should be watertight in order to be used outside.

The product should function within an environmental temperature of -10 degrees C- +40 degrees C

The product should function in an environment with a humidity between 0 - 95%

The product should have a non-technical look

The materials should be able to resist outdoor environment

The product should provide a signal when batteries are low

The product should require low maintenance

The product should work 24/7/365

User

The user should be able to provide subjective input

The user should be able to connect the product to the window on the outside

The user should be able to disconnect the product from the window

The user should understand the feedback given by the product on level of noise and air quality

The user should be able to personalize settings of the product.

Business

The product should be less expensive than professional measuring equipment

The product should cost around €200,-

The product should collect data