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Deliverable 3.10

Interface guidelines for occupant-centered smart climate control systems

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SUMMARY

The Brains4Buildings project aims to develop methods to design new smart building climate management systems that, among other things, reduce energy consumption, increase comfort and respond flexibly to user behavior. We set out to develop design guidelines to help B4B stakeholders when designing innovative user interfaces for such systems.

We built upon our prior user research and requirements (deliverables 3.04 & 3.09) to formulate *design dimensions*. The dimensions encompass the different elements of user control and system feedback and the range in which they can exist. The design dimensions played a key role as a foundation for the design process and during evaluation and analysis.

Within this work package, we ultimately want to gain a deeper understanding of the elements of the design dimensions and to formulate design guidelines. Building climate systems are generally designed for the specific context/building they are built into and thus the goals for the user interfaces can vary greatly. Therefore, a well-defined use case was necessary, which we defined in collaboration with one of our work package partners - Spectral.

We chose an iterative approach to design for the use case, moving between design, prototype and test phases, depending on the insights gained along the way.

Finally, we synthesized a list of key insights that led to design guidelines. In our final deliverable (D3.11) we aim to evaluate these guidelines.

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1 INTRODUCTION

Within the Brains4Buildings project, our contribution to work package 3.4 focuses on the roles, relationships and interactions among occupants, the building climate system, and facility managers. With this focus, we add insight and perspective on the challenges defined in the project.

This deliverable presents design guidelines for innovative interface design of building management systems and the process that led to these design guidelines. The guidelines from this deliverable can be adopted by partners in the Brains4Buildings consortium and developers of building management systems to create suitable interfaces that meet user needs and, as we poetically call it: *"support the dance between the building and its users."*

In this document, we will present the relevant design dimensions that formed the basis for our iterative design process, as described in Chapter 3. Chapter 4 presents the key insights from user testing and the resulting design guidelines. In conclusion, we will elaborate on the limitations of this study, the impact on practice and future work in the Brains4Buildings project, including the next steps towards Deliverable 3.11.

1.1 Previous Work

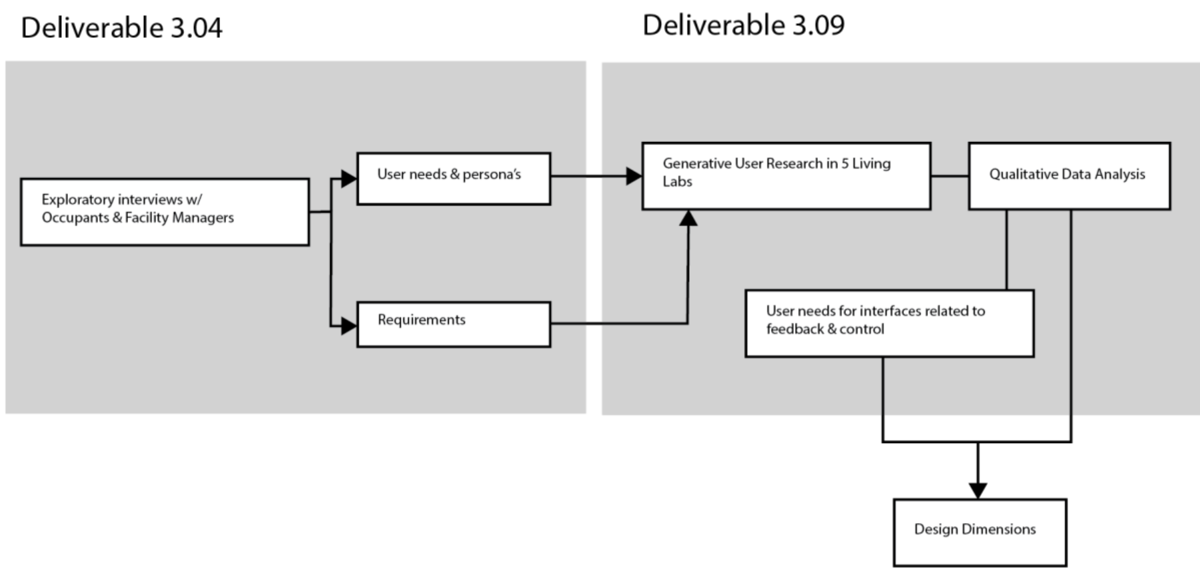


Figure 1: Diagram of previous work, for content, see Deliverable 3.04 and 3.09

In our first Deliverable 3.09 we identified relevant user needs and requirements based on interviews with occupants and facility managers (figure 1). Generative user research methods were employed in Deliverable 3.04 to research the user needs for innovative Smart Building interfaces, particularly regarding feedback and control (figure 2). A few notable topics of interest for the designing of such interfaces were:

- communicating the status of the climate control systems,
- supporting occupant climate choices and communicating the impact of said choices,
- and designing interfaces that align with the actual functionality of the climate system.

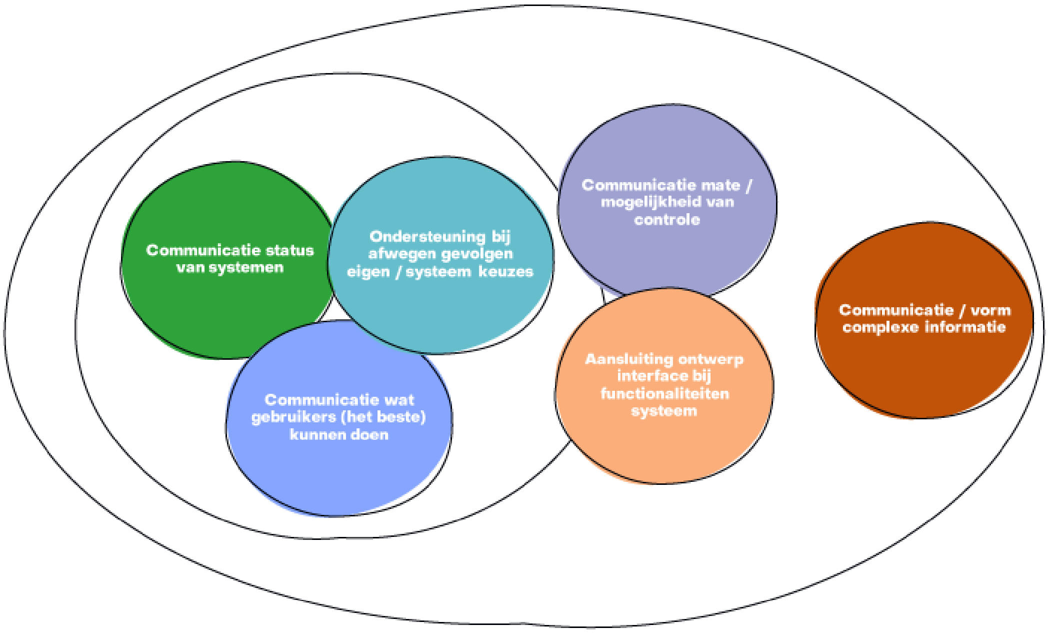


Figure 2: Topics of User Needs for Smart Building Interfaces.

This deliverable (D3.10) adds to this work, translating the requirements and user needs into a workable framework of Design Dimensions.

1.2 State of the art

While there are idealised visions of building climate systems that are fully automated, data-driven, and capable of regulating the "perfect" climate for the occupants, there is growing consensus among designers of such systems that a more balanced, user-centric approach is advisable. Among other factors, human behavior and comfort levels can be too unpredictable for even the best smart systems (Zeiler et al, 2014). There are also issues of cost and complexity. Advanced sensors and control systems are required to fully automate a data-driven building climate system, which is increasingly unfeasible in large, complex buildings. Attempts at fully automated climate systems often result in a high number of complaints from occupants whose agency has been (partially) taken away. Such a technology-driven view of the building environment, therefore, often leads to occupants employing adaptive strategies to reach their desired level of comfort while the climate system classifies humans as irrational disruptors of the ideal climate (figure 3).

