A BREATH OF FRESH AIR: TOWARDS OPTIMAL INDOOR AIR QUALITY

INVESTIGATING INTERVENTION STRATEGIES FOR ENHANCING OCCUPANTS AWARENESS, COMFORT AND HEALTH

SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE

Danny de Vries
14495643

Master Information Studies
information systems
Faculty of Science
University of Amsterdam

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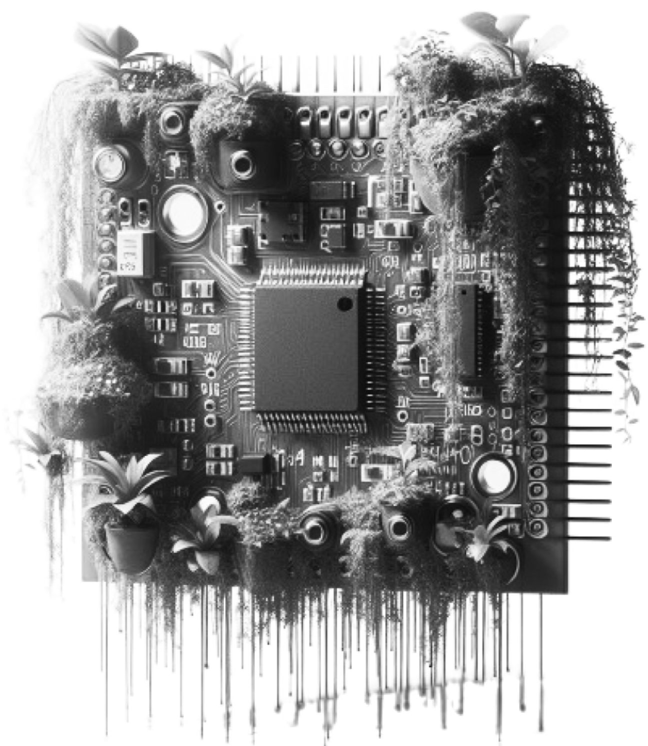


	UvA Supervisor	UvA Examiner
Title, Name	Dr. H. (Hamed) Seiied Alavi PhD	Examinar
Affiliation	University of Amsterdam	University of Amsterdam
Email	h.alavi@uva.nl	examinator@uva.nl

ABSTRACT

Suboptimal Indoor Air Quality (IAQ) have been identified to pose health risks and affect the cognitive performance of occupants within indoor environments. The study investigates occupants' awareness and perceptions of IAQ, facilitating occupants adoption of preventive measures. Employing a user-centered mixed-methods approach, the research employs Post-Occupancy Evaluation (POE) methods to elicit occupants' understanding of indoor air quality and utilizes sensory monitors to collect and measure common pollutants in specific indoor environments. These insights guide the development of 'Phair', an interactive data physicalization that visualizes real-time air quality data which was subsequently evaluated and usability-tested with occupants. The results of the user study reveal a lack of awareness among users regarding indoor air quality, while evaluations of the prototype demonstrate that physical hardware displaying real-time data can effectively increase occupants' awareness.

KEYWORDS

Human-Building interaction, Indoor air quality, Living Lab, Data physicalization, Smart buildings, User-centered design.

1 INTRODUCTION

Globally, it is estimated that people spend approximately 90% of their time indoors [27, 41] and breathe 11.000 liters of air per day [12]. Suboptimal indoor air quality (IAQ) conditions affect building occupants' experiences of comfort and insufficient ventilation in indoor environments is proven to play significant roles in occupants' well-being, health, and cognitive functions [25, 49].

The perceived comfort of occupants is influenced by the overall Indoor Environmental Quality (IEQ) consisting of several key metrics (e.g. mechanical ventilation, temperature regulation, natural lighting) to create a combined IEQ index for a specific indoor space [28]. Among these metrics, indoor air quality stands out as a crucial factor deserving special attention due to its invisibility to occupants [43], polluted air goes undetected by smell or sight, underscoring the importance of monitoring and maintaining optimal indoor air quality.

Furthermore, mechanical ventilation systems in buildings operate discreetly and are frequently insufficient for ventilation in densely populated small rooms like meeting rooms, laboratory offices, or hot-desking work areas [42], which contributes to occupants' perceived lack of control. Since these systems are typically automated [34] and cannot be directly regulated or controlled by occupants themselves [24].

This creates an interplay between occupants' effects on comfort, built environments, and computing technologies (see Figure 3) researched in an overarching interdisciplinary field of study, known as Human-Building Interaction (HBI) [1]. This research specifically focuses on understanding occupants' needs through in-the-wild [38] studies gaining insight into occupants' awareness, collecting indoor air quality data in designated spaces, prototyping data physicalization devices to visualize indoor air quality, and using these designs as data probing tool [53] evaluating their effectiveness with the overarching objective of obtaining insights into occupants' comfort levels and facilitating their adoption of preventive measures against poor indoor air quality [52].

While research on defining comfort within indoor buildings [2], gathering and analyzing sensory air quality data [12], and the effects of poor air quality are prevalent [27], there remains a research gap in understanding occupants' behavior and their subjective needs, along with limited research on how design solutions that visualize environmental data and computing installations can empower occupants, particularly within the field of physically visualizing data to convey IAQ to building occupants in real-time.

