Pebble

Enhancing the indoor air quality through plants

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ABSTRACT

As clean air improves productivity (Kosonen & Tan, 2004; Wargocki et al., 2000) and health (Annesi-Maesano et al., 2013; Jones, 1999), air quality is becoming an important aspect to improve. As a result, more and more research focuses on how to improve the quality of indoor air(FANGER, 2003; Kim et al., 2008). In this work, we aimed to explore new ways to improve the quality of air using a Data-enabled Design approach. First, we deployed a sensor kit in the house of a potential user to measure certain air parameters and user actions. We explored the design context by combining sensor data with interviews to spot irregularities or patterns of interest. Based on these findings, 4 design opportunities were proposed, after which one was selected for the continuation of the project: world's most sustainable air filter, plants. During the second phase, we deployed a new prototype at a second participant. Using the new sensor data and interviews, we iteratively developed our concept and explored different methods to incite users to improve their indoor air quality. We conclude by incorporating our findings into our concept: Pebble. A kit that allows you to grow your own customized air filter over time.

Authors Keywords

Data enabled design; user research; air quality

INTRODUCTION

For educational purposes, we were challenged to design a solution to create a healthier living environment, by either changing the environment and/or the behavior of the user (van Kollenburg, Bogers, 2019a). In this study a Data-enabled Design approach (van Kollenburg, Bogers, 2019b) was taken to tackle this challenge in two distinct phases. In the first phase, called the contextual step, we aimed to obtain a profound understanding of the defined context: indoor (student) housing. During the second phase, the informed step, the insights of the contextual step were used to design and deploy a first iteration. The deployed iteration is continuously adjusted and evaluated in situated explorations (van Kollenburg, Bogers, 2019b). The approach ensures an iterative design process in which the consecutive iterations are based on findings (from both sensor- and qualitative data) of in-context prototype deployments. We aim to conclude this study with two main insights. First, the final iteration will be proposed providing an interesting research direction for future studies. Second, we will reflect on how the Data-enabled Design approach fitted this context and challenge, allowing others in the field to consider whether their particular challenge might fit Data-enabled Design.

Throughout this work, we will refer to the healthiness of an environment as the indoor air quality. Throughout the study, the definition of good indoor air quality has changed throughout different phases and iterations. The used definition will be described in those sections.

CONTEXTUAL STEP

First iteration

In order to gain a contextual understanding of our design space, we conducted a study in which several probes were deployed (see Figure 1). The participant lived in a two-story house with two other residents (see Figure 2). During this initial phase, we aimed to obtain an understanding of the relationship of the residents and their current air quality.

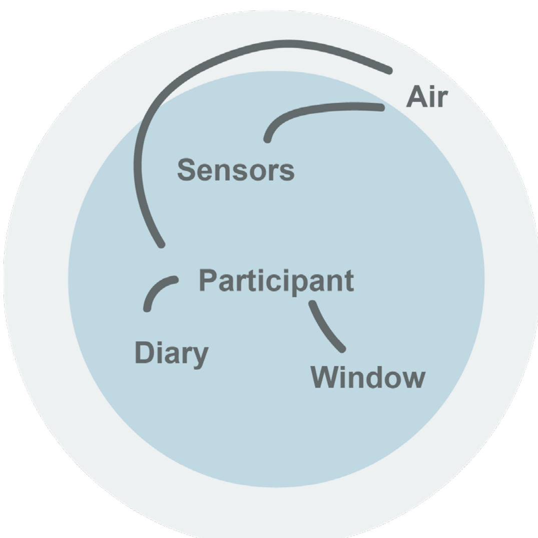


Figure 1: ecosystem during first iteration

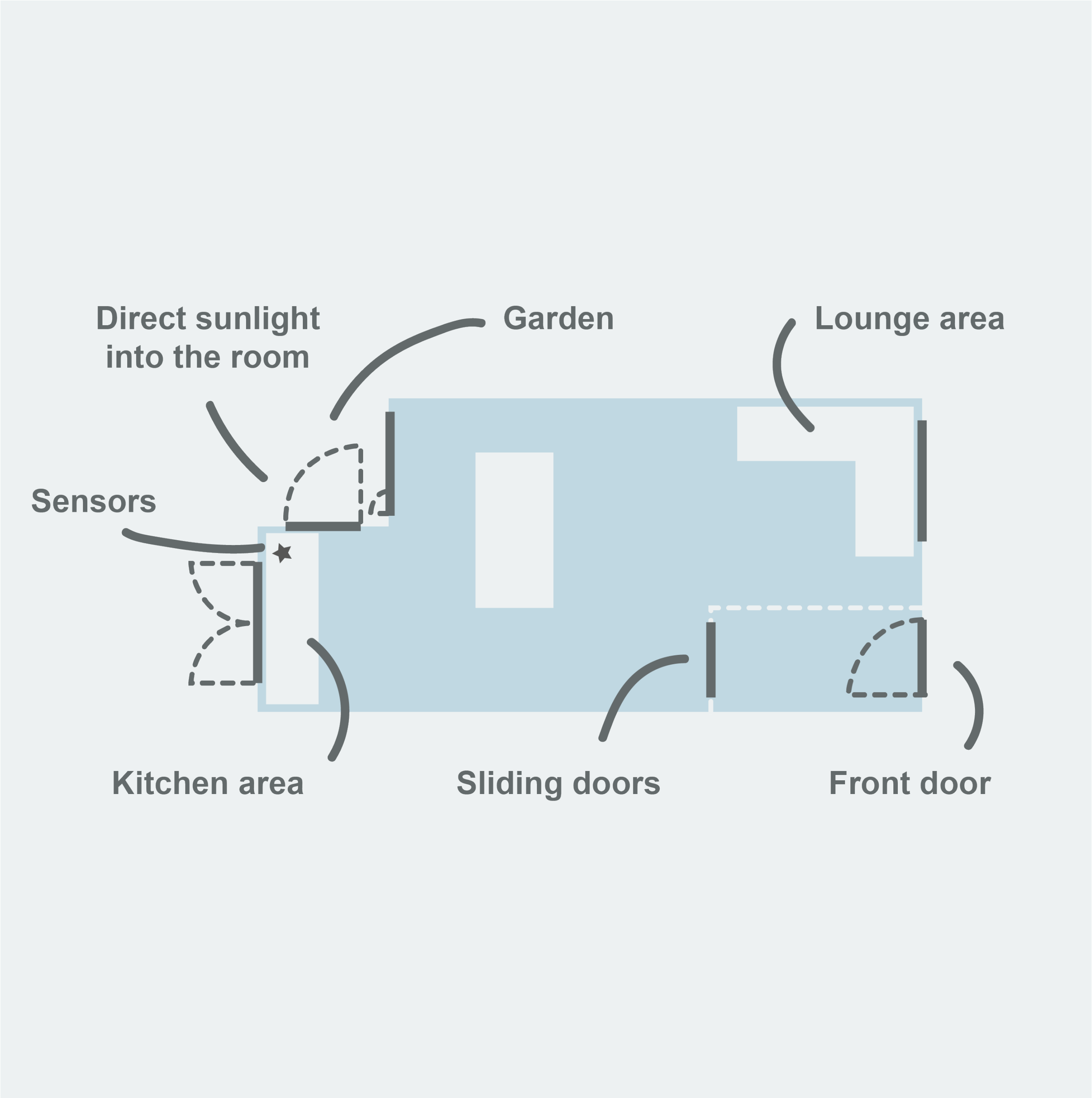


Figure 2: Map of living space of the first participant

Therefore we made a sensor kit which included a particle-, temperature-, humidity-, gas-, pressure-, and altitude-sensor (see Image 3). The participant placed the prototype in his home in a kitchen area, relatively close to ventilation facilities (see Image 1).

Additionally, we used a diary study (see Image 2). In this diary the participant could indicate when he was at home, what activities were performed and rate the perceive air quality of that day. Since we assumed that opening/closing windows would have the most impact on the air quality, we included a list (see Image 4) on which the participant could indicate that he had opened the window.

