THINGS AS CITIZENS

A DEMONSTRATOR OF THINGS THAT DISTRIBUTE CLEAN AIR IN THE CITY

LOUISE HUGEN

MASTER THESIS

02 DESIGN

COLOFON

Master thesis
Things as citizens: A demonstrator of Things that distribute clean air in the city
22nd of March, 2018

Author
Hugen, L.M.

Supervisory team
Prof. Dr. Giaccardi, E. (Delft University of Technology)
Ir. Smit, I. (Delft University of Technology)

Institution
Master Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

THINGS AS CITIZENS

A DEMONSTRATOR OF THINGS THAT DISTRIBUTE CLEAN AIR IN THE CITY

LOUISE HUGEN

MASTER THESIS

02 DESIGN

ABSTRACT

This thesis contributes to the PACT (Pure Air for Cities) research project. The PACT project aims to develop novel methods and tools for understanding and demonstrating how intelligent things can act in concert with people and connect to existing data and cloud services.
This second part of the thesis describes a concept of three Things that is designed according to the design qualities model, as introduced in report 1.
The design qualities model describes the design criteria for Things with agency, where the criteria allow Things to be perceived as citizens in the urban environment. The design process focusses on the co-performance between Things and citizens. As such, the design is created from both Thing and human perspective. One of the applied strategies is the creation of storyboards of a specific situation in the city from both a human centred and Thing centred perspective.

Air purification is chosen as a context which the goal of the concept is to provide and distribute clean air in the city, as envisioned by the PACT project.
To this end, an analysis of air pollution, air purification and the dynamics of citizens in the city is conducted prior to the design process to create a concept that would be valuable to citizens to co-perform with.
The basis of the concept is the design of the system, which was set up according to the analysis and design qualities model. Two micro interactions between Things and citizens are worked out in more detail to demonstrate how the Things of the system would behave during an encounter in the city.
The concept is validated by means of a qualitative study. The aim of this study was to identify if the design qualities are recognizably implemented in the design of the behavior of the Things. The conclusion is that the design qualities were recognized by majority of the participants. The concept is thus a successful demonstrator for Things as Citizens.

PREFACE

This second report describes my design process of a system of three Things according to the design model that I previously created. It has been a whole new experience for me to try to design from a human centred and Thing centred perspective simultaneously.
I have had a lot of help from people from different fields to create the final design. Therefore, in addition to the preface of report 1, I would like to thank the following people for their time.
Andrez Stankiewicz, thank you for meeting and sharing your vision of air cleaning in the city and for providing me of information about photocatalytic oxidation and PCO reactors, it helped me to understand the technology behind air cleaning and helped me to set up a realistic concept regarding the air clean technology.

Maria Luce Lupetti and Iohanna Nicemboim, thank you for brainstorming about the micro interactions. You have helped me to think outside of the box and not to forget about Thing centred design.
Javier Alonso, thank you for the meeting during which we discussed the swarm behavior of the Things of the concept. It helped me to incorporate ideas for the team behavior within the concept. Thanks to Boaz Floor who has lend the robot for the user test and helped me to create the physical prototype.
I want to thank Lot and Jozine for being my assistants during the user test. Last but not least, thank you Jozine for bearing the cold during the making of the movie on one of the coldest days of the year.

INTRODUCTION

This second part of the thesis describes the design process of a concept designed according to the design qualities model that is created in report 1. The aim of this design project is to create a speculative concept to demonstrate how citizens and Things can co-perform in a city environment. The concept is a system consisting of three Things with agency for the provision and distribution of clean air in the urban environment.

The design qualities model of report 1 is included in the design process as a design vision for the concept. Moreover, a new method is applied for the design of this system, called rule-based design. Rule-based design is situation-oriented and focusses on the relations between actors, humans and Things, and the timely interactions between them. Furthermore, rule-based design focusses on the ability of a Thing to interpret situations according to certain rules and therefore enables an open and interactive space for the user to interpret the Thing and to interact with it according to his or her own preference. Rule-based design is chosen as it fits with the design vision of co-performance and the design qualities model.

This report presents the design steps in chronological order. First, the design brief is presented, which includes an analysis of the air pollution problem in the urban environment and the air purification system and principle. It also includes an introduction to the design case, as a specific everyday object in the city is already chosen for the Things of the concept.

The design brief closes with the design goal and the design vision.

The second chapter describes a brief analysis of the dynamics of the city life based on citizens' activities. Chapter three is about the system of the concept based upon the results of previous described analysis and the design vision.

It is expected that Things and citizens will mainly perform their practices beside each other and will only have brief moments of co-performance to adjust their practices. It is therefore decided to work out subtle moments of co-performance within micro interactions. Micro interactions are brief, single-task interaction moments between the Things and the citizen. Chapter four describes three storyboards that are created to identify micro interactions between citizens and the Things according to the system concept and the city dynamics. Chapter five describes two micro interactions that are chosen to work out in detail, with a focus on the behavior of a Thing and its visual appearance. During the design of both micro interactions, the design qualities model is used as a focus.

Chapter seven describes a user test that is conducted in order to validate the design of the micro interactions and to validate that the design qualities are successfully implemented. Finally, chapter eight describes the final design of the concept.

CONTENT

01 DESIGN BRIEF

PROBLEM DEFINITION

Air pollution in the city

Air pollution in the city is a growing concern; it is becoming world's largest single environmental health risk according to research of the World Health Organisation (WHO, 2014). In the Netherlands, air pollution levels exceed the limits established by the World Health Organisation, demonstrating the importance to reduce air pollution in the air.

Much research is already conducted in order to make the amount of air pollution in Amsterdam visible and to provide solutions. Amsterdam has set up a plan to promote the purchase of electric cars in order to reduce the air pollution caused by traffic (Giaccardi & Smit, 2017). Yet, only 25% of the air pollution in Amsterdam is caused by traffic. The government of Amsterdam also plans to plant more trees in coming years (Giaccardi & Smit, 2017). Another project initiated by het Longfonds, the national lunch organisation (Longfonds, 2018), is the launch of an application that indicates the level of air pollution per city, to raise awareness among citizens of the significance of the problem. Other initiatives are smart lab projects to map the air quality in the city. Smart lab The Waag, a non-profit organisation (Boonstra, 2014) runs a project whereby citizens can measure the air quality with a toolkit in their direct environment.

Yet, these solutions are partially preventive and have a passive approach. Planting trees or replacing current cars for electric ones will not reduce the peaks of air pollution that are caused on certain parts of the day, e.g. in the morning during traffic jams.

Besides, both are sustainable solutions but have a long term approach, which means that in the meantime the air pollution danger remains for the health of citizens.
The application of het Longfonds only gives an indication of the situation. Beside the air condition, the app also provides information for citizens to improve the air quality. However, that only goes so far as a written advice to take the bike or public transport more often. This means that citizens are left on their own and have limited power to protect their health in the public environment.

A new method for air purification in cities

The PACT research project envisions a new solution to the reduction of air pollution: an active approach. PACT envisions an intelligent air purification catalysis system that is able to sense the peaks of air pollution and is able to generate and distribute clean air over the city based on this data. The system exists of intelligent everyday objects in the city that can collaborate and target air pollution on a local level. Each everyday object, or Thing, is dynamical and has an integrated catalyst. By this means, the Things can actively contribute to the air quality in the city.

ORIENTATION

In order to understand the air pollution problem in more detail and to shape the scope and goal for the concept, further research is conducted about the following aspects:

- Air pollution and the impact on people's health
- Citizen's activities and air pollution hotspots in the city
- The air catalyst and its working principle

AIR POLLUTION

Air pollution is a complex dilemma to tackle. There are many toxic materials in the air that can harm a human's body at different places. This paragraph introduces an overview of the toxic materials that occur in the city and to what extent. Moreover, this paragraph shows what kind of impact each toxic material has on the human body.

Types of air pollution in the urban environment

The types of air pollutants in the urban environment are various. Figure 1 shows an overview of the most common pollutants in European cities. As can be seen in the figure, up to a third of Europeans living in a city are exposed to air pollutant levels that exceed the quality standards of the EU or the WHO. In the Netherlands, the life expectation of the population is reduced by one year because of air pollution (RIVM, 2013).

NOx (including both NO and NO2), Ozone and Particulate Matter are the most common pollutant sources in the urban environment (EEA, 2017). Particulate Matter is a category of all kinds of tiny particles, often invisible to the eye. Particulate Matter is formed by cluttered smaller pollutants and they are therefore secondary pollutants (EEA, 2017). NOx pollutants are mainly caused by the combustion of fuels by vehicles and have a molecular structure (EEA, 2017). Ozone is caused by a reaction between NOx and VOCs in the presence of sunlight (EEA, 2017).

Figure 1: The exposure to harmful levels of air pollution by Europeans (Guerreiro, 2013).

The air purification method for this project mainly transforms VOC's, Volatile Organic Compounds, and is sometimes applied to the transformation of NOx. Organic compounds are chemicals that contain carbon and are found in all living things. Volatile Organic Compounds are organic materials with a high vapour pressure by room temperature (EPA, 2018). Harmful VOCs are often caused by ignition, such as the ignition of fuel in cars (EPA, n.b.). However, they also appear due to construction work, such as the vaporisation of VOCs in liquid paint or in building materials (EPA, n.b.). Typically, harmful VOCs are not acutely toxic, but could cause the development of photochemical smog under certain conditions (EPA, 2018). Moreover, VOCs and NOx parts are often cluttered to form Particulate Matter (EEA, 2017).

The effect of air pollution on the human body

The general belief is that air pollution affects your lungs, as you breathe in the polluted air. However, it appears that air pollution is affecting many more organs in the human body than only the lungs. Figure 2 shows an overview of the effect of each individual toxic material on the human body. The most occuring health issue caused by air pollution is premature death. Heart diseases and strokes are the most common reasons for premature death related to air pollution (EEA, 2017). In addition, air pollution increases the development of a wide range other diseases such as cancer or cardiovascular diseases, differing in short-term and long-term health effects (EEA, 2017). Remarkably, seven out of ten people are unaware of the health effects and seriousness of air pollution according to Michael Rutgers, director of het Longfonds (Longfonds, 2018). Air pollution is thus an invisible danger to the majority of the population.

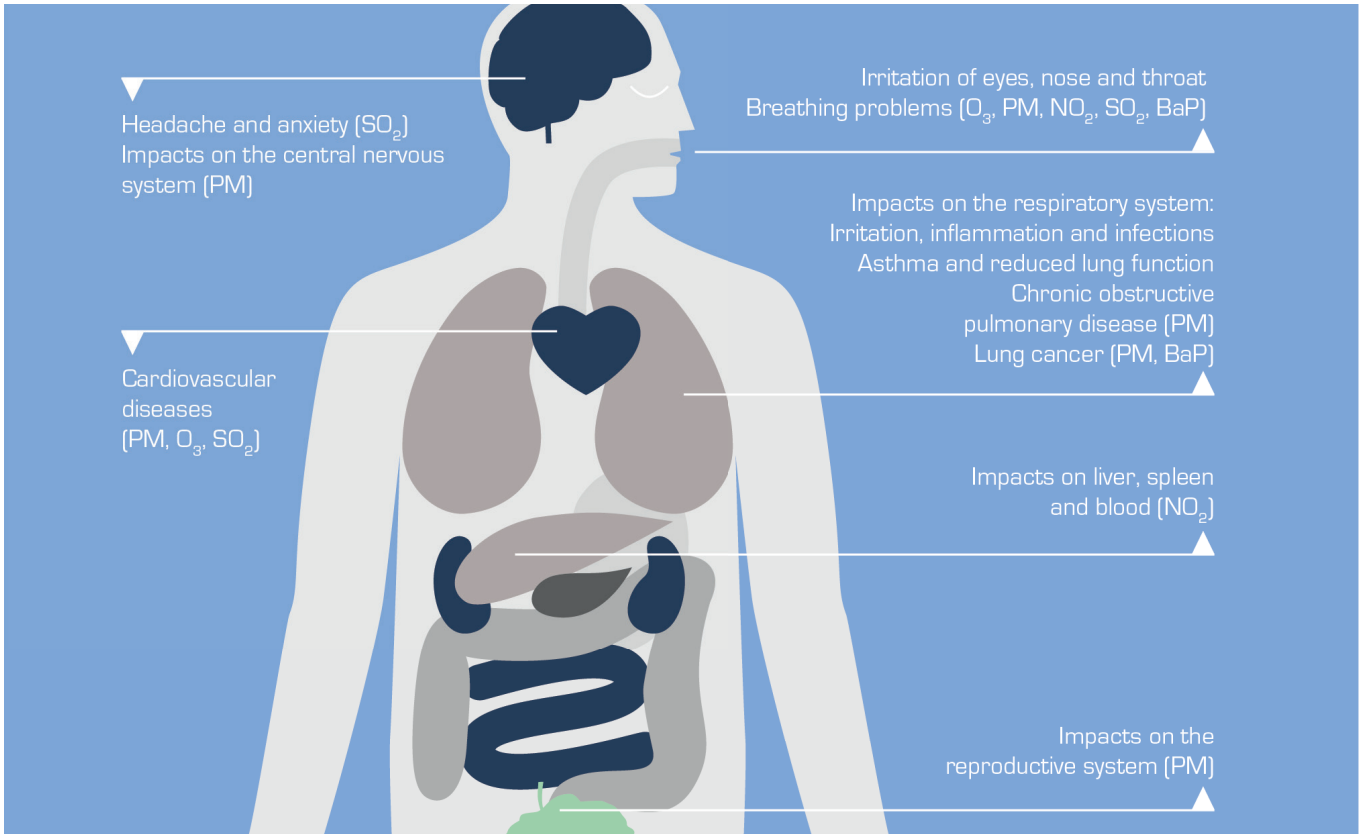


Figure 2: The impact of air pollutants on the human body (Guerreiro, 2013).

AIR POLLUTION WITHIN THE CITY CONTEXT

Research has been conducted by Airlabs (2015) to discover the type of places in the city where citizens are exposed to air pollution most. Airlabs is an organisation based in the United Kingdom which researches and develops air purification systems for the city environment. Airlabs (2015) calls these places air pollution hotspots: specific places in the city on a micro level where air pollution causes the most damage. These air pollution hotspots are determined by three main factors:

1. low ventilation
2. a high density of people or people spending a lot of time at one place
3. a high emission of pollution

Generally, these three factors are combined on city sidewalks. At sidewalks, low ventilation occurs due to high buildings and street canyons; high emission of pollution is caused by masses of traffic such as busses and cars that pass regularly and crowds of people are walking throughout the day. The high amount of pollution in these areas has a radical effect on humans' health as these are places that humans tend to spend their time, e.g. to wait for the bus or to have lunch at an outdoor cafe. These places on the sidewalks are therefore the context for the concept because the high concentrations of air pollution can be damaging the health of a great amount of citizens.


"AIR POLLUTION IS AN INVISIBLE DANGER IN THE CITY
EFFECTING OUR HEALTH MORE THAN CITIZENS IMAGINE"

AIR CATALYSIS

The air purification method for this project is photocatalytic air purification. Photocatalytic air purification is a chemical method that applies the photosynthese principle to undertake a series of reactions with pollutants in the air to mineralize them with the by-products carbon dioxide and water. A photosensitive semiconductor, for example titanium dioxide (TiO2), absorbs ultraviolet (UV) light to form reactive hydroxyl radicals in the presence of oxygen and water vapor (Zhong & Haghighat, 2015). Typically, the Titanium Dioxide serves as a catalyst because it is inexpensive, durable and less toxic than alternatives. The source of the UV light can be an artificial light as well as sunlight.

Air purification by means of photocatalytic oxidation has become increasingly popular during last years, as this method requires less energy than other air purification methods and hence is the more sustainable solution (Zhao & Yang, 2003).

Moreover, the method is inexpensive, safe and stable; it promotes ambient temperature oxidation and requires no chemical additives. Above all, there is no residue after the process. This is in contrast to other air purification methods, such as carbon filters that filter out the harmful chemicals in a solid form (Zhao & Yang, 2003). This paragraph shows the chemical and technical principle of photocatalytic oxidation, to understand the working principle and the challenges.

Chemical principle

As explained in the introduction, photocatalytic air purification uses the photosynthese principle to change harmful molecules into mineralized, nontoxic forms. Typically, photocatalytic air purification is applied to mineralize pollutants of the Volatile Organic Compounds group (Zhao & Yang, 2003). Research is also conducted to apply photocatalytic oxidation for NOx and other pollutants. Note that

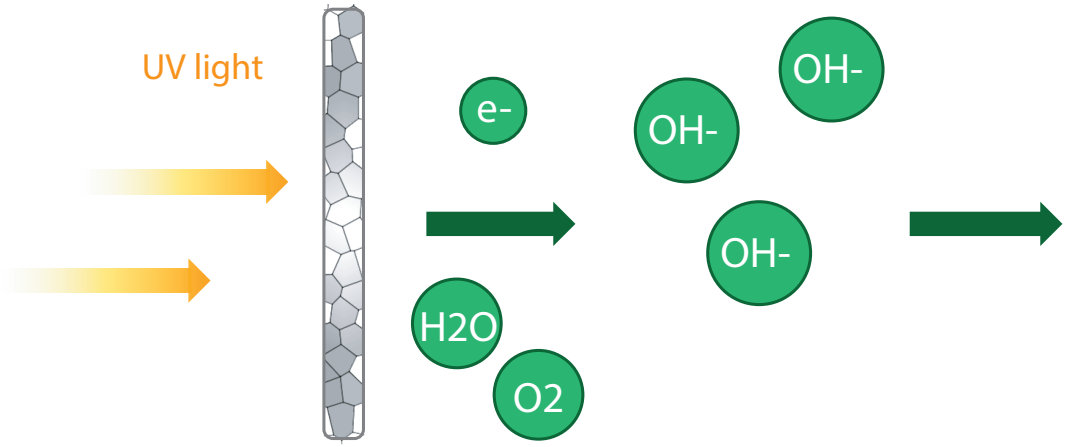


Figure 3: An overview of the chemical process of Photocatalytic oxidation.

VOCs and the other pollutants are molecules; other harmful materials such as particulate matter are cluttered structures of solid materials that cannot be deconstructed in less harmful forms by means of photocatalytic oxidation. However, changing molecular pollutants into harmless products fore comes partially the creation of particulate matter.

The following steps of the process explain what happens during the chemical reaction of the photocatalytic oxidation of VOCs and NOx (Zhao & Yang, 2003; Zhong & Haghighat, 2015). The process is also visualised in figure 3.

1. The process starts with the advection of the pollutants carried by the airflows that enter the catalyst.

2. The airflows touch the surface of the catalyst, the TiO2 layer. Hereby, mass transfer of the pollutants, or reactants, of the airflows take place to the exterior of the surface. The reactants are adsorbed onto the interior of the catalyst surface.

3. An important step is the formation of hole-electron pairs in the catalyst layer, caused by the energy of the photons of the UV light. The activation of TiO2 by UV light, in the presence of oxygen, can be written as follows:

$TiO_2 + hv \rightarrow h+ + e-$

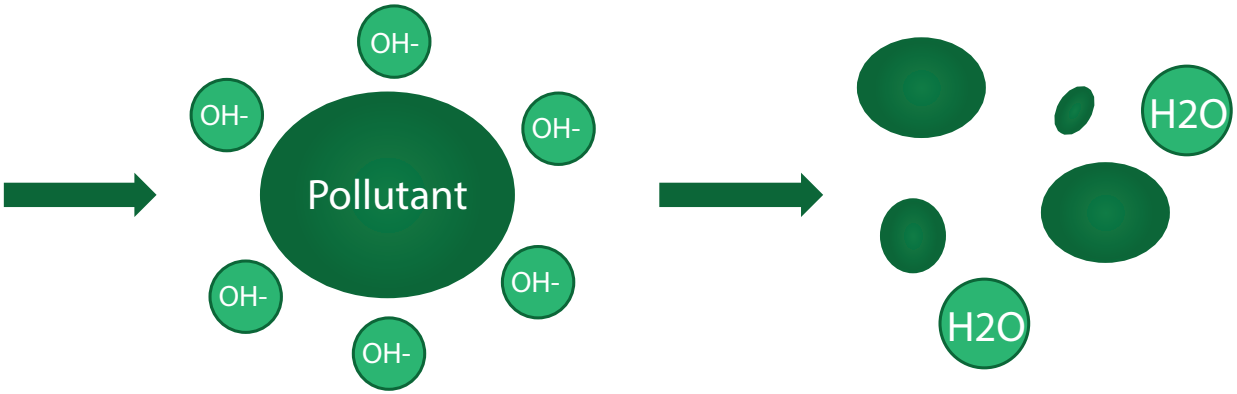
h+ and e- are hereby oxidizing and reductive agents. The oxidative and reductive reactions, in presence of water vapor, are as follows:

$OH- + h+ \rightarrow OH$; $O_2 + e- \rightarrow O_2-$

4. Now the photochemical reaction takes place between the reactants, the OH- molecules and oxygen. The pollutants are hereby deconstructed.

$OH- + pollutant + O_2 \rightarrow products\ (CO_2, H_2O, etcetera)$

5. The reaction products are desorbed from the catalyst surface and return to the main airflows.



Technical principle

The technical principle mainly involves the interior design of the catalyst. There are several technical challenges and certain structures needed for the catalyst in order to get the desired chemical reaction. The first challenge is that only the air that is in contact with the Titanium Dioxide layer will be cleaned, this means that the air should go through the air catalyst with an efficient air flow. Typically, an air catalyst has a tube structure to twist the air flow in such a way to maximize the contact with the Titanium Dioxide catalyst. Second, the UV light should contain enough energy to release the electrons in the layer. The strength of the light source is thus crucial for the working principle. First, this means that sunlight cannot always be used for the chemical reaction, as the light intensity can be too low on certain days. Second, the light needs to be perpendicular on the catalyst surface to maximize the chances of energy transmission between the photons of the UV light and the catalyst surface. There are three common structures for the catalysts, each illustrated in figure 4.

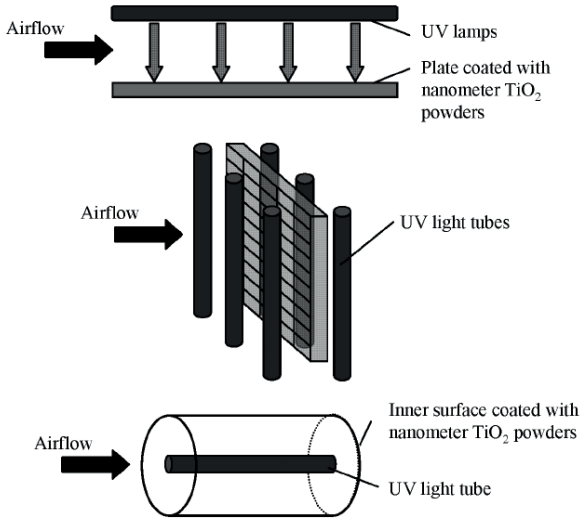


Figure 4: Three typical photocatalytic oxidation structures for a catalyst (Yang et al., 2004).

A typical setup for the air purification by means of sunlight is shown in figure 5. The setup exists of several glass plates covered on both sides with a TiO2 sol gel. The plates are ordered vertically with a small distance in between. The air flow is parallel to the catalyst plates. The irradiation of the sunlight is perpendicular to the surface and is let through a glass window. The whole is based within a tube construction to optimize the airflow within. Note that the setup is used as an experiment and is small as compared to normal catalysts: 20 x 20 x 20 centimeters. It is assumed that the size of this type of catalyst can be scaled.

The setup is frequently used for the purification of water in larger catalysts, as can be seen in the figure at the right.

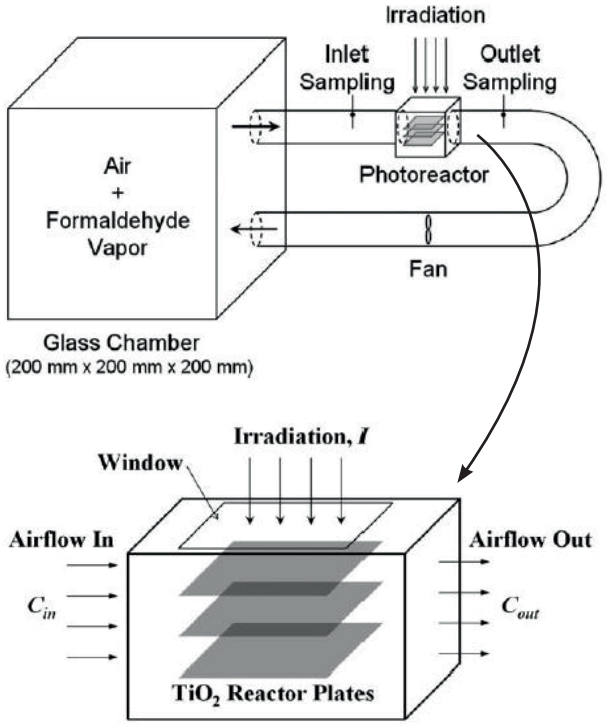


Figure 5: A typical catalyst for solar photocatalytic oxidation (Leung et al., 2006).