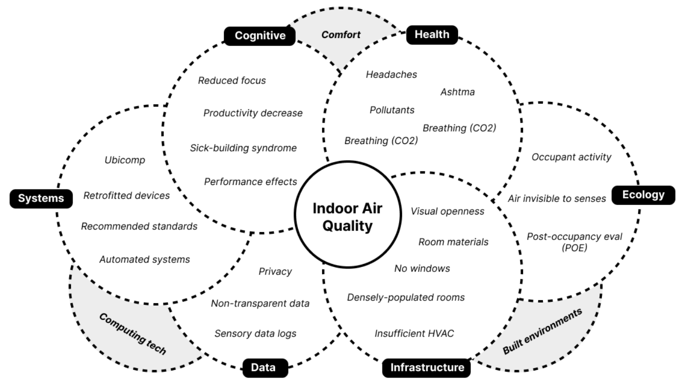


Figure 1: Complexity diagram providing an overview of the effects of IAQ and needs of occupants [2, 12, 25, 27, 41, 49]

1.1 Research questions

In order to research intervention strategies for improving indoor air quality, the following main research question is formulated:

RQ: *How can real-time sensory measurements and future predictions of air quality be physically visualised in specific indoor spaces integrating both environmental information and elements that increase awareness among occupants facilitating their adoption of preventive measures against poor air quality?*

To effectively answer this main research question, this research is guided by the following supporting sub-questions (*sq* for sub-question) that also serve as objectives to delineate the necessary knowledge:

- **SQ**1: *How can environmental information related to air quality, such as pollutant concentrations and ventilation rates, be incorporated into the visual representations?*
- **SQ**2: *How do different types of physical visualizations impact occupants' understanding of air quality and their willingness to adopt preventive measures?*
- **SQ**3: *How do occupants' perceptions and behaviors regarding indoor air quality change over time, from pre to post-installation of the physical representation of poor air quality?*

2 RELATED WORK

Given the focus of this research is studying Human-Computer Interaction (HCI) within Built Environments (BE), this research draws from various related work including the subfield of Human-Building Interaction (HBI) and subsequently narrows its focus to Indoor Air Quality (IAQ) and Post-occupancy Evaluation (POE) for the scope of this research. Furthermore, it examines notable findings from previous approaches to mapping and encoding sensory data in a new area of research called Data Physicalization (DataPhys).

2.1 Human-Building Interaction

Buildings increasingly incorporate new forms of digital interaction [31, 35], which means new inherent connections between 'people', 'built environments', and 'computing' research in an area called Human-Building Interaction (HBI) [1, 47]. This research area is dedicated to exploring the design of built environments that may incorporate computing to varying degrees [45]. A logical extension where indoor spaces are increasingly retrofitted with sensing devices [35]. Understanding how people use different spaces in a building through computing can inform design interventions aimed at improving the utility of the space and the well-being of occupants. [48].

Current research into architecture and built environments indicates that a significant portion of the data collected by these computing devices is not necessarily transparent or comprehensible to occupants [40], and indoor spaces are designed without much thought of placing computing devices integrated within the environment [22, 26] leaving users with a perceived lack of control over their indoor comfort.

2.2 Comfort within buildings

Indoor occupant comfort is achieved in interaction with the environment and is represented in four respective dimensions; thermal, respiratory, visual, and acoustic [2]. Indoor Environmental Quality (IEQ) [28] indexes serve as metrics for assessing the aforementioned properties of comfort within indoor environments with Post-Occupancy Evaluation (POE) [15] and Perceived Environmental Qualities (PEQ) [43] methods being employed to gauge occupants' perceived comfort [10].

Studies on indoor environments focus on 'static' IEQ conditions using sensors to sense environmental conditions based on the buildings' physical characteristics to meet various recommended standards such as ASHREA 62.1 [1], ISO 16814 [2]. Discrepancies between measured IEQ conditions and occupants' perceptions have also been reported in studies. For instance, research indicates that occupants generally have a low awareness of Indoor Environmental Quality (IEQ). While occupants perceive the environment as 'satisfactory', actual sensory measurements within the environment reveal quality levels below recommended standards. [43]. Recent studies have shifted their focus towards the active role occupants play within the built environment, viewing their behavior within a building as akin to a 'living ecology' [29] rather than perceiving comfort solely as 'static' properties of the building itself.

[1]https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2
[2]https://www.iso.org/standard/42720.html

2.3 Indoor Air Quality

A suboptimal indoor environment has reportedly been associated with health-related problems such as headaches, throat irritation, and asthma [27] as well as a decrease in cognitive functions such as tiredness, effects on performance and productivity and a lack of focus [49] [14]. A phenomenon referred to as the Sick Building Syndrome (SBS) [17, 33]. Many of these symptoms are primarily associated with respiratory comfort and are closely tied to Indoor Air Quality (IAQ) concerns [25]. Effective ventilation strategies have been shown to significantly alleviate SBS symptoms [17].

The advancements of real-time IAQ monitoring systems leveraging Internet of Things (IoT) sensor technology have facilitated progress in both the measurement of IAQ and the implementation of interventions aimed at enhancing it [32]. Indications of poor air quality are gathered by measuring common pollutants with a focus on molds and allergens (humidity), volatile organic compounds (VOC), and carbon dioxide (CO2) [27] where occupant behavior and the number of occupants within indoor space have a specific negative effect on CO2 levels [16]. These indoor climate factors are related to the building occupants' behaviors and need special attention to be considered in assessing the IEQ conditions and determining if adequate ventilation is present [14]. It is crucial to recognize that when occupants experience symptoms, it signifies that a suboptimal air quality situation has already occurred.