Figure 3: Adaptive strategies employed by occupants: adding an alternate temperature scale to the thermostat with a black marker (left) and taping sheets of paper to the window as a personal solar screen (right)

Although a fully automated climate system might ultimately be more energy-efficient, there is a case to be made for individual occupant comfort and satisfaction, which often translates to healthier people and higher productivity levels. As Levin states: “If users are allowed to participate in determining the characteristics of their environment, they are far more likely to be satisfied and comfortable” (2003). We, therefore, plead for a holistic design approach that actively involves occupants and enables them to make fundamental decisions about their building’s indoor climate.

With the advent of technology and the field of human-computer interaction (HCI), numerous design principles and guidelines for interfaces that have been tried and proven have been established. Examples are the 10 usability heuristics for user interface design (Nielsen, 1994), or patterns related to specific contexts such as mobile interfaces (Hoober & Berkman, 2011). However, we see a lack of such guidelines for approaching challenges for innovative building climate control systems, especially those that rely on sensors and automation and allow for manual control or input by occupants.

We aim to propose a set of guidelines for designing interfaces that can be used by the B4B consortium and other designers and developers of buildings, their climate systems and interfaces.

2 DESIGN DIMENSIONS

At the start of working on this project phase, we had collected a large set of quantitative data, from interviews, generative user research methods and input from the B4B consortium (figure 4). While this formed a thorough basis for understanding the occupants' concerns, needs and dreams (Sanders & Stappers, 2013), a more concrete framework was necessary for our interface designs.

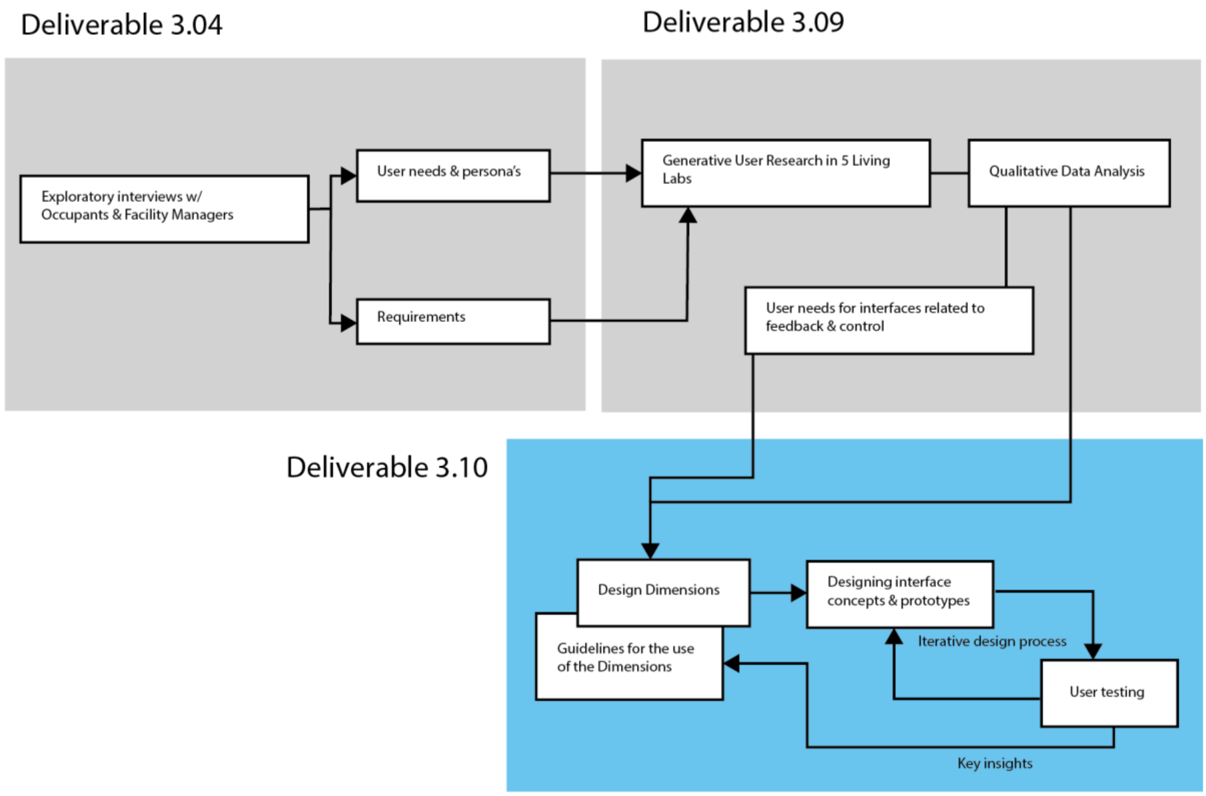


Figure 4: Diagram of work for Deliverable 3.10, connected to previous work

After analyzing the data from all previous research activities, a set of design dimensions was defined, which can be used to analyze existing solutions and generate new ones. We differentiate dimensions determining levels and types of control given to occupants and dimensions relevant to the feedback given from the system to the occupant/facility manager. While some aspects are binary (e.g. the system either gives visual feedback or not), most dimensions exist in a spectrum. For example, controls for a climate system can be mounted to a wall (static), accessed through a mobile app (portable) or a mix of both in varying degrees.

In this chapter, we present the design dimensions which formed the basis for the design process described in the following chapter.

2.1 Control & Feedback

The dimensions relate to two elements of climate control: one impacts how occupants interact with the system/interface (Control), and the other determines what the interface returns and how (Feedback).

The Control category can be split further into Form, Agency and Resolution. Form determines the placement, shape, physicality and construction of the controls. Choices made in the Agency dimensions affect the range of control occupants have on the climate. The scope and level of detail of control is determined in the Resolution dimensions.

The Feedback category defines dimensions as Transparency, Form, and Content. Transparency represents three types of feedback (system status, advice for occupants, and effect on indoor climate). While Form determines the level of detail, modality, activity level and frequency of the feedback, Content determines the context to which it pertains. Figure 5 shows these dimensions and their underlying aspects. In section 3, Research Method, we will elaborate on these aspects and their characteristics.