DESIGN GOAL

As described in the introduction, there are almost no actions that citizens can take themselves in order to clean the air other than to strive for a more sustainable lifestyle. Citizens can contribute to projects to measure the air pollution in their environment, yet this is a rather passive and limiting approach. Often, the initiative for these kinds of projects should come from the citizen, whereas most citizens are even not aware of the health impact. Ironically, the victims of air pollution are the citizens themselves.
The goal of this project is to develop a concept that involves citizens by providing co-performance with the air cleaning system. Involving citizens indirectly raises more awareness among them about the risk of air pollution and empowers citizens by providing an active solution.
It is important that the air purification activity is seen as a side activity for citizens. As citizens have their own agenda, it means that air purification should fit in this agenda in order to create the opportunity for citizens to be involved.

So the project has the following three unique selling points to differ from other air purification initiatives in cities:

1. Involvement of citizens in an active solution

2. Raise collective awareness among citizens

3. Fitting the everyday life in the city

SCOPE

For the scope of the project, the context for the air purification system is specified in more detail and a design case is chosen to focus on a single type of everyday object in the city.

Figure 6: A representation of a streetview.

Context - future streetview

The context is defined by the most polluted areas in the city, namely the sidewalks of the street where pedestrians and cyclists go by or spend their time.

A representation of a streetview is created to work with throughout the project, see figure 6.

4.2 Design case - delivery system

The design case for the Things of this project is a delivery system comprised of self-driving delivery carts. A self-driving delivery system is chosen as a channel, because it has a dynamic function, It enables the Things to move around and to tackle the air pollution problem as a dynamic team within the city. Moreover, the delivery carts already have a purpose to drive around. Adding an air catalyst to a delivery system makes sense, instead of making a special driving vehicle for it.
In addition, the system guarantees the health of citizens regarding air pollution as citizens are not physically involved in the case of a delivery system. As the air catalysts will be placed mainly around polluted areas, it would be convenient if there are no citizens around.
Within the delivery team, the Things act together as a swarm; they collaborate with each other based upon a shared ruleset. The air catalyst can be activated during driving or when the Things stand still. It is assumed that the Things often need to stand still to clean the air, as the process of photocatalytic oxidation needs time.

For this project, the Things are property of the government and they can be rented by a delivery company such as Amazon. The delivery will be from central storage points in the city to citizens around. A citizen can choose a greener delivery option during purchase online: that the Thing can choose an alternative, longer, route to clean more air in polluted areas. The citizen will only have to compromise on delivery time, which is an attractive option because of the limited sacrifice.

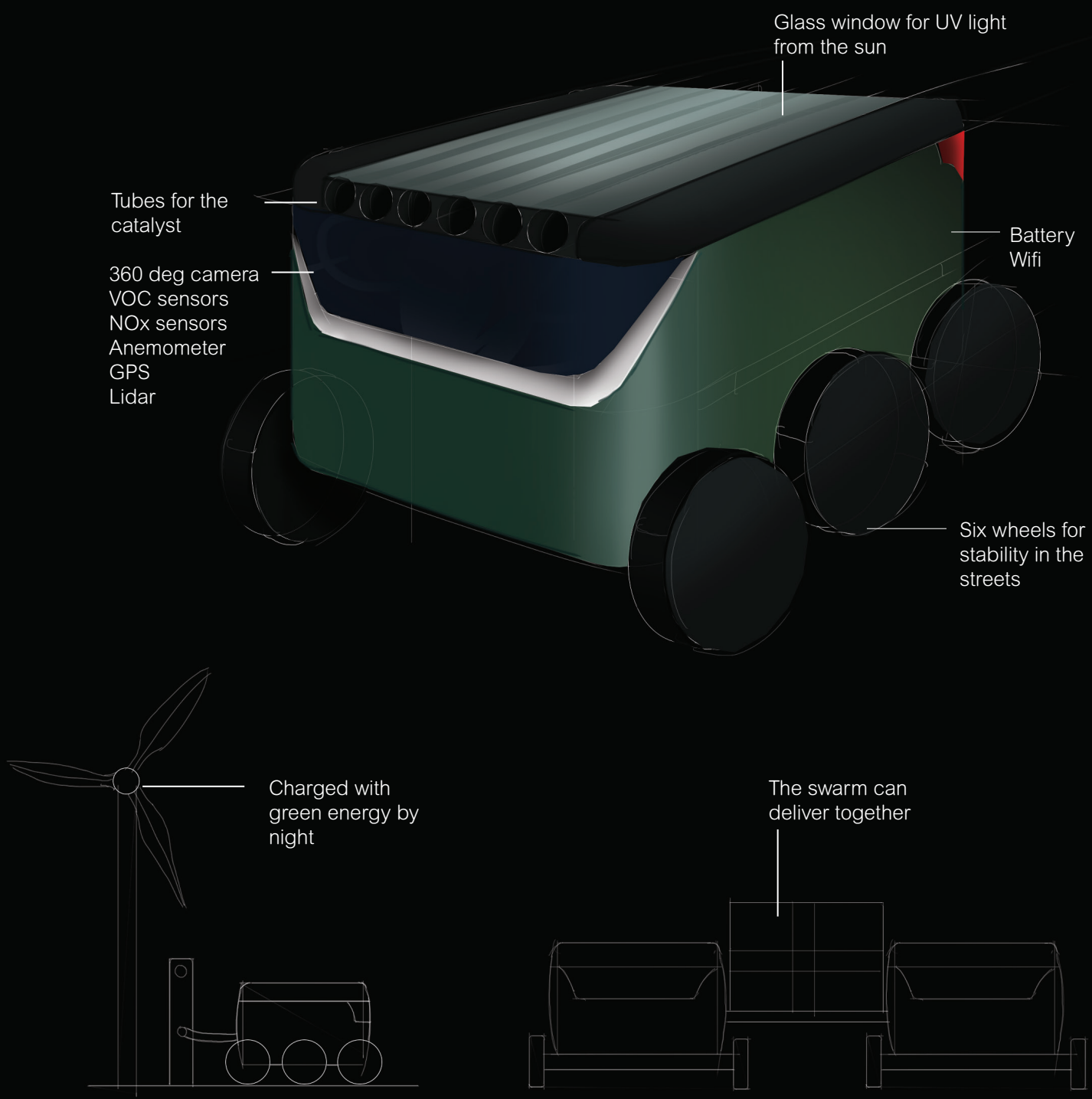
The Things are designed up till concept level. The design of the Things is based upon the bots of an existing delivery system named Starship. The design of the catalyst is based upon an existing setup for sunlight photocatalytic air purification that has proved to have satisfactory air purification efficiency (see chapter 1).

The Thing has six wheels, which makes difficult movements such as stepping on and off pavements easier. The wheels are placed some distance beside each side of the Thing to create more stability. It has a 360 degree camera, lidar and GPS track to navigate and move around, being able to identify the environment and to learn from traffic situations. The package will most of the times placed within the Thing and the Thing can be opened by the citizen that receives the package after the lit is being unlocked.

To enhance the swarm experience, the Things can be stacked to deliver bigger packages together. Notice that the combined team of Things have an increased capability of air purification. The Things are simply attached by sliding in a platform in the side of each Thing. No package will be placed on top of the Thing as it will block the sunlight for the air catalyst.

The catalyst is built on top of the Thing. The catalyst exists of a parallel set of tubes made of glass. The beginning and end of each tube has a fan to optimise the airflow within. Within each tube, a stack of glass plates coated with TiO2 sol gels is vertically placed in order. The whole is covered with a glass plate to keep the catalyst clean. Sunlight will come from above and will be filtered through the glass tube and plates within. On days with bright sunlight, the UV waves will be high enough in energy to create the desired reaction within the catalyst. On days with no sun, the UV light on the bottom of the catalyst within the lit will be activated to maintain the air purification. Even though, no literature is found about a driving vehicle with an integrated sunlight air catalyst, it is assumed for this concept that the principle will work, as in theory it will.

Figure 7: A visualisation of the concept as presented in this paragraph.


Glass window for UV light from the sun
Tubes for the catalyst
360 deg camera
VOC sensors
NOx sensors
Anemometer
GPS
Lidar
Battery
Wifi
Six wheels for stability in the streets
Charged with green energy by night
The swarm can deliver together

DESIGN VISION

This paragraph presents the design vision, which is the design qualities model of report 1. This model is based on the notion of Things as Citizens and introduces design qualities for co-performance between citizens and Things in the urban environment. A depiction of the design qualities model can be seen in figure 8.
The design qualities model proposes a democratic dialogue between Things and citizens for co-performance in urban environment. In other words: as partners that understand and act according to urban culture.
The model is divided into two main circles that each represents the requirements of citizens and the capabilities of Things in order to create a democratic dialogue. Both requirements and capabilities are divided in four main themes based on four democratic values. The requirements and capabilities are summarised as follows.

Citizen requirements

1. Ability to understand decisions made by Things
Citizens should be able to understand decisions made by Things. An understanding should happen through the Thing behavior and capabilities. The Thing could for example show its sensitivities based on a sentience related behavior of a human.

2. Provision of space for negotiability
Citizens can question a Things' decisions and negotiate with Things to change their decisions or behavior. A human supervisory team should be present as a mediator in the background, in order to create harmony in the dialogue between citizens and Things.

3. Involvement in the background because of profound trust
Citizens require a Thing to work in the background, as citizens have an 'on the go' experience. It means that they need to trust that the Things are capable to perform or exist in the city by themselves and that Things have no wrong intentions.

4. Engagement in collaboration based on intrinsic motivation
Citizens should be engaged to co-perform with Things based on citizens' own intrinsic motivation. As citizens already have a goal in the city, they will only be interested in the co-performance with Things when it is valuable to them and their limited time.

Thing capabilities

1a. Able to promote its sensitivities
Things are able to share their unique sensitivities, e.g. sensor readings, to citizens if citizens show an interest in it.

1b. Able to show the lack of ethical sensitivites
Things are designed in a way that they avoid situations where decisions based on consciousness and morality are necessary. It is important that the design of the Thing and its behavior do not resemble human qualities as this could cause higher expectations than possible in certain situations or co-performance in general.

2. Able to react in multiple ways and to be partially directable in its actions
Things can react in multiple ways towards citizens. They open up space for negotiation as they are partially directable in their actions. However, not every Thing decision can be altered by citizens, as they are equal partners to each other.

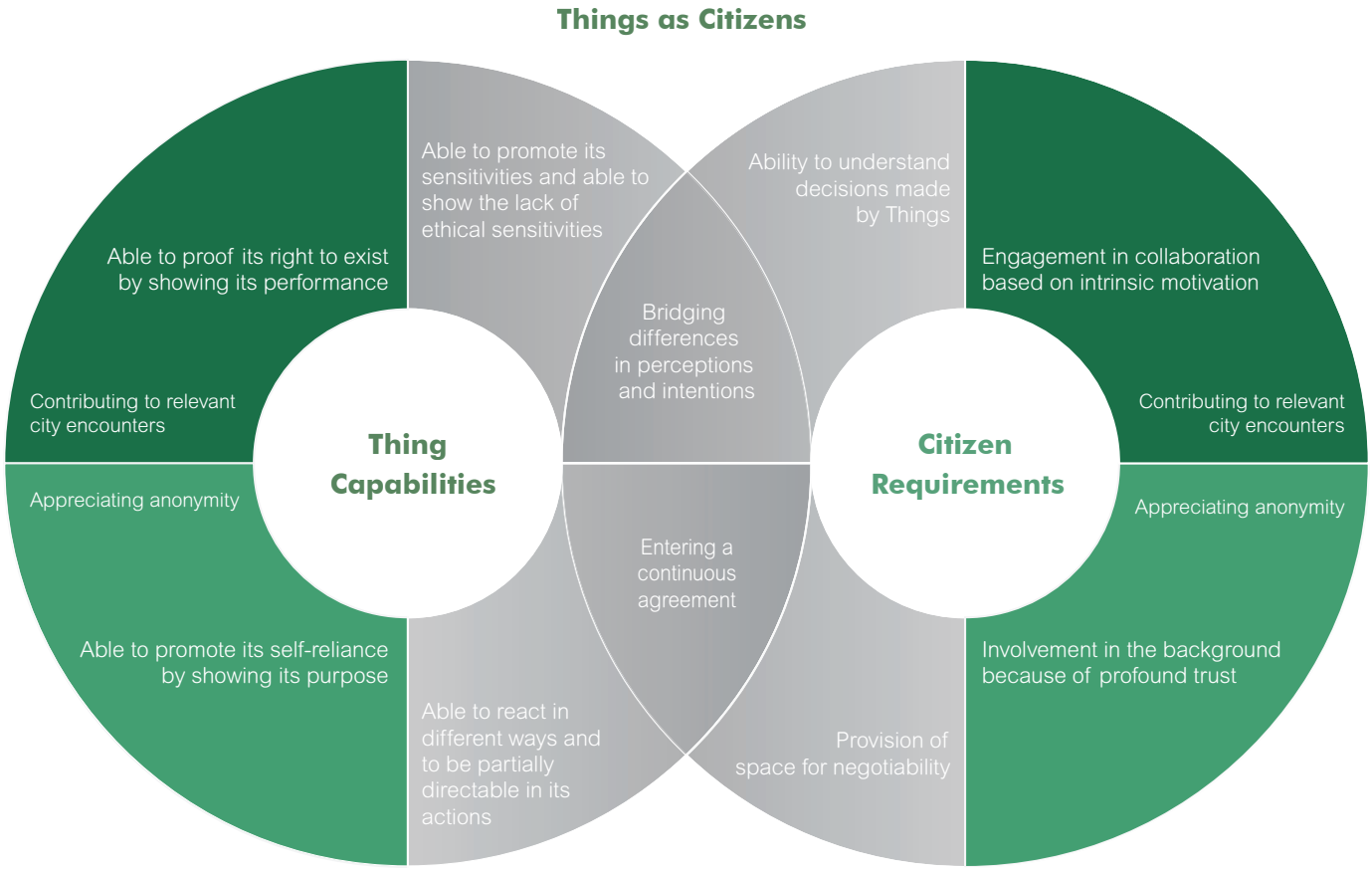


Figure 8: The design qualities model.

3. Able to promote its self-reliance by showing its purpose

Citizens are strangers to each other. It is important that Things behave as strangers towards citizens as well. Things should prove their self-reliance, through predictable behavioral patterns or by clearly showing their intentions, in order to be accepted as strangers.

4. Able to proof its right to exist by showing its performance

Things are capable to prove that they have a reason to exist and be part of urban culture in the city as they prove their contribution. Things are able to show their contribution by means of design cues that show the, valuable, performance related to the purpose of the Thing.

02 CONTEXT

As described before, the target group of this design project are citizens that are directly exposed to high concentrations of air pollution in the city. These are pedestrians and cyclists that spend their time near the roads. In order to see how co-performance can be created, the context of citizens and their activities in the street is analysed. This is called the city dynamics, as it is a dynamical environment that changes over time. A sketch is created of the street environment at a specific time based on what activities citizens do while being outside.

CITY DYNAMICS

Previous research has shown that citizens often have a functional attitude and purpose while being located in an urban environment, see report 1, section 4.2. They often are in the city to travel from A to B; so the city life is a more or less an 'on the go' experience. As citizens have other purposes in mind that are situated in a context other than the public environment itself, the majority of activities in the urban environment are often small and rather functional in order to get to the destination of their actual purpose, e.g. walking in the park, doing groceries, going to work, visiting relatives, etcetera. Small activities are based on the travel itself or on activities that need to be done before arrival, such as getting cash from the cash machine, finding a place to stall the bike or to park the car or throwing waste into a bin.

Walking and cycling

According to research of the Gemeente Amsterdam (2016) about the active life and movement behavior of citizens, most citizens take the bike or go walking when they need to go somewhere. Especially in parts of the city where it is crowded and where there are a lot of houses, work facilities and resources such as supermarkets, other shops, schools, work facilities, etcetera. Hereby 39% of the walking activities of Amsterdammers are for groceries and 21% of the bike rides are to travel to or from work.
A feeling of safety plays a big role in the decision for citizens to walk or cycle. Safety is created by a clear overview of the environment, good lightning facilities, etcetera. Moreover, the maintenance of the public space is also important, such as the quality of the roads and the cleanliness of the space. The safety of transport plays also a big role in the decision to take the bike. As speaks for itself, the harder it is for citizens to park the car nearby, the less citizens will own a car or take the car for smaller activities.

Daily life in the city street

Based upon the activities of people and the amount of time spend at certain locations such as at home, at work or during resource and leisure activities, a graph is created to show the crowdedness within a city of time throughout the day, see figure 9. One moment during the day is chosen to work out more specific into a street overview of the city dynamics. This streetview is presented on the following two pages.

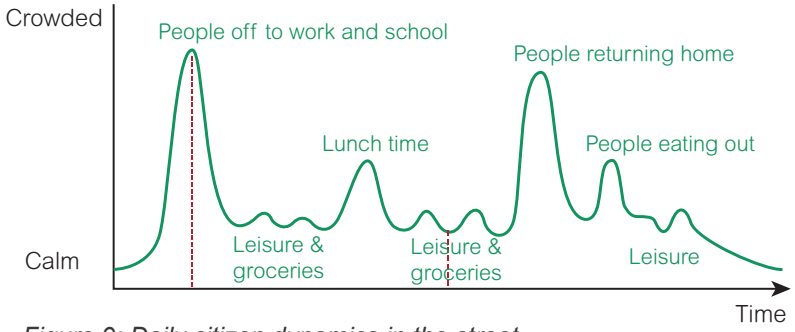


Figure 9: Daily citizen dynamics in the street.

8 AM STREET VIEW

In the morning, most activities are work related or are related to the schools and kindergartens. Another activity in the early morning might be for example to let the dog out, but these activities are limited or temporarily. Citizens go to their work or to the schools by car, public transport, bike or walking. They are familiar with the surroundings and could be rushed as they plan their travel strictly on time; why would you be too early? Some of them will be lost in thoughts or already planning ahead the following activities. Some will come from another neighborhood and will start their working day in the street, others will leave to another neighborhood for the same reason. The environment may not feel safe to everyone in the street, such as parents with children, and could be overwhelming or chaotic by the many travellers around. It is one of the busiest times of the day.

Mental attitudes

Safe	Unsafe
Relaxed	Rushed
Clear	Overwhelming
Routinized	Open and exploring

People are in a hurry

People go to work
walking, by car, biking


Crowds gather for public transport
Pets are taken out
People are routinized
Kids are brought to school

03

SYSTEM

This chapter describes the system of the concept. The chapter starts with the main goals of the system, which are created based on the design qualities and a survey among citizens in the Netherlands. Following is a description of the system hierarchy, the data analysis on different scales, the behavior of the Things and the behavior of the Things as a team. A wireframe of the concept is presented as a final result, which also shows the rule-based properties.

MAIN GOALS OF THE SYSTEM

Citizens' interests in air pollution and air purification

A questionnaire is send towards a random selection of citizens in the Netherlands, to investigate their opinions and specific interests regarding air pollution. This research is conducted to see how the system could be of most interest to citizens; to optimize the co-performance and to increase the value of the system. The results of the questionnaire can be found in Appendix 10.1. One of the main interests of the respondents was to know how air pollution affects their health. It means that citizens are mostly focussed on health rather than the air pollution itself. Information about the types of air pollution was for example not valuable to the respondents. It means that the focus of the system should be on health. In other words: it should proactively ensure the health of citizens regarding air pollution.

Remarkably, 80% of the respondents showed an interest in being actively involved. It means that the co-performance could involve an active dialogue between Things and citizens. Therefore, the Things in the system will act as a shelter nearby citizens to protect citizens from inhaling the polluted air. Two other main interests of citizens were to discover the cause of air pollution and to know how air pollution can be reduced. Even though it is not in the scope of the project, as the focus is rather on the use of catalysts, it is valuable to highlight this interest. Naturally, a system that promotes these functions could have an increased value for citizens. Citizens also showed an interest in knowing how effective the system is and how it works. These functions should be implemented as well as it fits with one of the design qualities to show its performance.

An overview of the main goals

The essence of the system is based upon the focus on health, which was already defined in previous paragraph based upon the results of the questionnaire. Additionally, four main goals are generated for the system. Hereby, co-performance is chosen as a basis. Logically, the first main goal of the system is to detect air pollution. Regarding co-performance, it becomes interesting if citizens are able to report air pollution as well. By this means, Things as well as citizens can detect air pollution together. It gives citizens the freedom to agree or disagree with the system. The second goal is based upon the essence and a relative simple solution to prevent citizens to inhale polluted air: to warn citizens in advance of air pollution zones in the city whereby citizens can avoid these zones in their turn. The third goal is the unique function of the Things because of the integrated catalysts: protecting citizens by purifying the air near citizens. Simultaneously, citizens can use the Things as shelters. The last goal is not included in this concept, but added as a main goal because it is a function that would promote the proactive behavior of the system and is expected to increase the interest of the citizens. See figure 10 for an overview of the main goals.

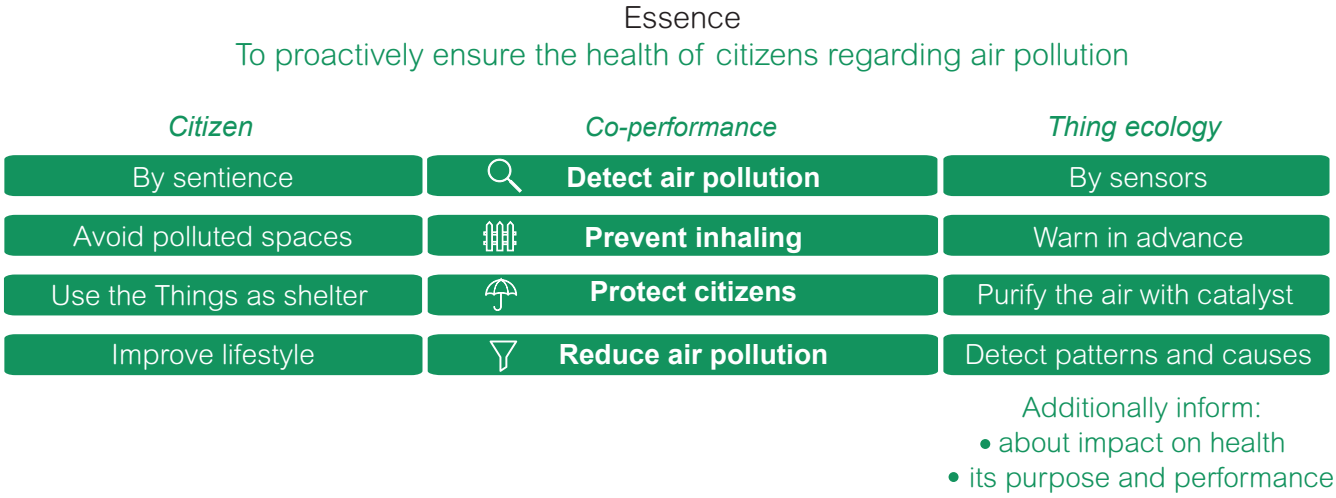


Figure 10: Main goals of the system.

SYSTEM HIERARCHY

In order for the system to work on a big scale in the city with individual Things moving around, it becomes necessary to create a system hierarchy. On top of the hierarchy is a supervisory team of humans. This team serves as a mediator between the Things in the system and the citizens in order to create an equal dialogue. The main system controls the Things and is supervised at all times by the supervisory team to evaluate its performance. The system can be intervened at all times by the supervisory team to forecome errors caused by the lack of consciousness of the system; e.g. if Things start to clean in the wrong environment or if the system does not react anymore. Underneath the main system are teams of Things, they will be assigned to a location to go to. The assignments are regulated by the main system which keeps an overview of the teams. Team forming is variable, so the amount of teams and the content of the teams differs over time. Figure 11 presents the hierarchy.