The existing literature on IAQ offers quantifiable and validated methods for measuring IAQ through sensory data. It underscores the complexities associated with IAQ and emphasizes the significance of developing solutions to ensure occupants receive adequate ventilation.

2.4 Data Physicalization

The research domain known as data physicalization [3, 21] has emerged as a notable area of study, emphasizing the creation of physical data visualizations making the invisible tangible and interactible by encoding data in physical artifacts [36]. This shift from focusing on individual artifacts to a broader environmental context facilitates the physical embodiment of computing [13]. Data physicalization has the potential to positively influence the perception and exploration of data [21, 46, 50], presenting distinct advantages over traditional 'screen-focused' data representations, such as 2D canvas displays (e.g. digital dashboards) [18, 20], particularly in the context of Indoor Air Quality (IAQ) where a 'physical data visualization' serves as a fitting metaphor for rendering 'invisible' indoor air.

These tangible artifacts usually come in the form of ubiquitous computing (ubicomp) [9] device that seamlessly blends into the environment, essentially making the computing devices 'disappear' [51]. These devices are frequently employed as persuasive technology, strategically designed to gently nudge individuals towards behavior change leveraging the emerging notion of pervasive sensing to subtly enhance users' awareness regarding the impacts of their decisions [7, 37]. This method of persuasive design serves as a powerful tool in calmly extending users' awareness, helping users understand gathered data, and the consequences of their actions, and gaining insight into their behavior [8]. A systematic analysis of over 60 representative data physicalization papers [39] show that only numerous approaches to studying computing devices within indoor spaces and interactivity with occupants have been explored in prior research to nudge occupants to a desired behavior but limited design solutions (f=3) have been developed and explored to focus on airflow and none (f=0) with a specific focus on indoor environments and air quality.

This framework of data physicalization and persuasive technology establishes the theoretical foundation for the creation (prototyping) and the evaluation (usability testing) of the design solution within this research.

3 METHODOLOGY

To answer the research question this study uses a human-centered approach (often referred to as Design Thinking) commonly found in Human-Computer Interaction studies consisting of four phases; 1) user studies to *understand* the user, 2) *data collection* methods and analysis of the situation as field trials, 3) *ideation* and experimental design of a prototype and 4) *evaluation* and usability testing of the prototype [23, 53]. This mixed-methods approach (both qualitative and quantitative) helps understand occupants' needs and informs the design and technical set-up of the prototype evaluating the effectiveness by focusing on the user's needs from the start of the study [38]. For the first phase, an online questionnaire was conducted to *understand* occupants' awareness of indoor air quality (see Section 3.2), for the second phase a lab setting was created with IAQ monitors to do *data collection* and gain insight into environmental data which in turn informed phase three the *ideation* and creation of the prototype. In the last phase participants *evaluated* the prototype and performed usability tests.

3.1 Case study building

This study will be conducted in association with the Digital Interactions Lab [3] and will utilize the recently opened Lab42 [4] building at the UvA Amsterdam Science Park [5] as its primary case study location. Lab42 is an energy-neutral, flexible, and adaptable faculty building that facilitates collaborations among students, researchers, and businesses [6].

3.1.1 Space usage. The buildings's layout is strategically organized into different zones, each serving various functions, ranging from quiet individual work to spaces that allow for collaborative work. Lecture halls, learning rooms, and open learning spaces make up the two lower floors, with the upper four being primarily assigned to the university academic staff, meeting rooms, and external offices (see Appendix H).The overarching interior theme in the design revolves around 'tech' and 'nature' aiming to cultivate a fresh, light, and warm comfortable ambiance. Lab42 is an example of a smart building or living lab where sensing devices are retrofitted throughout the building to automatically adjust lighting, temperature, and the focus of this research regulating air [5]. This already provides a base of environmental data that can be used and extended for further analysis. Since most of the space within the building is designated as informal learning space and another large part of the building is designed as meeting rooms (see Appendix H), working areas these functions of focussed work and collaborative meetings can be heavily influenced by reduced cognitive performance as a result of poor indoor air quality.

3.2 Questionnaire survey

To understand and collect occupants' subjective awareness and satisfaction of IAQ a survey was created to gather quantitative data within the building as a form of Post Occupancy Evaluation (POE) (see Appendix H).

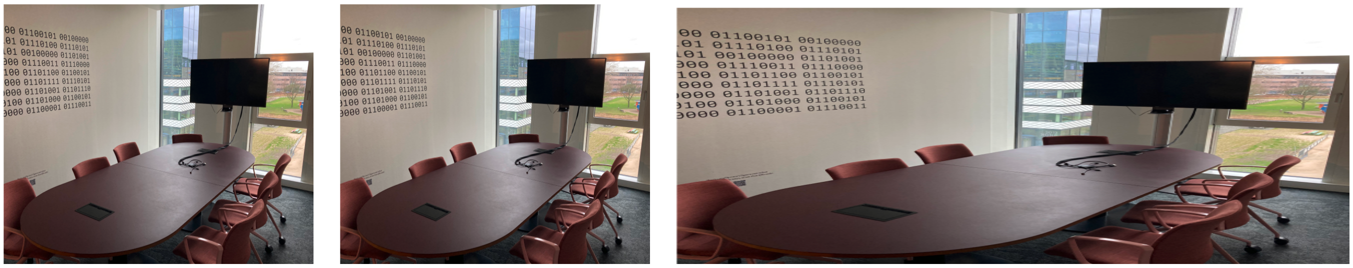
3.2.1 Questions. The questions were based on two POE studies with a focus on indoor air quality [42, 43] and used standardized questions (e.g. Q-bank) and scales (e.g. Likert-scale). The survey consisted of a total of 9 questions (5 multiple choice, 3 Likert scales, 1 not mandatory open question) consisting of questions about:

