Improving Air Quality Through Informed Cleaning Instrument Choice

A Data Enabled Design Appoach to Improve Indoor Air Quality

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ABSTRACT

In this pictorial, we document our design explorations focused on improving indoor home air quality while following the data-enabled design process proposed by Janne van Kollenburg and Sander Bogers. We begin by collecting information regarding the eCO2, TVOC and airborne particle levels in the participant's bedroom using situated prototypes. This data is then synthesized with diary studies and interviews regarding the habits and perceived air quality of the participant. This offers rich, contextual insights which then informs design explorations. These directions included an app which prompts the user to schedule and track their cleaning, gamification to motivate consistent cleaning habits and displaying raw air quality data. In order to improve indoor air quality, we propose to give users real time access to easily understandable dust data, while also offering the possibility to learn about the effectiveness of their chosen cleaning utensils and practices. We conclude the pictorial with possible future steps and recommendations.

Authors Keywords

Air quality, Dust, Data-enabled Design, Cleaning habits

INTRODUCTION

This project is an exploration into how to improve indoor air quality in the home environment, following a data enabled design process as proposed by Janne van Kollenburg and Sander Bogers in the book Data-Enabled Design [6]. For this project, we chose to focus on the context of the student bedroom as it offers a unique scenario, acting often as not only a sleeping area, but an all purpose space. We originally chose to explore cO2 levels, however our data never reached levels associated with health problems as our participant was able to regulate their own c02 levels adequately as can be seen in figure 3. Through the diary study and subsequent interviews, it became clear that the dust in the room was not regulated by the participant frequently, recording that the air often felt stuffy, heavy and dusty.

We then moved to measuring the dust in the room of our second participant, and asked them to record their cleaning habits. In the data we observed consistently high readings followed by a dramatic rise and then a steady decline in the dust levels. When compared with the cleaning diary, it was seen that the participant did relatively little cleaning throughout the week followed by a longer, more thorough cleaning. When asked to elaborate on this moment in an interview, the participants shared that the data reflected that they do not clean consistently, which leads to "panic cleaning" when a visitor is coming over. Here we found our design opportunity.

As research shows that regular cleaning positively impacts the dust levels [3] we created a series of prototypes aimed at motivating the participant to clean consistently to lower dust levels and improve air quality. These iterations included a mobile app to schedule cleaning, gamified elements such as maintaining their streak, and sensors on cleaning utensils to correlate their usage with their effect on the dust levels. In order to improve air quality, these explorations lead us to propose to provide users with real time access to easily understandable dust data, while also offering the possibility to learn about the effectiveness of their chosen cleaning utensils and practices. We conclude with possible future steps and our recommendations for future designs in this domain.

APPROACH

During this project, we followed a data-enabled design approach as laid out in Data-Enabled Design by Janne van Kollenburg and Sander Bogers [6]. As summarized by the authors, “data enabled design is a situated design approach that uses data as creative material when designing for intelligent ecosystems” [6]. In the diagram to the right, we have applied our own experiences to the method visualization presented in the data enabled design book [6]. The original can be seen in appendix B. As presented in figure 1, Data-Enabled design spans two different scenarios: in our case these were the participant’s bedroom and behind the scenes as a group. The methodology emphasizes the importance of a situated design approach [6]. In our case, sensor probes and design prototypes were situated in the participants’ student bedrooms. While you sacrifice the control of a study conducted in, for example, a studio, a situated design approach affords a richer, more holistic insight into complexities of real life.

To accommodate having prototypes in-situ, it was necessary to be able to adapt them remotely. This facilitates being able to respond quickly to insights and allows flexibility to adapt the parameters of a probe if more, or different, data is needed.

The data-enabled design approach is a continuous loop of contextual information informing and inspiring design directions and is characterized by two distinct phases: the contextual step and the informed step. The contextual step as we refer to it in this pictorial is the gathering of sensor data, diary studies and participant interviews, and using them to generate insights. The informed step is considered taking these contextual insights and translating them into design explorations which are then reintroduced in-situ. If more contextual data is needed to make informed choices, the approach offers the flexibility to do so simultaneously.

DATA COLLECTION

In the first contextual probes, data was gathered using the OOCSI protocol [4] in combination with the Data Foundry platform [5]. Data was gathered every 3 minutes on the eCO2 and TVOC levels and communicated to the Data Foundry platform using OOCSI. The collected data by the Data Foundry platform was then exported and interpreted using different programs. Rawgraphs.io [2] gave a general insight into the collected data such as the quantity and first general observations. Then Python was used to filter certain data, by for example applying a low-pass filter to see the effect on the data. Furthermore, Python was used to be able to convert the data to another format, for example reduce the data set or recognize movement durations of an accelerometer. The new generated datasets were then exported to a new csv which could be imported into Microsoft Excel or Rawgraph.io to further analyze the data.