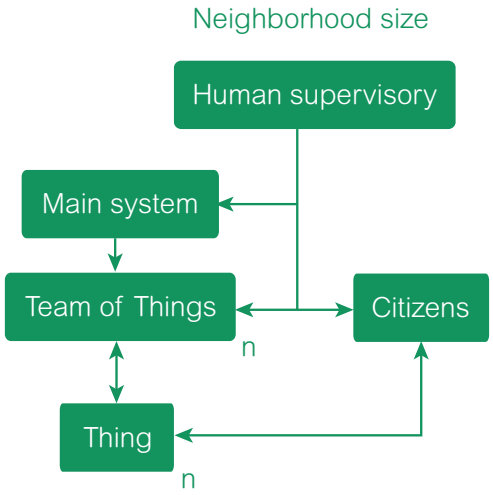


Figure 11: The system hierarchy.

DATA RELEVANCE ON DIFFERENT SCALES

The air purification system will have different tasks on different scales in the city. The three different scales (main system, teams and Things) are presented in figure 12 to show what data is relevant in order to perform the main goals as described in previous section.

Main system

The system of the neighborhood focuses mainly on detecting the amount of air purification and the location of crowds of citizens within certain zones (parts of streets). Moreover, the main system has an overview of the locations of the active and inactive cleaning Things. Beside the sensors on the Things, additional sensors are placed around the city to detect air pollution in zones where there is no presence of the Things. Based on the amount of air pollution and the position of the crowds of citizens, the system can make a division of teams. Ideally, teams should be send to zones with a high amount of air pollution and a large presence of citizens.

Team of Things

For teams, communication is the most important factor for data. Teams should have a shared database to compare their own measurements of air pollution in order to detect the air pollution concentrations in the street more specifically. Additionally they need to include individual measurements on the wind direction in the database. Moreover, they need to know each other's exact locations in order to divide themselves across a zone. A more precise location of the citizens is needed in order for the Things to strategically decide where to stand.

Individual Thing

The individual Thing acts as a data collector for the main system and for the database of a team. The Things collect data about the air pollution and wind using their sensors. The location of citizens is detected via their camera vision.

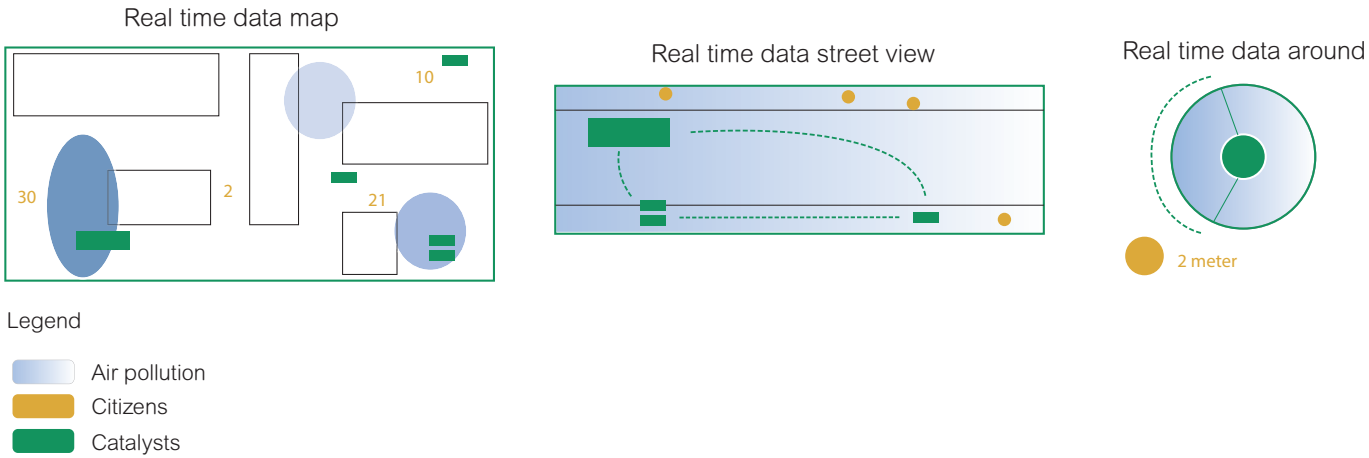


Figure 12: An overview of the relevant data per scale. In order: the main system, team and individual Thing.

PROACTIVE BEHAVIOR

An algorithm within the main system can ensure proactive behavior of the system. By searching for patterns in the city dynamics and the condition of the air pollution, the system is able to anticipate on the situations in advance (figure 13). This way the system can position a certain percentage of the teams to clean in advance.

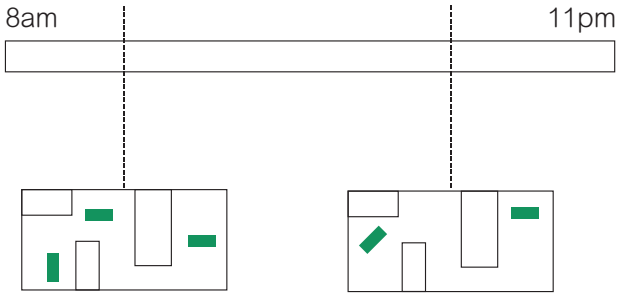


Figure 13: An example of the learn capabilities of the system. The system can look for patterns in air pollution locations and citizen dynamics.

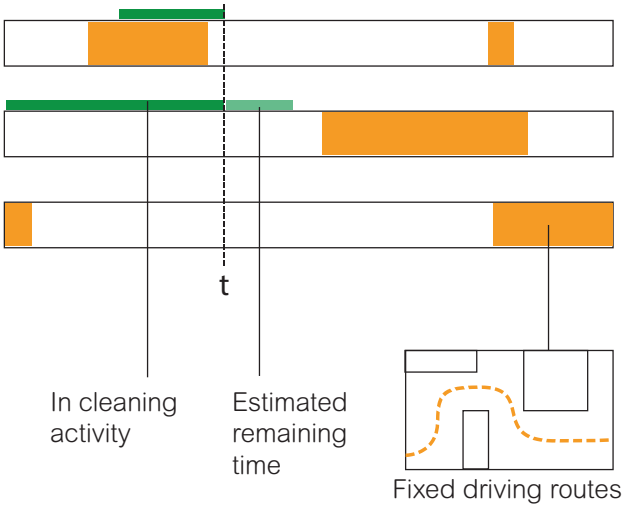


Figure 14: An example of the agendas of three different Things.

TEAM FORMING

Teams are formed by the main system based on the current locations and the availability of the Things. As can be assumed, each Thing will receive tasks for delivery at certain times from the delivery system. So each Thing has an own unique agenda for delivery times and for fixed driving routes, as illustrated in figure 14. The Thing can purify the air on free routes when it has no task from the delivery system and can clean during fixed driving routes when there is polluted air on these routes. Each Thing also has an agenda for air purification, so they can be busy in a cleaning task or available. It means that the amount of available Things depends on the individual agendas, which creates a complex mathematical construction.

SYSTEMATIC BEHAVIOR OF TEAMS

As the individual Things move around and act in teams, they behave and act as a swarm. A swarm is a large amount of robots that act and decide together in a group and collaboratively work towards shared goals. Swarms come in many forms and sizes. For this project, the Things in the swarm can reason and act independently from each other. They are conscious of the Things that they team up with or are in direct sight. The factors described in this paragraph are a range of tasks that define the swarm behavior (Kolling et al.,2016). These factors give an idea of how each team of Things behaves collaboratively.

The first step of collective behavior: the communication about location

Before teams can even perform together, they need to be aware of each other. Teams will know their designated location by means of a shared database of the city and its maps, GPS and lidar control. Hereby, a Thing can communicate to the system or a team database what its exact location is. As Things work in teams, the Things will only know the GPS locations of Things that they are teamed up with. They will thus only be aware of the Things that they are teamed up with or the Things that are in direct sight.

Area coverage: a certain movement behavior to efficiently clean as a team

Area coverage describes how a swarm disperses across the environment. As a team of Things knows each others' locations, they can make an estimation when the team will be ready and complete to perform a task in a certain street. The Things will disperse across the street based upon the most polluted spots, the traffic dynamics (moving objects), static objects and the amount of walking or cycling citizens. This coverage is complex; Things can easily make mistakes, even though they have intelligent capabilities. For example, a Thing should not block a whole crowd of walking citizens on a pavement if it can be avoided or stand still in the middle of the street as it could cause accidents. Based upon air pollution data in their collective database they will need to estimate the amount of Things needed to clean in certain spots in the street, in order to disperse as optimal as possible. After this analysis, they will choose their locations based upon real time tracking of the city dynamics in order to prevent being an obstacle for citizens. Teams can memorize for each situation which locations at which time are acceptable in order to optimize the choice of locations. As teams split up after they reached their shared task, they can update optimal location choices to the main system in order to create a collective database about the acceptable locations.

Forming a cohesive group by aligning individual movement

Flocking and formation control ensures appropriate separation (to avoid collisions), alignment (of their velocity) and cohesion (to ensure they are centered amongst the other Things). Cohesion includes a predescribed behavior to create movement patterns between the individuals in order to form a large pattern. It is important that the teams form a cohesive pattern, as it has been proven that humans need to be able to visualise the swarm state and the swarm dynamics in order to be able to understand it (Kolling et al., 2016). When working in teams, Things should thus have a pattern to approach citizens or to move in the streets if they are near other Things. This behavior will create a predictable dynamics for citizens, forecomes scared citizens by means of 'unsudden' movements and thus increases the chances of trust by citizens.

WIREFRAME OF THE SYSTEM

Figure 15 shows the wireframe of the system. The wireframe is based on the functioning of the main system, the teams of Things and the individual Thing as previously described. Four points in the system are selected that can be influenced by citizens in order to create co-performance. These points are marked in orange. This way Things and citizens can agree or disagree with each other and negotiate about decisions.

Additional explanation of the figure:
*An optimal division means that the Things are placed in zones with high air pollution concentration and/or a large amount of citizens.
**The most effective situation depends on the agendas of individual Things and the locations of available Things at that time, the most optimal division and the city dynamics at the moment of decision or what is forecasted.
***The goal is continuously renewed and depends on the goal alignment with the team and the orders of the main system. Moreover, it depends on the real time data of the individual Thing and the collective database of the team.

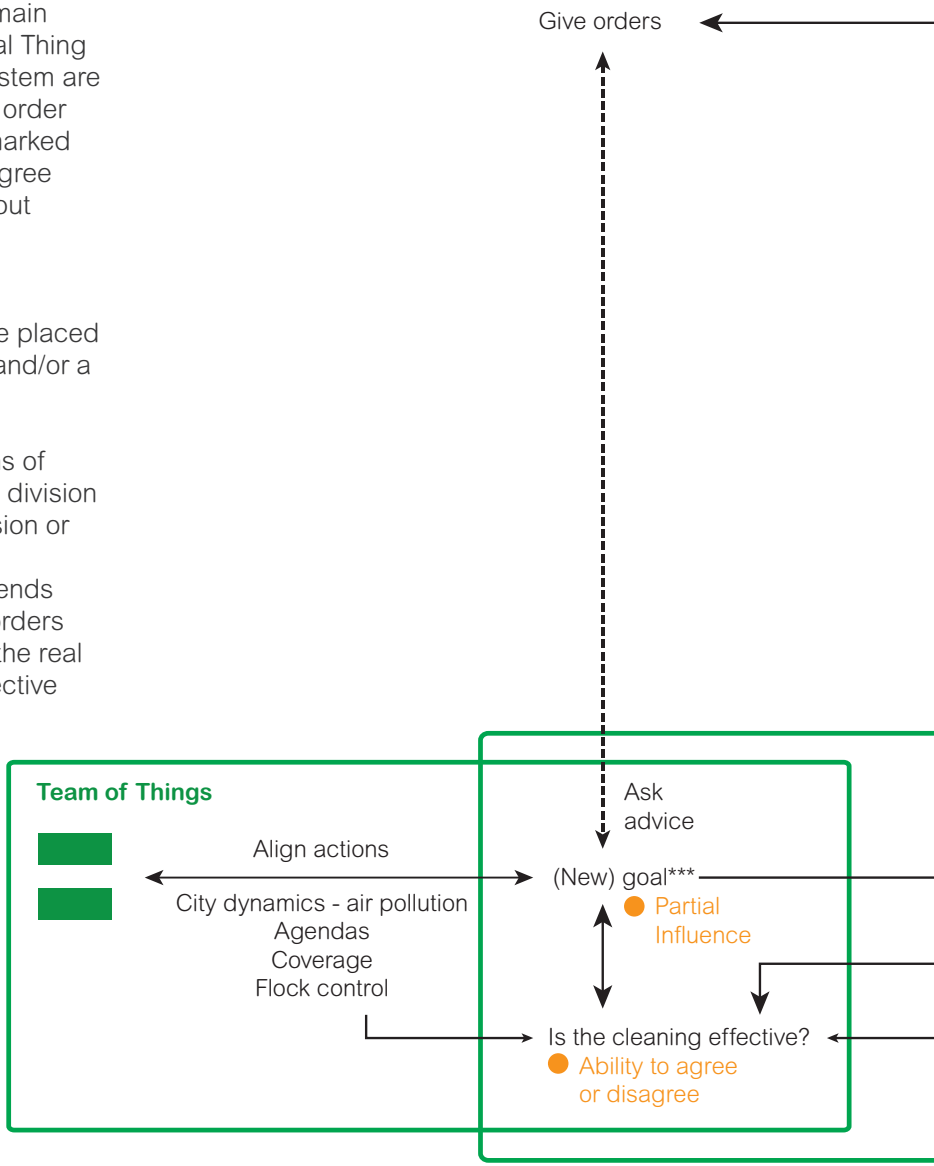
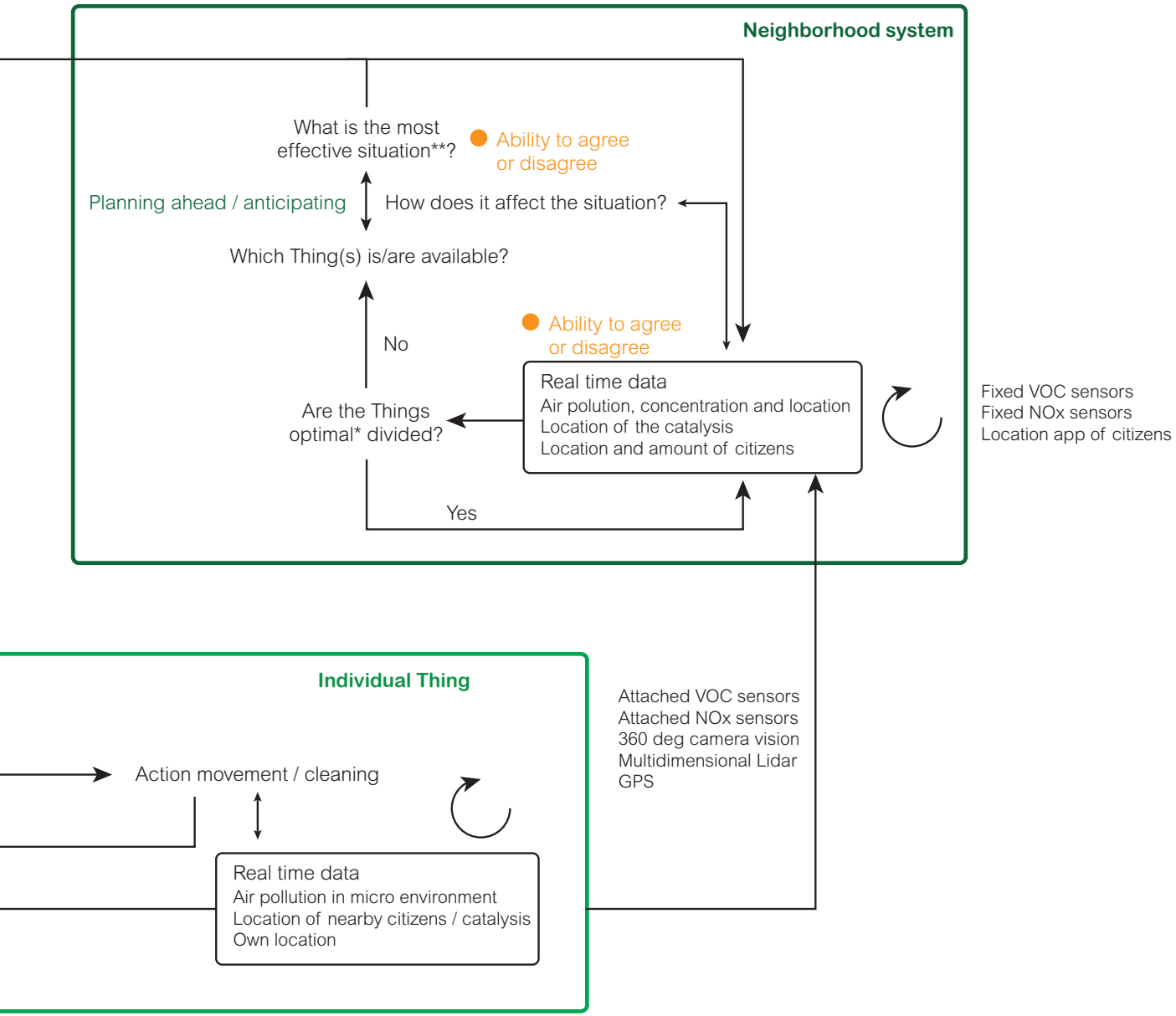


Figure 15: The wireframe of the system.


Neighborhood system
What is the most effective situation**?
Ability to agree or disagree
Planning ahead / anticipating
How does it affect the situation?
Which Thing(s) is/are available?
No
Ability to agree or disagree
Real time data
Air polution, concentration and location
Location of the catalysis
Location and amount of citizens
Are the Things optimal* divided?
Yes
Fixed VOC sensors
Fixed NOx sensors
Location app of citizens
Individual Thing
Action movement / cleaning
Real time data
Air pollution in micro environment
Location of nearby citizens / catalysis
Own location
Attached VOC sensors
Attached NOx sensors
360 deg camera vision
Multidimensional Lidar
GPS

Three storyboards are created to show how the city dynamics and the system could come together in the city. These storyboards are based upon three different scenarios with three citizens with each a different goal. A model about appropriate behavior is created in order to create a realistic scenario whereby the system would be responsive to specific situations. This model is used to create three different situations for the citizens. The scenarios are based upon the three relevant main goals of the system. Each storyboard is then analysed by means of an interaction scheme that maps the states and actions of the citizen and the system. The storyboard as well as the interaction scheme are created from both a human and Thing perspective. By means of this model, micro interactions are identified between the citizen and the Things.

04 STORYBOARDS

A MODEL FOR APPROPRIATE BEHAVIOR

As described in report 1, chapter 1, the performance of practices is done by people according to a certain appropriate behavior. This appropriate behavior is situation dependent and changes over time. Imagine a citizen with a goal, e.g. on his way to work, in a certain situation. Several factors, such as the weather and his wellbeing determine how other citizens or Things can interact with him or how they should perform a practice with him. An overview of relevant factors for the city context is visualised in figure 16. These factors are based upon the context factors as described in report 1, chapter 2.2 and based on the city dynamics, as described in chapter 2 of this report.

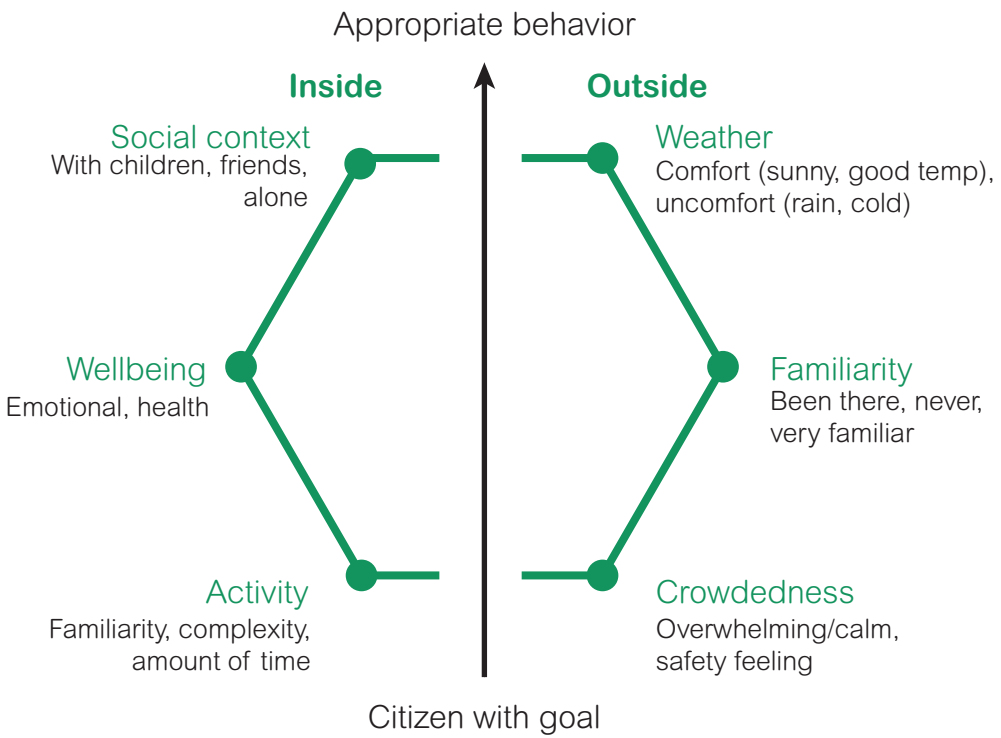
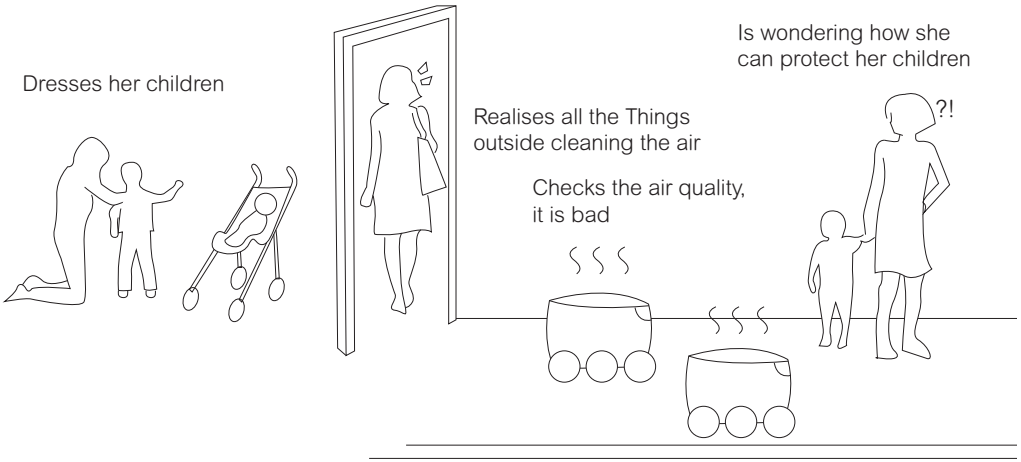


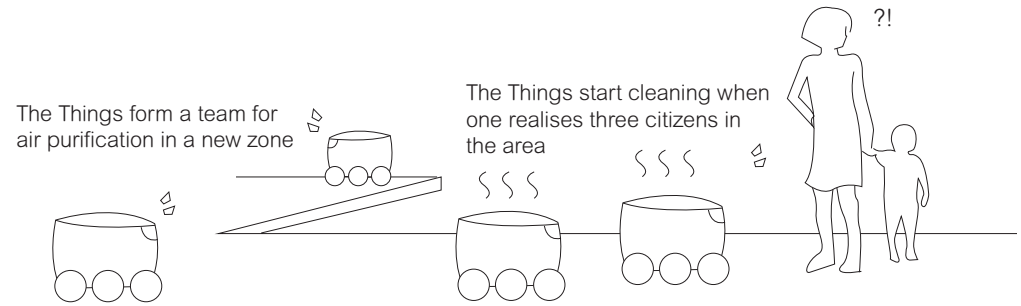
Figure 16: The situation of a citizen defined by multiple context factors. Appropirate behavior in urban culture depends on the situation shaped by the context factors.