(1) *Activity and occupancy:* the rough location the occupant is within the building, how often the occupants use the building for various activities, and how they would describe the occupancy in their current space.
(2) *Awareness and satisfaction:* how aware the occupant is of the current air quality in the space, how the occupant perceives the air quality in the current space, and how satisfied the occupant is with the air quality in the current space.
(3) *Health and cognitive symptoms :* if the occupant experiences any health or cognitive symptons based on the air quality in the current space.

3.2.2 Participants. The survey was distributed via handouts with QR Codes using eligibility criteria based on demographic characteristics to occupants present at the informal learning spaces of the atrium, first floor, and second floor. There were no additional inclusion criteria besides the sample size of respondents being present in the case study building. Additionally, handouts were attached to the tables using stickers. All instances of participation were voluntary and conducted without remuneration. Distribution of the survey was open for participation for four weeks within the Lab42 building which recorded XX (n=XX) responses in total of which after cleanup a total of XX (n=XX) responses were included in the final dataset. On average, participants used the Lab42 building 3 times a week for various activities (min=1d, max=5d, Mdn=3d) and most occupants from the sample size were located on the ground floor ((f=8)) as opposed to the first floor ((f=34)) and 2th floor ((f=34)). No personal identifiable information such as age and gender were collected during the survey and ethical considerations (e.g. consent forms) were taken into consideration (see Appendix H).

3.2.3 Data analysis. After the distribution of the survey completed analysis of the collected data was performed in the form of data cleanup and exploratory data visualization. In Python (Jupyter Notebook format) [6] Libraries such as Numpy [7] were used to clean the data (e.g. remove non-consenting users) and visualization libraries such as Seaborn [8] were used to create graphs and plots (e.g. boxplot the likert-scales) to get an overview of the collected data and gain insight into understanding the occupants.

[3]https://uva-dilab.com/
[4]https://lab42.uva.nl/
[5]https://www.amsterdamsciencepark.nl/
[6]https://jupyter.org/
[7]https://pandas.pydata.org/
[8]https://seaborn.pydata.org/



(a) Figure 1 **(b) Figure 2** **(c) Figures 3 and 4 combined**

Figure 2: Impressions of the ideations and prototyping phase

3.3 Air Quality Monitoring

To gather data about the current situation of air quality within the building and understand the current situation within the building in terms of air quality data we retrofitted IAQ monitors (see Appendix H) to two specific meeting rooms within the building. This data collected was further used to inform and acts as a basis for the design of the data physicalisation (see 3.2).

3.3.1 Technical set-up. We deployed the monitors in meeting rooms occupants regularly use which allowed to understand occupants behavior and perception under real-world corporate settings as opposed to a controlled lab setting. We refer to them as the small room (room A) and the large room (room B). The small room's is XX m2, and commonly used for small-size meetings (seven seats), while the large room's ones is XX m2 (fourteen seats), which is more preferable for hosting larger-size meetings and seminars. Two commercially available indoor climate data loggers were installed using 3D printed mounting plates, a AirCheq Touch Aero [9] in the smaller room and a Atal ATU-CT ClimaTrend [10] in the larger room. Both monitors use industry-standard (e.g. Senseirion and SenseAir) sensors to measure common pollutants and were mounted (e.g. between 80cm and 120cm from the ground) and calibrated (e.g. intervals, polling rates) as described by both manufacters installation manuals.

Table 1: Sample Indoor Air Quality Data

Time	Humidity (%)	VOCs (ppm)	CO2 (ppm)
08:00	40	0.05	500
09:00	42	0.06	520
10:00	45	0.07	550

3.3.2 Data logs. The data gathered by the sensors provides insights into various standardized measurements related to common pollutants that affect IAQ such as molds and allergens (humidity), volatile organic compounds (VOC), and carbon dioxide (CO2) (see Table 1). We cross-referenced the data logs with two weekly schedules based on the internal booking systems of the rooms based on the timestamped data to align the values of the sensors from the data logs when meetings were scheduled. Data analysis is performed similary as described in section 3.2.3 were data was cleaned to remove data from mainly non-opening hours and plotted and visualized to visually explore patterns in the data and cross-reference them with meeting times.

3.4 Ideation and requirements

As a starting point for creating a physical representation of the air quality data we base our research on the growing interest in establishing theoretical and design foundations for *data physicalisation* [8, 18, 39] on how to encode the properties and use a common design language [36, 44] established by systematic reviews of data physicalization projects. The overall goal of the prototype is described in the following definition:

> *a data-driven physical artifact whose geometry and material properties encode data that aims to augment a nearby audience's understanding of data insights.*

Before prototyping the design solution we first describe the intentions and scope of the physicalization. We derived five relevant dimensions based on the literature; *audience, intention, interaction, philosophy, representation* [18, 39].

3.4.1 Design philosophy. Minimize interuption cost, notion of calm technology, ideal situation use persuasive techniques to help them take preventive actions.