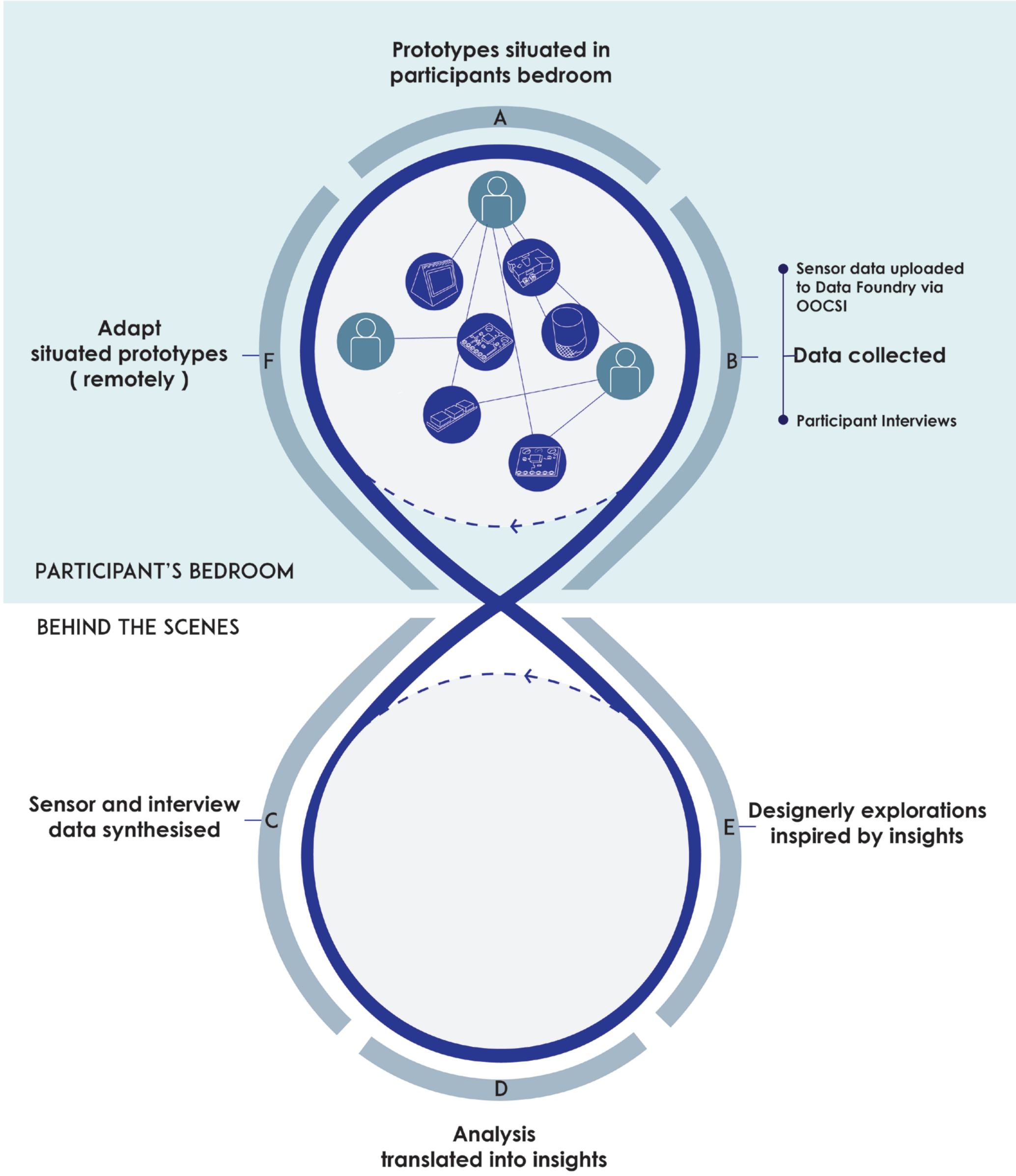


Figure 1: Adaptation of the data enabled design process loop

FIRST PROBE

The first contextual probe was introduced to the participant's bedroom for a period of 4 days. Over those four days, sensors measured the Carbon Dioxide (CO2) and Volatile Organic Compound (TVOC) levels [figure 3]. An activity tracker worn by the participant also offered sleep data, including duration and depth. The fidelity of the prototype was chosen as such that it focuses more on the generation of new knowledge than on validating design ideas [11].To gather better insight into the participant's perception of the room's conditions, a daily dairy was introduced, asking the participant to rate their experience of things such as how humid the air was, how stuffy the room felt and their physical symptoms (appendix A). They were also asked to detail the timing and reasoning behind open or closing their windows.

INSIGHTS

The first contextual step offered general insight into the participant's living situation (student room), the surroundings (e.g. noisy neighbors) and daily activities (e.g. morning coffee with roommates). In terms of sensor data in relation to the air quality, we observed decreasing CO2 levels when windows were open, and increasing CO2 levels when there were more people in the room. Despite the fluctuating CO2 levels, the peaks did not rise above 2100 parts per million (ppm) and were for a short time see figure 3. It was found that those peaks did not reach any critical levels [12].

Together with the participant, the patterns and outliers in the sensor data, diary study and his own experience were discovered. It appeared that when talking about the perceived air quality, the participant was more focused on the draught, stuffiness and dust levels in the room then the actual CO2 levels, reporting "my room often feels stuffy. The air feels heavy and dusty." Stuffiness was defined as stale, muggy and saturated air which can be improved by cleaning and air circulation [3]. Improving the perceived air quality was an important and interesting topic according to the participant. The following design opportunity was formulated "Focus on reducing the "stuffiness" and dust levels in the room by motivating the user to clean more often.".

To get more insights about improving the stuffiness and dust in a room, some related work has been analysed. When you're talking about indoor air quality, there is certainly a direct link between dust levels and air quality [7]. For those homeowners who don't clean on a regular basis, it increases the amount of dust, allergens, and other air pollutants that can be expressed in particulate matter (PM), PM is made up of particles that are small enough to be carried by the air and can be breathed in by people. These particles can be a threat to human health [10] but with the right cleaning routine these particles can be filtered out of the air. A good cleaning routine contributes to better indoor air quality through the reduction of airborne dust mass [3]. In other words regular cleaning will improve air quality.

A good cleaning routine consists of cleaning walls, light fixtures, furniture, bathrooms, tile and carpeted floors, and windows. The following popular cleaning utensils cover most of these actions: Vacuuming, dusting, sweeping and getting rid of clutter [1].