Human perspective

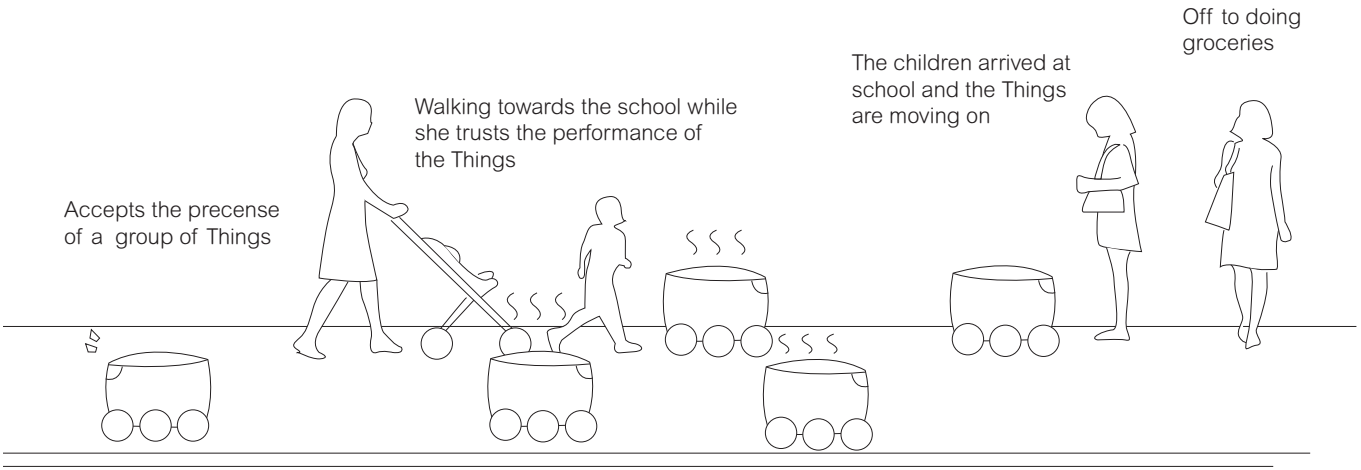


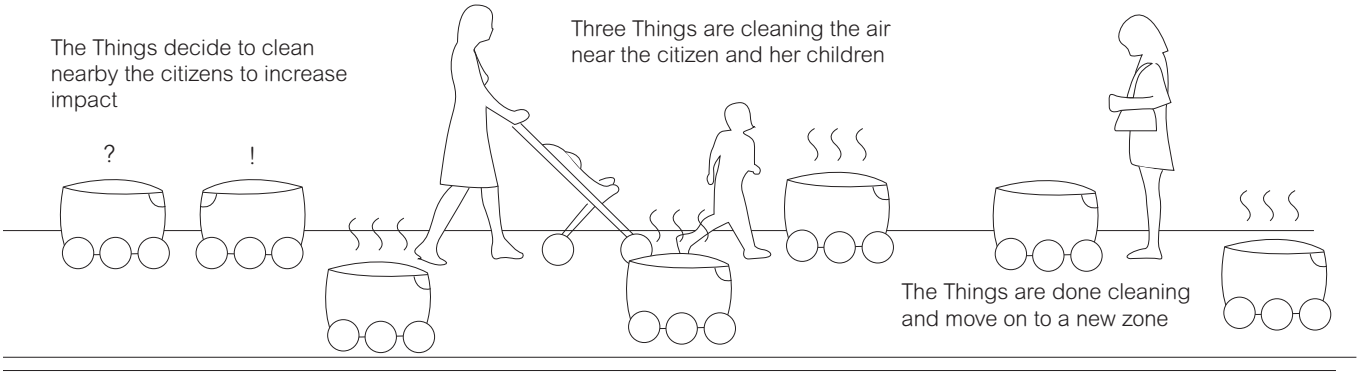
STORYBOARD 1

A mother needs to bring her children to school and kindergarten in the morning. She has a day off at work, so she has no hurry during activities and feels rested and calm. During the walk towards the school and kindergarten, the mother needs to pay attention to the children to make sure that they are safe and do not run away. In order to do so, she leaves in time every morning. She is very familiar with the environment of the street in the morning and knows the regular citizens on the way. However, it is crowded in the morning street, which makes it a little bit difficult sometimes to guarantee the safety of her children.

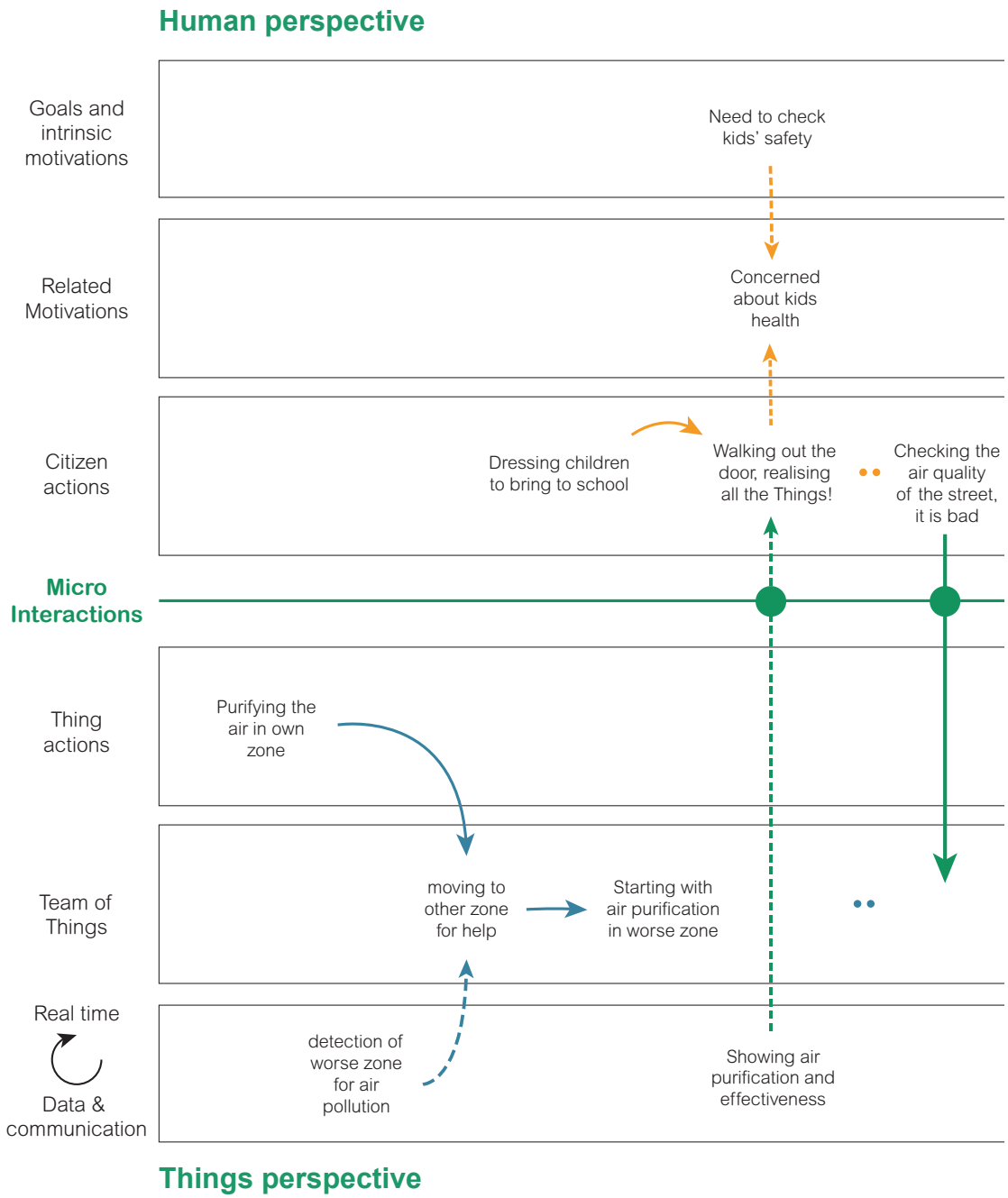


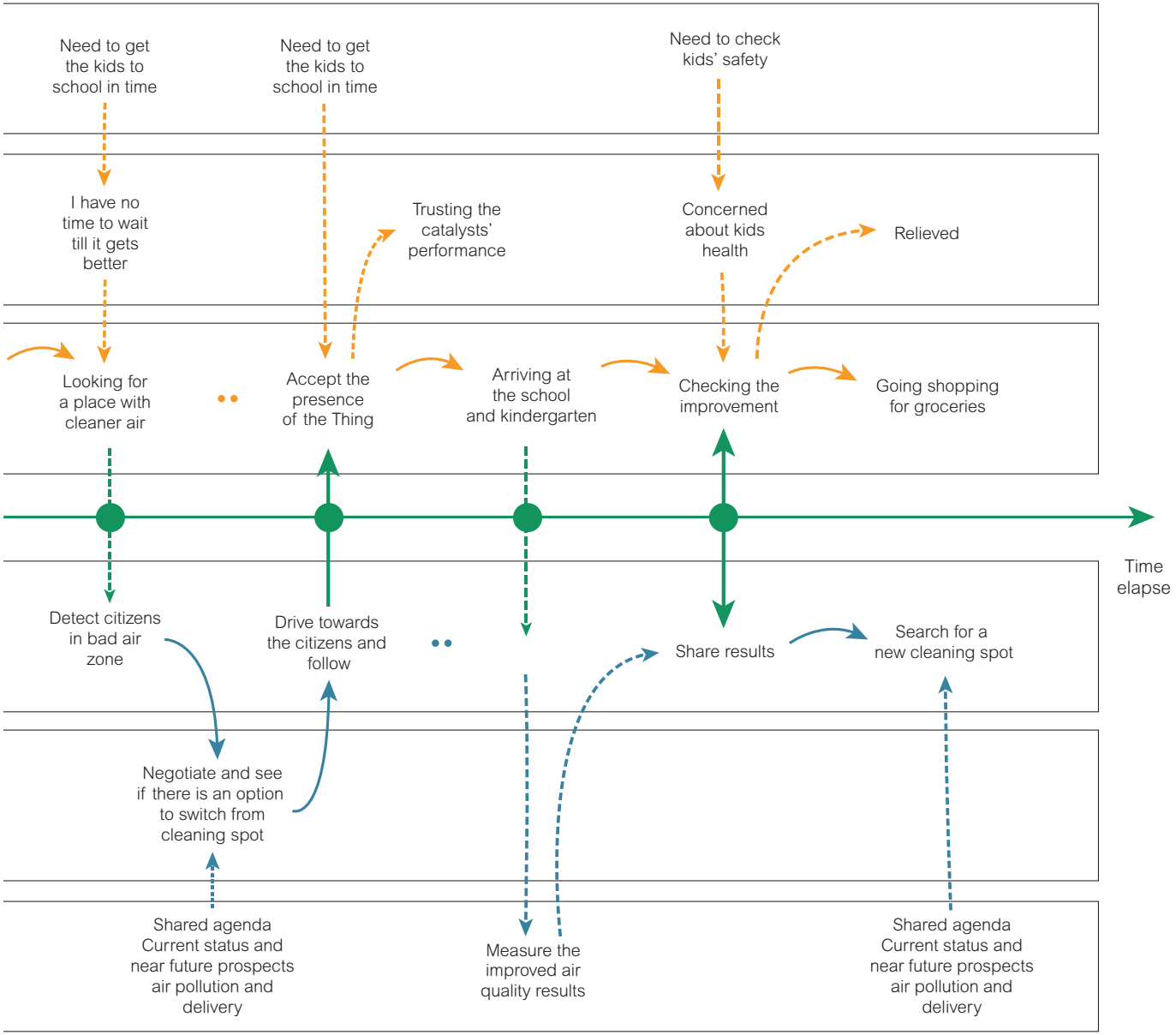
Things perspective


Accepts the precense of a group of Things
Walking towards the school while she trusts the performance of the Things
The children arrived at school and the Things are moving on
Off to doing groceries

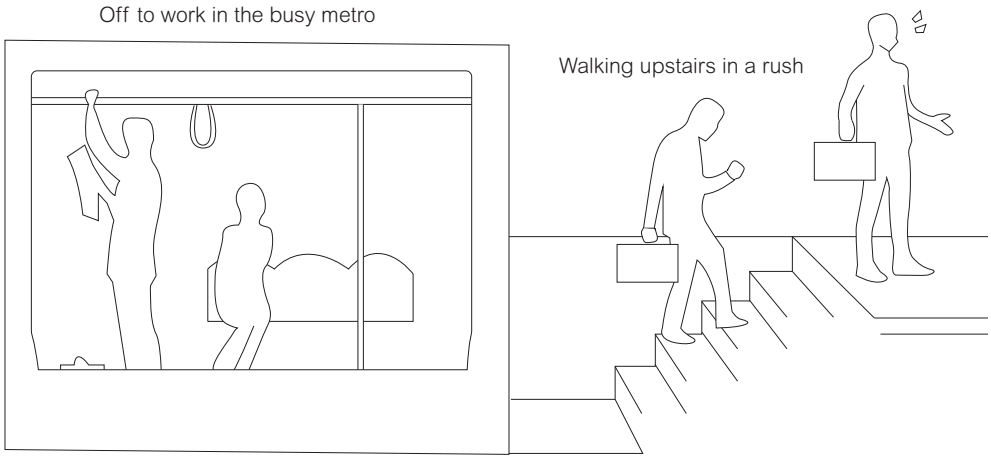

The Things decide to clean nearby the citizens to increase impact
?
!
Three Things are cleaning the air near the citizen and her children
The Things are done cleaning and move on to a new zone

INTERACTION SCHEME 1



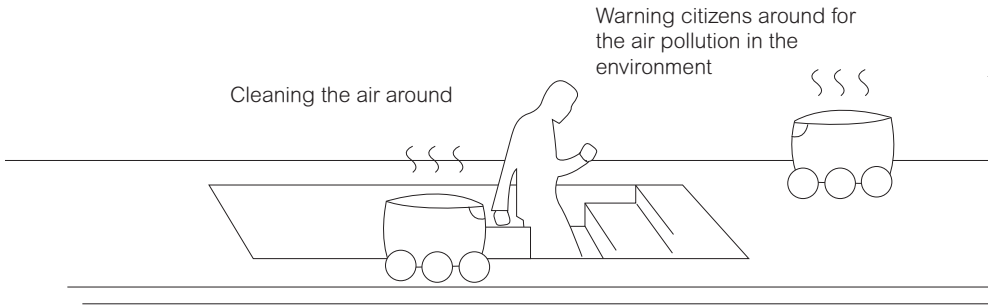

Need to get the kids to school in time
Need to get the kids to school in time
Need to check kids' safety
I have no time to wait till it gets better
Trusting the catalysts' performance
Concerned about kids health
Relieved
Looking for a place with cleaner air
Accept the presence of the Thing
Arriving at the school and kindergarten
Checking the improvement
Going shopping for groceries
Time elapse
Detect citizens in bad air zone
Drive towards the citizens and follow
Share results
Search for a new cleaning spot
Negotiate and see if there is an option to switch from cleaning spot
Shared agenda Current status and near future prospects air pollution and delivery
Measure the improved air quality results
Shared agenda Current status and near future prospects air pollution and delivery

Human perspective

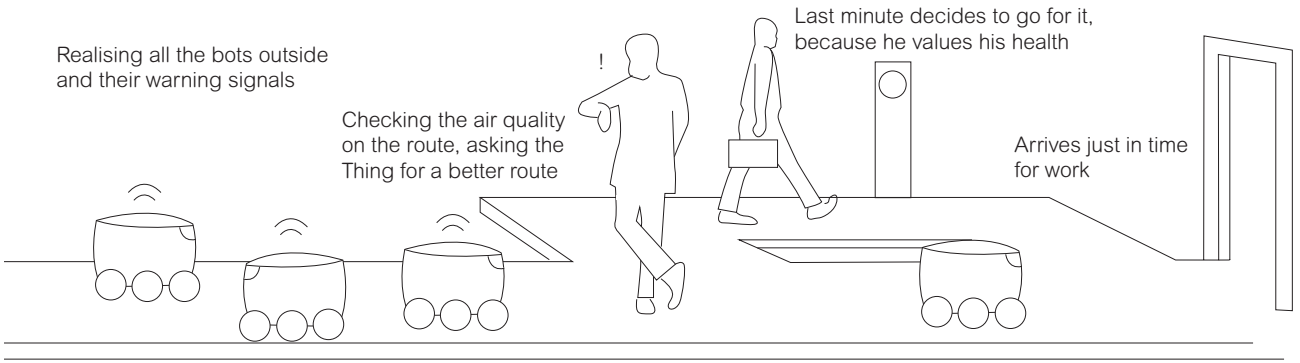


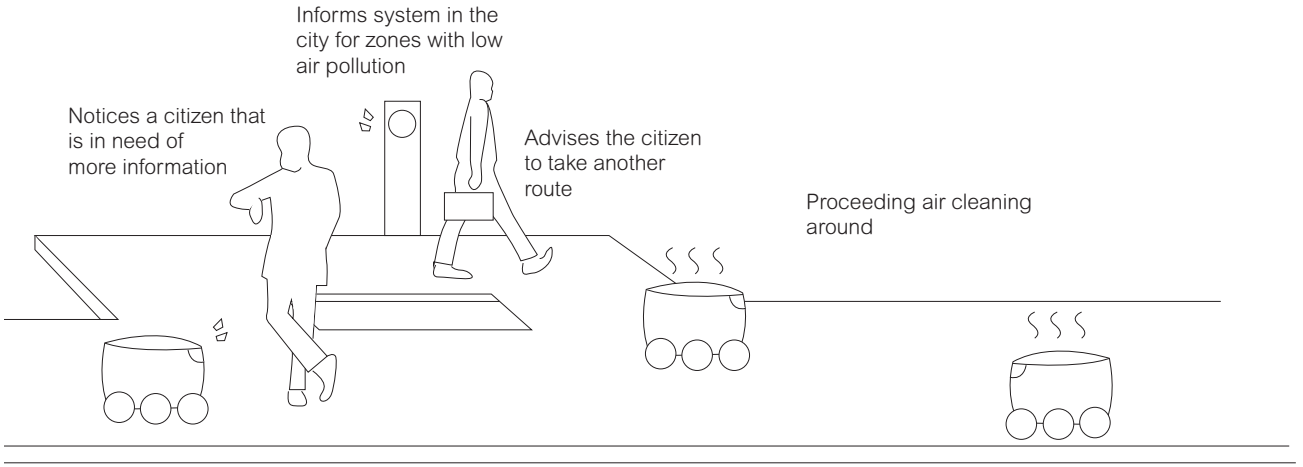
STORYBOARD 2

An employee is heading off to work in the early morning, commuting the same way as he always does. He is traveling alone and is in a rush, he should have left a little earlier from home. His travel route is very familiar to him, however he does not know the neighborhood and streets around so well. The traveling starts with a part on the subway and he walks the last part through the neighborhood of his work. It is very busy on his route, as he is not the only one that takes this subway and busy street.

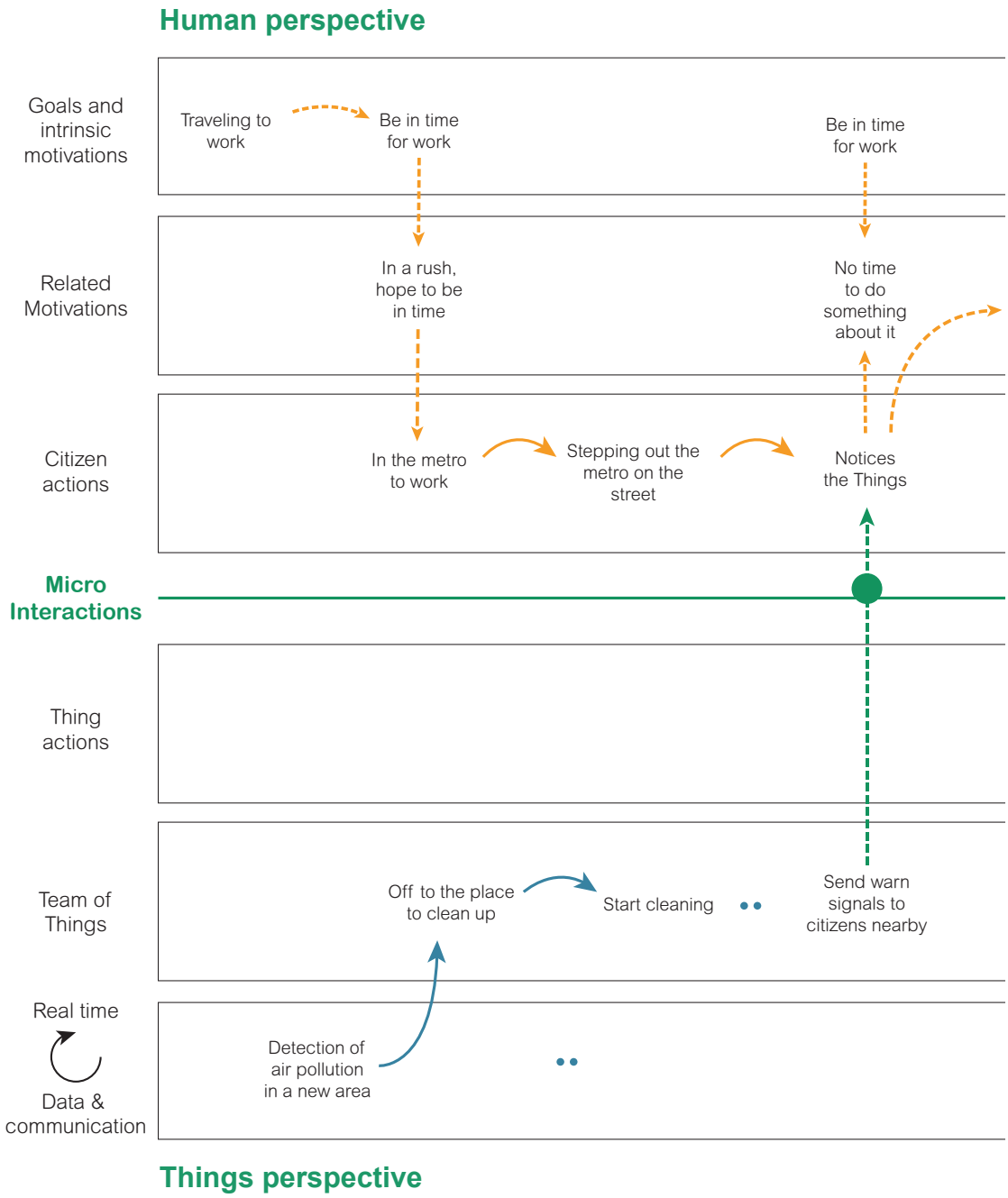


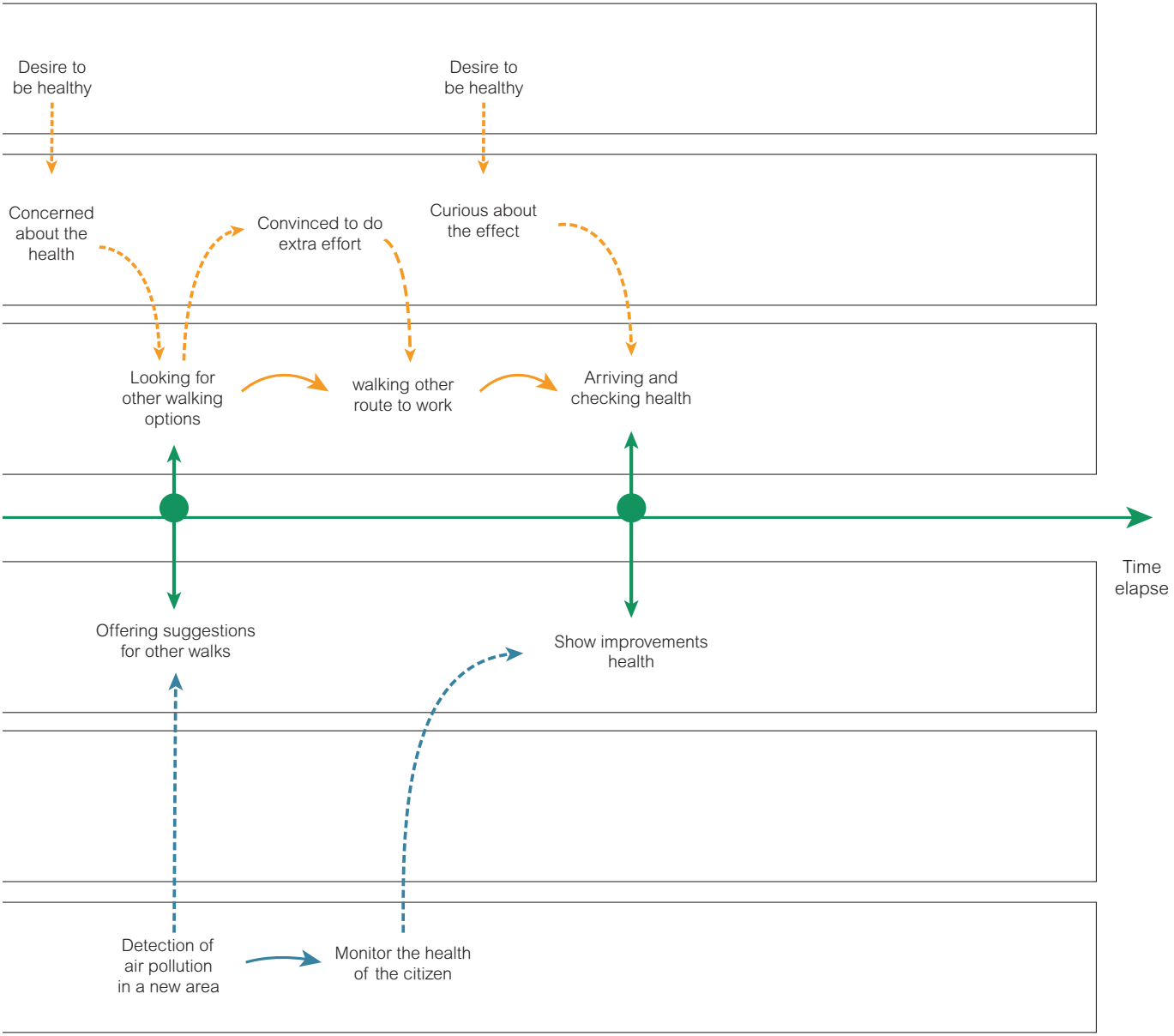
Things perspective


Realising all the bots outside
and their warning signals
Checking the air quality
on the route, asking the
Thing for a better route
!
Last minute decides to go for it,
because he values his health
Arrives just in time
for work