3.4.2 Data representation. Write about data scale (stevens) nominal, ordinal and numerical. Needs electronic components (e.g. microcontrollers, sensors) and non-electronic components.

3.4.3 Audience.

3.4.4 Intention.

3.4.5 Interaction.

3.4.6 User requirements. Based on this scope and the survey we describe the user requirements ("UR" for "User Requirements") of the design solution in further detail in the form of requirements, in user story format, ranked based on the MoSCoW method:

UR1: The system should provide a user-friendly interface.
UR2: Users should be able to register for an account with a valid email address.
UR3: Upon registration, users should receive a confirmation email.

[9] https://airteq.eu/producten/touch-aero/
[10] https://www.atal.nl/atu-ct-climatrend-binnenklimaat-datalogger

UR4: The system should allow users to log in securely using their credentials.
UR5: Users should be able to create, update, and delete their profiles.

3.4.7 Concept models. For the concept models two existing datasets were used as a starting point for brainstorming and inspiration. First was the DataPhys gallery [11], a collection of 372 entries classified as data physicalizations. The second was a combination of three state of the art papers with systematic reviews of physicalization with a combined examples of around 132 entries classified as data physicalization of which both academic and non-academic samples. Out of these twelve (f=12) entries ((f=8) academic, (f=4)) were selected for further review based on the similitary and aligment with the before described dimensions of which three (f=3) projects (Physikit, other, other)with a focus on the environmental property of air (but not necessarily air quality within indoor environments). Additionally

3.4.8 Concept diagrams. Based on the user requirements and ideation and concepting from the Communication and Multimedia Design (CMD) Methods Pack [12] and Design Method Toolkit [13] by the Digital Society School (DSS) three low fidelity (lo-fi) concepts were further elaborated (see Figure 3) in order to choose one to create for the user studies and evaluation.

(1) **Concept-1: Desk Planter (Aspen)** A desk planter or tree in the corner of the room with soil in it.Follows the organic growth of a 'seed' of a flower or tree from seed to sprouts to full flower. The better the air quality the more or faster the plant grows. Movement of the leaves can indicate the wind.
(2) **Concept-2: Hanging Sculpture (Bluebird)** A hanging planter type set-up with strings that 'grow' from the ceiling. Fresh air makes movement of the strings. People can walk by, feel the material (e.g. humidity). Can touch, allows most interactivity. Taking inspiration from kinetic sculptures and hanging / floating sculptures.
(3) **Concept-3: Wall Kinetic (Crocus)** A moss-like structure on the wall with flower bulbs embedded. The flowers 'open up' based on better fresh air. Taking inspiration from kinetic sculptures.

Concept selection was based on weighted physicalization criteria from the literature, a harris profile and expert reviews (N=4) feedback. Also technical limitations of the provided hardware (e.g. real-time data output of monitors, cost of hardware, availability of electronic components,) and limitations in the technical set-up of the building (e.g. space in the meeting rooms, not allowed to alter furniture) were choosing criteria. Based on aggregration of these criteria the *Bluebird* concept was chosen to be further developed into a high-fidelity prototype.

3.5 Prototype

Based on the requirements, data physcalization desgin principles and concept models exploration a final high fidelity (hi-fi) version of the prototype was developed that functioned as a proof-of-concept of the physical design solution and utilised in the user study for evaluation.

3.5.1 Concept description. *Bluebird* (see Figure 3) is a hanging kinetic type sculpture inspired by organic nature materials and the shapes of hanging planters that encode the environmental properties of indoor air quality data. It is meant to be hang from the ceiling in small to medium rooms (xM2) and changes based on real-time air quality monitor data. Strings (plant branches) either become lengtheir or smaller simulating the growth of a plant. Movements of the leaves indicate the freshness of air and movement.

3.5.2 Electronics and components. A controller device running on a Arduino Uno R3 [14] microcontroller with a MKR Motor shield is used [15] to control six 360° MG90S type Micro Servo Motors [16]. Attached to these motors are pulleys with fishing line simulating the growth of the hanging planter and so that the string can be moved up and down.

3.5.3 Crafting technologies and materials. The strings, leaves and housings of the electronics and mechanical hardware are created using additive manufacturing (3D Printing) using a Fused deposition Modeling (FDM) technique using Polylactic acid (PLA) plastic filament in various colors. The electronics enclosures and plant models were modeled using computer-aided design (CAD) software. A digital fabrication technique commonly found in data physcalization prototypes [4]. To create leaves representing textile or fabric custom properties were defined withing the 3D printing software (Slicing) to remove top and bottom layers and create a thin layer of infill.

3.5.4 System Architecture and software. The microcontroller uses custom firmware written in Arduino code [17] (similar to C++) that receives real-time data from the air quality monitors using the LoRaWAN [18] communication protocol to control the mechanics of the prototype. This arrangement of hardware is commonly found in Internet of Things (IoT) architecture set-ups and follows the notion of Edge Computing with a (1) sensing, (2) networking, (3) processing and (4) application layer [19, 30].