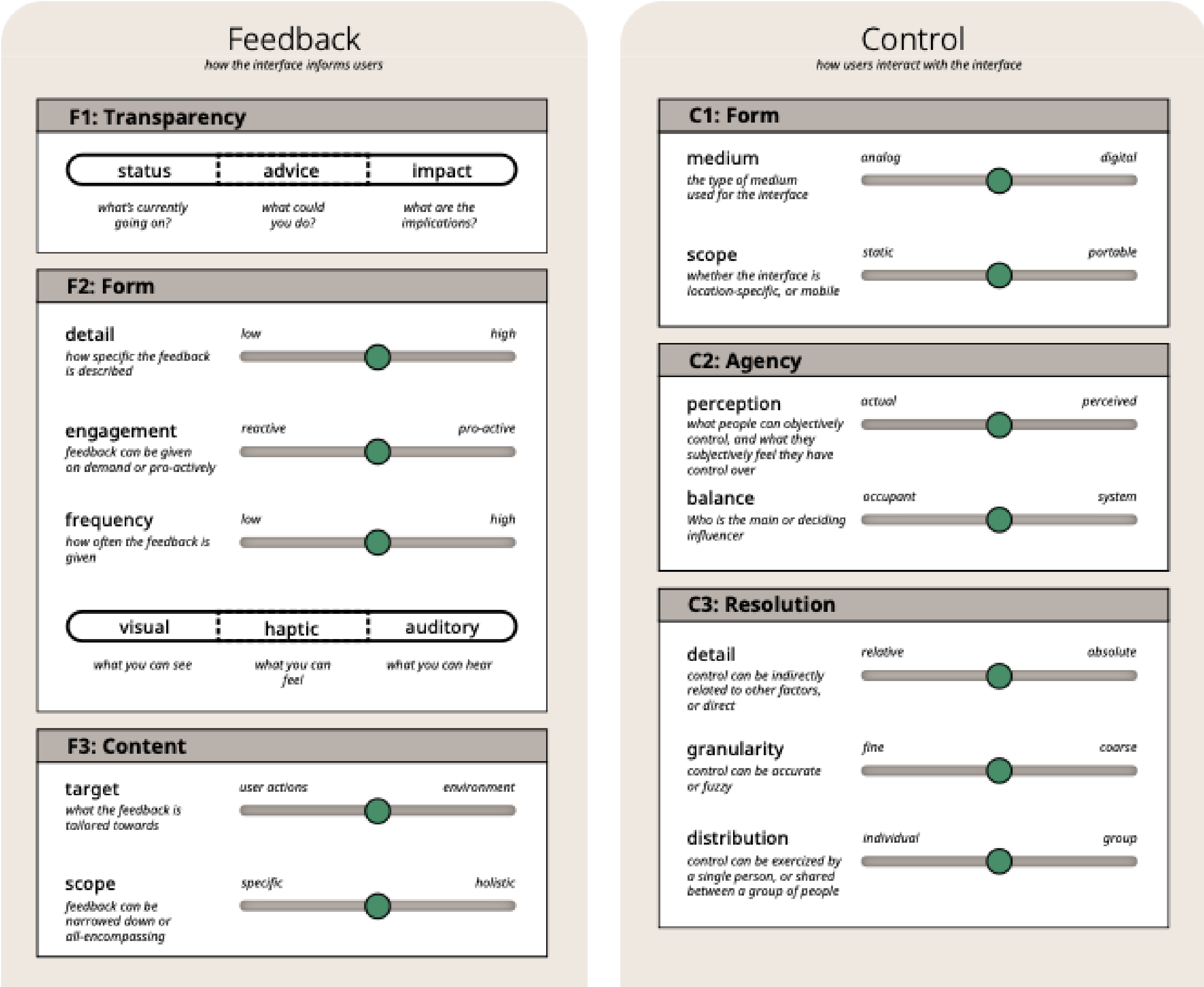


Figure 5: Design dimensions for interfaces

3 DESIGN PROCESS

After defining the design dimensions, an iterative design approach was employed to create and test various interface concepts (Brown, 2008). In this chapter, we summarize this approach, the methods used and important insights from each activity.

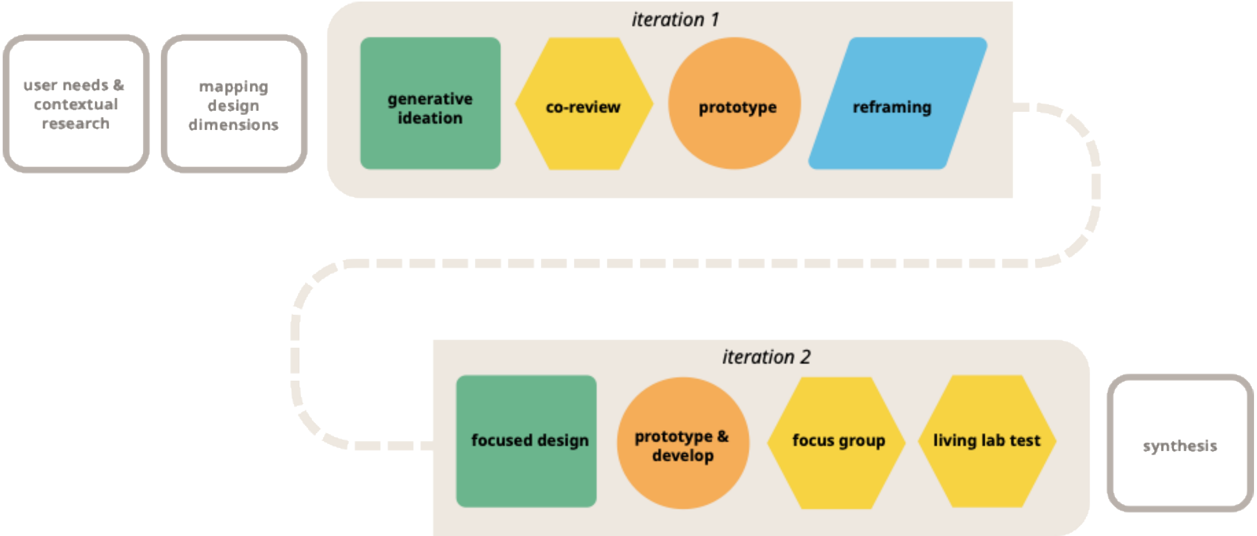


Figure 6: The iterative design process for the study

3.1 Benefits of an iterative design process

An iterative approach allows revisiting previous work, gradually building insights and designed solutions. This allows early mistakes and tweaking along the way (figure 6). The number of iterations is typically tied to the available resources. An iteration consists of a designing phase, often a diverging process exploring different possible outcomes based on user insights, a prototyping phase, a user testing phase used to reflect upon the design to find out if the designed intentions work as intended, and a reframing phase, meant to include stakeholders to specify the overall design direction and make informed and collectively supported design decisions and set the scene for the next iteration. Work for this deliverable included two iterations, with multiple smaller iterations in the designing and prototyping phases to improve and tweak designs.

3.2 Iteration 1

Mapping Design Dimensions

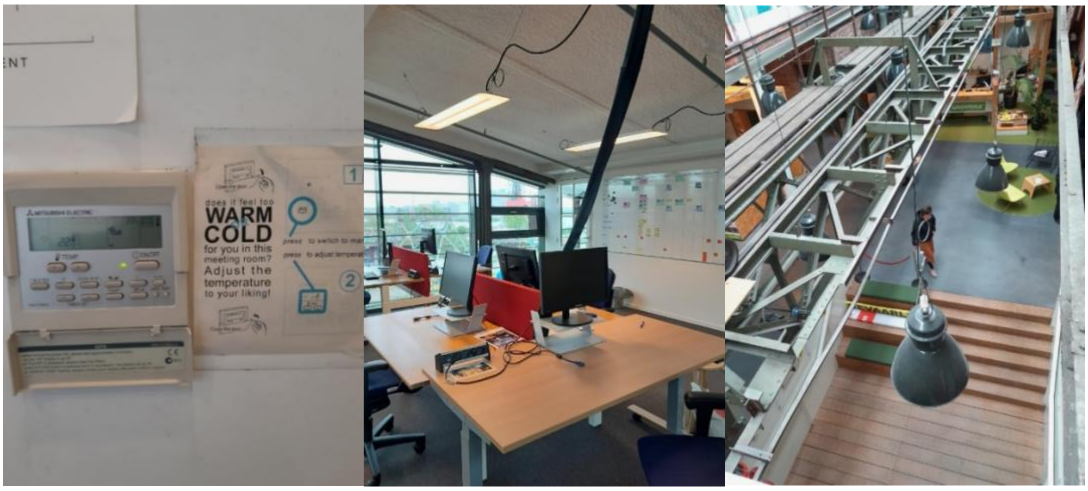


Figure 7: Photos of the HINES building, location of the first use case

While the overall requirements for a user interface are relevant for all climate management systems, the individual user needs can differ for each building and system. For example, a university building knows various user groups, including students who move through the building frequently, staff who mostly occupy a static workplace, and lecturers who use both classrooms and “static” desks.

To create a scope for the first iteration, work package partner Spectral and the design team defined a use case and determined a building to design for (HINES building in Amsterdam, figure 7). After presenting Spectral with the design dimensions, we asked them to map their current interface and what direction they would like to explore and why (figure 8). For example, Spectral’s current interface provides feedback mostly in a reactive way, in response to the user's actions or the status of the environment or climate control system. They have defined an area for exploration to see what effect a more proactive feedback system could have.