Informs system in the
city for zones with low
air pollution
Notices a citizen that
is in need of
more information
Advises the citizen
to take another
route
Proceeding air cleaning
around

INTERACTION SCHEME 2

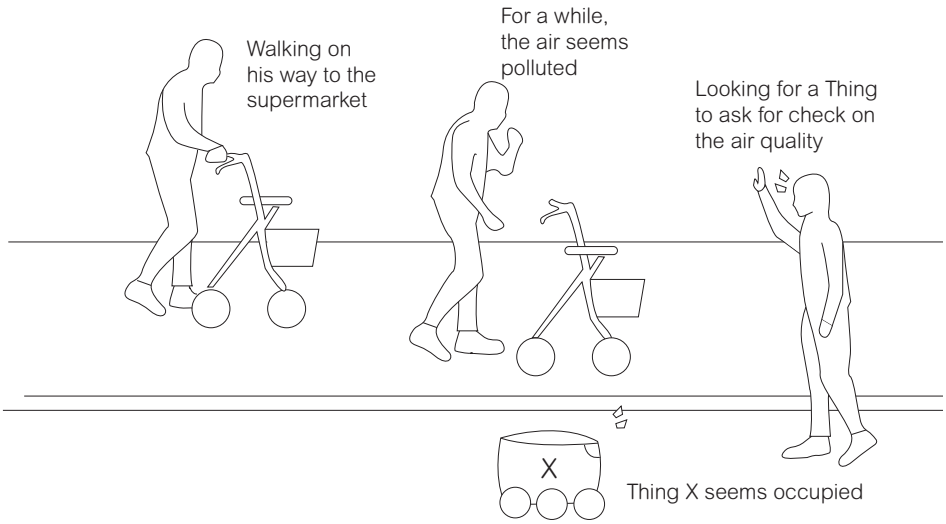



Desire to be healthy
Desire to be healthy
Concerned about the health
Convinced to do extra effort
Curious about the effect
Looking for other walking options
walking other route to work
Arriving and checking health
Time elapse
Offering suggestions for other walks
Show improvements health
Detection of air pollution in a new area
Monitor the health of the citizen

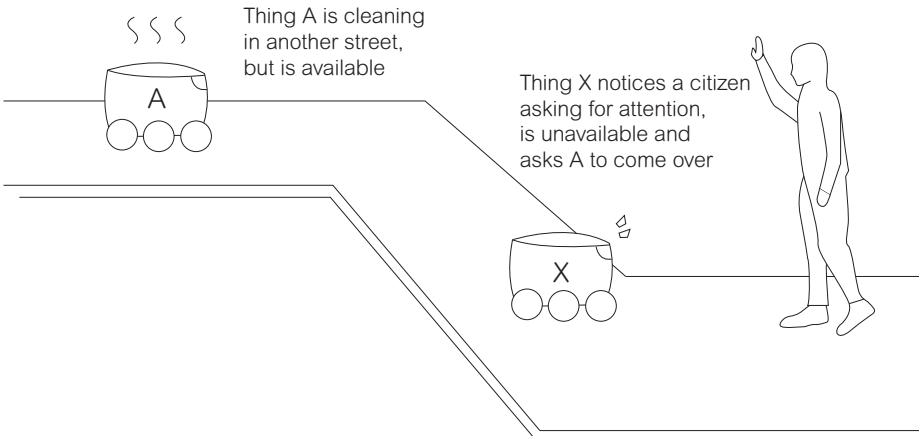
STORYBOARD 3

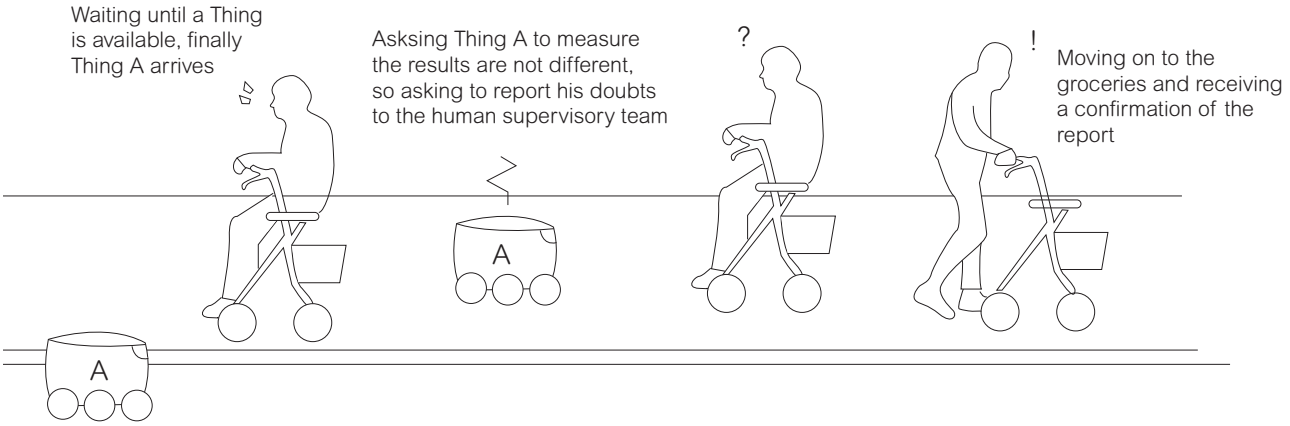
A citizen is doing groceries in his leisure time in the afternoon. He is walking with a walker on the pavement and takes his time to walk towards the supermarket. He is old and has difficulty to walk, but he still manages to life on his own. The streetview is calm as there are not many people on the street. He does not come out of the house that often, so he is not very familiar with the street environment. However, he goes to the supermarket three times a week and is thus familiar with the route.

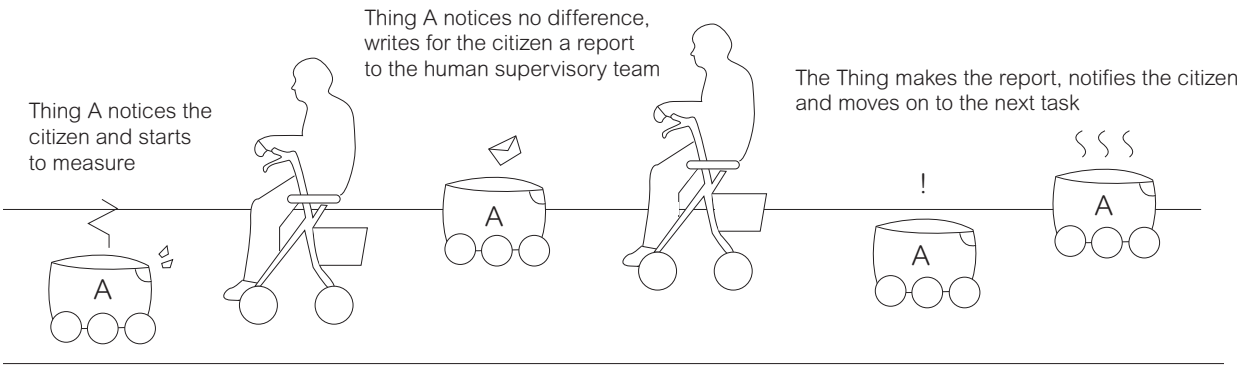
Human perspective



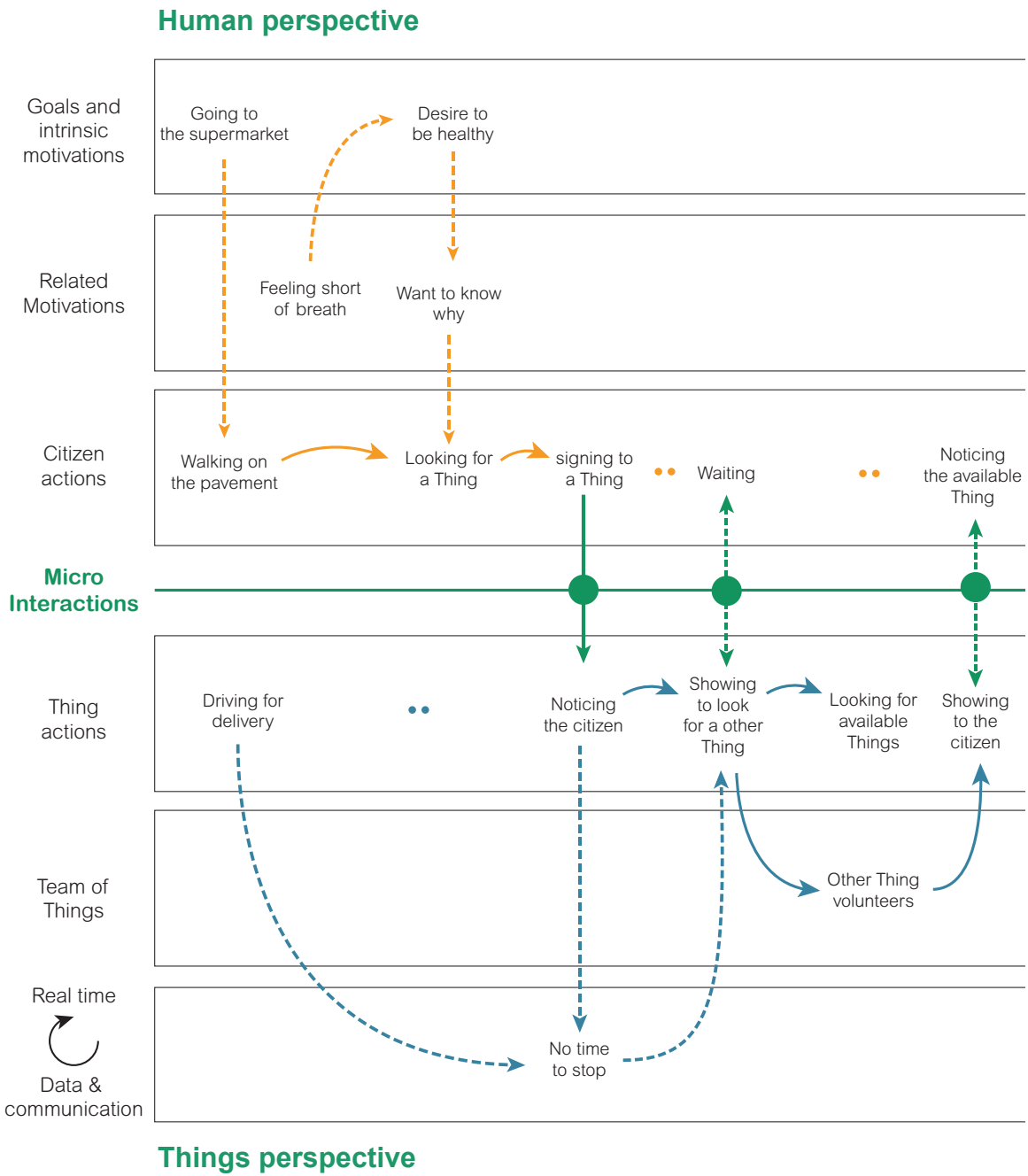
Things perspective

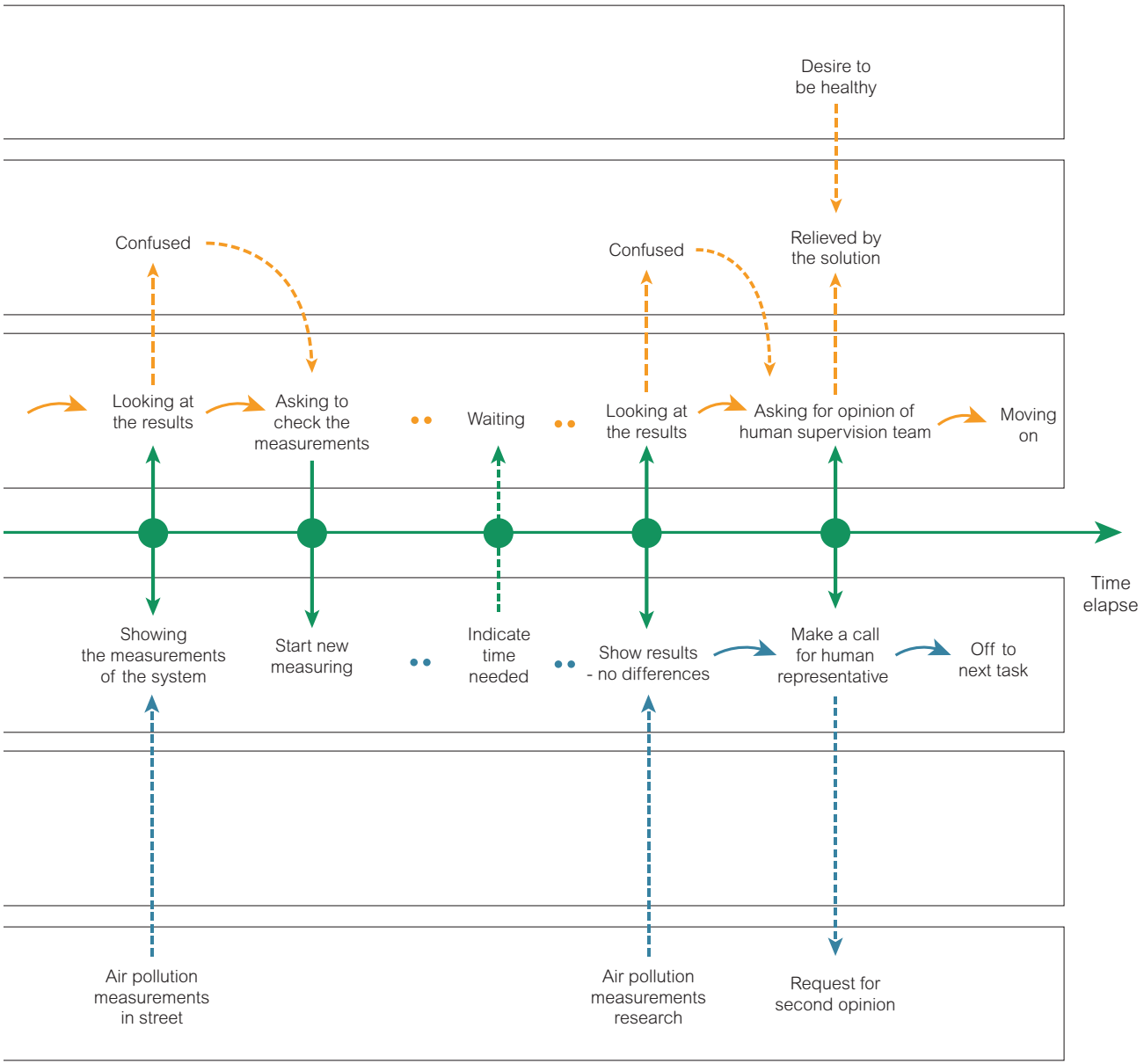



Waiting until a Thing is available, finally Thing A arrives
Asksing Thing A to measure the results are not different, so asking to report his doubts to the human supervisory team
?
!
Moving on to the groceries and receiving a confirmation of the report
A
A


Thing A notices the citizen and starts to measure
Thing A notices no difference, writes for the citizen a report to the human supervisory team
The Thing makes the report, notifies the citizen and moves on to the next task
!
A
A
A

INTERACTION SCHEME 3




Desire to be healthy
Confused
Relieved by the solution
Confused
Looking at the results
Asking to check the measurements
Waiting
Looking at the results
Asking for opinion of human supervision team
Moving on
Time elapse
Showing the measurements of the system
Start new measuring
Indicate time needed
Show results - no differences
Make a call for human representative
Off to next task
Air pollution measurements in street
Air pollution measurements research
Request for second opinion

Two micro interactions, in which the concept is involved, are worked out. The micro interactions are both derived from the three different scenarios. The choice for these two micro interactions is made based upon the possibility to incorporate the design qualities. The following micro interactions are chosen:

1. The moment that a citizen realises the presence of Things and looks at the air pollution status that they show.
2. The moment that the Things start to approach nearby citizens to clean in their environment.

The first paragraph introduces a framework that is applied during the design of the micro interactions. Subsequent paragraphs describe the development of the Things´ design based on both micro interactions and the design qualities.

05 MICRO INTERACTIONS

MICRO INTERACTIONS FRAMEWORK

Micro interactions are interaction moments during a single use case; they only contain one task. Dan Saffer (2013a) proposes a framework for the design of these micro interactions. This framework is presented in figure 17. The micro interaction is split up in four elements that need to be incorporated in the design phase:

1. Trigger: The trigger is the event that initiates the interaction. It is a cue that stimulates the user to take action.
2. Rules: The rules outline what happens during the interaction. Rules can vary and are different for specific situations.
3. Feedback: The feedback refers to what has happened according to the rules and gives the user feedback on the procedure of the micro interaction; e.g. whether the user succeeded or not.
4. Loop and modes: Loop and modes become interesting when the micro interaction repeatedly occurs. What could be engaging and interesting during the first time of the micro interaction, can be boring or dissuading for the user after the hundredth time. The micro interaction could therefore develop over time, evoking surprise and joy for the user to engage during the micro interaction.

MOVEMENT AS A FOCUS FOR THE DESIGN

As the options for the interface design are numerous, a specific type of interface is chosen in order to keep the design consistent. Movement is chosen as movement alone is sufficient to reveal intent of a Thing (Sirkin et al., 2015). Hereby, typical anthropomorphic cues, such as a face or a voice, are not necessary. Although according to research, a head position or eye gaze enables people to form a focal point during communication (Koay et al., 2013). This focal point is essential for a Thing to express its intentions.

Another argument for the focus on movement is that humans naturally communicate most of their intentions with body language, according to the rule of personal communication (see figure 18). If Things need to share their perceptions and intentions, it makes most sense to use a communication channel that humans are familiar with.

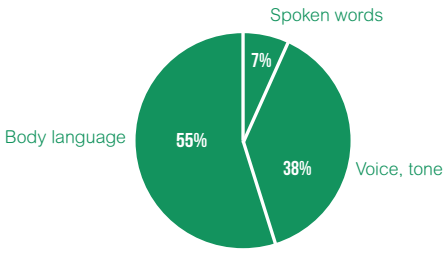


Figure 18: Albert Mehrabian's 7-38-55 Rule of Personal Communication (Belludi, 2008).

Figure 17: The micro interaction framework developed by Dan Saffers (Saffer, 2013b).

EXPOSING THE AIR QUALITY BY BREATHING MOTION

SYSTEM STATES

The focus of design for this micro interaction is to bridge the differences between a Thing and a human. In order to bridge the differences, the Things should show the air quality by means of an expression that is closer to the sentience of a human being. According to Marenko & Allen (2016) it is important to design a design cue that is native to the design function in order to communicate the intention of the Thing. It creates a better sense of intention and enhances the feeling of an 'inner life' of a Thing, which in return makes it easier for citizens to bridge the differences. Moreover, a design cue that is native to a Thing's function also reveals the purpose of the Thing. As air pollution has an effect on health, and is mostly known as causing health problems in the lungs, it is chosen to use breathing as a metaphor for the air quality. The way that the Things move, as if they are breathing, shows whether the air is clean or polluted. Using the micro interaction framework, it looks as follows:

Trigger The sensor of the Thing signals the nearness of a citizen.

Rules Depending the state of the air pollution, the Thing is breahting accordingly.

Feedback the citizen indicates in his or her behavior that he or she did notice the message.

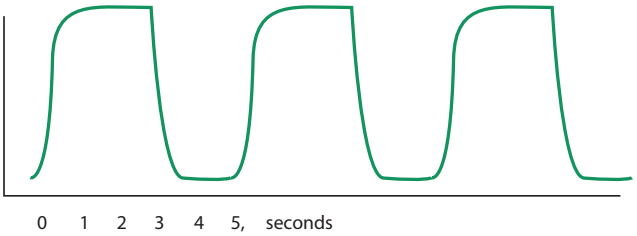
Loop The breathing pattern is continued until it is understood by the citizen.

Note that both the Thing and the citizen have a passive part in the interaction, the interaction is limited by the perception of the Thing by the citizen.

BREATHING MOTION DESIGN

A relaxed breathing motion of the Thing shows that the air is healthy and a cramped breathing motion of the Thing shows that the air quality is dangerous. There should be a range in between both states, but for this concept only the two states will be worked out. In order to create proper breathing motion, two graphs are studied of a normal breathing pattern and a hyperventilation breathing pattern. See figure 19 for the differences in motion.

Normal diaphragmatic breathing



Chest breathing during hyperventilation

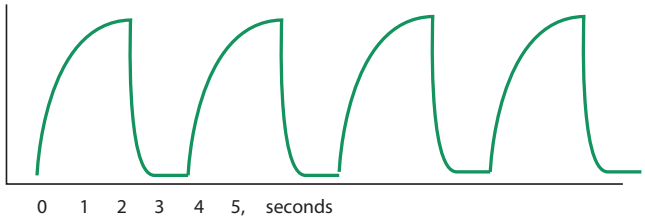
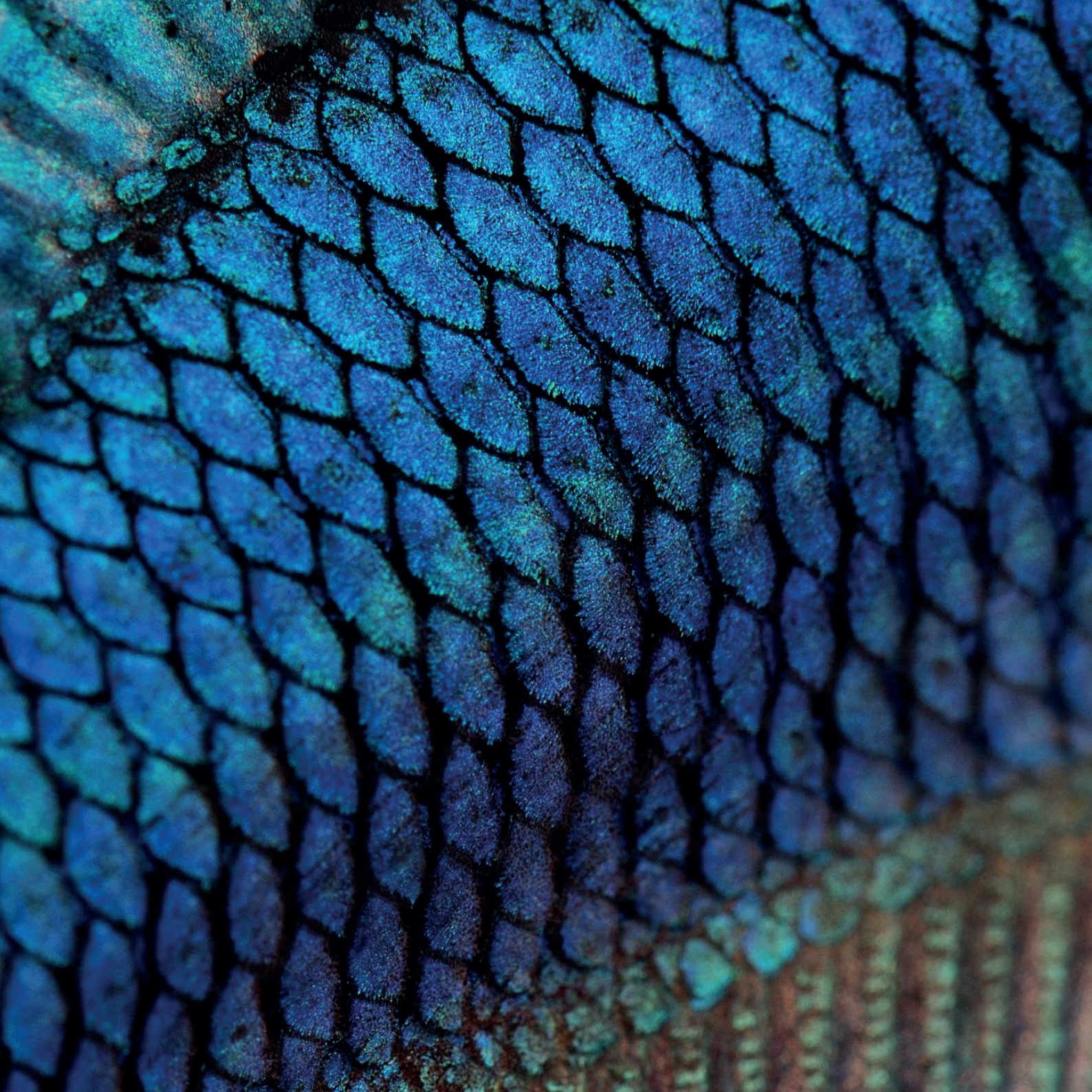


Figure 19: The different breathing patterns of normal breathing and chest breathing (Normal Breathing, 2018).