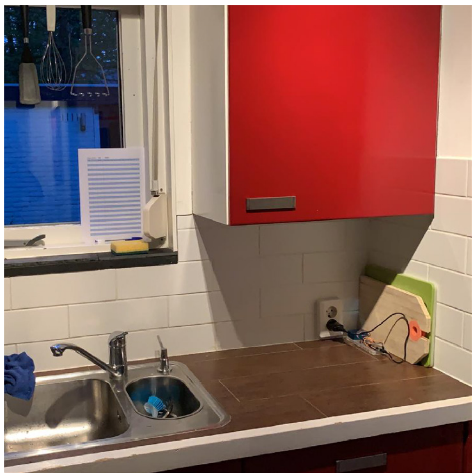


Image 1: Probes in context.

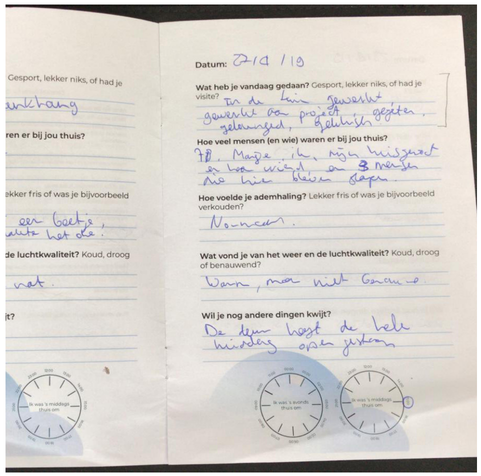


Image 2: Filled in diary.

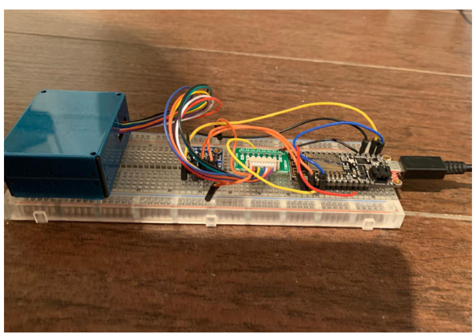


Image 3: Sensor kit.

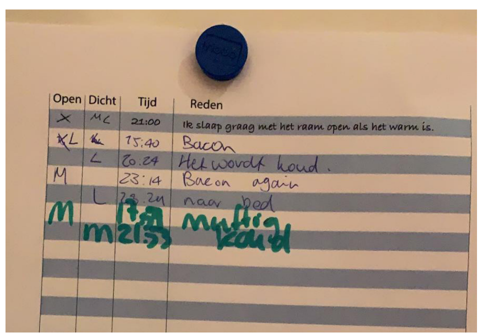


Image 4: List of open and closed windows.

Due to technical issues we were not able to gather any sensor data at this point. However, through the remaining probes we were able to conduct an interview with the participant. During the interview, we obtained several insights (described in the second iteration), which were used to adapt the research probes.

"The door has been open the whole afternoon."

- Diary entry

"Can you recall why the door was open that day?"

- Researcher

"My housemate was frying bacon the whole day and it smelled really bad. The smell stayed for hours after she was done."

- Participant

"Warm. But no itches."

- Diary entry

"Can you explain why you decided to write that down."

- Researcher

"I have hayfever and usually when it's this dry outside I start getting itches. That day I didn't feel anything, maybe because there wasn't much wind."

- Participant

Figure 3: Anekdotes from the interview.

CONTEXTUAL STEP

Second iteration

Firstly, we identified four main themes that influence the participant's behavior when it came to air quality. These themes were cooking, smell, temperature and hayfever. Therefore we redesigned the diary allowing the participant to log these themes. This diary design included easy and closed questions (see Image 5).

Secondly, the participant indicated that the threshold to log the state of the windows was high as it was a hustle to write down the time and reason of interacting with the window. Therefore we added a magnetic sensor to automatically track the state of the windows.

Finally, the partner of the participant played an important role in the indoor air quality. Therefore we included the partner into the ecosystem, allowing her to add her own diary entries (see Figure 4).

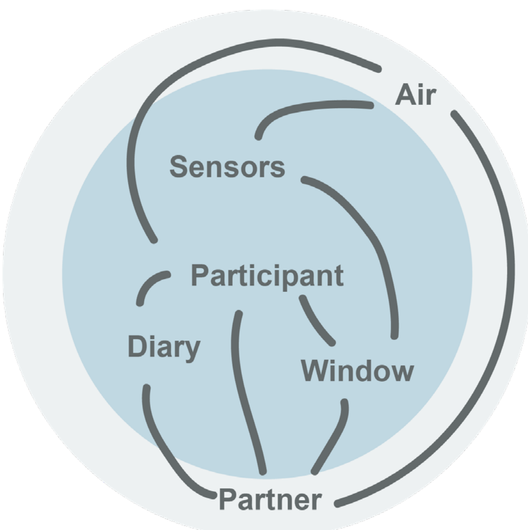


Figure 4: Ecosystem during second iteration

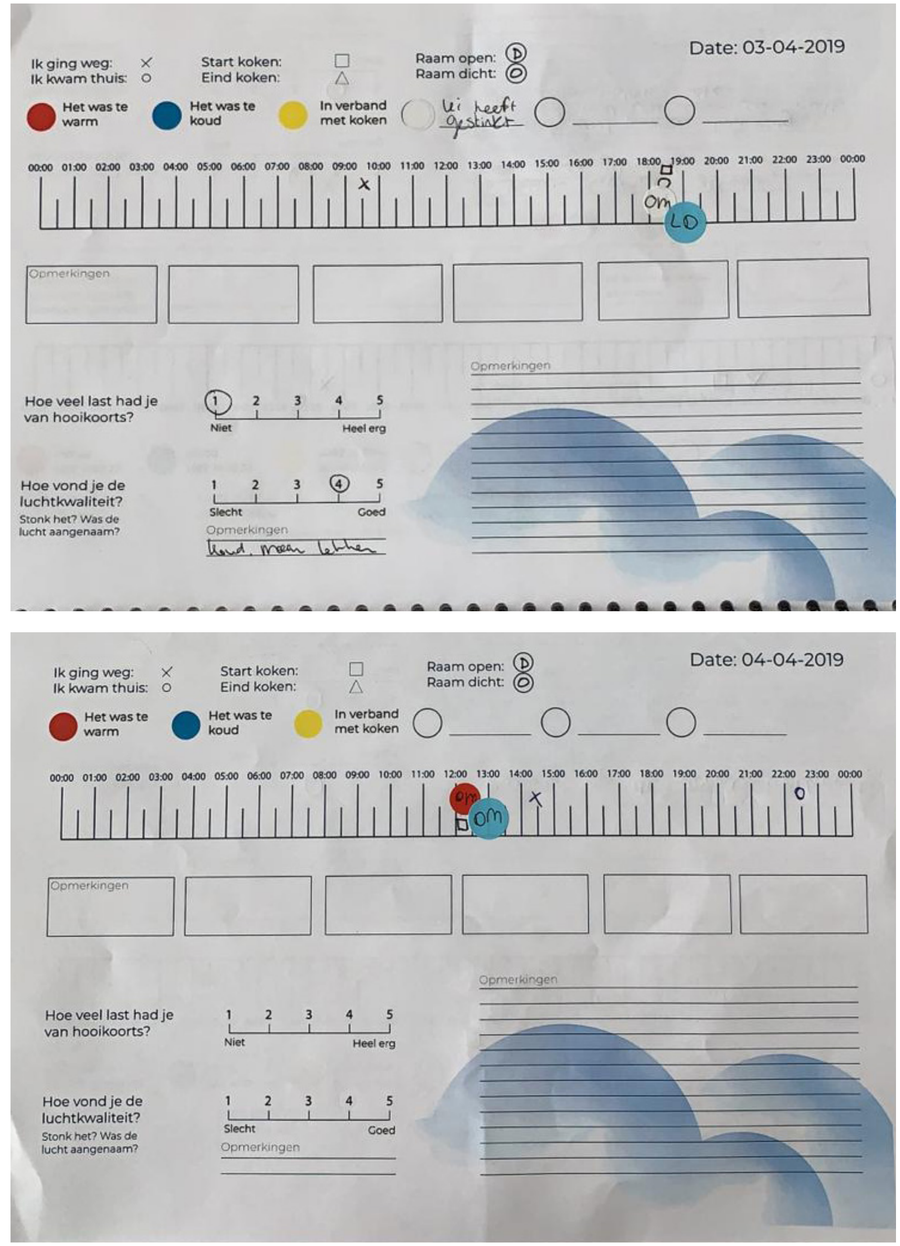


Image 5: Diary used during second iteration

Findings

From the diaries we noticed that the partner of the participant had much more interactions with the windows than he did. From a specific diary entry (see Image 6), we could also see some remarkable behaviour: The partner of the participant opened the window because of onion smell and the participant closed the window shortly after because of a cold temperature.