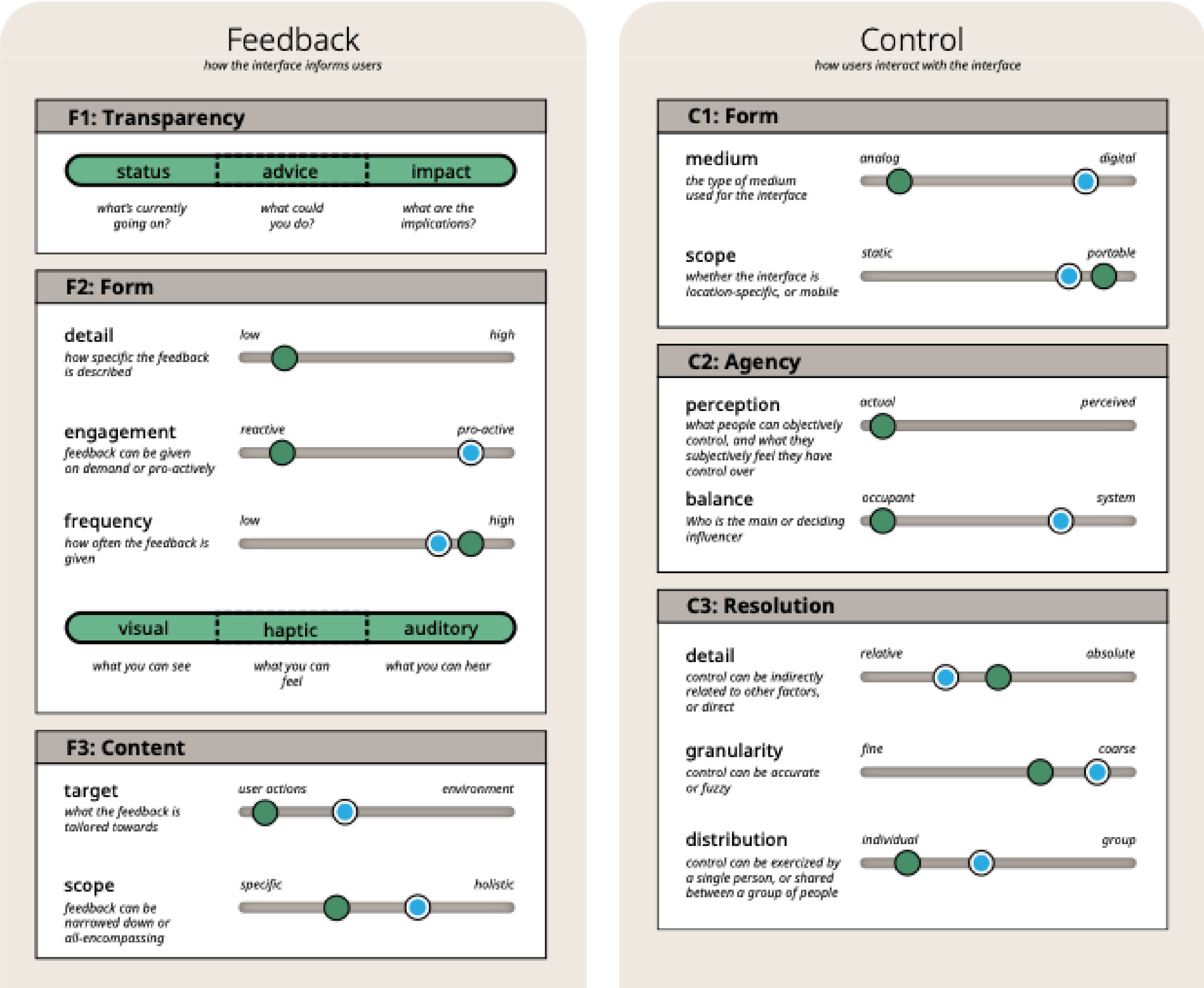


Figure 8: The design dimensions as present in Spectral's interface (green) and as goals for exploration within the study (blue)

Design

From there, various concepts were sketched in an initial ideation phase (examples in Figure 9). Valuable ideas from different sketches were selected and fused into a full-fledged concept to prototype and test with occupants.

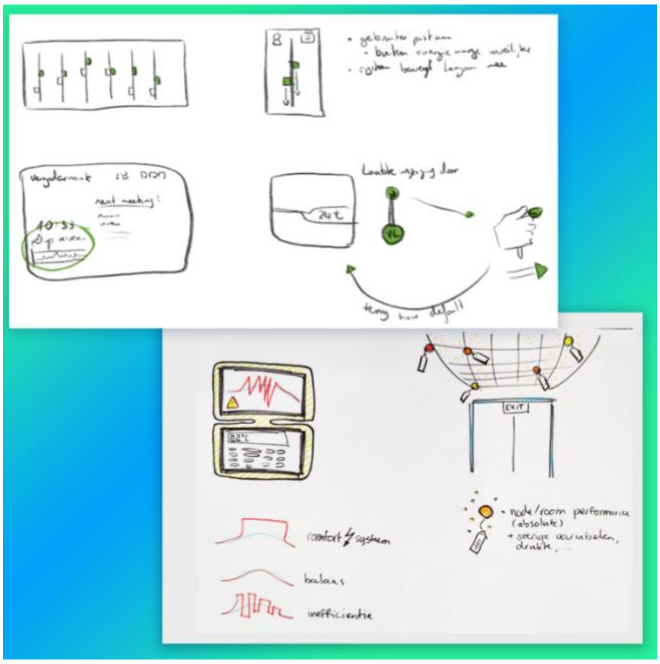


Figure 9: Sketches for early concepts

Concept & Low-fidelity prototype

The resulting concept gives occupants a "droplet" – a keychain-like tag that identifies them to the climate control system (figure 10). When they wish to change any setting on the climate control panel, they must first hang their droplet on a hook near the panel. The panel registers the droplet through NFC technology (Near Field Communication), enabling the occupant to input their settings.

With this concept, we aimed to explore the effects of tipping the design dimension for Distribution (in Control) towards the Individual in a group environment such as a shared office space. The HINES building has various flexible workspaces and meeting rooms. Hence, the droplet attempts to increase occupants' awareness of the portability and impact of their comfort preferences within a space with conflicting needs.

The chosen concept was prototyped in a low-fidelity manner to make the most fundamental aspects of the design tangible.

This prototype was used in the Reframing session and presented during the Healthy Buildings Conference to gather feedback from building management professionals. Below, these sessions and the gathered feedback are summarized.

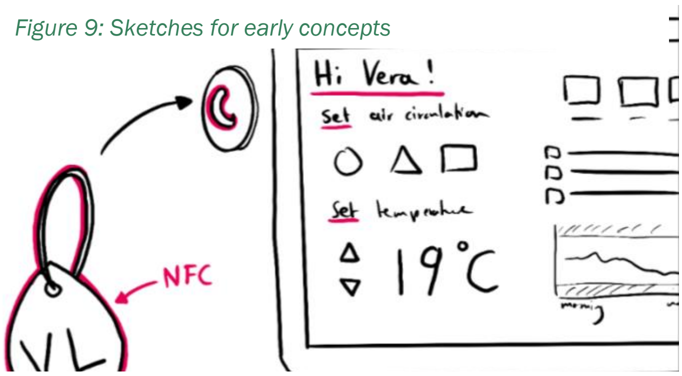


Figure 10: Part of the low-fidelity prototype of the "Droplet" concept

Healthy Buildings Conference

The Brains4Buildings consortium hosted several living room sessions at the Healthy Buildings Conference in Nieuwegein. The design team used this opportunity to present preliminary findings and their first concept to potential stakeholders. While some participants were intrigued by the droplet and its tactile and individual nature, most raised concerns about the applications for such a solution in a highly flexible space and about its distribution of control. The two most named concerns were forgetting the droplet during the day and conflicts between occupants over climate needs. Feedback from this session was used to inform the design decisions in the second iteration.