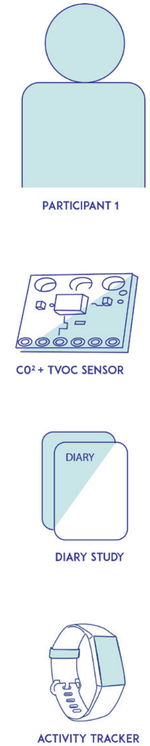


Figure 2: Interviewing participant 1

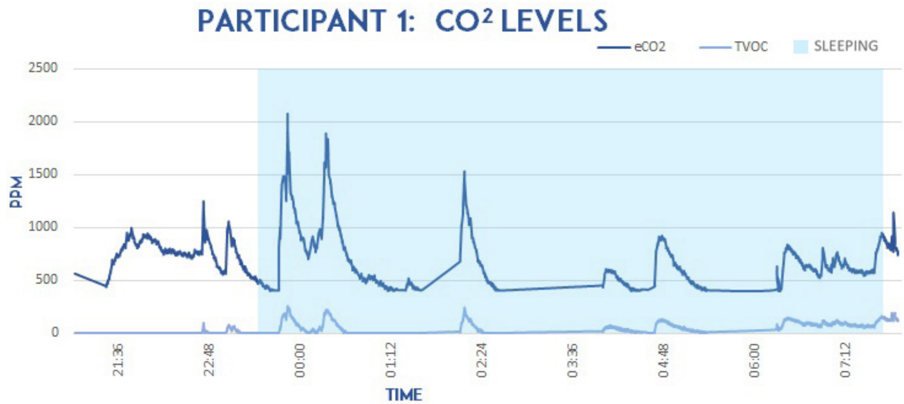
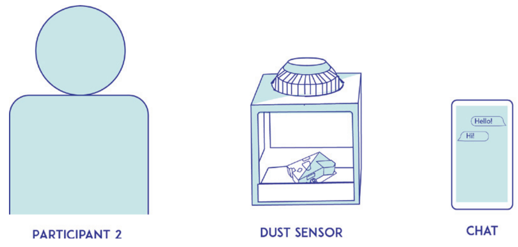


Figure 3: CO2 levels in participant 1's bedroom

SECOND CONTEXTUAL PROBE

A dust sensor which monitors airborne particles and their sizes was placed in the second participant's bedroom. A chat service was used in replacement of a paper diary study, allowing us to ask for more immediate contextual information in response the the data that we observed. The participant was asked each day through the chat whether they had done any cleaning, and if so what did they do and for how long. We also asked questions regarding how they prioritize cleaning in their schedule, and how clean and tidy they prefer their house to be.



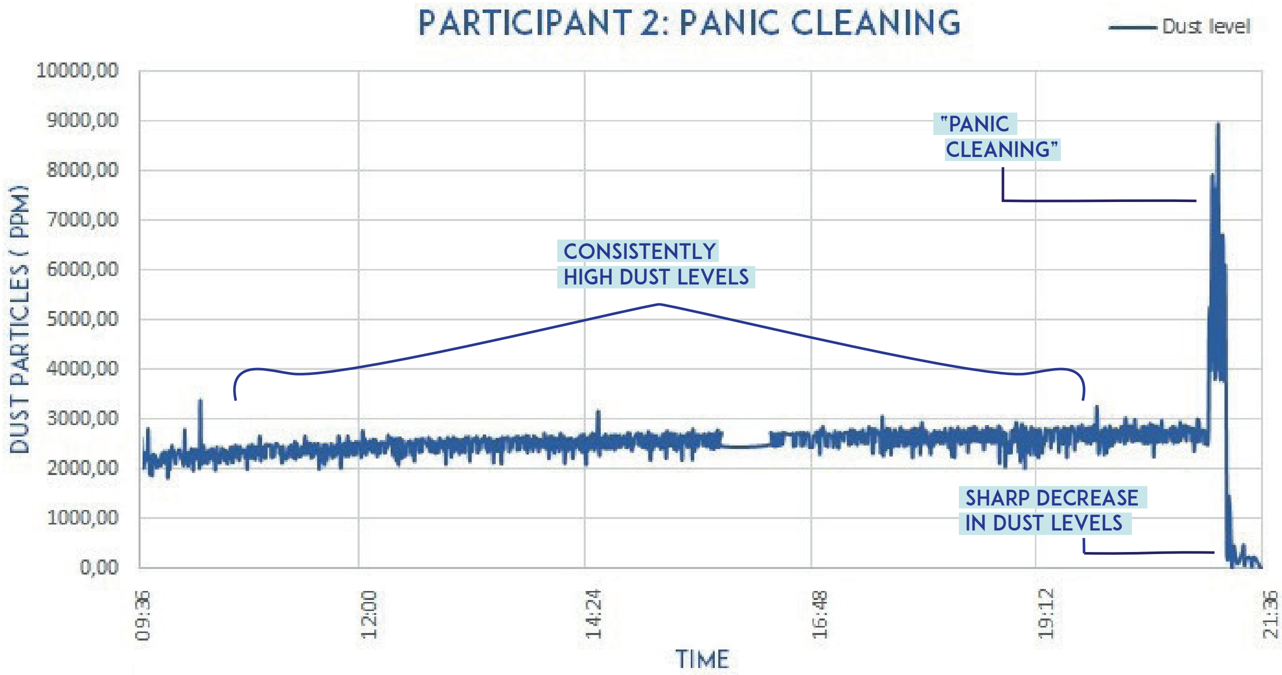


Figure 4: graph of participant 2's panic cleaning practice

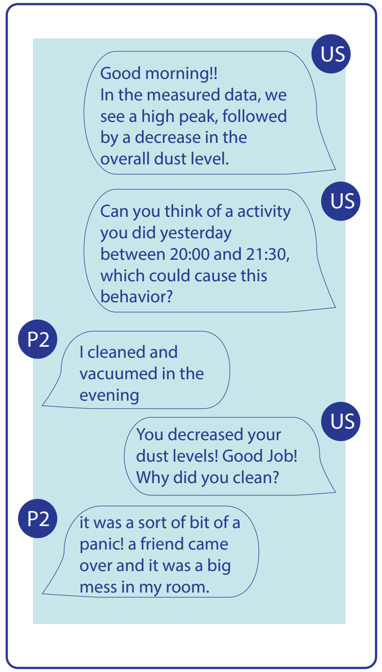


Figure 5: chat with participant 2

INSIGHTS

In the data, we observed consistently high readings followed by a dramatic rise and then a steady decline in the dust levels [figure 4]. When compared with the cleaning records, it was seen that the participant did relatively little cleaning throughout the week followed by a longer, more thorough cleaning. The peak which can be seen is a result of the cleaning unsettling the dust into the air. When asked, participant 2 shared that "I do a big panic cleaning when somebody is going to visit me." According to participant 2, this panic clean was extremely stressful for them. It became clear that this panic clean only arises when there was a visitor and that he felt social pressure to invite a visitor to a clean house. Furthermore the impact of the "panic clean" on reduction of dust levels was very short term, and the dust levels had risen to a much higher level again after 1 day. That is were we saw our design opportunity and decided to go further into the direction of solving the panic cleaning.