During the interview, the participant revealed that his partner is much more sensitive to temperature or mustiness. He also said that she prefers cold temperatures and he prefers warmer temperatures. This can sometimes result in the behaviour as described earlier. He also speculated that his partner sometimes opens or closes windows without it making any sense: for example when she feels hot during a hot day and that by opening the window, hot air flows inside.

Figure 5 shows a summary of the data entries. The participant and his partner each have different needs in regard to the air quality. And act on it very differently.

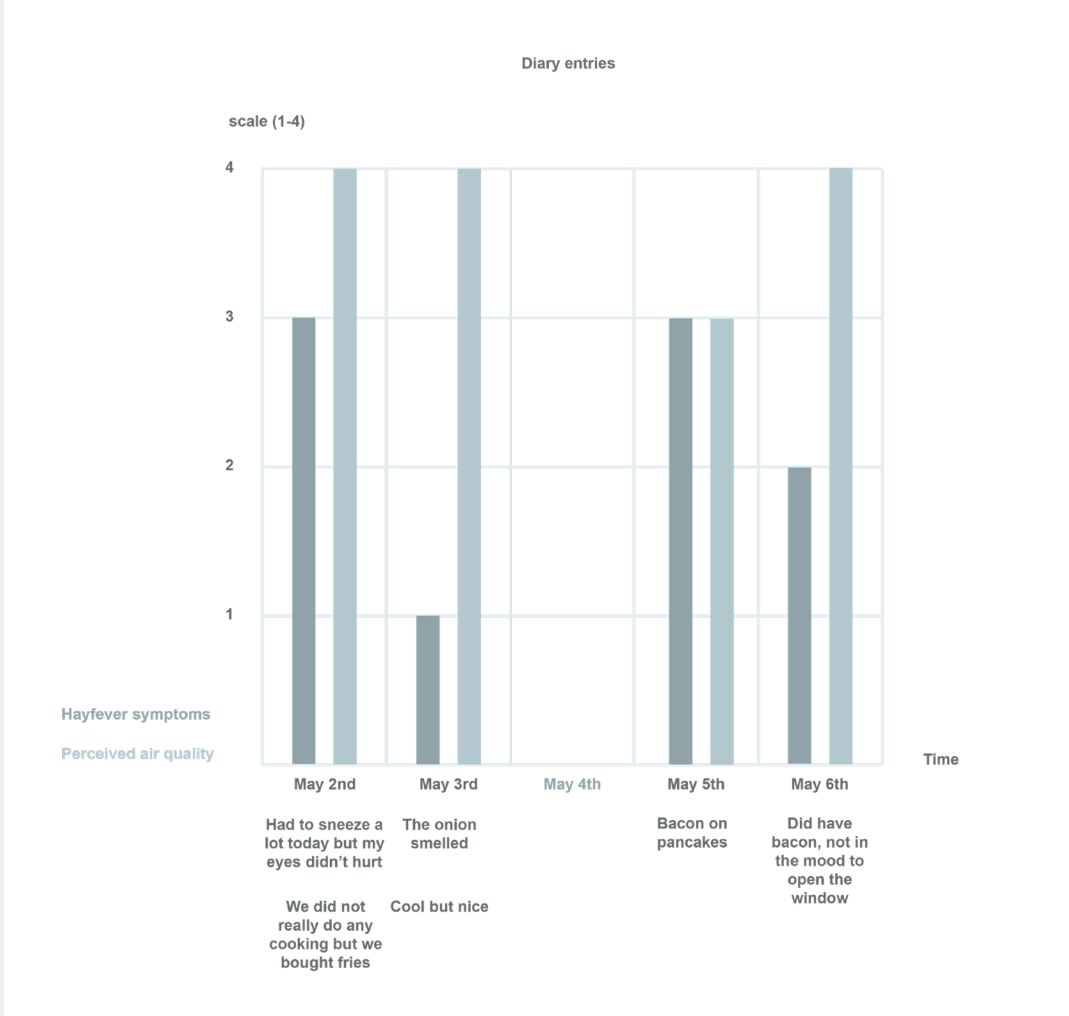


Figure 5: Overview of diary entries

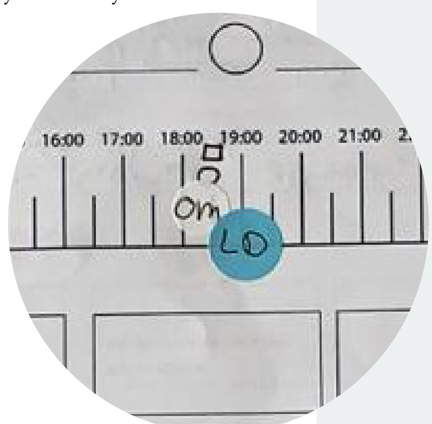


Image 6: Diary entry

Image 7: Interview with the participant

According to the diary the participant had experienced strong hayfever symptoms during that week. He talked about that he already expected that to happen since it had not rained for days and the temperatures were high. We learned that although he sometimes expects his symptoms to arise, he does not really do anything in order to prevent it. “I’ll just let it happen” he said. The participant does have preventative medication but he waits until after his symptoms arise to take the medication because they make him feel sleepy.

Other insights were with regard to the awareness of the traffic pollution and the participant’s behavior when he is caring for his plants (see Figure 6).