Reframing

During a reframing session, stakeholders and designers get together to evaluate the design/research process outcomes thus far. The goal of reframing is to take a critical look at the definition of the research or design goals and to add to, subtract from or shift the goal to better align with learnings gained along the way. We used reframing at the end of iteration 1 to discuss the findings and to define goals for the second iteration. These reframed design goals formed the basis of the second iteration:

- Design the interface as a bridge between facility managers and occupants so that both can act and control comfort (up until now, we were somewhat skewed towards designing from an occupant-centric mindset.)
- Focus on the (dis)balance of the system vs. user control and/or aim towards a more harmonious, balanced system. For example, think about 'dampening' effects on user controls.
- Afford autonomy so occupants take control of their own comfort.

Change of use case

Prompted by a change of tenants in the HINES building and complications with recruiting participants for our study, Spectral and our design team decided to focus the second iteration on their own offices.

3.3 Iteration 2

In the second iteration, sketches were made based on the insights of the reframing session (see Figure 11). Our team explored the potential interactions, mechanics and implications of the concept. Later, these sketches were formalized as digital screens, enabling a more detailed discussion and the development of a prototype suitable for testing in a living lab.

The concept can be described using the defined design dimensions (see next pages).

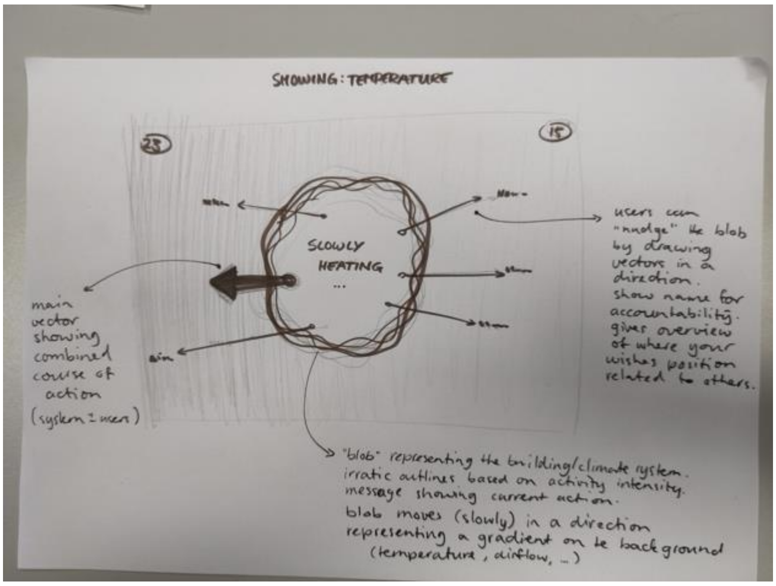
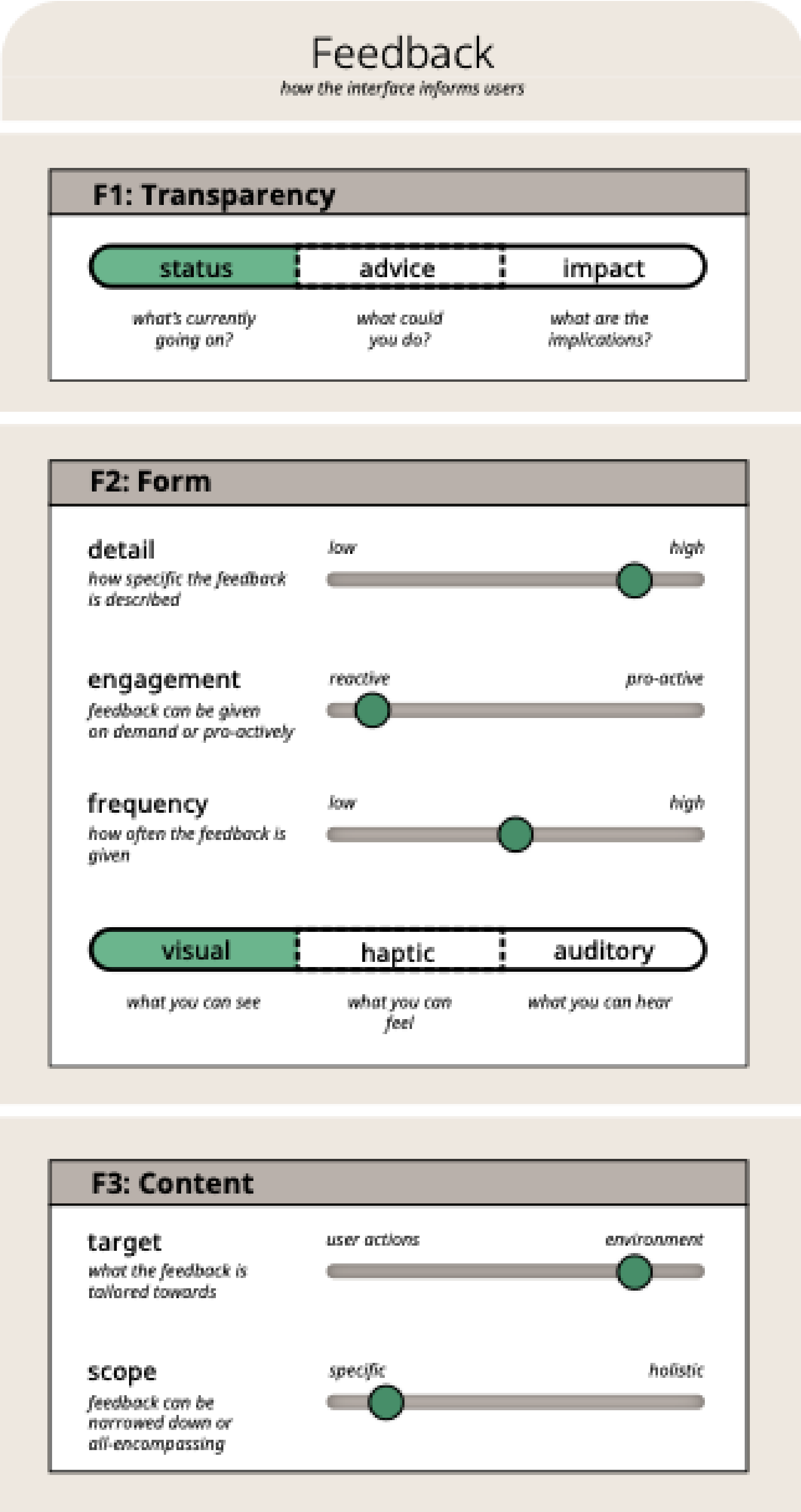