FIRST INFORMED DESIGN PROBE

From the insights gained during the conceptual step, a design direction was formulated in which the user could schedule their cleaning routine within a phone application. To set a schedule, they would need to document the intended frequency, cleaning instrument to be used and the intended duration of the routine. When the user is following their routine as planned they receive the points associated with their task. When they fail to abide by the schedule, the accumulation of points is reset and the user has to start over, thus losing their “streak”. Through gamification it was hypothesized that the user would be more motivated to stick to their schedule. Cleaning tips and reminders were also sent through the app.

MOBILE APPLICATION

To be able to make quick iterations on both a function and interface level in real-time, a Cordova app was used which was showing an externally hosted web interface. In the Cordova application, a push notification system was implemented in order to send notifications to the participant without the participant having to open their phone. Furthermore, a Google Cloud Firestore was present to update the user interface in real-time, like in-app notifications and schedule changes without the need to refresh the screen. Note that only informational and non-personal data was stored inside the Google Cloud Firestore.

VERIFICATION OF COMPLETION

A movement sensor is placed on the different cleaning instruments, and then register the intensity and duration of the cleaning process. Alongside a dust sensor can monitor the effectiveness of the cleaning routine. By looking at the airborne particles before and after the cleaning has been done and particularity at their size. The systems can learn which cleaning instrument to suggest for an improved routine that increases the air quality.The user can be prompted to clean and is advised on which cleaning instrument to use. The modular approach can adapt to different home environments and cleaning styles. In theory it would be possible to look at the airborne particles before and after the cleaning process and determine which cleaning instrument is best suited to capture a specific sized dust particle type. The system can then learn which cleaning instrument to suggest in order to improve the air quality.

INSIGHTS: FIRST INFORMED DESIGN PROBE

After two weeks of deployment, an interview was conducted in order to learn more about participant 3’s experience with the prototype. The participant stated that they were used to clean once every 3 weeks and lacked a regular cleaning routine. When the system was installed into their home and prompted them to clean twice a week, the transition was too big and therefore they did not interact much with the system. According to the participant, the gamification aspect of the prototype felt detached and did not motivate them to clean in accordance to their self made schedule. The points assigned to a task in order to maintain a streak were reported to be too vague.

Finally, the application in mobile form was not engaging for participant 3, stating “it is just one extra buzzing app in my pocket”. By using an application, the participant was less involved with the prototype and did not frequently look inside the app. The participants wanted the information displayed in the app to be more present in the environment which it related to. Sharing that “I am not looking at my phone, wondering how dusty it is while I am out.”. Next to that, the participant was extremely curious about the actual dust levels occurring in their bedroom and was interested in seeing real time feedback about what happens to the dust when they do clean.

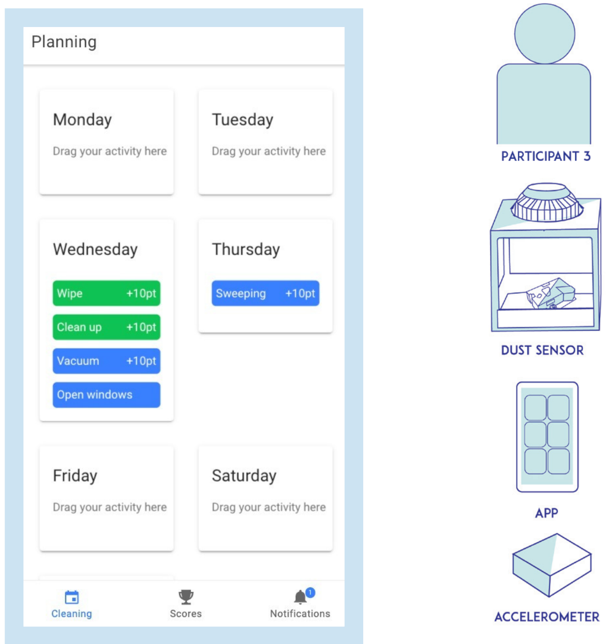


Figure 6: scheduling app

Figure 7: concept ideation sketch

SECOND INFORMED DESIGN PROBE

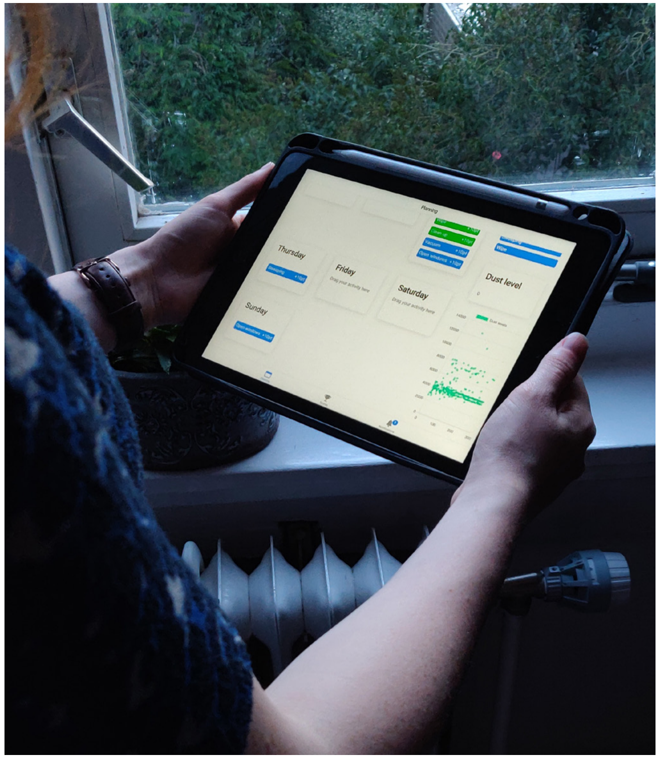
For the second iteration, the concept of improving the indoor air quality by prompting the right kind of cleaning instrument stayed the same, however the interface moved from a mobile application to an always-on display situated in the participant's bedroom. Furthermore the real time dust levels were displayed in reaction to the participant's feedback. This was used as a means to motivate the participant to clean instead of the previously used gamification. The interface was overhauled so that it became more easily accessible and the user could see the status of the system in one glance.The prompts to clean were now informed by the data which was gathered using previous data sets, making the system more accurate and therefore trustworthy for the participant.