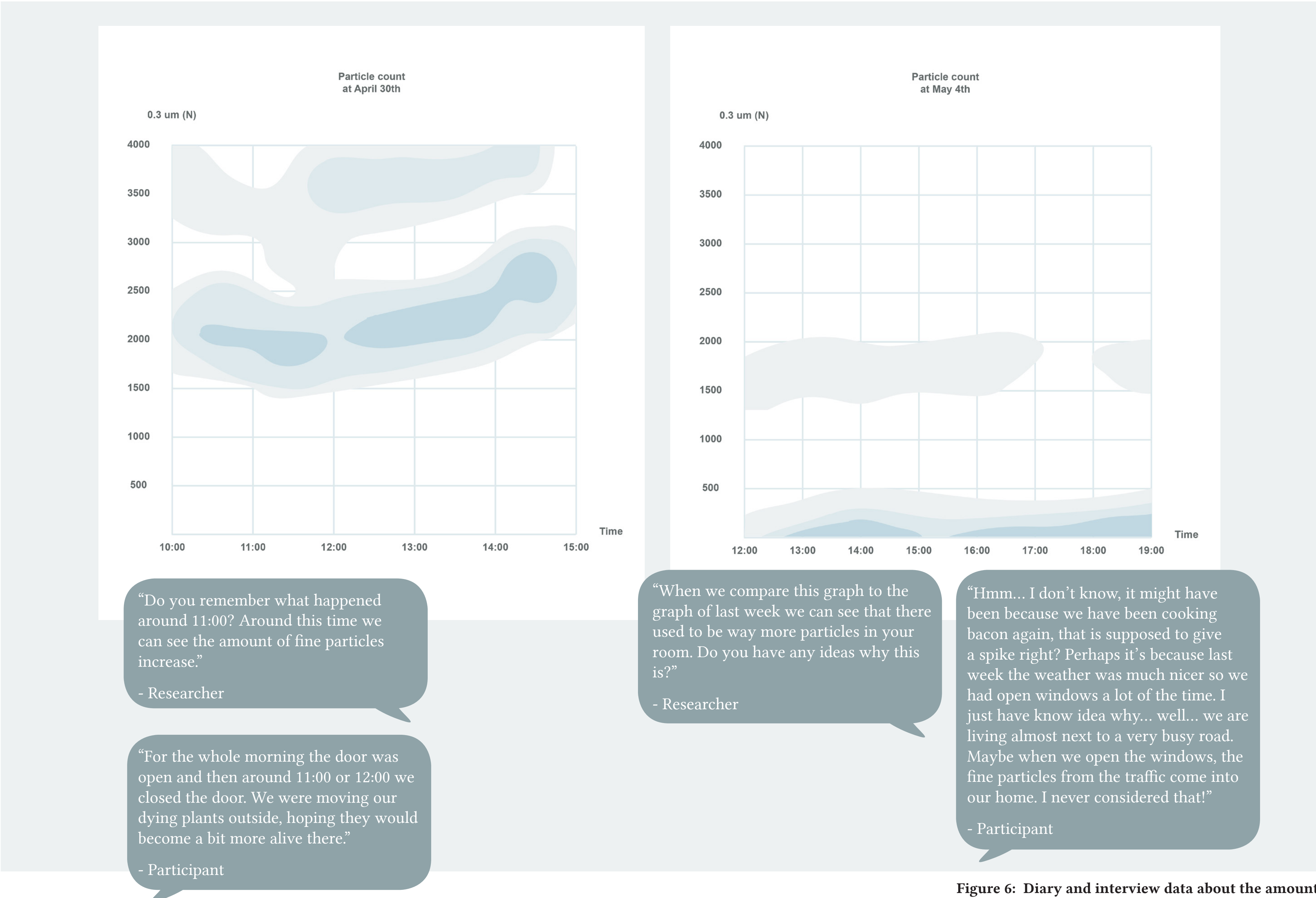


Figure 6: Diary and interview data about the amount of 0.3 um particles at April 30th and May 4th

INFORMED STEP

Conceptualization

Based on these findings, we defined multiple possible directions for our informed inquiry.

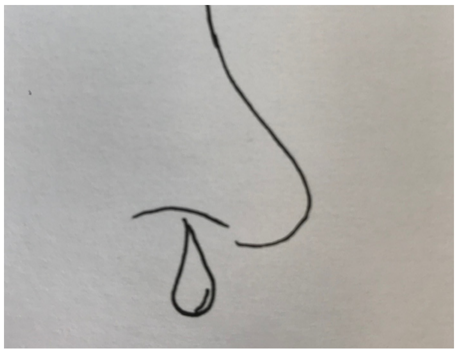


Image 8: Illustration of nose

Local Hay fever information

Information about specific plants (and their pollen) could be provided to the user, allowing medication to be taken prior to the arrival of the pollen and the annoying symptoms. While this seemed like an interesting approach based on the interviews with our participant, however, we were well-aware of the limited period (couple of weeks) where the potential product would be useful.

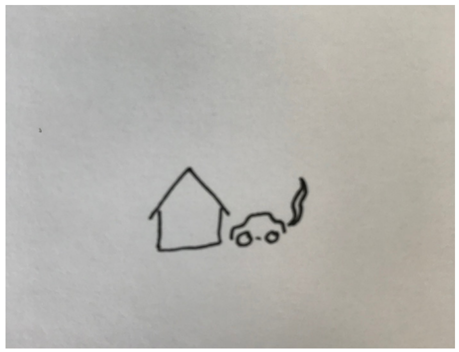


Image 9: Illustration of traffic pollution

Awareness

After we explained to our participant that there was a strong correlation between the amount of particles in the air and an open window, we found an interesting design opportunity. The participant informed us that he was unaware that the busy road next to his house had an influence on the amount of particles in his living environment. Generating awareness about these influences could help future users to improve their air quality. For example, by closing the window during rush hours.

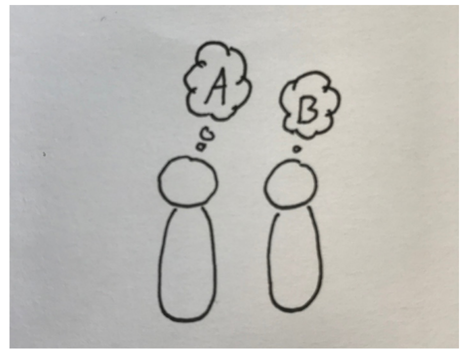


Image 10: Illusration of people with thoughts

Different preferences

Also, we learned that there was a strong difference between different residents of the house and their interpretation of air quality. This gap in preferences and sensibility was thought to be a design opportunity, as potential users could help each other to take care of their air quality together.

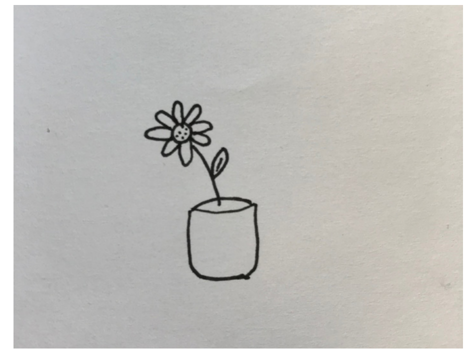


Image 11: Illustration of plant

Plants

The participant indicated to have trouble with maintaining the health of a plant. We recognized this problem from our own personal experiences and conversations outside this study, demonstrating its relevance. We argue that by helping our potential user to take care of a plant, the indoor climate will improve.

For the informed step we used our data-based insights from the contextual step as a starting point. We iteratively developed a concept while continuously reflecting and validating our design decisions and explorations through data. During this step, we aimed to allow our explorations to be executed remotely (situated explorations (van Kollenburg, Bogers, 2019b)). Despite this fact, our deployed prototype once required a physical update to be executed in the process.

While the design opportunities were still abstractly defined, it allowed us to choose a direction with a clear understanding of the design context. Choosing one direction allowed us to explore one of these concepts in-depth to conclude in a design proposal in the short timeframe.

During the informed step, we deployed at a different participant. She lives at her partner's one-room-apartment. (see Figure 7 and Figure 8).

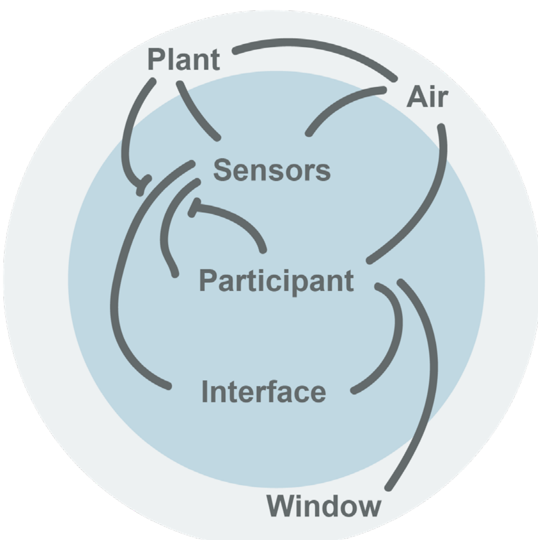


Figure 7: ecosystem during first iteration

Figure 8: Map of living space of the first participant

First iteration

We chose to continue our process focussed on taking care of indoor plants for two main reasons. Firstly, plants are able to clean the air by filtering certain gasses and absorb CO_2. Brilli et al., 2018; Smith & Pitt, 2011).

Secondly, as plants require certain environmental parameters to live optimally (e.g., humidity and light intensity), we could use the feeling of nurturing the plant. This as a motivation to ensure a healthy environment for both the plant as the user, similar to the positive effect on health and wellbeing of altruism (Lozada, D'Adamo, & Fuentes, 2011).

We envisioned a product that could coach you with this matter. You would pick a spot and the perfect plant would be sent to you. If it would not suit, you could return it or swap it with others perhaps. In this way the product was part of a bigger service.

For the first iteration of the informed step, we designed a prototype which we could use for the rest of the study. The prototype consisted of two parts: a plant coaster and an environmental air quality sensor. We chose to sense the air quality at another location then the plant coaster, as the coaster could be placed next to a window. An open window could drastically influence the sensing values, while we were aiming to sense the indoor air quality. The four LDR's in the plant coaster allowed us to see whether the plant needed any rotations to ensure an even light distribution over all sides of the plant.

During this iteration of the informed step, we were still aiming towards gathering some contextual information. For example, we needed to know the environmental parameters of the potential plant location to allow us to pick the optimal plant as we purchased several plants which demanded different levels of attention.