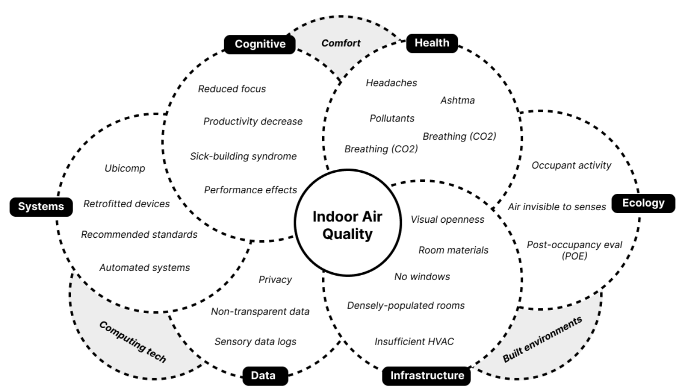


Figure 3: Bluebird data physicalization prototype in the lab

[11] http://dataphys.org/list/gallery/
[12] https://cmdmethods.nl/
[13] https://toolkits.dss.cloud/design/
[14] https://store.arduino.cc/products/arduino-uno-rev3
[15] https://store.arduino.cc/products/arduino-motor-shield-rev3
[16] https://www.towerpro.com.tw/product/mg90s-3/
[17] https://www.arduino.cc/reference/en/
[18] https://lora-alliance.org/about-lorawan/

3.6 Evaluation

The prototype was evaluated using common performance-related criteria that are widely used in HCI/Information Visualisation [36] and Grounded Theory studies [11]. We employed a field-based evaluation approach with accompanying methods (see Section 3.2) based on the Human-centered Design Kit by Ideo [19] and Delft Design Guide from the Delft University of Technology (TU) [20]. For evaluation criteria we used the intentions described in [36] and interview methodology similar to [20] as a baseline for evaluating the efficiency, memorability in in-person evaluation sessions. To measure the overall effectiveness and usability of the physicalization we used an adoptation of the Technology Acceptance Model (TAM) to gather insight into perceived usefulness, attitutde towards using and system usability scale [].

3.6.1 Hypothesis elicitation. On the basis of the research question and creation of the prototype four hypothesis ("H" for "Hypothesis") were formulated to evaluate on.

- H1: The system should provide a user-friendly interface.
- H2: Users should be able to register for an account with a valid email address.
- H3: Upon registration, users should receive a confirmation email.
- H4: The system should allow users to log in securely using their credentials.
- H5: Users should be able to create, update, and delete their profiles.

3.6.2 Participant sampling. The sample size of evaluation interviews was 8 (n=8) and accepted because the study findings reached saturation, meaning that new interviews did not yield new insights after the first five interviews. Participants were gathered through purposive sampling, as respondents had to meet the inclusion criteria ("C" for "Criteria") that needed to be checked before the interviews:

- C1: The participant needed to use a meeting room with the building a minimum of once a week
- C2: The participant needed to work within the case study week a minimum of 3 days per week

This resulted in a sample of X male, X female, consisting of various roles; from researchers from different labs, PhD candidates working at the labs to private company employees encompassing a range of ages (min=X, max=X, Mdn=X, IQR=X) and education levels. Participants used the meetings rooms on average X (min=X, max=X, Mdn=X, IQR=X) a week and worked within the lab42 building X (min=X, max=X, Mdn=X, IQR=X) a week.

3.6.3 Semi-structured interviews. Within the meeting-room lab set-up in the presence of the developed prototyped pre-arranged, semi-structured individual qualitative interviews were conducted with open-ended and nonleading questions (see Appendix H). The goal was to gather first impressions and gain insight into how occupants understand the communicated data factors of the prototype.

3.6.4 Participant observation. After the explorative questions participants were encouraged to in more detail view the prototype and interact with it as a field trial stating anything they noticed. Participants behavior was observed within the meeting rooms and participants were encouraged to think aloud when viewing and interacting with the prototype (see Appendix H). Informal leading questions were asked about improvements, design optimizalization and visual changes. The goal was to test the usability of the prototype and gather insight into the self-reflective properties of the prototype.

3.6.5 Effectiveness of the prototype. After the interviews and observations, the participants were asked to fill in a digital online with structured pre-defined questions form rating several properties of the prototype for their effectiveness (see Appendix H). The goal was to gather quantitative measurements about the usability and effectiveness of the prototype.

3.6.6 Transcription and coding. All interviews were anonomyzed and conducted in-person on-site and audio recorded with permission of the participants. The recordings were then verbatim transcribed using the build-in Microsoft 365 transcription tool [21] to avoid bias while note-taking. The transcribed interviews as textual data was processed via Atlas.ti [22] for qualitative coding.

4 RESULTS

The goal of the chosen methodologies (see 3.2) where choses to answer the research questions. Section (see 3.2) describes the results of the survey and section (see 3.2) shows key insights into data collection which address SQ1. Then the developed prototype will be presented in section (see 3.2 which addresses SQ2 and the results from the evaluation will be summarized in (see 3.2) to address SQ3.

4.1 Survey analysis

Show the results of the survey, preferably with graphs based on the likert-scale. Hypothesis is that awareness of indoor air quality among occupants is very low. This is comparitive to other studies performed that indicate the same results

4.2 Air Quality Monitors

Show graphs of the sample data. Hypothesis is that when meetings occur with more occupants after a while the air quality exceeds recommended standards.

4.3 Prototype

The prototype was hang-up at the two meeting rooms. Interaction set-up etc.

4.3.1 Design elements.

- **Sight**: visually see string become largers. Acts as a metaphor of plant 'growth'. The better the air quality the more the plant can 'grow'.
- **Movement**: if fresh air comes in we indicate this through movement as a metaphor for wind gusses between a field of grass or plants.