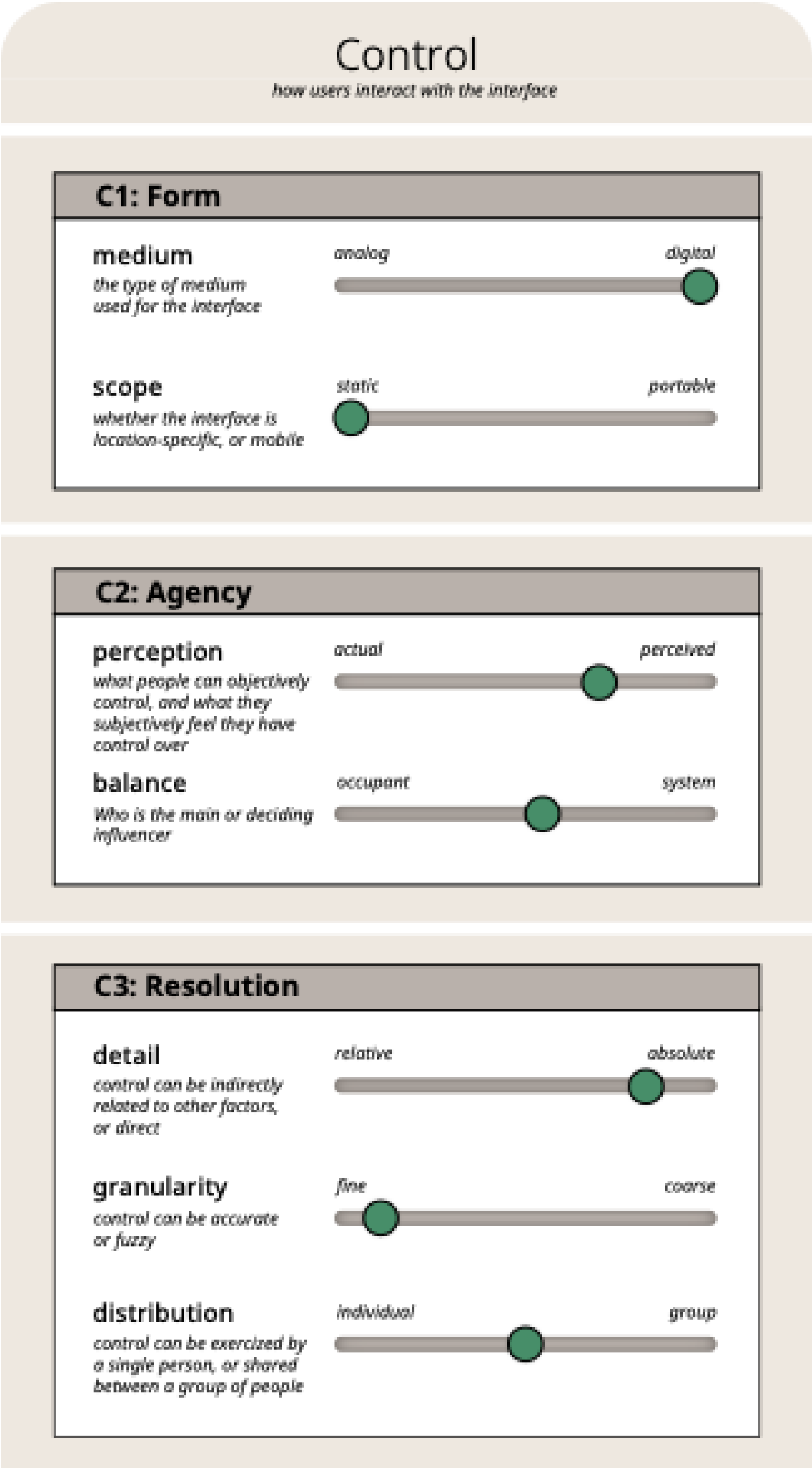
Figure 11: Sketch for final interface



The interface offers information on status, including the target temperature, active state and target time. It also indicates the level of 'flux' of the system, showing how the system is balanced relative to the occupants' preferences.

The interface primarily offers visual feedback, which can be augmented by auditory or haptic cues. The interface shows detailed information about its status and target and fuzzy feedback about the system's state of 'flux'. The interface passively provides feedback, visible to anyone inquiring about the screen.

The interface focuses on feedback on occupants' and the system's preferences rather than the environment. The feedback is centred around specific temperature metrics, although the system's flux could be considered a holistic state of the system.



Occupants can interact with the system through a visual, digital screen. The interface is located on static, fixed locations throughout the building.

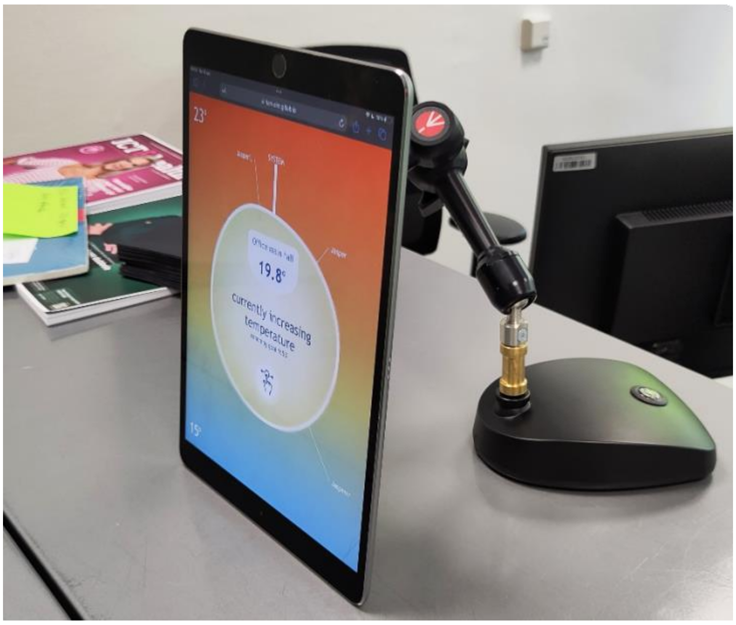
The interface offers a form of control by allowing users to add their vector to the 'pool' of forces influencing temperature. The system could remain largely in control, depending on the strength of the individual vectors versus the strength of the system's 'ideal' target.

The interface offers relative forms of control by allowing people to input their preferred temperature relative to the status and other people's vectors (warmer or cooler). While the canvas where users draw vectors offers fine-grained precision, the input is binary and imprecise (warmer or cooler). The interface shows the individual preferences of all actors, enabling group dynamics and accountability and possibly negative effects based on the adopted privacy features of the interface.

High-fidelity prototype

During the second iteration of the design process, a new concept was developed, and a high-fidelity prototype was created (figures 12, 13).

The design team wanted to test specific interactions and their impact on the occupant, so the final prototype needed to be usable in much the same way as it would have if implemented into an actual building management system.