We chose a diverse set of plants to choose from. Three of the plants (Pteris evergemiensis, Clusia rosea, and Crassula sunset) were selected for their ability to improve the air quality by filtering the air and absorbing CO_2 (Vtwonen, 2017) . As we were aware that our plant might be dilapidated by its caregivers, we selected a plant that required little attention as well: the Cactus. (see Figure 9).

After the environmental parameters were monitored for five days (Friday to Tuesday), a plant has been selected based on the measured sunlight and air humidity.

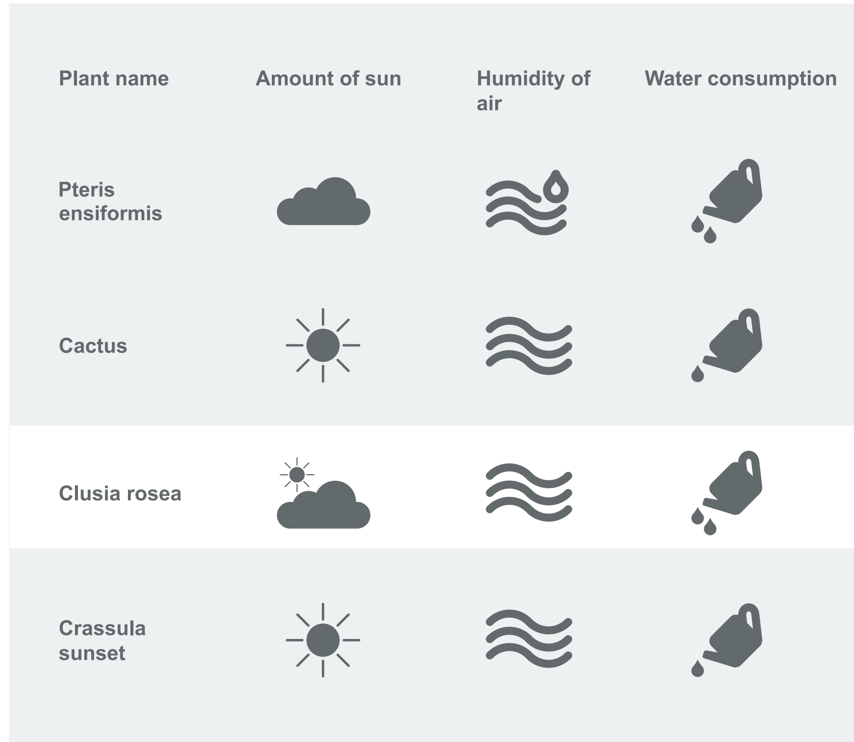


Figure 9: Plants which were collected and their required maintainance.

To imitate the service aspect of our concept, the plant was given with a "letter" containing information about gathering data and why this plant was suitable (see Image 13). The plant was then placed on the coaster by the participant (see Image 14).

During this phase, we sent mockups of the graphical user interface (GUI) which contained information on the gathered data (see Figure 10, 11 and 12). No requests of action were sent, as we believed this suited the calmness of a growing plant. This communication was done through a dedicated Signal channel ("Signal - Home," n.d.) to separate the "concept" from conversations with the researchers.

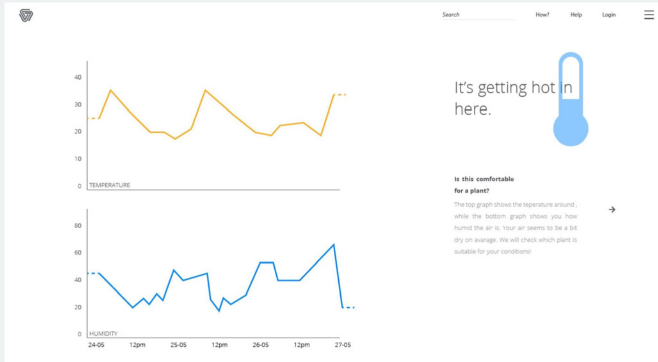


Figure 10: Graph abour temperature

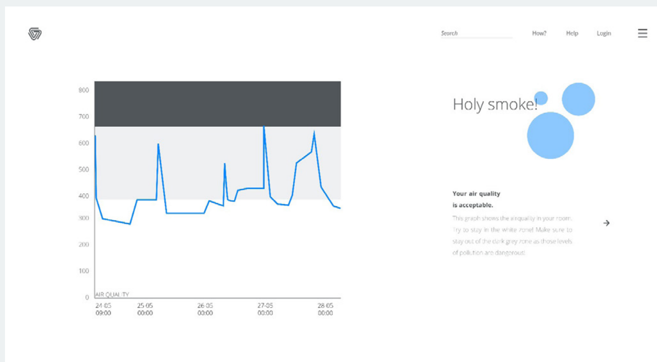


Figure 11: Graph about air quality

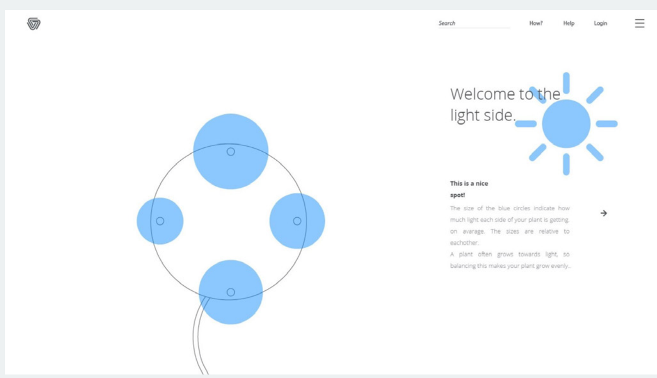


Figure 12: Graph about light intensity

Image 12: Installed moist sensor

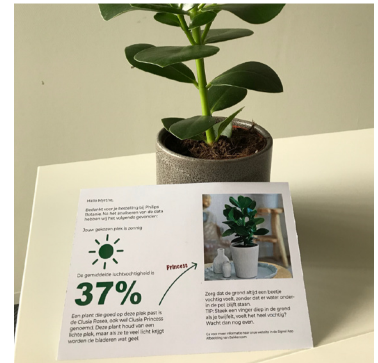


Image 13: Selected plant with letter

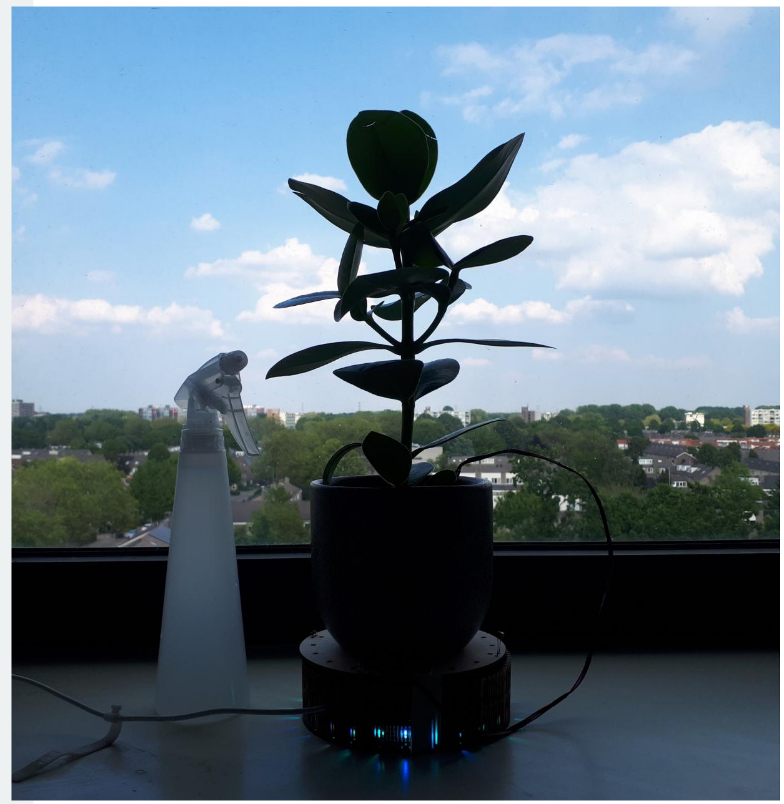


Image 14: Plant and coaster in context

Second iteration

In this iteration, the content of the GUI was tailored to prompt the participant with actions it could do to create a better environment for the plant, which would result in better air quality. The Signal-chat as described in Iteration 1 was used as a medium to communicate these plant-care suggestions.