4.3.2 Experimental set-up. Write about how the prototype is in the room. Installed (reference lab settings again). Reference figures in appendix for more photographs and impressions.

[19] https://www.designkit.org/methods.html
[20] https://www.bispublishers.com/delft-design-guide-revised.html
[21] https://www.microsoft.com/nl-nl/microsoft-365
[22] https://atlasti.com/

4.3.3 *Haptics.*
Write about interaction and haptics it support.

- **Sight**: visually see string become largers. Acts as a metaphor of plant 'growth'. The better the air quality the more the plant can 'grow'.
- **Movement**: if fresh air comes in we indicate this through movement as a metaphor for wind gusses between a field of grass or plants.

4.4 Evaluation

The evaluation methods (see 3.2) are used to assess the quality and impact of the data physicalisation with a focus on how users perceive the data embedded in the physical representation and what long-term impact it has on people.

4.4.1 *Understanding (qualitative).*
Did users understand the phys? Know what it was visualizing? Users reaction?

4.4.2 *Self-reflection.*
Makes you more aware of IAQ?

4.4.3 *Effectiveness (question answering).*
Suspected to change habits based on output? Attitude change? Behavioral stimulation.

5 DISCUSSION

5.1 Ethical considerations

5.2 Limitations

5.2.1 *Validity.*

5.2.2 *Prototype scalability.*
Concessions were made during the creation of the prototype. Limitations in time, hardware availability and technical limitations.

5.2.3 *Generalizability.*
Tested within the Lab42 building, so it's hard to test effectiveness are scalable to other university buildings.

5.3 Future work

Future work, the prototype to communicate more sensory properties. We envision fabric that holds water to communicate humidity etc. made of organic materials etc.

6 CONCLUSION

Write your conclusion here. Be sure that the relation between the research gap and your contribution is clear. Be honest about how limitations in the study qualify the answer on the research question.

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Appendix A ACKNOWLEDGEMENTS

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Appendix B ETHICAL CONSIDERATIONS

Before user studies were conducted, an application to the Ethics Committee for Information Sciences (ECIS) [23] about the methodology of this research, how data is being gathered and stored was made. Advice from the committee is still pending.

Prior to conducting the questionnaire survey and evaluation procedure, a domain expert from the Informatics Institute at the University of Amsterdam reviewed the methodologies involved. All individuals participating in the survey and evaluation process were obliged to confirm their voluntary involvement by carefully reading and signing a letter of consent, with the assurance that they retained the right to withdraw from participation at any point without the need for explanation. To uphold confidentiality and privacy, survey participation occurred anonymously, and all evaluation data underwent anonymization following the conclusion of the evaluation sessions.

Interacting with occupants within the building and interacting with participants of the usability tests of the prototype adhered to the the principles outlined in the UvA code of conduct [24].

Appendix C DATA STORAGE AND ARCHIVAL

Take some parts of the ethical application to describe data storage and archival of the devices etc.

Appendix D SOURCE CODE

In the spirit of open research, to support reproducibility and enable future work in this problem space the datasets, research notebooks, and prototypes in this work are publicly available on a GitHub organization with the working title 'viszlab' [25] using the MIT License. Several code repositories for different parts of the research can be accessed. The readme.md of the repository described the contents and how to perform the technical set-up:

(1) **Prototype**. Code and models for the physical prototype.
https://github.com/viszlab/prototype
(2) **Datasets**. Code and models for the physical prototype.
https://github.com/viszlab/prototype

A one-page website was created for shareability of this research. It's an online website which gives an overview of the research, allows for viewing the source coded of the prototype and allows for downloading of this paper. A live version is deployed on:

(1) **One-pager**. Code and models for the physical prototype.
https://viszlab.github.io/

[23]https://ivi.uva.nl/research/ethical-code/ethical-code.html
[24]https://www.uva.nl/en/about-the-uva/policy-and-regulations/
[25]https://github.com/viszlab

Appendix E FLOORPLAN AND LAB SET-UP

A diagram indicating where the sensors where installed. This shows the lab set-up in the two meeting rooms.

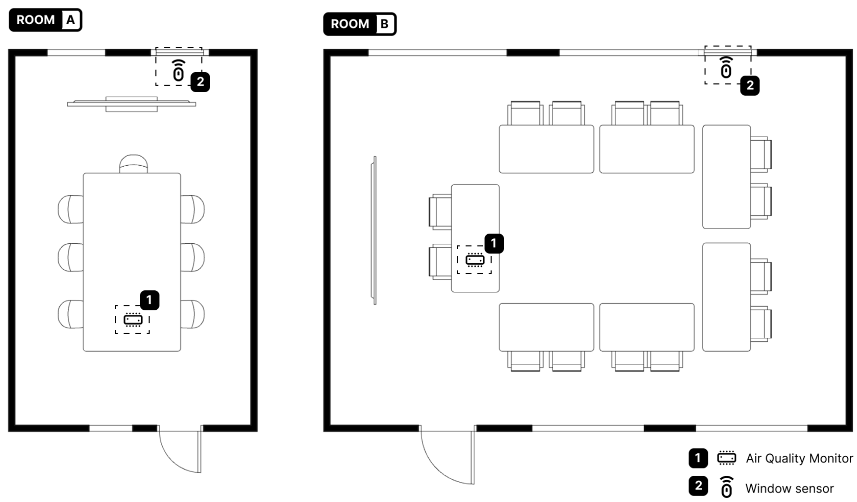

Figure 4: Diagram of the floorplan with sensors installed

Appendix F IOT ARCHITECTURE OF THE PROTOTYPE

System diagram which shows the IoT architecture of the prototype.