The normal breathing pattern shows a gradual changing curve that is in balance regarding the duration for breathing in and breathing out.
The hyperventilation pattern shows an abrupt change of state between breathing in and breathing out, with a steep curve downwards during the breath out time, shortening the breath motion. The breath in motion seems as if the lungs are trying to take in as much air as possible. The motions are translated into the motion for the two states of motion for the Thing.

Motion pattern

It is chosen not to make the whole body move as if the Thing is breathing. Instead a hexagon pattern is created that serves as a texture, wrapping parts of the body.

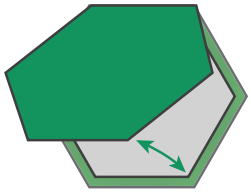


Figure 20: The breathing motion of a single hexagon.

During breathing each hexagon will slightly open up when breathing in and closes when breathing out, see figure 20. The texture is chosen as it steps away from the 'human-like' body motion and creates a unique new motion of breathing. Moreover, it can seem as if the texture wants to 'protect' the body of the Thing: heavier and shorter motion will cover the body more with the hexagons; whereas relaxed, longer motions will open up the texture to uncover the body. The hexagon is chosen as it fits perfectly when closed as a pattern and look almost similar to fish scales. The texture motion is visualised in figure 21.

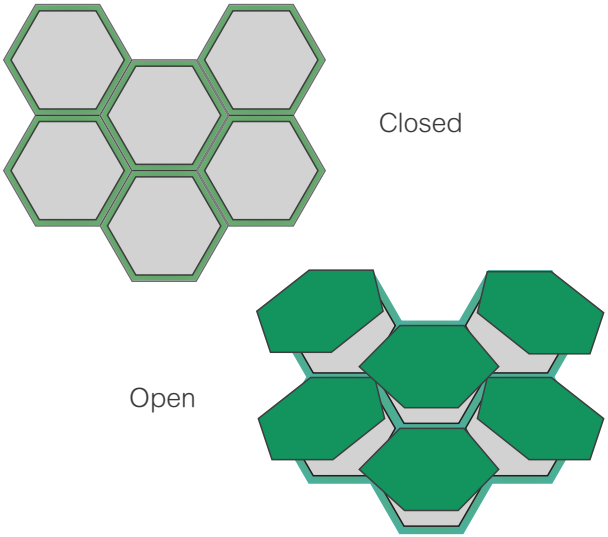


Figure 21: The breathing motion of the hexagon texture.

MACRO INTERACTION

Previous described texture will thus serve as the design of the micro interaction of an individual Thing. In order to create a macro level interaction between the Things, it will seem logical to copy the breathing pattern to the other Things. However, living beings do not breathe in the same pattern either, so copying the breathing pattern along the Things will seem creepy and unnatural. In order to create a more calm and natural expression, the Things will need to breathe asynchronous. Additionally, each Thing could have an own slightly deviating breathing pattern from the standard deviation of the breathing pattern, as every breathing pattern is unique for each individual. These adjustments should not affect the main goal; the distinction between the two states of breathing need to be clear.

CREATING INTERTWINING DYNAMICS BY DIALOGUE

The focus of this micro interaction is to create a continuous agreement between Things and citizens and to create trust and reliability. As Things will clean the environment in the city to ensure the health of the citizens, it means that they will need to come close to the citizens that stand still in polluted areas; e.g. the citizens that wait at a bus stop or citizens that have lunch outside. They could clean areas where a lot of citizens walk, at crowded pavements. It means that they need to be responsive to the city dynamics, as discussed in chapter 2. However Things lack the ability to respond properly to the city dynamics; e.g. when are they a contribution for citizens or how do they know if they stand in the way? The city dynamics is too diverse to have Things automated for it.
The solution is to create a dynamic and playful dialogue during which Things approach citizens and learn from this dialogue how they can integrate in the city dynamics. Things can move towards citizens to indicate that they want to clean nearby and citizens can encourage or discourage the Things to do so. According to the micro interaction framework, the dialogue is build up from the following elements:

Trigger: the Thing approaches the citizen(s) or a desired spot to start cleaning.

Rules: if the Thing is approaching, the citizen(s) can move the Things closer or away by use of gestures.

Feedback: according to the gesture of the citizen, the Thing will move closer or away. The movement of the Thing results in the feedback of the citizen.

Loop: According to the secure or insecure posture of citizens and their movement, a Thing can decide to approach the citizen in different ways.


Troon
Carrefour
express
1000

SYSTEM STATES

In order to create a dialogue with negotiation space, an extended version of the rules of the second micro interaction is created, see figure 22. Within these rules, a Thing will have various options to approach a cleaning spot in the city. A Thing can either choose to approach citizens or choose an open space to clean. If a Thing chooses to approach citizens, it can be encouraged or discouraged by citizens to stand near them. If there is no reaction, a Thing can just move over to that spot and start cleaning. The other option is to choose a random cleaning spot, without nearby citizens involved. Important is that a Thing is aware of the city dynamics, as the position of a Thing might hinder the dynamics. A Thing can go to a cleaning spot that is verified by the system to not be hindering the citizen dynamics or it can choose an unfamiliar spot. Choosing an unfamiliar spot means that a Thing needs to move at all times if citizens indicate that it is hindering their activities. Choosing a familiar spot means that Things can reject the request of citizens to move away. However, if the Thing is asked by multiple citizens to move away in a short amount of time, it should certainly do so. By giving Things the lead in the dialogue as they approach citizens and by giving them the option to reject a citizen's request as well, the Things become partners rather than assistants in the dialogue.

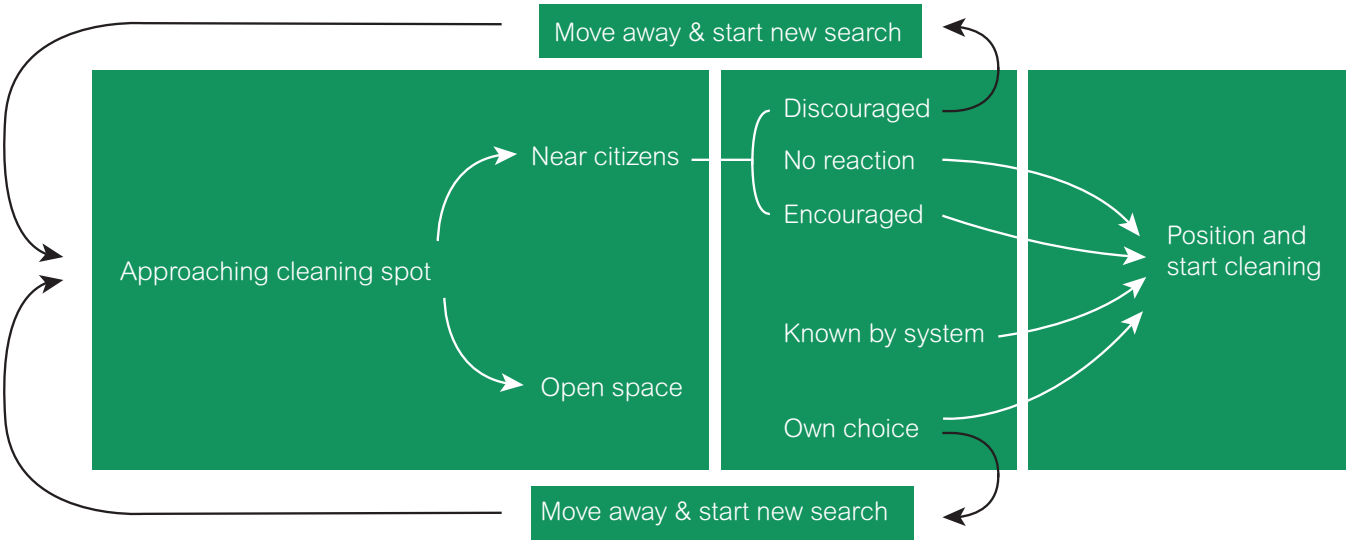


Figure 22: An overview of the system states to approach citizens or a cleaning spot.

APPROACHING BEHAVIOR

The moment that a Thing approaches a citizen is the exact moment that a citizen will meet the Thing for the first time. In the big city, it is not likely that the same citizen and Thing will meet each other on a regular basis. As the meeting is for the the first time, it is an important moment for a citizen to decide if he or she trusts the Thing or not. A Thing should therefore not jump onto a citizen, but rather slowly approach him or her, see figure 23. More importantly, a Thing should briefly pause at an appropriate distance to show the citizen that he or she can choose whether to approve of the Thing's company. Typically the approaching movement of a Thing should therefore stop at least three meters in advance, as this is an appropriate distance in public space, and move closer to two meters in front of the citizen after approvement, this is the social space. The distances are based on research of Hall (1966). Approaching should always happen in sight of a citizen.

Preferably, the speed of the Thing should be the speed of a slow walking person, which is around 2 km/h.

As some citizens will become familiar with the concept, it becomes more convenient if the Thing can approach the citizen in a more secure way.

A movement study is conducted whereby two participants played different dialogue scenarios between a Thing and a citizen to understand the art of dialogues (see Appendix 10.2). One result of the movement study is that a human that is familiar with the Thing will have a notorious different posture than a citizen that is new to the concept. Furthermore, it became clear that citizens would approve a faster and shorter approach if they are familiar with the dialogue. The Thing could in that case speed up a little bit and might even skip the pause in its approach if the posture of the citizen seems as if the citizen is very confident.

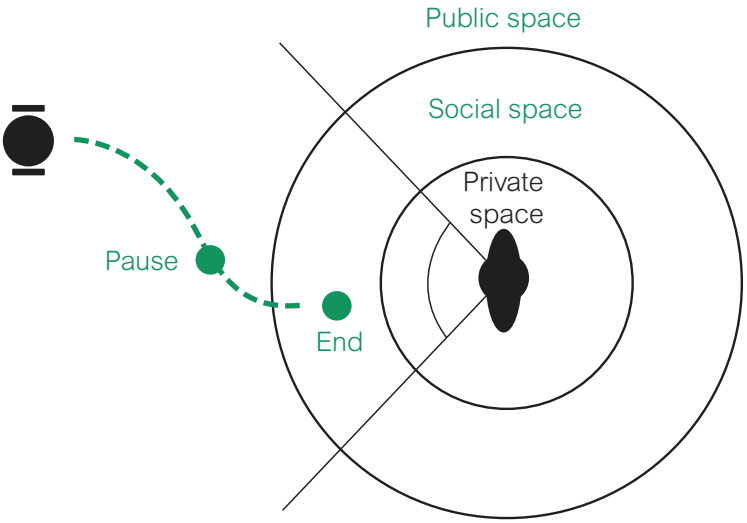


Figure 23: The approaching behavior of a Thing.

GESTURE RECOGNITION AND REACTION

The system can recognize two signs made by citizens' gestures, namely approval and disapproval. The idea is that citizens can have their own use of gestures, the system will be able to learn the various use of gestures using AI. As described before, the Thing itself can react on these gestures and can communicate its own decision based on three reaction patterns:

Disapproved The Thing will turn around and move away, as much as possible in opposite direction.

Approved The Thing will move closer, stand still and simultaneously turn on its integrated light as a confirmation.

Rejecting The Thing will turn its head, shaking it while simultaneously flickering the light.

MACRO INTERACTION

Most likely, a single Thing will not be able to clean the air for multiple citizens in one area. Often, multiple Things will be needed to clean a certain zone. Therefore, multiple Things will approach citizens at the same time and start the dialogue.

Approaching

The same principles of approaching for the individual Thing also count for a group of Things. Things should approach carefully, pause and wait for a response. According to research of human perception of swarm behavior by Dietz et al. (2017), individual swarm members should adjust their speed and smoothness of movement to each other and form a cohesive pattern. These requirements will make swarm behavior understandable, as it eases the citizens to form a mental map of the group. Considering these requirements,Things should adjust their speed and smoothness during approaching. Moreover, they should form a cohesive group during the approach in order to be understandable and predictable, therefore trustful, to citizens. A non cohesive pattern could look chaotic and might be frightening as the group movement seems to be unpredictable.

Team communication during the dialogue

Javier Alonso (Personal interview, Feb 12, 2018) describes the interaction between a human and a swarm in four main steps (see figure 24). The first step is the input level by a human on a higher level. Higher level means that the input is generated via an interface and that this input needs to be translated in the second step to make it readable for the system. In the first step, citizens have several degrees of freedom for the input. During the third step, the message of the input is communicated to all relevant members of the swarm. The last step is the most challenging and is to communicate the output to the human. Interaction with a swarm is more complicated than interaction with a single robot, as a human should understand how he or she can provide input and needs to understand who and in what form the members of the swarm respond to it.

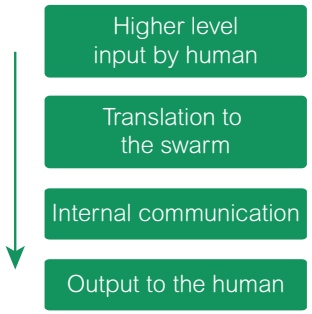


Figure 24: The communication channel for human-swarm interaction.

Before a citizen can give input to the system, he or she needs to be aware that the Things are approaching as a team. In order to ease the forming of a mental map for citizens, Things will need to form a team pattern prior to approaching the citizen. The Things will therefore first move to each other, briefly look at each other and then approach the citizen (see figure 25).
During the approaching movement of the team, the Thing in the middle should always be upfront. The citizen will be triggered to communicate the input to the upfront Thing. This form of interaction is called Leader Selection (Kolling et al., 2016). The selected leaders are expected to influence and lead the team of Things. The leadership ends when the dialogue ends. The leader will communicate the input from the citizens to the other Things.

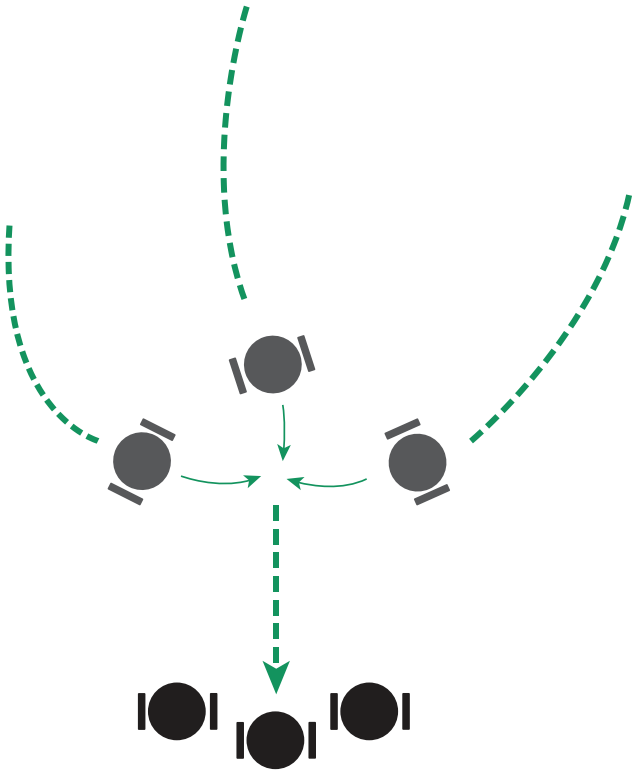
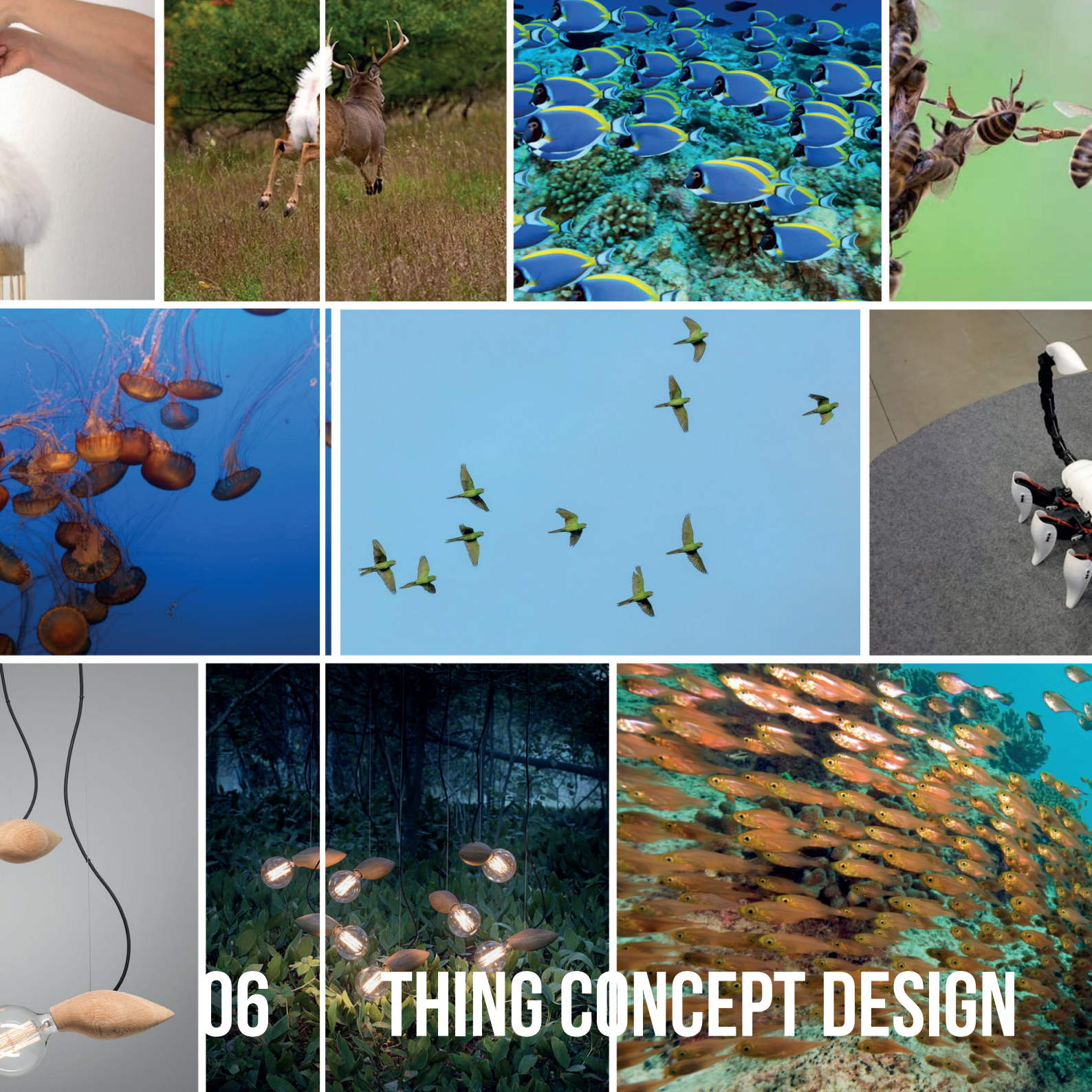


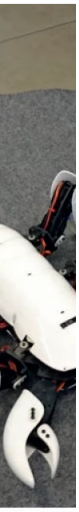
Figure 25: The approaching behavior of a team.

FORESEEN PITFALLS IN PRACTICE

Even though the design of the micro interactions fits the storyboards as presented in chapter 4, it should be acknowledged that in practice the dialogue would encounter some difficulties. One example is that it could be hard in a busy environment for a team to approach citizens all together as the movement will take a lot of space. Moreover, the system should become vandal-proof. Human supervisors should be able to identify misuse of the system. Furthermore, it is important to consider what would happen if citizens would simultaneously sign differently to the team: who is the team going to respond to? It would be fair to take everyone's opinion into account. As a start, it would be reasonable to always respect citizens who disapprove.



06 THING CONCEPT DESIGN



BODY DESIGN - FORM STUDY

A form study is conducted to develop the body of the Things. Different images of swarms and modern digital objects are collected in order to create a framework to design from (see the figure on the left for an impression). The main insight of the form study was that individual animals of a swarm are relatively simple in shape and have a unique feature that makes them easy recognizable for each other. The fish for example have a typical colour scheme with a distinguishing yellow colour on top. The deer has a white tail to sign to other deers that are in the back. However, each small swarm animal has a simple and organic form, e.g. the simple structure of the jellyfish or the simple forms of the birds. Remarkably, most swarm animals have a clear front and back. Looking at the design trends of modern digital objects, the design seems simplistic and clean. The details are subtle. The shapes are geometric, but slightly adjusted to a somewhat more organic shape. The design of the Thing is based upon a geometric shape, adjusted to a somewhat more organic shape, see figure 26. The typical design cue of the Thing is a hexagon rhythm; the lines of the body and details are inspired by the hexagon shape. The Thing has an indication of a head, which is created by a split line in the body. The camera suggests a pair of eyes and the backline of the body gives an impression of a neck. The added neck in the backline clearly distinguishes front and back of the Thing. The concept has four wheels, as it fits with the body shape and it is assumed that four wheels provide enough stability for the total body.

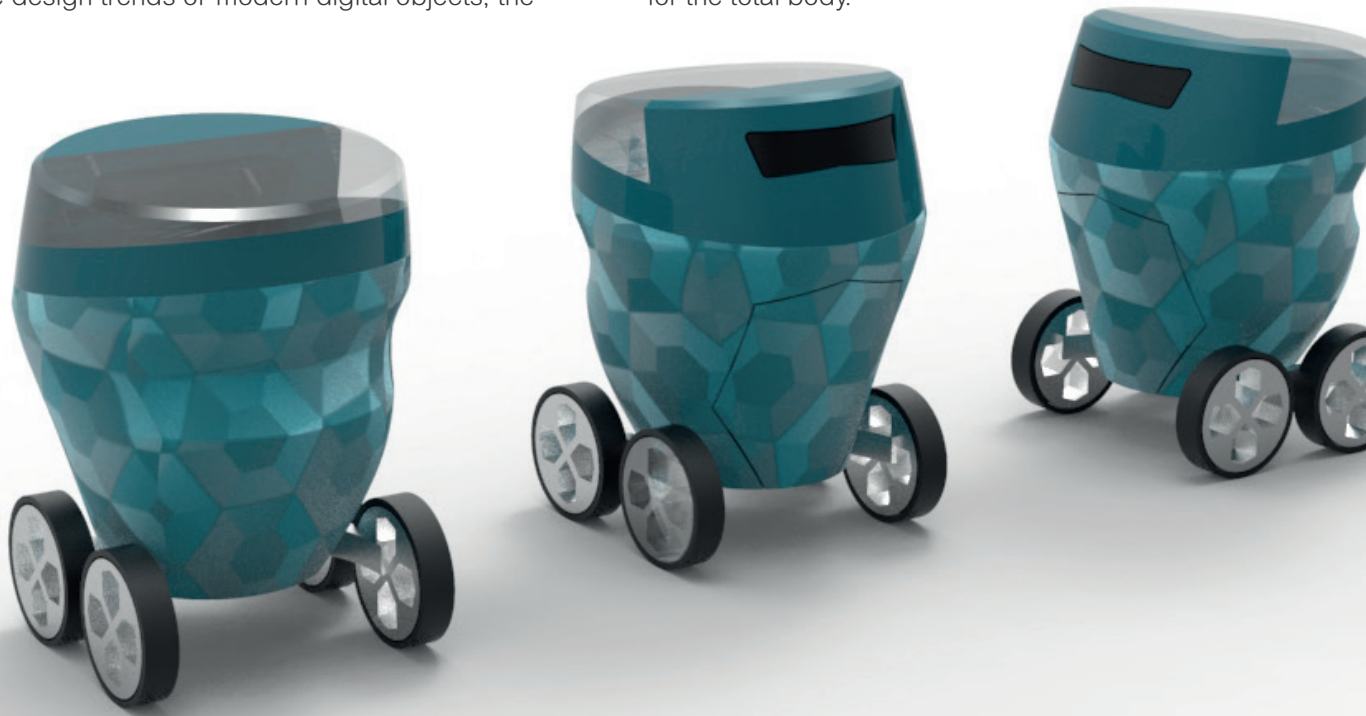


Figure 26: The design of the concept.