COMMUNICATION PROTOCOL

Looking at the technical side of this project, the code had to be flexible and the communication and data transfer between devices needed to be dynamic and easily implementable on multiple platforms like Arduino (sensors), NodeJS (server) and Javascript (app). Because of this, the choice has been made to use the MQTT over websockets protocol, which can be used by all used platforms. The MQTT protocol was used to show information on the Ipad interface about the system, like the real-time dust levels in the room and which accelerometers were enabled.

INSIGHTS

The Ipad situated in the context had more presence than the previously used phone application. This had the effect that the participant became more committed to the study and provided more insights about the concept. One of those insights was the fact that they did not fully understand the graphs. They were intrigued about the changes in dust levels, but did not know what the values mean, asking "Are my dust levels higher than the average?". Furthermore it was hard to prompt the participant at the right time. Most of the time when a prompt was sent, the participant was not able to act upon it because there were not at home. That's when the suggestion from the participant came to use the Google Home as the prompting device. The participant stated that for them, Google Home was frequently used and very convenient.



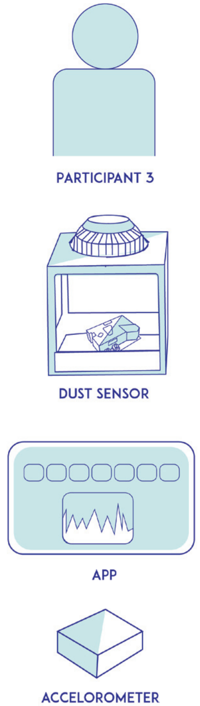


Figure 8: Scheduling app and real time data on Ipad

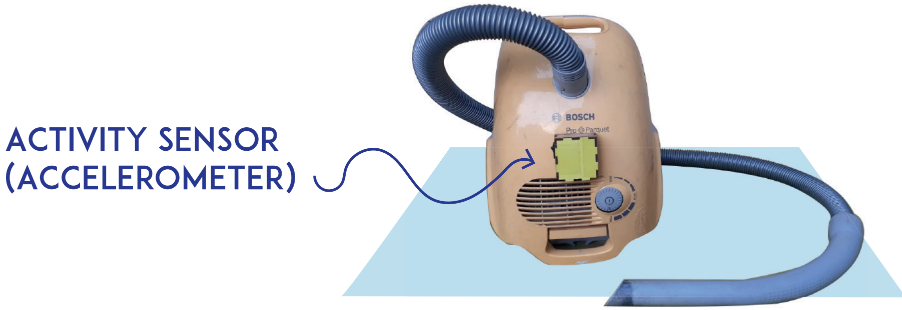


Figure 9: movement sensor attached to vacuum

CONCEPT PROPOSITION

The ecosystem consists of a hub containing an always on touch interface displaying real time dust levels along with 3 activity trackers (which contain accelerometers) associated with different cleaning instruments. Over time the ecosystem can learn which cleaning utensil captures a curtain dust particle size. The system can then prompt the user to clean and advise on which utensils to use for the most efficient cleaning routine.

NOTIFICATIONS

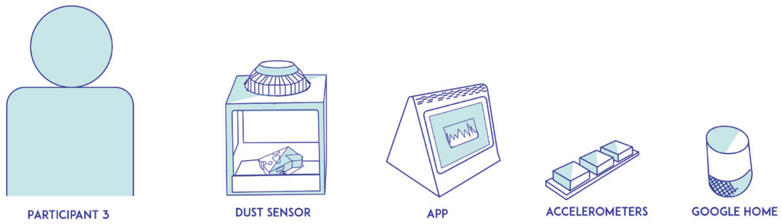
Using the insights from the previous iteration, where it became clear that the notifications were giving when the participant was either not present or was still asleep, it was important to make sure that the participant was awake and was present when notifications were broadcast. These two new parameters were added to the prototype in order to give better timed prompts. In order to track the presence of the participant, a python script on the raspberry pi is used. The python script is checking if any of the connected mac addresses to the local network is from the phone of the participant. If it is present, it will send its presence over a MQTT channel to the server. To make sure the participant was not sleeping when a notification was sent, the time frame of such prompts was within normal hours (from 12:00 till 21:00), which the participant chose as hours he/she would be awake. In the future this could also be done by the system itself, for example by checking the light intensity in the room (light off when present will indicate the participant is sleeping) or by tracking their sleeping behavior by a dedicated sleep sensor.

GOOGLE HOME

The prompting moved from the Ipad application to a Google Home situated in the context of the cleaning environment. There has been an internal debate about the implementation of this function due to the fact that this has a tendency to be more bespoke design than personal but it makes sense if you look at the trend, with the increasing amount of households owning a voice assistant [8].

FINAL INSIGHTS

To gain real insight into this iteration, it is necessary to leave the prototype in-situ for a longer period of time to fully understand and validate the design. One interesting insight already known is that participant needs to be informed with an unobtrusive sound prior to an audio notification. It was perceived as scary when the system starts talking without the consent of the user.