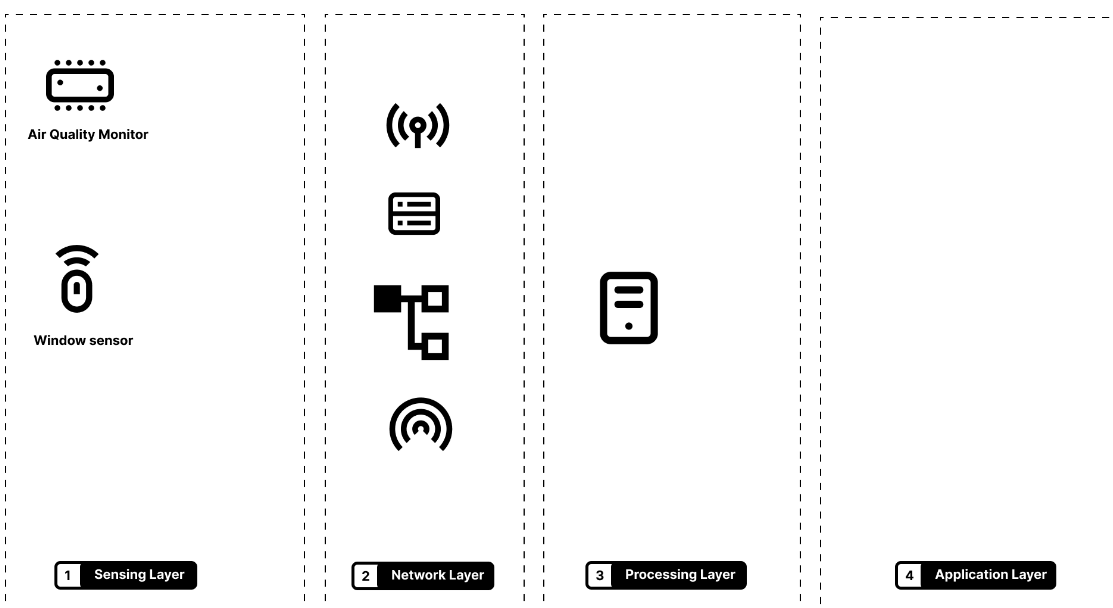

Figure 5: System diagram that shows the technical set-up of the prototype

Appendix G MEETING ROOM IMPRESSIONS

Figure 6: System diagram that shows the

Figure 7: System diagram that shows the

Appendix H BUILDING IMPRESSIONS

(a) first

(b) second

(c) third

(d) fourth

Figure 8: caption

Figure 9: System diagram that shows the

Appendix I PROTOTYPE IMPRESSIONS

Figure 10: System diagram that shows the

(a) first

(b) second

(c) third

(d) fourth

Figure 11: caption

Appendix J WEEKLY SCHEDULE

Horizontal boxplot that indicates an average week of booking in the meeting rooms scheduled.

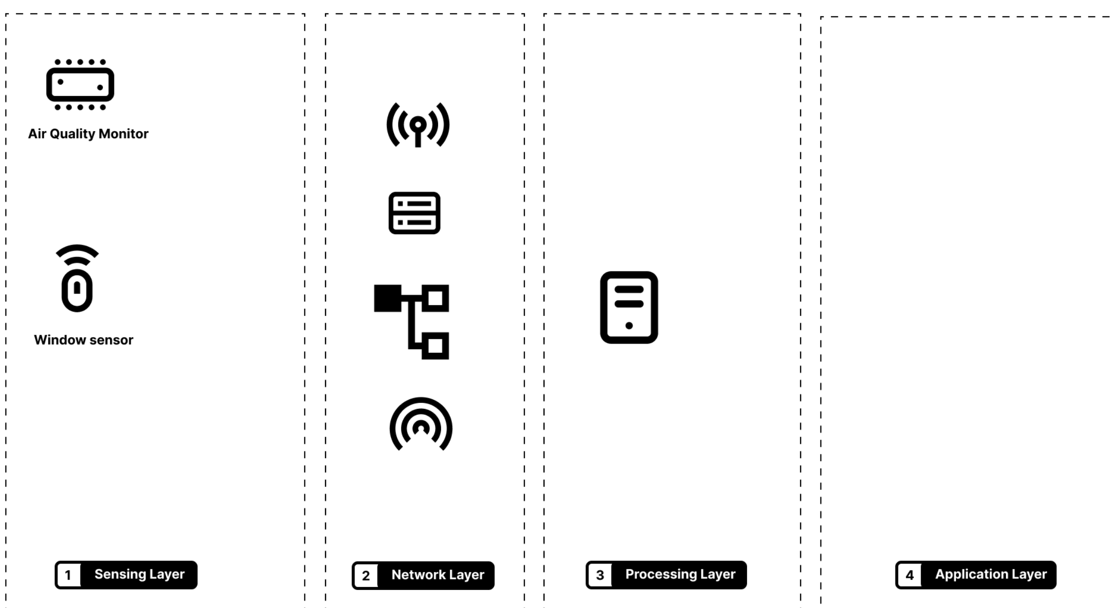

Figure 12: System diagram that shows the technical set-up of the prototype

Appendix K AIR QUALITY MONITORS SAMPLE DATA