SIZE

The size of the Thing is 80 centimeters in height and 50 by 50 centimeters in width and length. The height is somewhere between knee and hip length of a person, which keeps the overview of the whole city clear, but forecomes that people would trip over the Things. The width is in proportion with the height of the Thing and enables the Thing to deliver small packages such as clothes and food. Larger packages will be delivered by two or more Things, as described in chapter 1.

THE BEHAVIOR RELATED TO DIFFERENT ACTIONS

The Thing has several actions. Therefore it should have different behaviors according to these actions on the street to make itself understandable towards citizens. Firstly, it should make clear if it is open to citizens or if it is too busy delivering. Secondly, it should communicate if it is part of a team that is cleaning in the street or if it is on its own. Thirdly, it should communicate the air pollution levels in the street. Last, it should have clear distinguished reactions on the gestures of citizens if it approaches citizens.

Delivery or cleaning attitude

During delivery, a Thing will not be able to stand still and clean at certain places. It is important that the Thing communicates this state to citizens. In order to do so, the Thing will have its eyes fixed on the road and will bend over slightly, changing its body shape, to look occupied (see figure 27). During the delivery, it is possible for the Thing to clean, so the texture will be moving if it is cleaning, indicating simultaneously the air pollution level, and will be closed and silent at the moment that it is not.
During cleaning, the Things will mostly work in teams. The Things in a team will briefly make eye contact with each other and look around in general in order to communicate to citizens that they work together and have time to clean the air in the environment (see figure 28). If a Thing is cleaning, the body will illuminate.
The breathing texture will be moving at all times to show the air pollution level around (see figure 29).

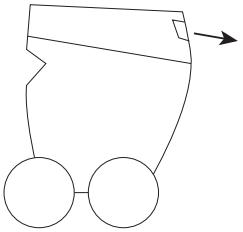


Figure 27: Delivery attitude: focussed on the road.

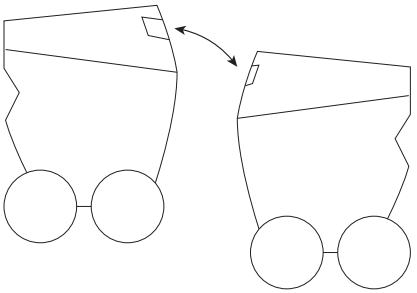


Figure 28: Cleaning attitude: open for communication.

Figure 29: Breathing pattern, showing the air pollution levels at all times.

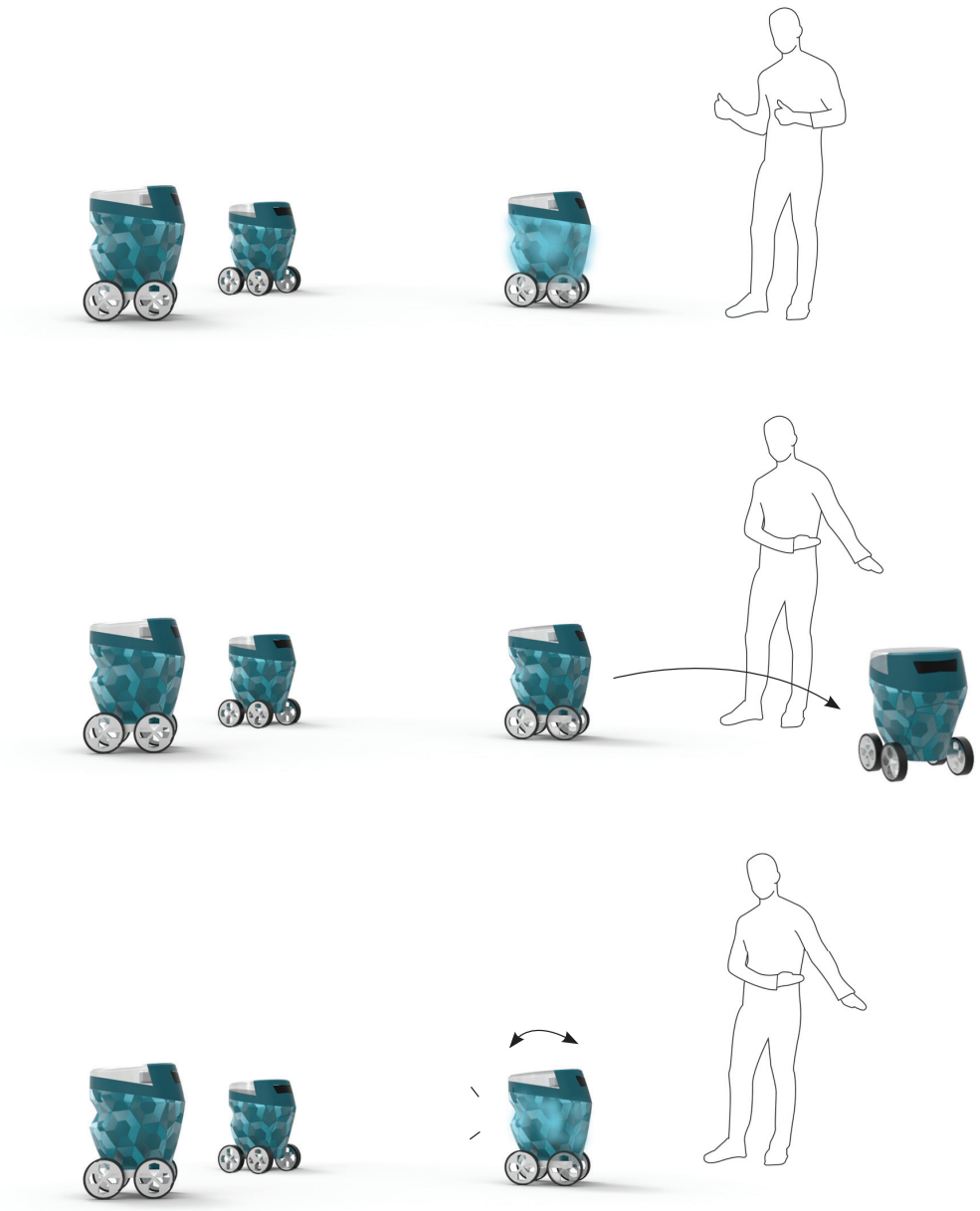


Figure 30: In order, the different reactions of Things during a dialogue with citizens.

The behavior during an approah towards a citizen

During the dialogue, there are three reactions possible by the Thing depending on the reaction of the citizen. The reactions are visualised in figure 30. The figure presents a team and the behavior of the Leader depending on the reaction of the citizen. Naturally, the team will copy the Leader's behavior. The three possible reactions are described as follows.

1. The citizen approves the Thing's company and the Thing comes closer, stops and illuminates its body to confirm and to show that it starts cleaning.
2. The citizen rejects the Thing's company and the Thing turns around and moves away,
3. The Thing does not want to move, even though the citizen asks to, so the Thing shakes its head by turning it and the light in the body flashes to indicate a disagreement.

07 EVALUATION

OBJECTIVE

A qualitative study is conducted to evaluate the design choices for the micro interactions. The aim of the study is to confirm whether the design qualities are recognizably implemented in the behavior of the concept. During the study, the experience of the micro interactions for the interaction with an individual Thing as well as with a group of Things will be evaluated.

METHOD

Participants

Six master students from IDE participate in the study. IDE master students are chosen as they can evaluate the experience with the demonstrator as a user as well as a designer. Therefore, they can come up easilier with suggestions for improvement. The participants participate individually.

Material

Two types of prototypes are used in this study. They are described here.

A physical moving prototype

A physical moving prototype will be used for the first part of the study. The physical prototype has a robot underneath that can move forward, backward, left and right on different speeds. On top is a construction of a body and a head, build up from laser cutted wood and craft paper. Remote lights are placed in the head to indicate the different system states of the Thing. Moreover, it has a head that can turn around remotely, as if it is looking at the participants. The prototype is navigated by two assistants to simulate the behavior, see figure 31. The first assistant remotes the movement of the body and will stand behind a dark glass, as to be invisible to participants. The second assistant will remote the light and turn the head of the prototype with a see-through cord. She will walk one meter behind the prototype.

Figure 31: The physical prototype and the research assistants.

Four short movie fragments

Four short movie fragments are shown on a big screen to the participant. The movie fragments are an addition to the physical prototype to show the proper visual design of the concept and to show the behavior of a team of three Things. Additionally the breathing movement is generated in one of the movies as it would be more realistic as opposed to an implemented element of the physical prototype. The movies are made in 2D and the Things are placed in a city context. Each fragment takes approximately 20 seconds. The first movie shows the breathing movement of three Things, see figure 32. The last three movies show three Things approaching the participant in three different ways, see figure 33.

Figure 32: The movie of the breathing motion.

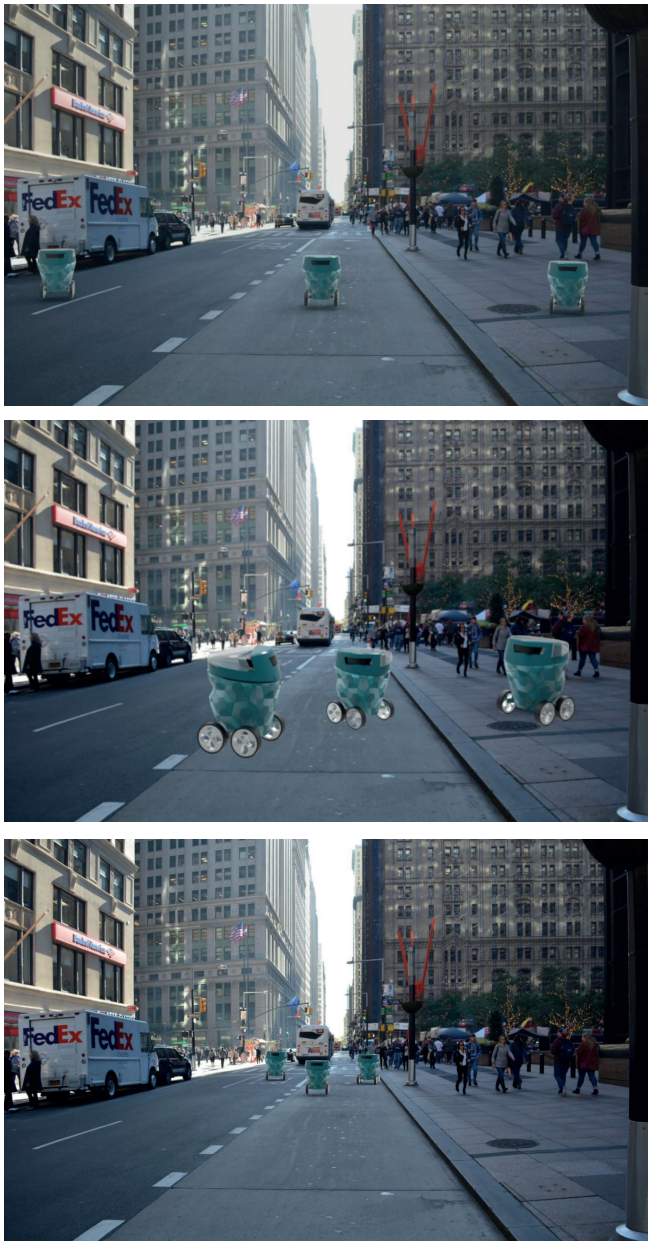


Figure 33: The movies of the approaching team behavior.

Structure

The study existed of three parts. During the first part, a roleplay will be performed with the physical prototype. The participant will first experience the interaction with the prototype and will afterwards be interviewed about the experience. The four short videos will be shown to the participant during the second part. The participants will experience the behavior of a group of three Things and will afterwards be interviewed about this experience as well. The third part is a semi-structured interview whereby the participant is asked to evaluate the concept. Before the interview, participants will fill in a form whereby they will score the concept on several points (see figure 34). The points on the form match with the design qualities as described in the design vision. After participants filled in the form, their scores will lead the interview in order to evaluate the concept. During the interview, the interviewer will mostly focus on the behavior of the concept. See Appendix 10.3 for the detailed structure.

Measuring

The study will take place in a room with cameras on the ceiling. These cameras will record video and audio during the study. The recordings will serve as a means to study participants' opinions and their behavior during the study. Moreover, the filled in evaluation forms will be collected to detect overlap of opinions between the participants.

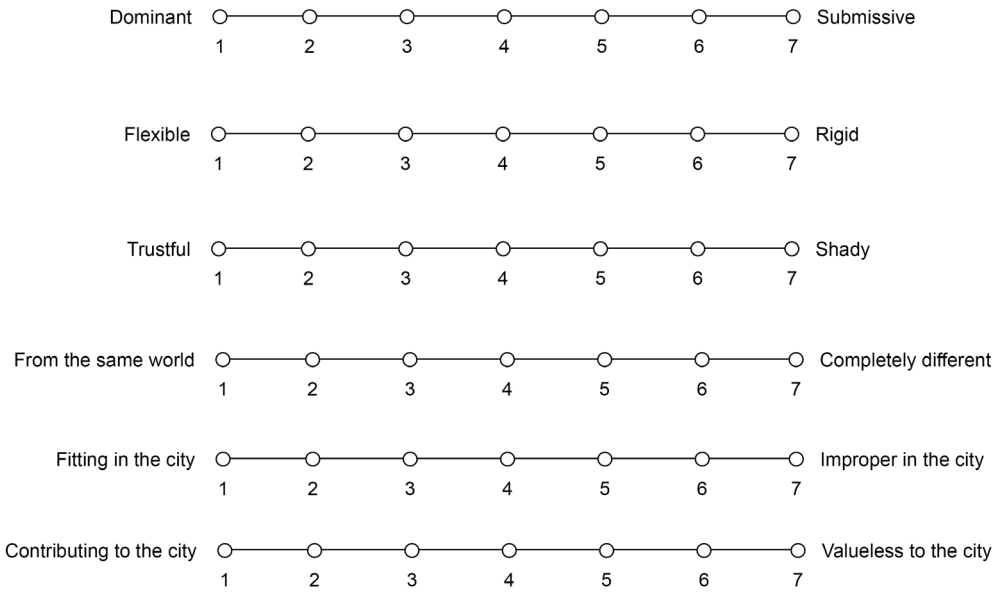


Figure 34: The evaluation form.

RESULTS

The prototype was lifelike and a new experience

The first impression of each participant is that they are excited, even sometimes a little bit scared, during the roleplay.

"It feels like he is watching.. that is kind of exciting.. I don't know" - Participant 1

Most of these feelings were caused by the fact that they found themselves being unfamiliar with the communication with a moving robot. Participants also indicated that it was sometimes hard to imagine that it would be implemented in real life, as it felt very futuristic. However, looking at the behavior and reactions of the participants it seemed that they could easily get into the scenario of the roleplay and the movies. As some participants said, it felt life like.

"Does it react to me now? Is it autonomous?" - Participant 2

Perceived individual behavior

The behavior of the prototype was understandable

In general, the participants noted that the Thing would be easy to understand if they would be familiar with it.

"If I know what it has to do, it is easy to understand. If it is standing still, it is busy cleaning" - Participant 4

The Thing shaking its head and flickering with the light was an indication that was clear to all participants. However, the light only as an indication that it was cleaning, was not enough.

"It has nothing to do with light, but with the air, a breathing movement would make more sense" - Participant 5

The participants often thought that the Thing was analysing the environment or themselves in particular at the moment that the Thing would move forward and 'pause' or stand still. For example, when participants were asked what it was doing if it was standing still and the light was turned on, participants tended to make more of it and thought it was meant to look at them. According to the participants, this was sometimes confusing.

"So if it turns on and it looks at me, I think: oh, it has something to do with me" - Participant 5

Additionally, one participant indicated that she sometimes lacked a confirmation of the Thing by means of an eye glaze or head movement.

"It is difficult because he has no eyes. If you look at someone and you see that someone is blinking or any movement, it is somehow a confirmation" - Participant 1

Participants were at ease with the behavior

During evaluation, the participants mentioned that they felt comfortable with the approaching manner of the Thing, as it would not move directly to them but wait till they responded to it.

"That it would not just run into you, but approaches you from a distance and asks you what to do. That I found very trustful" - Participant 3

All participants appreciated the multiple options of the Thing to adjust to citizens. They also understood and accepted that a Thing might keep its place. However, two participants showed their doubts whether a Thing should be able to stay at a fixed place, or whether there should be an option to remove the Thing if it is staying at the wrong spot and truly hindering citizens.

"And what if I push him now? That is a good one right? If I really want him to go" - Participant 2

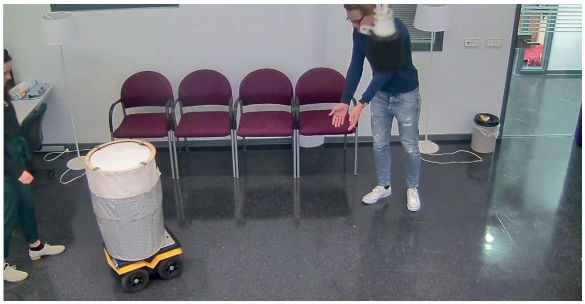
Various gestures were used during the roleplay

The gestures by the participants to reject the Thing resembled movements as if they were leading the Thing away or to another place. Except for one, participants did not make rejecting movements when they were asked to tell the Thing that they did not

approve their company, see figure 35. One participant indicated that she found it unusual to sign in the air. She preferred to touch the Thing to communicate.

Figure 35: Participant 1 leading the Thing away.

The variation of gestures was bigger for the accepting movements, see figure 36. The participants used a thumbs up or made a 'come closer' movement by making a closing movement with their hands.



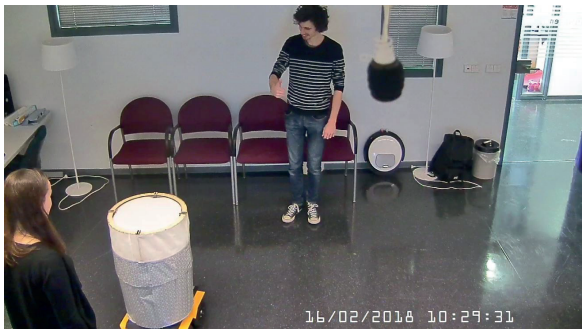


Figure 36: Participants 2 and 4 make different gestures.


FedEx

Breathing movement related to cleaning

All participants thought that the movement indicated that the Thing was cleaning. Faster movements meant that the Things needed to work harder than normal.

"I think that the air is more polluted if they move faster. It is kind of logical, the more polluted the air, the faster it has to clean"
- Participant 3

Most participants saw the movement as if it was breathing and thought it looked like the scales of a fish.

"These are beautiful movements, it seems like breathing, it is relaxed to look at"
- Participant 6

Sometimes the movement became confusing. One participant thought that the movement was purely implemented to stimulate the airflow. Another participant noted that he did not interpret the differences in movement as a different state of the air pollution.

Suggested improvements for individual behavior

The suggestions for improvement varied and seemed to be individual dependent. The most named suggestion was to add colour to the light to suggest different states. Furthermore, three participants suggested to create a more eye like screen in front, to make it more friendly and as if it is communicating, as a bar looks more like zorro or anonymous.
Some participants indicated that they missed the sound of cleaning. They expected a sound similar to the sound of air conditioning, as an indication that it is working.

One participant indicated that many scales on the surface of the Thing might be too busy for an already busy environment of the city.
Two participants showed interest in a display, which could state the exact level of air pollution or explain its reasons why it chose a place to stay. However, another participant did reject the idea of displaying measurements as she thought it would be meaningless as a number is vague to interpret if you are not familiar with it.

Perceived team behavior

The behavior of the team caused discomfort

Remarkably, most participants did not feel comfortable with three Things approaching them. The idea of three Things going at you is rather perceived as three Things trying to get you. Most participants did not see a reason for three Things to approach them, they found it overwhelming.

"But why are they coming at me in the first place? What do they want?"- Participant 2

The third fragment is chosen as the preferred behavior

All participants disliked the first fragment whereby the Things did not gather as a group before approaching the citizen. According to them, it felt as if the Things seemed to want to attack.

"The first one really felt like, okay, we are going to attack you, or something? They went straight to me and I thought help"
- Participant 5

Most participants liked the third fragment whereby the Things gather first from a distance and approach the citizen all together. One participant argued that this approach would fit better in the city as it enables busy people to prepare for it.

"Realistically, you are walking over there, or you are talking with someone (...) or navigation. I would be pretty scared if all three would suddenly be so close. If I would have seen them coming from far it would be more comfortable. - Participant 1

The second fragment was not perceived well by most of the participants, as they did not see the value of animating the communication between the Things.

"I don't really need that communicating idea, it does not affect me because these Things always communicate with each other" - Participant 3

However, two participants preferred the second fragment as they liked the idea of a character for the Things

"I liked the second one, because they did not have a straight direction, it seemed more like autonomous Thing, they were not looking at me at first." - Participant 2

The concept fits in and contributes to the city

All participants thought that the concept would fit in the city. Not only the looks, but also the flexible behavior and their ability to act autonomous at the right moment were seen as a positive aspect that would make them fit into the city.

"If you are in a hurry as a citizen or if you just do your thing, than the Thing can clean at its own speed next to the hurried citizens. I think the city is always busy, and this concept can just function beside the business and do its own Thing" - Participant 6

Furthermore, they appreciated that the Things would go look them up before they would stand beside the citizens.

"It suits in a public environment because it approaches you at ease and does not stand somewhere or act the way he wants to, but he first looks for contact."
- Participant 3

They also mentioned that they found a dynamical and responsive system more contributing to the city than if it would have been a static one. The most used argument was that they thought most citizens would not look at static clean places as they would have somewhere to go to.

"If people want to do something in the city, then they would not go to a specific cleaning place. I think that this way would only address to a small group of people."
- Participant 4

DISCUSSION

The following paragraphs describe the validation of the micro interactions based upon the comparison between the design qualities and the participants' evaluations.

The Things are perceived as partners

During evaluation, all participants rated the Things to be nor dominant nor extremely submissive. One participant mentioned that she did find the Things dominant if they would approach you in a team, but that it was not negative point if they would listen to you.

"It depends on the interaction that follows; if they together ask for my permission, or if I can send them away easily, I don't think it's a problem." - Participant 3

They did not perceive the Things to be submissive as they act according to their own data and do not listen to you as a citizen all the time.

"You do have the feeling that they work for you so they would be more submissive, but they can keep still if you ask them to go. So it does a little bit what he wants to do." - Participant 6

As participants did not perceive the Things to be dominant or to be submissive, it can be stated that Things were perceived as partners: equal contributors to air purification.

The differences between Things and humans are almost bridged by the communicative movements

Most participants indicated that the Things are understandable in their intentions. The combination of light and movement was well perceived and all participants understood the breathing movement, except for one participant that did understand the movement but thought it was part of the functioning of the system.

However, participants found it difficult to differentiate between whether a Thing is cleaning or whether it is making eye contact. The participants indicated that it is important to shape the camera form like eyes, as it enhances the experience to look at it. It might be awkward to make gestures to the Thing otherwise.

In case the Thing is just cleaning, it might be useful to design a separate 'looking' state, as otherwise it might look like the Thing is staring at you while it is just cleaning.

Participants also lacked a sense of confirmation during the dialogue. Especially during the moments that the Thing is waiting for a response from your side or confirming that it has understood your reaction. A small sound, different colour light, or movement of the head are enough to create a more confirmative behavior according to the participants.

Participants lacked an understanding of what is going on in the Thing. They feared that they would not notice if something is going wrong inside or they did not like to have no explanation of the Thing's choices. However, as stated in the design vision, it would be better to present this information somewhere in the background, for example in an application, as it is likely that most citizens are too busy in the city to have an interest. Interested citizens can find out by own effort how effective the Thing is at cleaning or simply to find an explanation of what the Thing is doing.

The Thing proves the ability of a continuous agreement

All participants perceived the Thing as being flexible, as it has multiple ways of responding to you and is able to change its mind. They accepted that the system could be at odds with your wishes, but doubted whether it is recommendable to keep the Thing in disagreement even if it is truly standing in the way of a citizen.