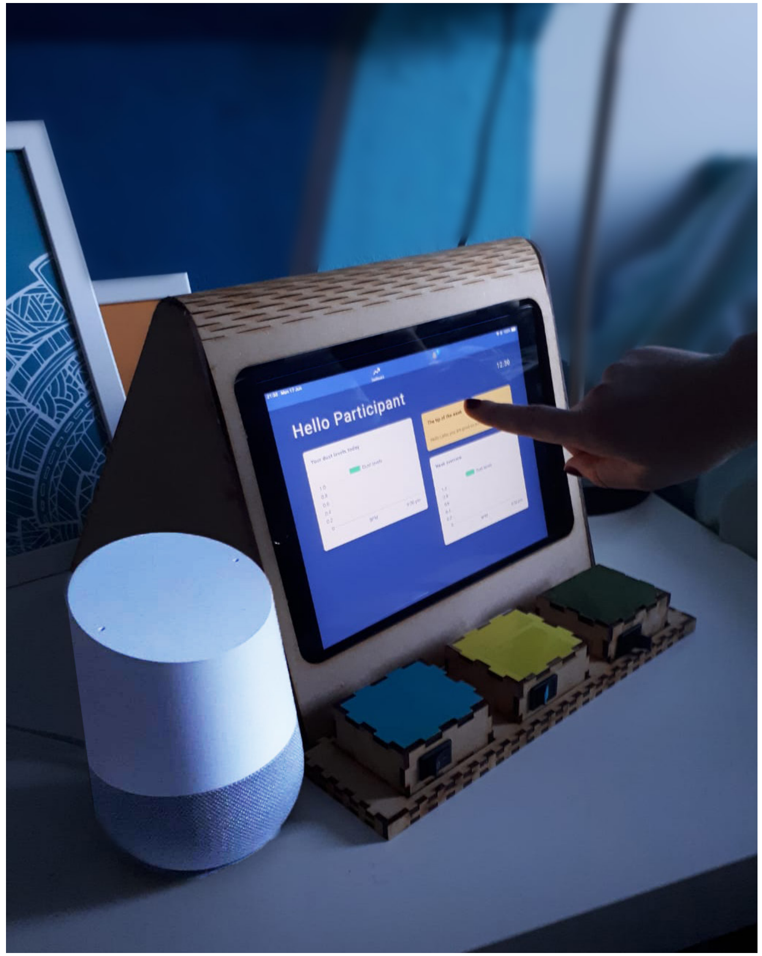


Figure 10: Concept proposition

DISCUSSION: CONTEXTUAL STEP

During the contextual step it became clear that combining participants' personal insights and perceptions with concrete sensor data offers a more complete understanding of the complexities of everyday life. It was the anecdotes and honest explanations offered by participants which ultimately inspired our design direction and it would not have been possible had we simple collected one or the other. Interestingly, we chose a somewhat arbitrary set of sensors for our first contextual probe. After receiving the design prompt, we had to work very quickly to set up a sensor so that we could dive into the topic and stay on schedule. While it felt rushed at the time, jumping right into the context allowed us to complete much more in 8 weeks than in situations where we have followed a more traditional process of make and validate. This initial fast exploration allowed us to identify the difficulties in setting up a situated probe very early in the process and we were also forced to learn the necessary technologies and methods very fast. It was much better than working for 6 weeks on a prototype only to find out that nothing works.

Looking at the readings, the first probe had a baseline around 480 ppm which is more than the global average of 414 ppm [9] this could be a calibration error, a deviation from the sensor or the baseline levels in the room could be higher than average.

It is important to mention that we had one week where our prototype did not function. The problems were a result of both technical and participant error. The problem could not be resolved remotely and thereby caused a delay in the research. To take back the time lost, the second iteration was done using a participant closer to the researcher so that trouble shooting could happen almost immediately. This worked well and the prototype iterated significantly faster, which resulted in a reliable prototype ready for participant 3.

During the subsequent week it meant that we had no new sensor data to work with, however the participant's personal experience became more valuable. During the first week we had learnt that it is best to collect accompanying personal anecdotes and information as close to the moment of action as possible. So if a participant closes a window, the reason should ideally be asked immediately as it can be very difficult to remember why at the end of the day, or the next. We achieved this by making the diary studies in such a way that the participant can give elaborate input about their activities and also relating it to air quality, it was not only helping with remembering particular activities on a certain timeframe, it also improved the engagement toward the study. Participants are thinking more along with the subject, and also gain new insights themselves which they did not noticed before. For example the participant was not originally that interested in their bedroom's air quality, by giving them a more extensive diary, they also started to reflect on what the triggers were to do certain activities. which allowed them also to learn about their habits.

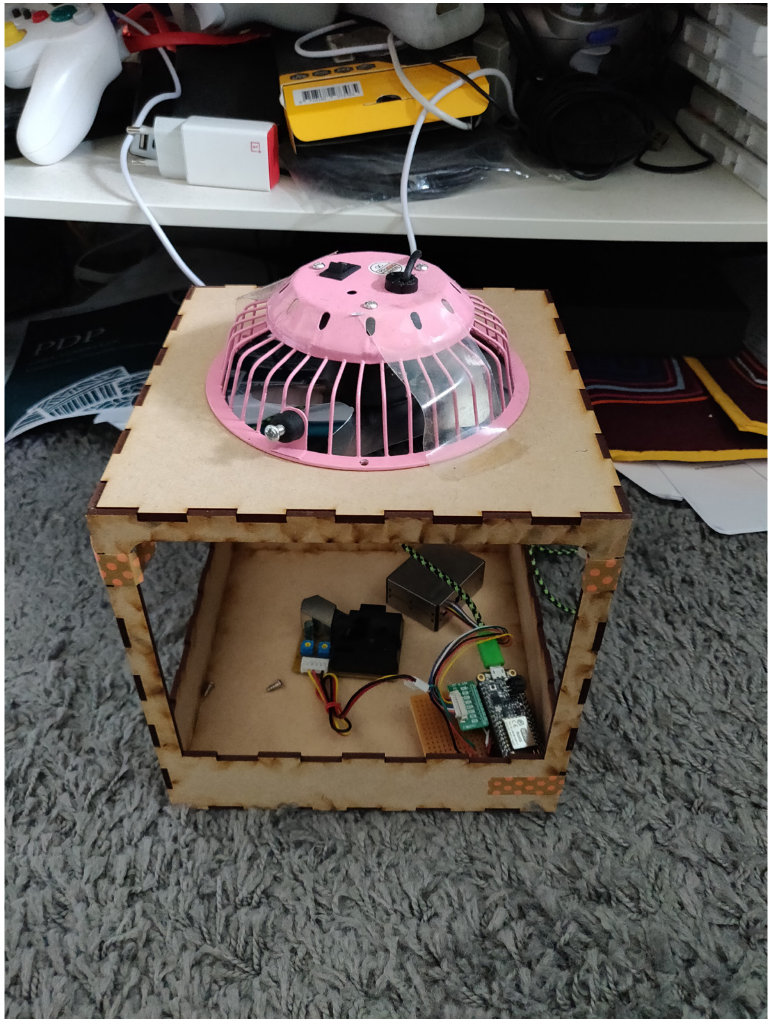


Figure 11: dust sensor

DISCUSSION: INFORMED STEP

The informed step took us into more concrete design prototypes and allowed us to test our design hypotheses informed by the contextual step. Through situated explorations we were able to gather real-time, meaningful feedback to quickly implement into a next iteration. The problems we encountered during the informed step, such as malfunctioning prototypes and forgetful participants were actually translated into insightful moments and informed our subsequent design decisions. By for example implementing an activity tracker to automatically register cleaning as opposed to asking the participant to write it down. The freedom to return to a more contextual exploration if more data was needed to confirm an assumption meant that our design process was flexible.