We used the LEDs on our coaster prototype (see Image 15) to inform the participant about an incoming message through two states:

Solid turquoise - See message at Signal
Blinking turquoise - Urgent! See message at Signal

In this phase we used the Wizard of Oz (Dahlbäck, Jönsson & Ahrenberg, 1993)] method, as one of the researchers acted out the system, pretending to be the plant. By characterizing the plant's behavior and responses, we aimed to further revoke the nurturing behavior of the participant by evoking empathy.

Before the deployment of the second iteration, we set a series of commands which could benefit the air quality of the participant's room (see Figure 14). The timing of the prompts was based on the daily patterns that were recognised from the sensor data (see Figure 13).

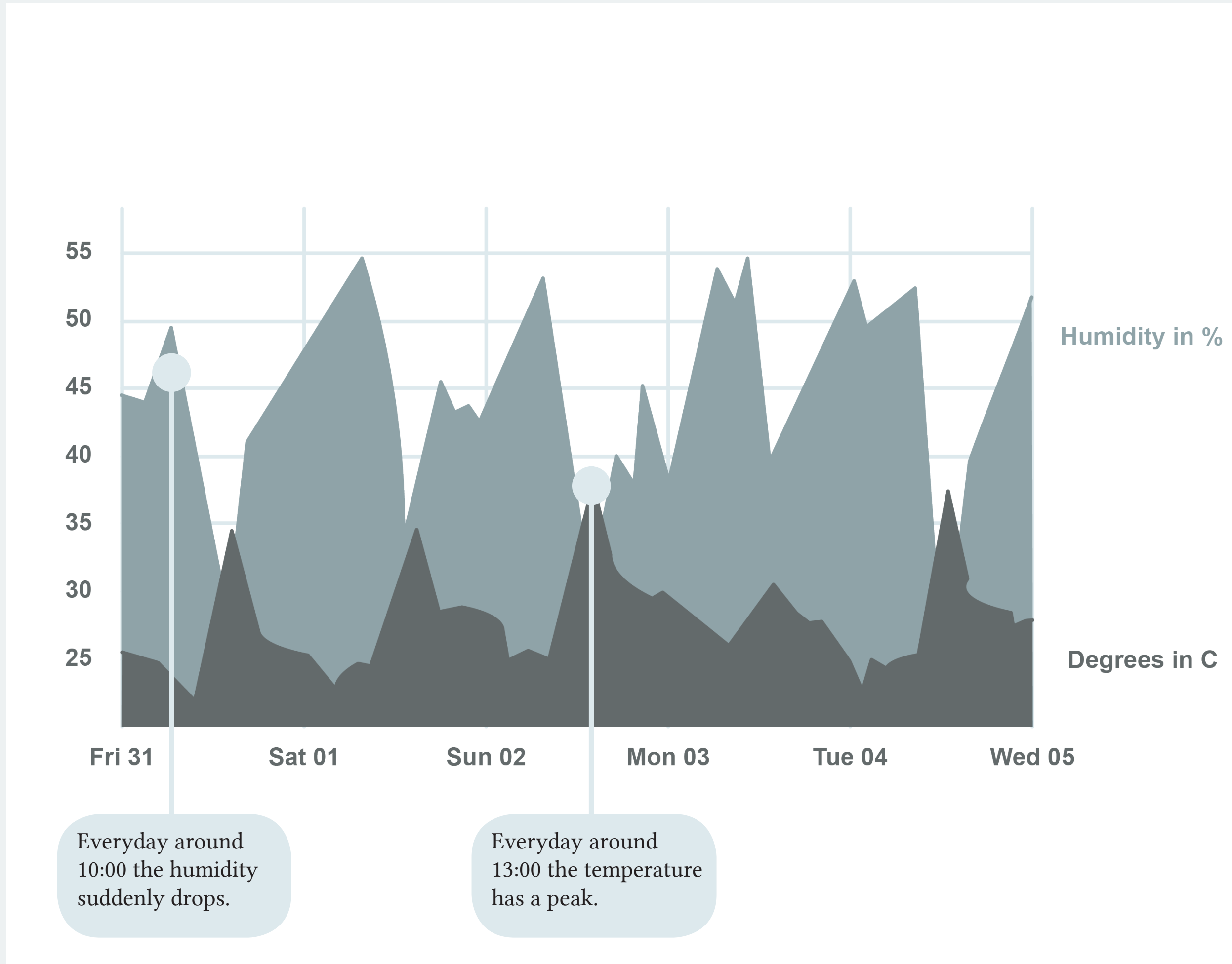


Figure 13: Humidity and temperature graph

Findings

During the interview with the participant, we learned that while the participant was motivated to take care of the plant, the prompts were often of no use. As we could only sense environmental values and no user actions (e.g., open/closed windows), we often asked impossible user-actions (see Image 17). For example, we would prompt the participants to open the window, while the window was already open. Therefore we decided to change the content of the messages from action-based to environment-based, hoping that the participant would find a suitable action herself.

Another insight was that the participant received most of our messages while being away from home (see Image 16). We therefore wanted to try a notification system that would only notify the participant when she got home.

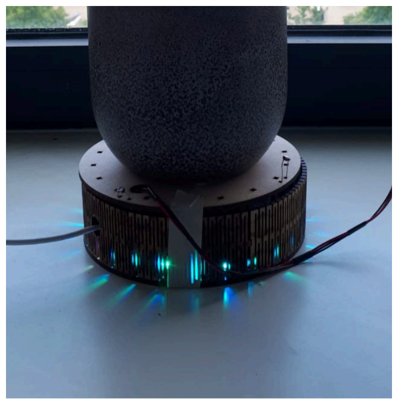


Image 15: Notification on the coaster

Nr.	Prompt examples
1	It is too hot, can you help me?
2	Yesterday I got so much sun, can you rotate me?
3	I am thirsty!
4	The humidity was so comfortable just an hour ago, could you please open the window?

Figure 14: The set of prompts we sent through Signal messages as plant

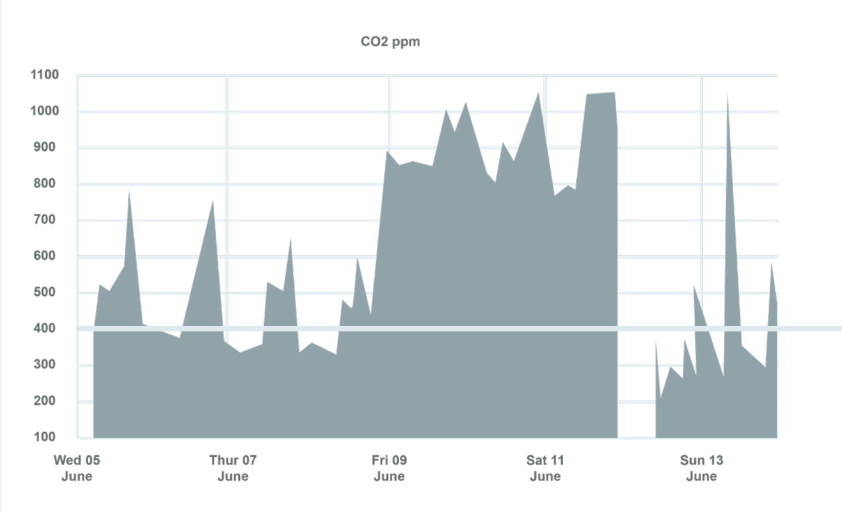
Image 16: Message of the participant that she is not at home

Image 17: Message of the participant that she already opened the window

Third iteration

As a substitute for instant messaging through Signal we decided to notify the participant at home using the coaster. With this adjustment we hoped to solve the issue of the participant receiving messages while being away from home and allow the participant to associate the feedback with the plant more than in the previous iterations.