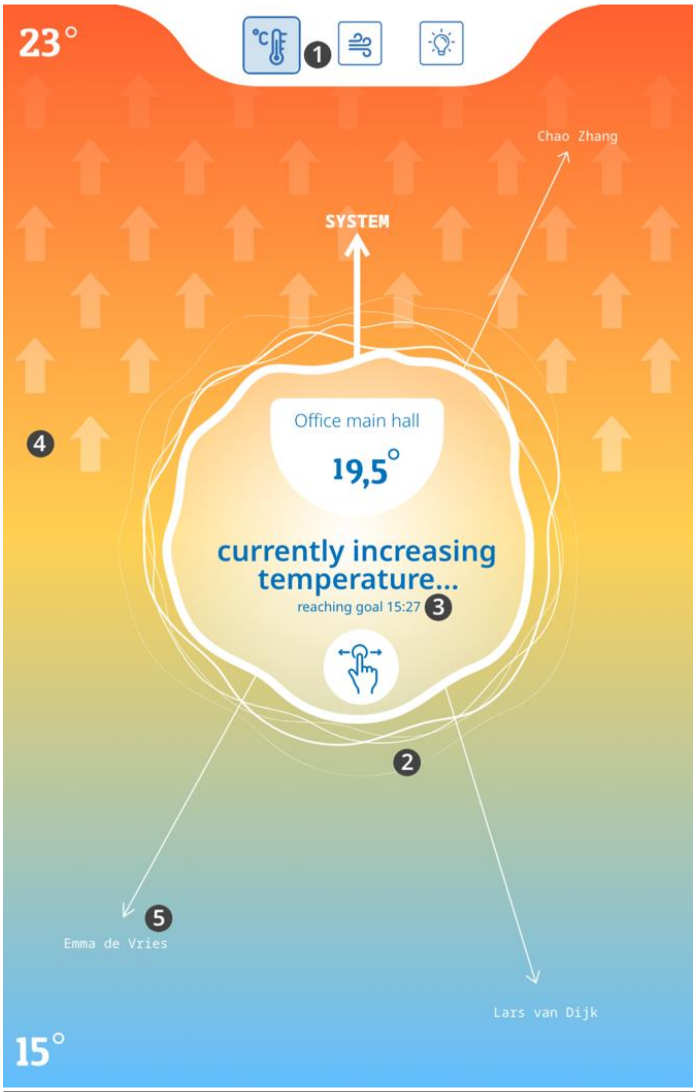


Figure 13: Screenshot of the final interface version for testing

Explanation of interface elements

1) different climate/HVAC properties
2) an animated "blob" representing the building/climate system. Erratic outlines animate based on activity intensity (working hard = more violent movement).
3) feedback based on what task the system is currently performing. potentially adding an ETA or explaining other info (weather patterns, etc.)
4) blob seemingly moves slowly on the gradient scale (but in fact, it's the background that moves, so the blob stays centred); movement is the sum of all vectors; though the system vector weighs heavily
5) individual occupants may "nudge" the blob in a direction they prefer by dragging a vector. individual user vectors may be small in 'force'. or maybe a total force shared by all current occupants. Vector is personalised to add accountability, though it may be undesirable due to privacy. this is a subject for debate. this allows occupants to see their own preferences relative to

Occupant testing

Seven employees working in Spectral's office were asked to test the interface. Professional roles and expertise ranged from UX designers to software developers and climate control system engineers. Participants were asked to imagine that the interface had been recently installed in their office and to use it as they would normally. A thinking-aloud protocol was used to observe their interactions, thoughts, emotions and motives. Where necessary, in-depth questions were asked to clarify and gather a deeper understanding of a participant's interactions.

Participants were generally positive about the interface, stating that they are "happy to see [the system] working on reaching [their comfort] temperature" and that it's interesting to see that there are differing comfort needs among co-workers. However, they state that they prefer input handled anonymously to prevent conflict between occupants. A topic most participants were curious about was the way the system determined the setpoint from the wide array of inputs and who was ultimately in control.

Detailed insights from the test can be found in Chapter 4.

Expert panel facility managers

A high-fidelity interface prototype is suitable for a test with occupants because they can interact mostly the same way they would normally do. However, there is no "actual" input to the climate control system and no data is collected from the inputs of the prototype. Still, we wanted to include the perspective of facility managers on our design to gain a deeper understanding of what aspects of the design would and wouldn't work, and which data they would be interested in.

Sitting down with three researchers and lecturers from the Bachelor program for Facility Management at the HAN, we introduced them shortly to the Brains4Buildings project before letting them try out the prototype and state their thoughts out loud.

After discussing their initial responses, we discussed several statements in a panel discussion format.

The most notable results from the panel discussion are summarized below:

- Experts noted that they have found that perceived control is more important than actual control in a lot of scenarios
- They raised concerns about the effect of the interface on the atmosphere around the office. Perhaps a more anonymous solution could overcome the tension the current version creates.
- One expert stated that they see advantages in displaying the shared perspective of the group of occupants.
- The experts agreed that the interface needs to display more realistic status feedback on when the comfort goal will be reached. Their biggest concern is that the interface might create reasons for annoyance among occupants if it sets unrealistic expectations about the speed in which temperatures can change, for example.

4 RESULTS – KEY INSIGHTS

Results from occupant testing and the expert panel were analyzed side-by-side to discover key insights (KI) relevant to occupants and facility managers. A selection of these insights is summarized below. Each key insight also forms the basis of one or more design guidelines.

KI1 – Occupants are becoming aware of *the dance* between them and the building

Occupants understand that their input plays a role in determining a setpoint temperature, but to them, there is no clear indication of how this setpoint is calculated. They don't see the priority the system gives to the different inputs or whether the system can overpower the occupant's input where necessary. Some occupants like understanding the system's workings behind the interface to anticipate its behavior and work around it. Others stated that more detailed information about calculating the setpoint or different weights to inputs is unnecessary and would overcomplicate their interface usage.

Guideline 1: *When designing interfaces with shared control, represent all relevant actors and their relative influence.*

KI2 - (Effect of) perceived and actual control

There are contrasting opinions regarding the effects of perceived and actual control given to the occupants. To some, perceived control seems to be more important than actual control. However, when occupants don't see their input (immediately) reflected by the system, that can make them feel much worse. Ultimately, we found that it's most important to indicate clearly to the occupant what actions/effects are within their control and leave out (technical) information about the climate system's inner workings and decision-making.

Guideline 2: *The user's input should be acknowledged by the interface, even when there might not be an immediate effect.*

Guideline 3: *Regardless of the level of agency occupants have on the building's climate, indicate the scope of possible actions they can take clearly and concisely.*

KI3 - Impact on social dynamics in the office

The interface was designed to highlight a shared work environment's dynamics and visualize the different comfort needs. Occupants and Facility Management experts are worried about its impact on the social dynamics in the office. During testing, two clear advantages of including names with the inputs were mentioned: occupants can see each other's preferences, which, ideally, could help them work together towards a compromise; equally, it would create social responsibility for one's actions, possibly leading to energy savings. *"The group's preferences impact how I would reach my comfort; if many are cold, I will adjust the temperature, but if it's just me, I'll put on a sweater."*

However, the disadvantages seem to outweigh the benefits, with occupants stating that they would "fight [their co-worker] if their preference is much different from [theirs]". Furthermore, knowing the comfort preferences of other, perhaps more authoritative, occupants could exclude or silence others or create a hostile or isolated environment.

Another occupant identified a possible behavioral effect of the interface, predicting that occupants will likely default to extreme inputs (at the minimum and maximum of the temperature range), to "cheat the calculations" and reach one's goal quicker when competing with many inputs.

Guideline 4: *While displaying all actors that may influence the system, the interface should disclose only the basics of the ecosystem (there is an actor) and omit the details of each actor (their preference, identity, etc.)*

Guideline 5: *When using social responsibility as a valuable tool for behavior change towards energy savings and a comfortable building climate for all, consider the social context (e.g. organizations with a shared sustainability goal and where employees agree to the intervention).*

KI4 – The accuracy of the comfort goal prediction is questionable

Those participants with knowledge of HVAC systems had doubts about the accuracy of the interfaces' prediction about when the shared goal will be reached. While the occupants stated that it "makes [them] happy to see it's working on reaching my comfort temperature", the facility management experts raised concerns about the delay/inertia of the climate system. They wondered if occupants may get frustrated if the system takes a long time to reach the desired temperature.

Guideline 6: *Use data from sensors and predictions to your advantage by presenting them back to occupants. The predictability of the system leads to greater satisfaction among occupants.*

KI5 - Data gathered from interactions with the interface may be useful to occupants, Facility Management and Building Management System developers/vendors

For occupants, their individual environmental footprint as feedback to their climate control input is a potential tool for behavior change. Location- and environment-based data could help occupants find alternative strategies to reach their comfort levels (e.g. are their office spaces in the same building that fit my preferences?).

Facility managers may benefit from similar location-based data from an occupant input perspective. With data collected from interfaces, for example, Facility Managers may evaluate how interactions differ between different areas of the building and what other factors beyond individual preferences could have an impact. The data can also support their analysis of the impact of interventions on the organizations sustainability and financial goals.

Lastly, we suspect that reporting data in more fine-grained detail will be a selling point for building management systems to building owners since it allows for evaluating climate goals and analysing occupants' climate routines.

Guideline 7: *While designing interfaces, remember which data may be gathered from interactions with them and how this data may be useful for Facility Managers and occupants.*

5 CONCLUSION

We set out to design different interface concepts to evaluate the design dimensions we had defined. We gained insights on how the dimensions could be used during the design process and how effective and accurate they are to describe and analyze interfaces.