"I did not like that it stayed put, I understand the idea, but as a citizen, I'm not convinced I like this." - Participant 2

Except for this small remark, it is proven that the Thing is able to have a continuous agreement with a citizen.

The Thing is perceived to be trustful, but the team behavior needs to be improved

Most participants found the Thing trustful. The way that the Thing approached them was the main argument for participants.

"The fact it won't just walk into you but approaches you from a distance and ask "Hey, what do you want to do", I found that very trustful." - Participant 3

The only improvements to make it more trustful are described in previous paragraph. One participant also mentions that trust is also created by the perception of the Thing, as it seems to truly do its job.

"I do really think it is there to clean air, that it really does its thing, it looks 'chill'." - Participant 6

For the team behavior, there is room for improvement. The teams were moving to fast towards the participants, which made them uncomfortable. The uncomfortable feeling can also partially be explained because it is hard for a human being to understand or visualise the behavior of groups of moving objects (Kolling et al., 2016).

Yet, if teams appear visibly from far and form a cohesive group before they start to approach humans, the approaching behavior would be less intimidating according to the participants.

The Things prove their right to exist with their valuable and suitable contribution

As could be seen in the results, the Things were seen as a valuable addition to the city. Moreover, the participants regarded the Things as a concept that would fit in the city. As one participant described:

"Well, it is, it is like a 'cleaning legion' that wanders through the city. Of course, that's not what it is but, it's always busy in the city and it fits in, it's like an ant colony." - Participant 5

One little remark on the breathing movement was that it could be too busy for an already chaotic and overwhelming city environment. This could simply be improved by enlarging the texture.

Interestingly, the shape of the Thing reminded the participants of a trash bin. However, it is not desirable that the Thing would resemble an existing everyday object as it should show its own and new function to the city. Mostly the front of the Thing reminded participants of a trash bin, so the design of the front should be reconsidered.

CONCLUSION

The results of the study prove that the micro interactions do incorporate the design qualities. A majority of the participants shared the same opinion about the behavior of the Things. However, there is room for improvement to incorporate the design qualities more convincible. These will be incorporated in the final design in the following ways:

- A new design for the eyes will be implemented, to enhance the look of an eye and to make the design of the eye less creepy.
- Two additional interface designs will be created to communicate the state of cleaning and the state of waiting for a response in a better way.
- The team behavior will be changed to a behavior similar to the third fragment: the Things will move slowly, approach as a team from far and will form a group before approaching.
- The overall design will be reconsidered as it should not resemble an existing object such as a trashcan in the city. The Thing should show a unique function.

08 FINAL CONCEPT

ADJUSTMENTS

This chapter presents the final design of the concept. The recommendations in the conclusion of the evaluation study, chapter 7, are implemented in the final design to improve the Thing and its behavior. The adjustments for the final model are described on this page. The design cues are briefly summarized and presented on the following two pages.

Visual appearance

The overall body shape of the concept remained the same, but the design of the head is modified. Instead of making the form of the camera glass into the form of eyes, it is chosen to create a more clean and subtle look by avoiding the form of eyes. Instead, the eyes will appear on the glass as a digital layer.

Breathing texture

The breathing texture remained the same, only now it indicates the air pollution level around as well as that it is cleaning. Initially, there were two design cues for both: the breathing motion indicated the air pollution level and the illumination of the body represented that it was cleaning. However, seperating both makes no sense, as the motion already indicates that it is cleaning and the speed of the motion indicates how polluted the area is.

Sounds

Sounds are added to enhance the understanding of the Thing's behavior. An air conditioning sound is added in addition to the breathing texture to indicate that the Thing is cleaning.
Furthermore, the Thing can make small sound during the dialogue in order to indicate that it is waiting for a response.

Lightning

The body will not constantly illuminate anymore when it is cleaning. However the light of the Thing will brighten slowly when it has understood that a citizen approved its company and will flash its light if it rejects a citizens request to leave.

Team behavior

The teams will not make very expressive eye contact, as that type of behavior was perceived as creepy and unnessecary. Instead, the Things will adjust their color to the team's color and will come together first and adjust their movement before approaching a citizen.

Clean facial look

No indication of eyes in the form design of the camera glass, so the Thing has a clean and natural look.

Breathing motion texture

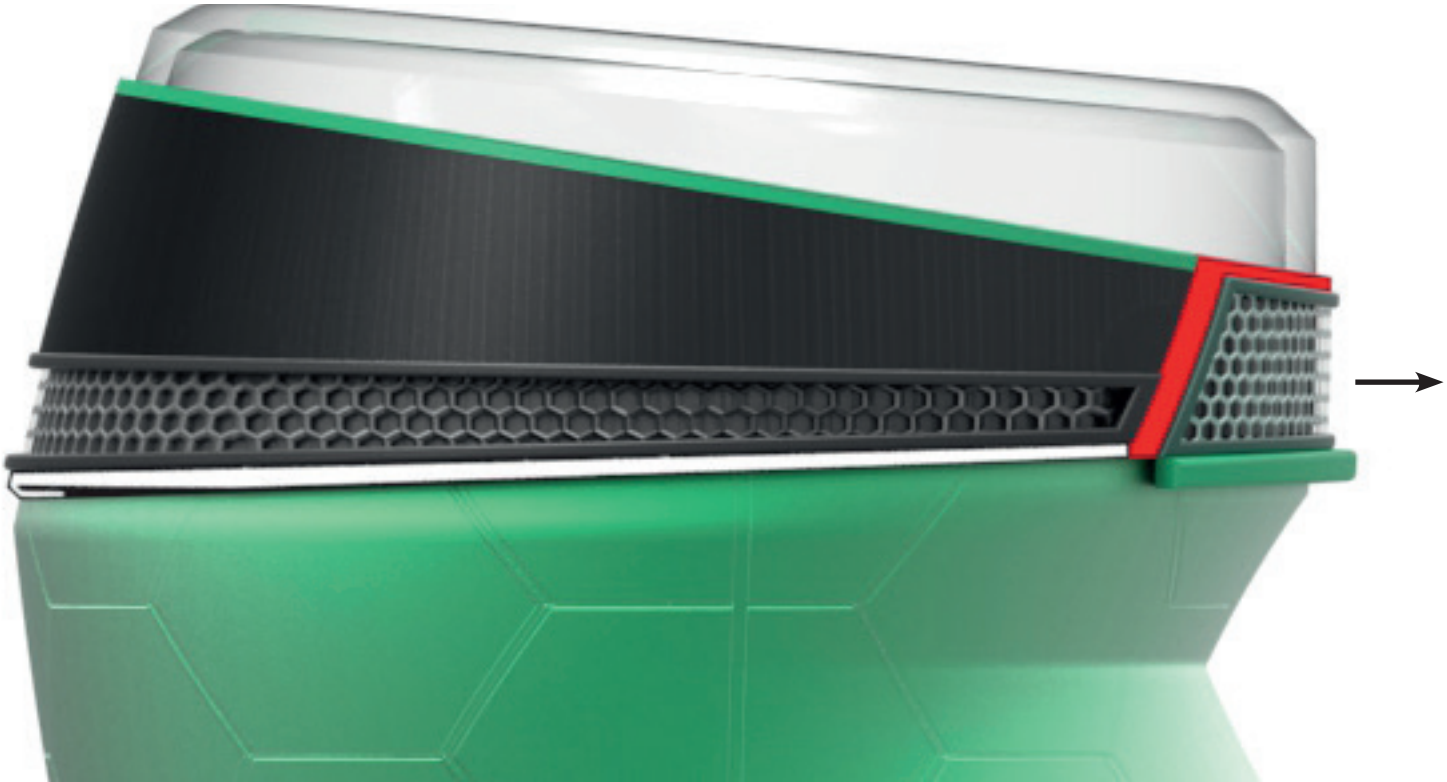
Unlike in the previous concept, the breathing texture of this concept shows the air pollution level and if it is cleaning, or not, at the same time.

Sound of air cleaning

In addition to the moving texture, the Thing will make an air conditioning like sound to make clear that it is cleaning.

Additional behavior design cues

The concept has three additions to the behavior design cues of previous concept:
1. Eyes appear when it is driving around or approaching citizens, so citizens know where to look at.
2. The Thing is able to make a sound if it is waiting for a citizens' response. This is expected to improve the understanding during a dialogue.
3. The Thing can now close its eyes while cleaning on the street, so it does not seem as if it is making eye contact to you as a citizen.



BIBLIOGRAPHY

Airlabs (2015). Air Pollution Hotspots. Retrieved at 4th of March 2018 from http://airlabs.com/2017/10/09/air-pollution-hotspots/

Boonstra, R. (2014). Measuring air quality. Retrieved at 4th of March 2018 from https://waag.org/en/blog/measuring-air-quality

Dietz, G., Washington, P., Kim, L. H., & Follmer, S. (2017). Human Perception of Swarm Robot Motion. In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (pp. 2520-2527). ACM.

EEA (2017). Air quality in Europe: 2017 report.

EPA (2018). Technical Overview of Voletile Organic Compounds. Retrieved at 4th of March 2018 from https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds#3

EPA (n.b.). Voletile Organic Compound Emissions. Report on the environment.

Giaccardi & Smit (2017). Pure Air for Cities of Things - Introduction Presentation. Retrieved at 4th of March 2018.

Hall, E.T. (1966). The Hidden Dimension.

Koay, K. L., Lakatos, G., Syrdal, D. S., Gácsi, M., Bereczky, B., Dautenhahn, K., ... & Walters, M. L. (2013). Hey! There is someone at your door. A hearing robot using visual communication signals of hearing dogs to communicate intent. In Artificial Life (ALIFE), 2013 IEEE Symposium on (pp. 90-97). IEEE.

Kolling, A., Walker, P., Chakraborty, N., Sycara, K., & Lewis, M. (2016). Human interaction with robot swarms: A survey. IEEE Transactions on Human-Machine Systems, 46(1), 9-26.

Saffer, D. (2013a). Microinteractions: designing with details. " O'Reilly Media, Inc.".

Leung, M. K., Tang, S. M., Lam, R. C., Leung, D. Y., Yam, W. C., Ng, S. P., & Vrijmoed, L. L. (2006). Parallel-plate solar photocatalytic reactor for air purification: Semi-empirical correlation, modeling, and optimization. Solar energy, 80(8), 949-955.

Longfonds (2018). Nieuwe mobiele check maakt luchtvervuiling zichtbaar. Retrieved at 4th of March 2018 from http://amsterdam.longfonds.nl/actueel/nieuws/nieuwe-mobiele-check-maakt-luchtvervuiling-zichtbaar-11

Marenko, B., & van Allen, P. (2016). Animistic design: how to reimagine digital interaction between the human and the nonhuman. Digital Creativity, 27(1), 52-70.

RIVM (2013). Roet aanvullende maat voor gezondheidseffecten luchtvervuiling.

Sirkin, D., Mok, B., Yang, S., & Ju, W. (2015). Mechanical ottoman: how robotic furniture offers and withdraws support. In Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction (pp. 11-18). ACM.

WHO (2014). 7 million premature deaths annually linked to air pollution. Retrieved at 4th of March 2018 from http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/.

Yang, R., Zhang, Y. P., & Zhao, R. Y. (2004). An improved model for analyzing the performance of photocatalytic oxidation reactors in removing volatile organic compounds and its application. Journal of the Air & Waste Management Association, 54(12), 1516-1524.

Zhao, J., & Yang, X. (2003). Photocatalytic oxidation for indoor air purification: a literature review. Building and Environment, 38(5), 645-654.

Zhong, L., & Haghighat, F. (2015). Photocatalytic air cleaners and materials technologies–Abilities and limitations. Building and Environment, 91, 191-203.

Images

Belludi, N. (2008). Albert Mehrabian's 7-38-55 Rule of Personal Communication [Graph]. Retrieved at 4th of March 2018 from http://www.rightattitudes.com/2008/10/04/7-38-55-rule-personal-communication/

Guerreiro, C. (2013). The exposure to harmful levels of air pollution by Europeans [Graphic]. Air quality in Europe: 2013 report.

Normal Breathing (2018). Breathing patterns [Graph]. Retrieved at 4th of March 2018 from https://www.normalbreathing.com/d/etco2-capnography.php

Saffer, D. (2013b). The structure of Micro Interactions [Graphic]. Retrieved at 4th of March 2018 from http://microinteractions.com/what-is-a-microinteraction/

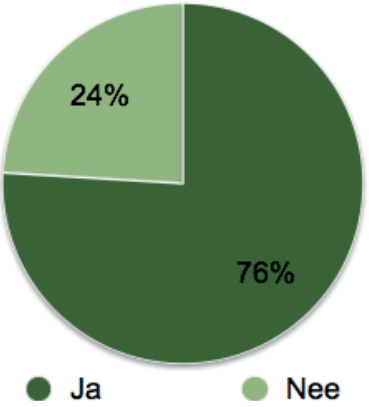
APPENDICES

10.1 AIR POLLUTION QUESTIONNAIRE

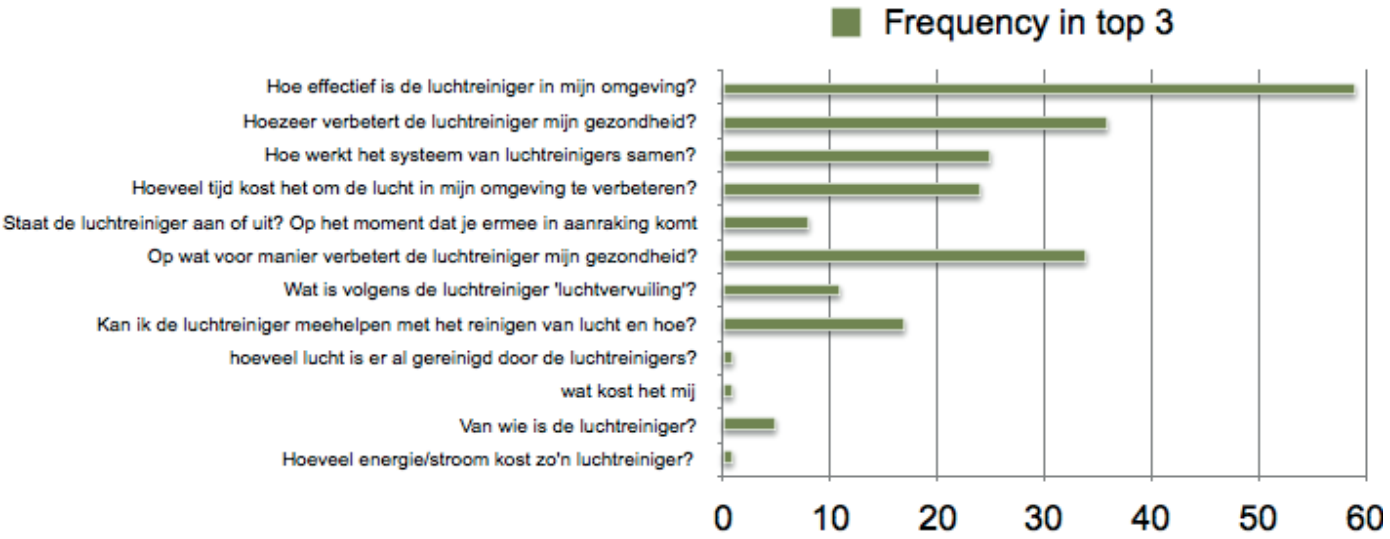
A questionnaire is set up to investigate the interests of Dutch citizens regarding air pollution and a clean air distribution system. The aim is to identify the drive of citizens to co-perform with the Things of the system. The questionnaire is filled in by 79 respondents. The results of the three main questions are shown in the figures of this appendix.

From the following list, respondents chose a top 3 of what they would want to know about air pollution.

76% of the participants would like to be actively involved if an air purification object would be installed in their neighborhood.



From the following list, respondents chose a top 3 of what they would want to know about air purification.



10.2 MOVEMENT STUDY

A movement study is conducted in order to study the principles of a dialogue. The movement study exists of the analysis of a roleplay between two participants. One participant acted according to a Thing, the participant with the umbrella, and the other participant acted according to a citizen. The participants were limited to using gestures and facial expressions during the roleplay. The two participants received a script which they had to follow. The script contained six scenarios. During the roleplay, both participants did not know the content of the script of one another to prevent biased reactions or behavior. After the roleplay, each scenario was analysed by means of video material. Each scenario is described on the following pages followed by a short conclusion.

Script 1: The first time that a citizen and Thing have a dialogue

Both participants have received short instructions for their characters. The participant of the Thing will observe the citizen and try to confirm with the citizen if they are walking together. The participant of the citizen will try to walk next to it and will observe if the Thing understands it.

Both are walking towards each other, slowing down, making eye contact.

The citizen angles her head slightly backwards and both start to turn their body to align movement.

After a few seconds hesitating and confusion, the Thing initiates the interaction by raising the brows and nodding, exaggerating. The citizen responds by doing the same.

They nod again, as a sort of confirmation that they have a sign for understanding each other.

Conclusion

Although probably citizens will try to understand first how the Thing works before they take action, it is important that it is clear who initiates the dialogue. Moreover, during first dialogue, it could be useful for citizens and Things to confirm their understanding.

Script 2: A citizen and Thing that are used to having a dialogue

Both participants will replay the scenario of the first script, only now they have to imagine that they are used to the dialogue.

Both are walking towards each other, at the same speed, citizen is tilting the head, being confident, both align their bodies.

The citizen confirms first, with an enthousiastic nod. She raises her brows simultaneously.

The Thing reacts with a clear nod back, using same characteristics.

Both start to look ahead, adjust the speed and continue their walk, as if it is a routine.

Conclusion

Clearly, less communication is needed when both are used to having a dialogue. They observe the reaction of the other with certain expected behavior in mind. Their reactions are faster as they feel confident with their actions.

Script 3: The first time that a Thing stops the dialogue

The participant of the citizen remains playing the end of the scenario of the first script, so she has to walk next to the Thing. The actor of the Thing has received a new instruction to stop the dialogue, by making clear that she has to go and by confirming the end of the dialogue.

Both walk together at the same speed, looking straigth ahead.

The Thing stops, turns and slightly bends forward, signing 'change' to the citizen. The citizen does not notice it.

The Thing is already folding its cleaning function, while the citizen turns around and suddenly realises the change.

The Thing makes eye contact after folding and raises the brows, tyring to communicate the change.

The Thing leaves and the citizen stays behind, confused and not sure about what happened.

Conclusion

The participants have shown a clear miscommunication during the scenario. As the citizen notices too late what is happening, it seems as if the Thing has an own agenda. The citizen becomes confused, even more after the Thing leaves without it waiting to confirm that the citizen has understood what happened.

Script 4: The Thing stops a dialogue with an advanced citizen

Both participants play the same scenario of script 3 again, only now they have to imagine that they are used to the scenario.

Both walk together at the same speed, looking straigth ahead.

The Thing stops and folds in the function. The citizen looks back and notices it.

The Thing has folded the cleaning function and makes eye contact.

Both the Thing and the citizen starts to make a nod, as if thanking each other.

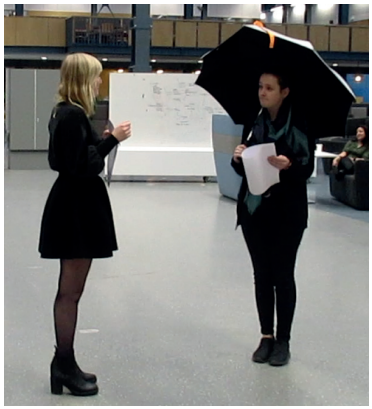
Both the Thing and the citizen start to leave, while the citizen shortly looks back to see the Thing leaving.

Conclusion

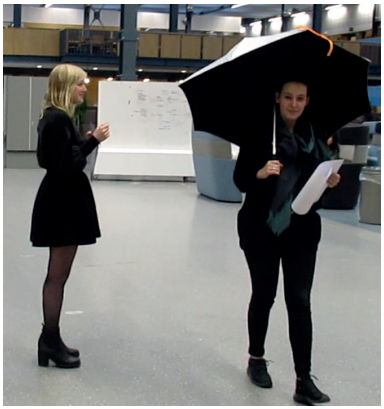
The participants did not change the beginning of their act, the Thing is still suddenly stopping. They opt that there would be another attention raising feature such as sound, as a citizen might continuously look straight ahead. They seem to copy the same nodding behavior of previous scenarios into this scenario as well.

Script 5: The Thing communicates to be unavailable to a new citizen

The participant of the citizen is asked to replay the scenario of the first script, so to follow the Thing. The participant of the Thing is asked to indicate that it has no time to let the citizen follow it.



The Thing makes a sad face to the citizen that just walked to the Thing. Head is bended forward.



The Thing starts to walk away, and looks back 'do you understand', while the citizen is left, confused.

Both participants start to laugh as they realise that the interaction was completely unclear.

Conclusion

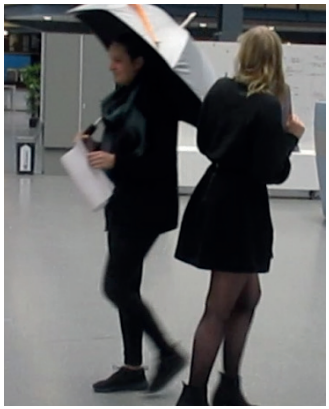
The communication of the Thing was obviously not clear to the citizen. Apparently, only a facial expression was not enough for the citizen to understand the intention of the Thing. Once again, the Thing did not wait until the citizen understood its intention, leaving the citizen clueless behind.

Script 6: The Thing communicates to be unavailable to an advanced citizen

Both participants play the same scenario of script 5 again, only now they have to imagine that they are used to the scenario.

The citizen starts to walk towards the Thing. The Thing is slowing down, shaking its head in advance.

The Thing is looking sad and raises the shoulders, while the citizen watches.



Both the Thing and the citizen start to move in opposite direction.

Even though the citizen indicated that she understood what happened, she looks back at the Thing that leaves.

Conclusion

The participants did not change the beginning of their act, the Thing is still suddenly stopping. They opt that there would be another attention raising feature such as sound, as a citizen might continuously look straight ahead. They seem to copy the same nodding behavior of previous scenarios into this scenario as well.

10.3 STRUCTURE OF THE EVALUATION STUDY

0. Introduction of the case

The participant is introduced to the topic and concept. The participant is told that the study is about the air purification in the city by an amount of Things with integrated catalysis. A picture is shown to show the visual appearance of the Thing. For the first part, the interaction with a single Thing is act out in real life, following is a semi-structured interview. For the second part, a small team of Things is shown on screen, to evaluate team behaviour.

1. Roleplay and semi-structured interview

A script is developed for the participant to get into a story of a citizen. The script exists of two parts:
1. The participant is first asked to pretend to walk around in the city and to go and wait at the busstop
2. At a certain moment the participant comes in contact with the physical prototype, which is driving around
3. The prototype notices the participant and is making contact by slowly approaching and turning the 'head' in the direction of the participant.
4. The Thing will settle near the participant and the light will be turned on. The participant is asked what it will mean.
5. The participant is asked to show the Thing that it is inappropriate to come close at the moment using gesture movement, the Thing should therefore move away.

6. The participant is asked to pretend to walk in the city again to the bus stop.
7. The prototype will approach the citizen again, but will keep moving to and moving away of the participant, as if in doubt. While looking
8. The participant is asked what it does.
9. Then, the participant is asked to encourage the Thing to come closer using gesture movement. The physical prototype will go near the citizen and the light turns on.
10. After a while the light stops and the robot moves away.

11. The robot moves around and goes in front of the busstop
12. The citizen is asked to go to the bus stop
13. The citizen is asked to gesture that it is not a good time
14. The robot stays in place, lights turn on and off, indicating it cannot move
15. The participant is asked what it means.

Following is a semi-structured interview with the participant with the following questions:
1. Did you understand the intentions of the Thing?
2. What factors of the Thing (e.g. speed, smoothness of movement, other interface decisions) do support your opinion?
3. How do you think the interface of the Thing could be improved to make the intentions of the Thing more understandable?

4. Did you feel at ease with the way that a Thing approaches you?
5. How do you think the interface of the Thing could be improved to make you feel more at ease with the behaviour of the Thing?

2. Video and semi-structured interview

Movies are shown on a screen that portray the following scenarios:
1. Three Things breathing, with two different sequences. The participant is asked to tell what it means. The participant is asked what supports the opinion and is asked how it can be improved.
2. Three Things that approach citizens in three different ways. The participant is asked what he thinks of each movement, regarding comfort and clearness of intention, and is asked to make a top 3, explaining why.

3. Evaluation form

The participants will fill in the evaluation form prior to the last questions. Once the form is completed, the participant will be asked to explain their scores. During this interview, the main subject will be the behavior of the Thing and team of Things.