DESIGNING FOR THE INDIVIDUAL

During the study there were 3 separate participants, each with their own living environment and different surroundings. Those differences were reflected in the data collected, both sensor and diary study. During the study we noticed a difference in air quality preferences, cleaning routines and dust levels. One participant was more triggered by the relatedness of the others were as another participant was more triggered by their own autonomy. Even though the overall project showed contrast between participants, each step was tested with only one. We had to be conscious that we were essentially designing for the individual and not the general population. We knew that insights we gained from participant 1 could potentially work for participant 2 and not for participant 3. Taking the gamification aspect for example, where the second participant was very motivated by the social aspect, the third participant was not, and instead was more motivated by her own health conditions. As we are designing for the general public, it is important to identify the common narratives and separate those from the more unique personal preferences. By testing with a variety of different participants, it becomes possible to identify this common thread, however the study could be improved by including even more participants in each iteration.

DATA DRIVEN VS. DATA ENABLED

During the informed step, the shift was made between a more data driven approach than a data enabled approach.During the iteration were the mobile planner app was introduced, the gathered data was mostly used as an output of the system to gain insights about the cleaning activities. But this data was not yet used as a direct input to the system. The data was interpreted by a human, and therefore could be subjective, which can result in suboptimal decisions. In order to make quick iterations and move towards an intelligent ecosystem it is important that the data will also be used as a direct input to the system. By doing so, the system can evolve over time, in optimal conditions even without a human being present. The first steps towards such an intelligent ecosystem has been started in the last iteration. Were the data is used as a metric to notify the user on the right time and can immediately measure if those prompts did result in certain activities of cleaning which closes the loop. Measuring the right metrics is critical, by the creation of this closed loop it is possible to define those metrics in a fast-iterative process. In the future steps it will also be possible to use AI in order to let the system learn by itself which metrics are relevant to accomplish the interaction with the end-user.

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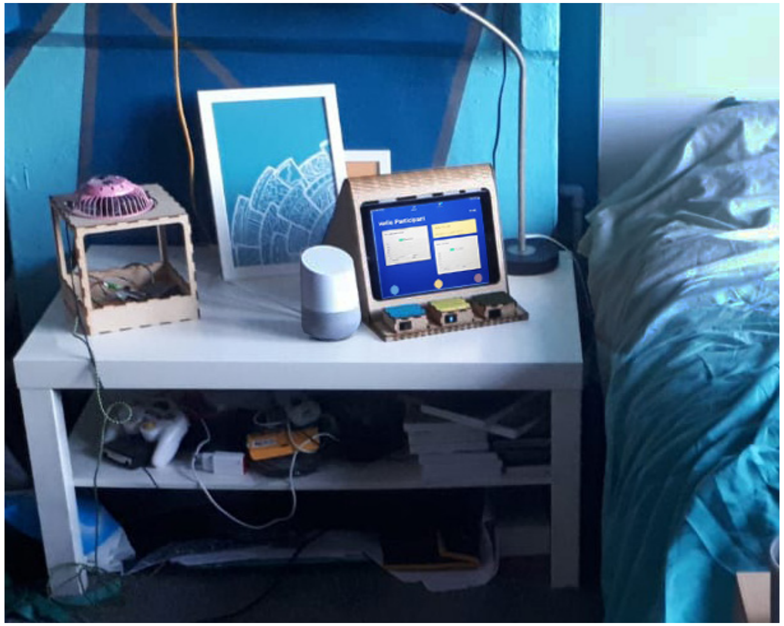

Figure 12: Prototype in participant 1's bedroom

Figure 13: Display dock with movement sensors and Google Home

ETHICAL CONSIDERATIONS

To be able to learn and gain insights about the behavior and experience of the user, it was required to collect personal data from our participants. We made sure all data collected was related and useful for the study. Furthermore, the time and effort a participant had to put into it was minimalized, without losing valuable data. For example, the tracking boxes which would track the cleaning instead of writing it down by themselves. The personal data included sleeping data, dust levels, window states and CO2 levels. Before this data was collected, a consent form [appendix c] has been signed by the participants. During the process new data collections or purposes arise, which could get in conflict with the morale of the participant. Therefore, before a new data type or purpose was implemented, like keeping track of the presence of a participant in a room, a consent of the participant was asked through the chat.

FUTURE

We suggest two main future directions. The first opportunity involves the cleaning activity trackers, while the second focuses on notification and prompt optimization. We first suggest that the cleaning activity tracker could play a greater role in the current intelligent system. By implementing techniques such as machine learning, the system could learn over time which is the user’s most efficient cleaning routines and practices. This can be achieved by correlating the activity trackers information with the air quality measurements. Another interesting future direction is a broader and is applicable for other fields. Prompting or notifying a user without disturbing their daily routines can be challenging. The data-enabled design approach could be useful in order to optimize the timing of user notifications and prompts, without disturbing them in an unpleasant manner. We suggest exploring which parameters influence the best timing, such as sleep or user presence, and how well these preferences can hold true for a larger user group.