We covered most of the design dimensions during the design, prototype, and testing phases, which allowed us to learn about their impact on the design. However, a few were touched upon less and thus require further research and evaluation:

Feedback > Form > Modality: Visual | Haptic | Auditive | Other

The dimension of modality depends on the climate controls and interactions included in the interface. We want to learn how different modalities may impact the dance between the building and the occupants.

Control > Form > Scope: Static <> Portable

So far, our designs have primarily included a static, location-based interface. Even those that included portable elements (e.g. the droplet) still revolved around a central screen for climate inputs. What would happen if occupants could impact the system from anywhere? We are curious to see how design decisions within this dimension impact factors such as occupant behavior, satisfaction levels and energy efficiency.

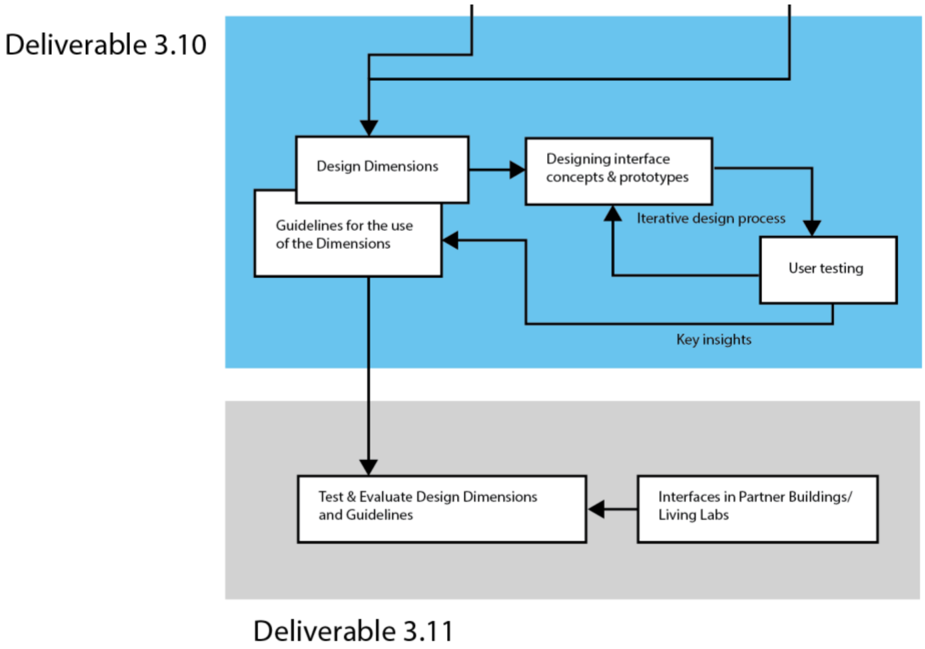


Figure 14: Diagram of next steps

We can conclude that the design dimensions are key when designing, analyzing and evaluating interfaces. However, we also found that before implementing them yourself, it is necessary first to understand the impact of design choices within them. The list of design guidelines we defined in this deliverable may be an effective supporting framework for this. We aim to test the guidelines with the dimensions and report on our findings in deliverable 3.11 (figure 14).

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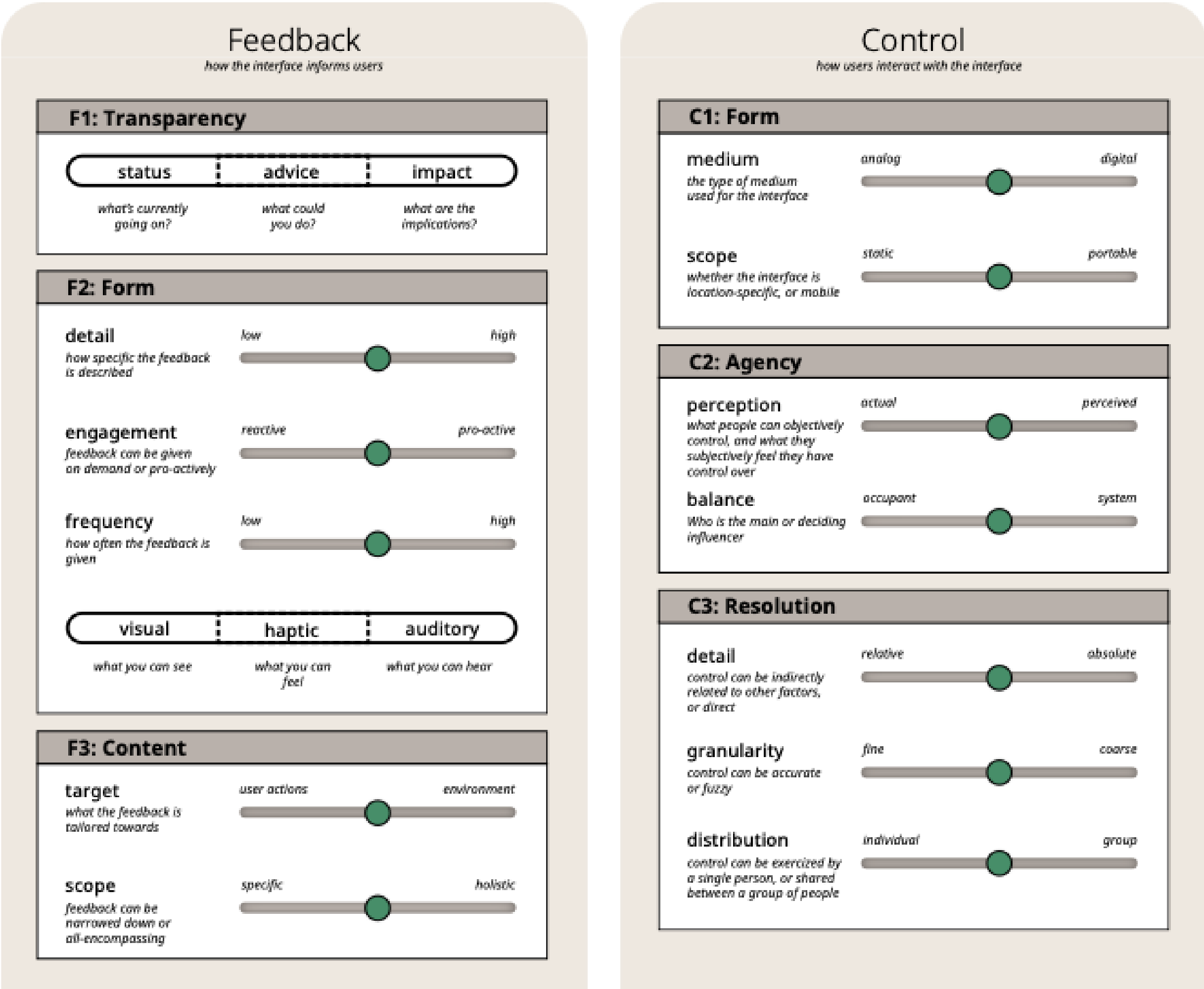
APPENDIX 1: DESIGN DIMENSIONS



APPENDIX 2: DESIGN GUIDELINES

The following list contains the design guidelines extracted from the key insights:

1. When designing affordances for mutual control, represent all relevant actors and their relative influence.
2. User's input should be acknowledged by the interface, even when there might not be an immediate effect.
3. Regardless of the level of agency occupants have on the building's climate, indicate the scope of possible actions they can take clearly and concisely.
4. While displaying all actors that may influence the system, the interface should disclose only the basics of the ecosystem (there is an actor) and omit the details of each actor (their preference, identity, etc.)
5. When using social responsibility can be a valuable tool for behavior change towards energy savings and a comfortable building climate for all, consider the social context (e.g. organizations with a shared sustainability goal and where employees agree to the intervention).
6. Use sensor data and predictions to your advantage by presenting them back to occupants. Predictability of the system leads to more satisfaction among occupants.
7. While designing interfaces, remember which data may be gathered from interactions with them and how this data may be useful for FM's and occupants.