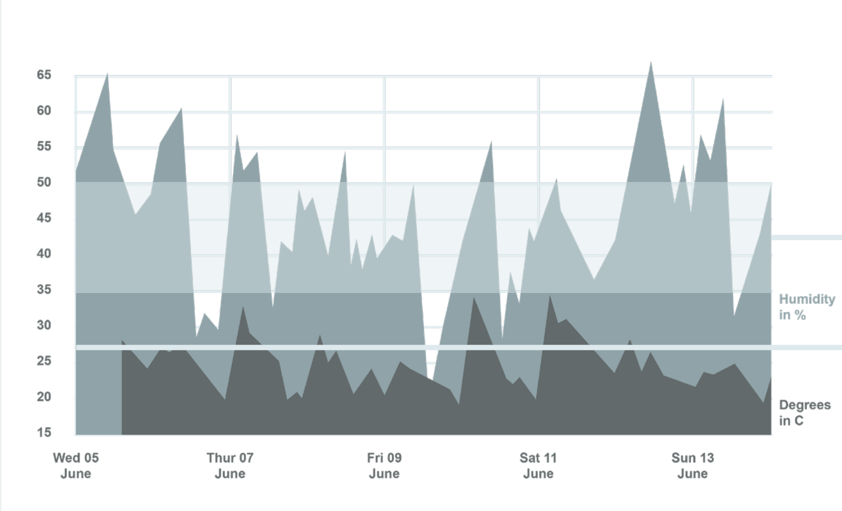
Using the sensor data from the previous iterations, we redefined good indoor air quality. Instead of using absolute values for temperature, humidity and carbon dioxide, we used the relative minima from the sensor data (see Figure 15 and 16). The identified minima were used as a threshold for each parameter (Appendix II).



The maximum threshold of CO2 pmm is 400

Figure 15: CO2 graph

Humidity is most stable between 35% and 50 %



The maximum threshold of the temperature will be 26 degrees

Figure 16: Humidity and temperature graph

Through the different colors and animations in the coaster the participant was notified if a certain parameter crossed a threshold (Appendix II). The colorcode legend was shared with the participant.

We chose to manually set the color on the plant coaster as it would allow us to change the thresholds to enforce animation activations. During this iteration, we tried to determine whether the participant would be motivated to take action based on LED light exclusively. In this iteration we primarily focused on open-ended prompts, allowing the participant to act more creatively with as aim the quality of air for itself (Animation 3, 6, 7, 8). Also, we tried to determine what kind of notifications would be relevant for the user as one might, for example, have no idea how to proceed against a humid environment. The main difference with Iteration 2 is that the aim of improving the air quality is aimed at human benefit, rather than focusing on the plant's health.

In order to facilitate this process, a simple Android smartphone application was built in the software Processing (Processing.Org, n.d.) to allow the researchers to quickly assess the sensor states and to set the LEDs to the right color/animation (see Image 18).

We allowed the participant to turn off the LEDs (see Image 19) and asked her to log all actions which possibly affected the indoor air quality. This was done by sending a message in Signal so that all researchers could see notes and act appropriately if needed.

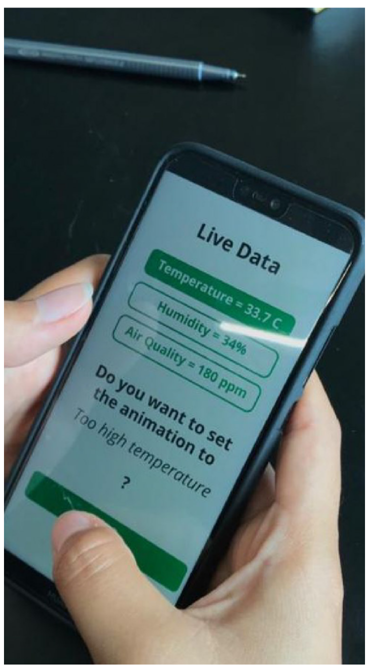


Image 18: Researcher interface

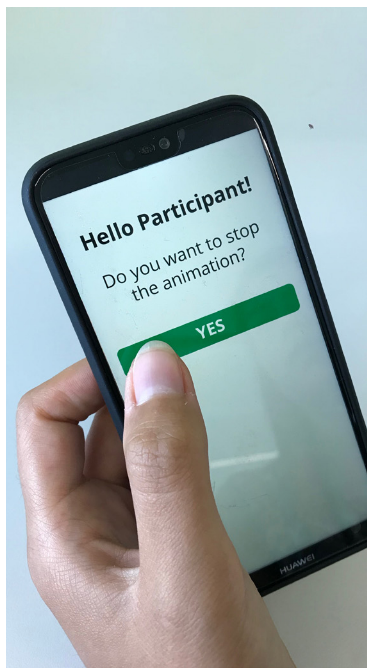


Image 19: Participant interface

Findings

During the closing interview, we learned that while the participant was motivated to take care of the plant, the prompts through the LEDs were not effective. The outside temperatures during Iteration 3 approached 30 degrees and the participant had limited resources to influence the state of the air temperature indoors. For example, all the windows were open most of the time, which was the leading element to control the temperature (Figure 17).

Besides, the participant mentioned that the color-coded LEDs were hard to understand, not at all time perceivable and in between sunset and sun dawn too bright. Hence, the effects of the LEDs were so far not effective in evoking a more caring attitude to benefit the quality of indoor air.

Overall insigts

Despite our expectations, our participant preferred to receive notifications on her phone rather than on the coaster. She explained it felt more visible, was easily accessible and the text format allowed for more actionable content.

It fitted better in their everyday life and was not very disruptive, as push notifications were turned off. Whenever the participant got a notification, they could read a prompt on their mobile phone and execute the action when it suited. Since the LED prototype did not allow this process, the prompts were quickly negated.

Since the home of our participant was a single-room apartment, resources to manage the indoor climate were limited. For example, all windows were already open and with the lack of an air cooler, the temperature could not be lowered any further.

"You showed that it is hot. I knew, but there was nothing more I could do"

"I liked when it told me what to do so I didn't have to think about it"

- Participant

"Prompts via Signal had made me care the most for the plant, since those were the easiest and then I knew what to do."

" I thought about the plant everyday and was constantly reminded to take care of it."

- Participant

"I did not really do anything with the lights. I preferred using the phone application anyway"

- Participant

Figure 17: Anekdotes from the interview.

Concept proposition

As a result of the process described in this pictorial we propose the concept Pebble. Pebble would be an air sensor that measures CO_2 levels, temperature and humidity, similar to what was used in this study. These sensors would be put in a container, mimicking the shape of a pebble, with a soil-moisture sensor fixed to its bottom.

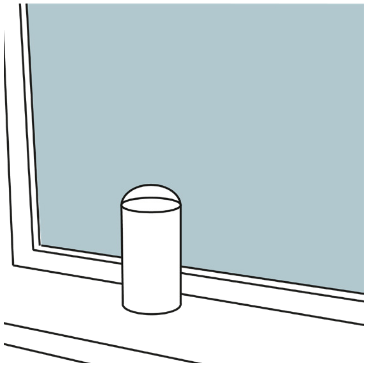


Figure 18: Pebble in front of window

After purchase, one would place it on a spot where they would like to keep a plant .

Figure 19: Receiving the plant

After several days, measurements would be completed and a suitable plant would be delivered to the customer.

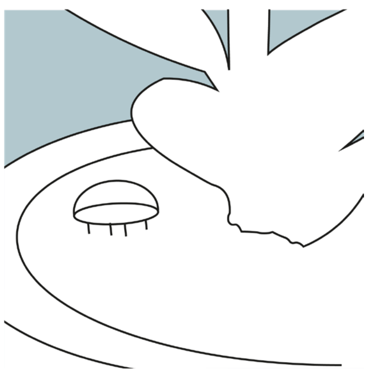


Figure 20: Positioning Pebble

The moist sensor can now be revealed and put in the soil so that the Pebble is able to sense when the plant needs water.

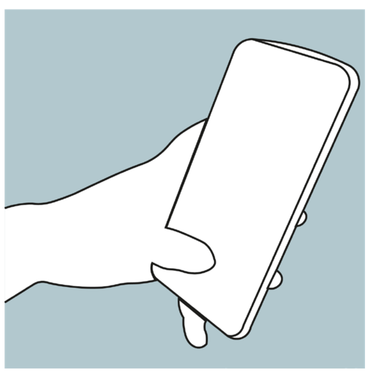


Figure 21: Receiving coaching

Now, the user can receive tips and data on how to take care of their plant...