CONCLUSION

Through following the data-enabled design approach, we have been able to quickly understand the context, ideate and iterate on the topic of air quality. The method has provided a framework which facilitated a lot to be accomplished in a short period of 8 weeks. This study examined the possibility to reduce airborne dust particle levels, by giving the user easy access to their dust data. It was found that displaying data in an intuitive and easy to understand manner was important to stimulate the correct response from the participant, and that a consistent cleaning effort makes a greater difference in dust levels than one larger, less frequent, cleaning session does. In a broader sense, we identify opportunities to improve notification timing and within the topic of air quality, we see opportunities for further exploration on showing users the effect of their cleaning instruments. We conclude that the data-enabled design approach is well suited in explorations such as this one, and has been more practical and holistic that more traditional design processes.

ACKNOWLEDGEMENTS

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APPENDIX A

Questionnaire

Draw a layout of the room (Windows vs sensor vs bed)

Day 1

Bed time: ....

Wake up time: ....

Windows: closed open

Comments about windows (eg. Slightly open, fully open, only one open, etc.)

....

....

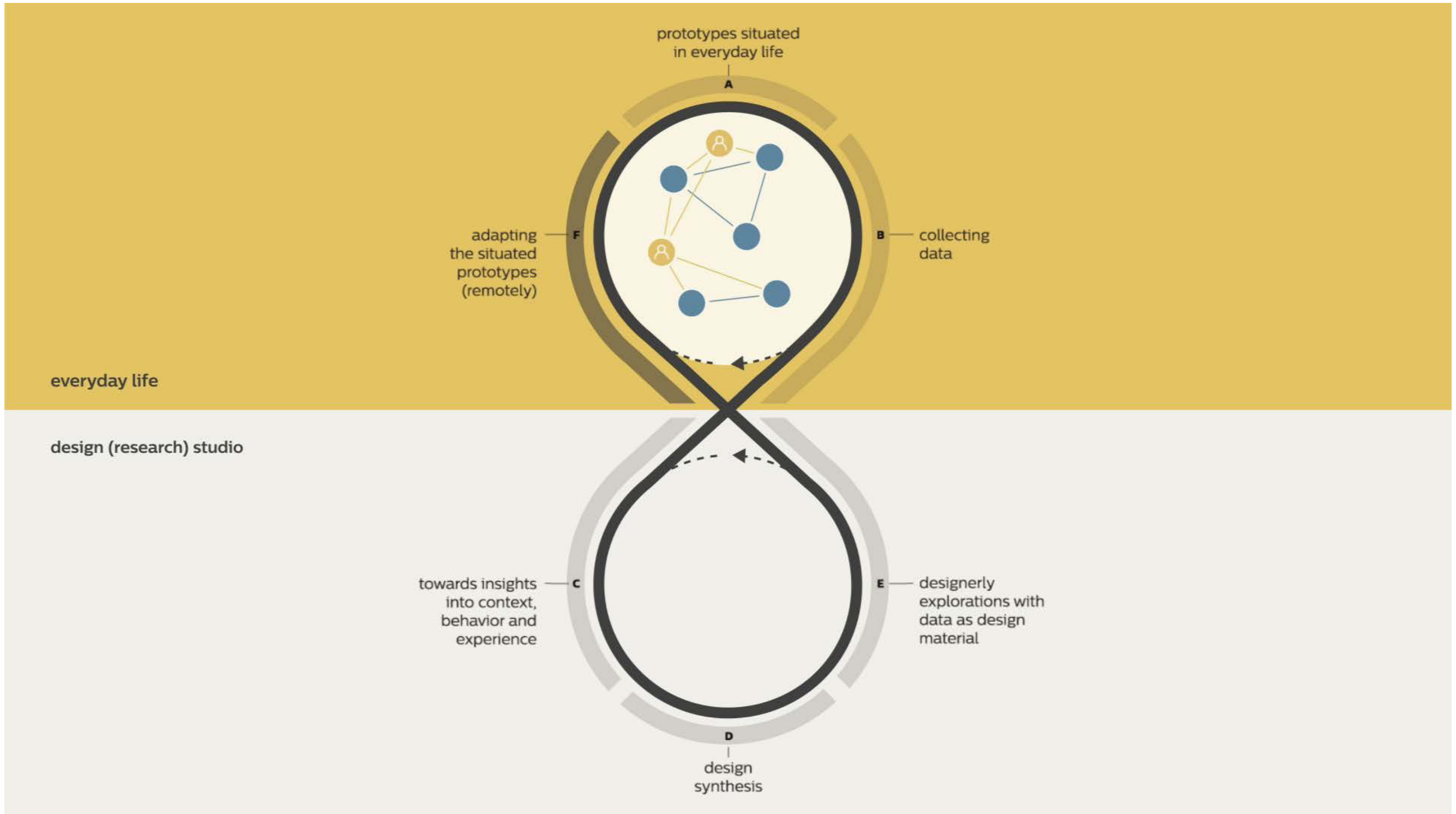
....

....

How many people where in your room during the day? ....

Sleep environment		
Temperature	Too hot	Too cold
Air humidity	Too humid	Too dry
Freshness of air	Stuffy air	Fresh air
Draught	Draughty	Stagnant air
Noise	Quiet	Noisy
Symptoms		
Headache	No headache	Headache
Mental state	Uptight, irritated	Relaxed, content
Alertness	Alert	Sleepy
Rested	Well rested	Tired out
Wellbeing	Good	Bad
Sleep symptoms		
Quality of sleep	Very poorly	Very well
Duration of sleep	More than enough	Very little
Lightness of sleep	Very deeply	Very lightly
Ability to fall asleep	Very easy	Very difficult

APPENDIX B



1. Janne van Kollenburg and Sander Bogers. 2019. Data-enabled design. Eindhoven.

APPENDIX C

Consent Form for Data Enabled Design Course

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 28/04/2019 or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves audio recorded interviews, diary study, indoor CO_2 levels, TVOC levels, sleeping time.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for reports and presentations.	☐	☐
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	☐	☐
I agree that my information can be quoted in research outputs	☐	☐
I agree to joint copyright of the collected data to Daisy O'neill	☐	☐

Signatures

______________________	______________________	________
Name of participant	Signature	Date

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

_________________________	___________________	________
Researcher name	Signature	Date

Study contact details for further information: Daisy O'neill, d.oneill@student.tue.nl