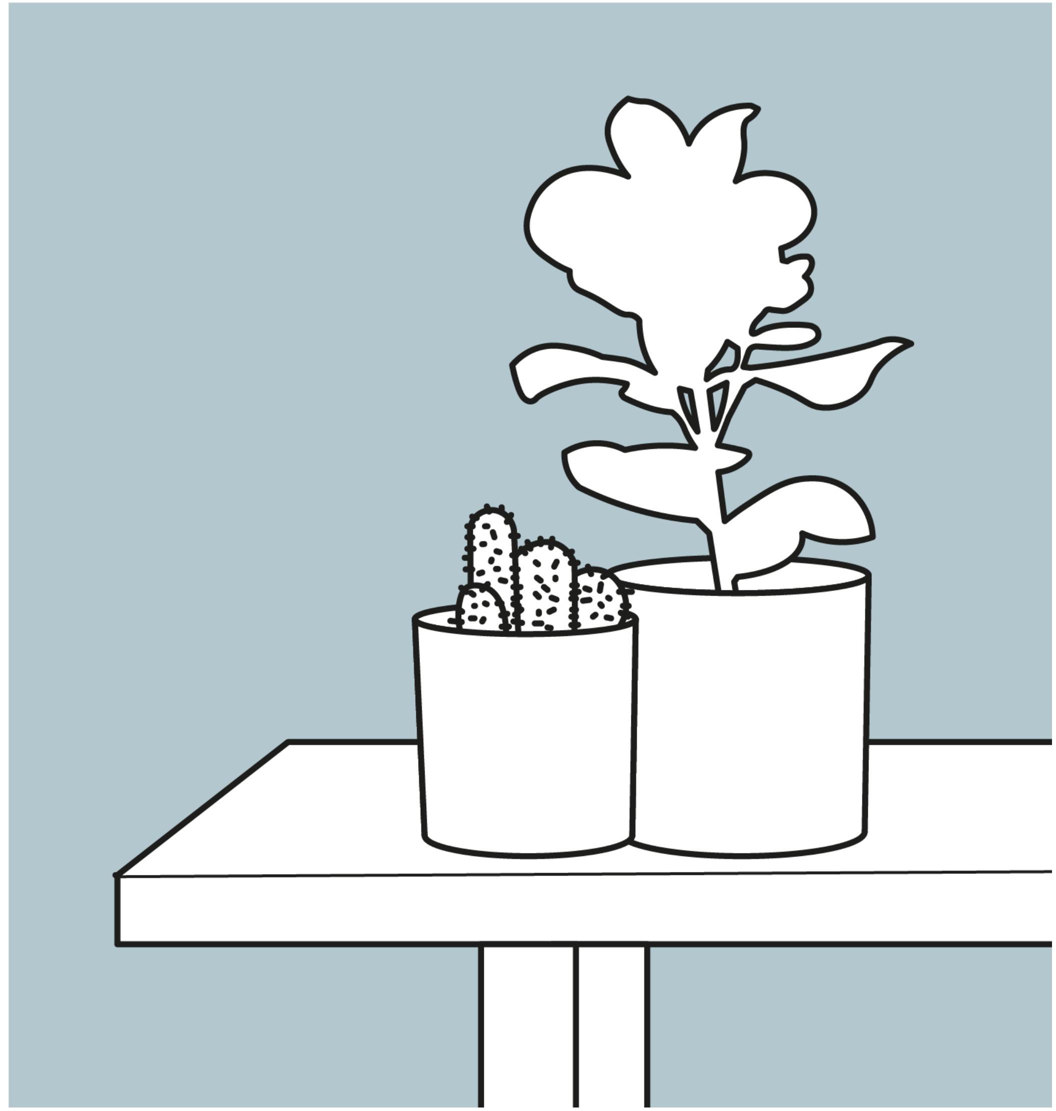


Figure 22: Growing an air filter with Pebble

...and grow their own air filtering system.

DISCUSSION

In this study a Data-enabled Design approach was taken to explore novel ways of creating a healthier living environment by improving the indoor air quality. During the contextual step, several insights upon the explored context were found. As plants seemed like a novel direction to improve the indoor air quality, this direction has been selected for further exploration. During the informed step of this study, a remotely adjustable prototype has been deployed for four weeks to conclude in our final iteration: pebble. Through this data-enabled design approach we through rapidly iterating learned that messaging was the most promising medium to motivate people in creating a healthier living environment. For future studies in the field of Human Computer Interaction (HCI) we recommend others to explore the benefits of this medium by using a similar design approach. More research is required to demonstrate whether user actions significantly improve the measured air quality.

Over the course of the study, we learned that the Data-enabled Design approach provided us with a detailed understanding of the problem and the context. During the contextual phase, we obtained diverse insights and design opportunities in the selected domain. We believe the approach could be beneficial to find novel approaches when tackling challenges that are well explored in previous work. Moreover, Data-enabled Design is thought to be an approach in which easily overlooked details can be uncovered. During some studies, field deployments propose a risk as researchers are uncertain about the involvement of participants, the interpretation of the deployed prototype, and possible breakdowns. Data-enabled Design proved to be an efficient methodology to limit the involved risk of these deployments, as they can be continuously adjusted. We encourage other research to use this approach, as interesting design directions can be found and explored while limiting the amount of involved risk.

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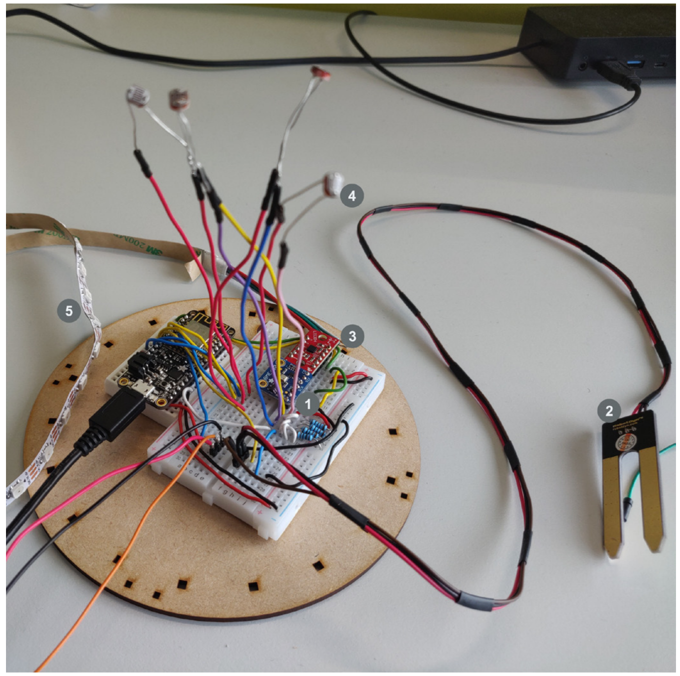
APPENDIX I - HARDWARE OF INFORMED STEP



The plant coaster

Actuators: LEDs (5)

Sensors: Humidity (1), Temperature (1), Pressure (1), Altitude (1), Soil Moisture (2), Accelerometer (3), four LDR’s (4)

The environmental air quality sensor

Actuators: Single LED (could be used to provide feedback when exceeding the threshold (the threshold could be adjusted remotely).

Sensors: Air quality sensor detecting the presence of carbon dioxide, ammonia, nitrogen oxides, benzene, alcohol and smoke (further referred to as air quality).

APPENDIX II - ALL ANIMATIONS WHICH WERE SET TO INDICATE INFORMATION TO THE USER

Animation nr.	Color (animation)	Cue or action	Threshold	Priority
0	Off	-		
1	Yellow	Open window		
2	Blue	Water plant		
3	Orange	Teperature too high	26 C	2
4	Turquoise	See signal		
5	Turquoise blinking	Urgens! See signal		
6	Purple	Too humid	50% or above	3
7	Pink	Too dry	35% or below	3
8	Red	Bad air quality	400 ppm	1
9	White rotating	Rotate plant		