Designing for a more accessible zero energy system

with a focus on visually impaired users

Alina Boyuklieva

Master thesis

Designing for a more accessible zero energy system

Published August 23rd, 2022

Author
Alina Boyuklieva
MSc. Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

Graduation Committee

Chair
Stella Boess
Applied Ergonomics and Design
Faculty of Industrial Design Engineering
Delft University of Technology

Mentor
Tomasz Jaskiewicz
Design Conceptualisation & Communication
Faculty of Industrial Design
Delft University of Technology

Company mentor
Juliëtte Mohamed
Sustainability Advisor
Ingenieursbureau Amsterdam

Gemeente Amsterdam

TU

ENERGIE LAB ZUIDOOST

"The one argument for accessibility that doesn't get made nearly often enough is how extraordinarily better it makes some people's lives. How many opportunities do we have to dramatically improve people's lives just by doing our job a little better?"
— Steve Krug

Summary

In the recent years, many older buildings are being transformed into more sustainable zero-energy housing. However, next to its advantages, there are many challenges that still have to be tackled. One of the main ones is the mismatch between residents' expectations and systems' functioning. This report analyses the specific case of a demo-apartment in Reigersbos, Amsterdam and applies an Inclusive design perspective with a focus on visually impaired residents. The main goal is to develop a solution that will decrease the gap between residents and systems.

Through literature research, user interviews and field research of the demo-apartment, the challenges of the case are defined from a human-centered design perspective. Then, the accessibility limitations are identified on the basis of the conducted accessibility research. Different Inclusive Design tools and suitable approaches for designing together with visually impaired users are described.

As a result, three design interventions are proposed. The first one is targeting the stakeholders, responsible for choosing the systems and products in a renovation. It is a Booklet that provides specific guidelines and recommendations for the decision makers to follow. Its aim is to help them improve the outcomes of a renovation. While this tool still has to be evaluated in the projected use scenario, according to interviews with experts, it is a much needed product.

The other two proposals are concepts called 'Tactimap' and 'Breathing Walls' which embody the main user needs identified during the research phase. Their target group are the end users, namely visually impaired and the wider public. The evaluation confirmed that the 'Breathing Walls' concept has promising potential for future development. 'Tactimap' on the other hand turned out to be less prospective at this moment.

The exploration of the three concepts contributes knowledge to the field of zero-energy renovations and Inclusive design. In addition, the recommendations from the booklet can be applied immediately in the renovation of Reigersbos so that it becomes better fitting to users' needs.

Introduction

Sustainability goals

Amsterdam aims towards zero-energy housing until 2040 (Gemeente Amsterdam, 2020). In order to achieve this goal, many housing renovations are being planned and currently taking place, one of which is the refurbishment of 288 housing dwellings in the Reigersbos neighbourhood. Located in the southeastern part of the city, it consists of buildings constructed in the early eighties. The project aims towards providing the inhabitants with a more comfortable indoor climate, improving their quality of life, while still complying with their budget and user needs.

The challenge

Completely replacing the ventilation and heating systems, as well as the facade, will contribute to the energy transition. Nevertheless, many challenges have been faced when introducing these technologies in similar contexts in other locations. The misfit between the user needs and the systems' feedback mechanism and interface seems to be one of the main obstacles towards the acceptance of the new technology. (Boess, S., 2022a) Moreover, the actual usage of the systems differs from the scenarios that the system designers envisioned. (Becchio, C., et.al, 2018) That leads to residents breaking them, altering them towards hazardous environments, and feeling that they cannot trust them (Boess, S., personal communication, Novermber, 2021). Solving that complex issue requires in-depth research into the topic on many levels that will reveal the reasons behind users' mistrust and unacceptance and also possibilities for improvement. The ambition is to make design proposals that are as independent as possible of the specific conditions of a refurbishment project and applicable to more kinds of renovation.

A short-term monitoring project on resident needs, indoor climate and energy usage has been conducted in a first prototype apartment. This apartment is available for user research and prototyping of solutions and its purpose is to develop requirements for the renovation. TU Delft has run this monitoring project. In addition, my graduation project contributes knowledge on residents' specific needs and requirements and translates them into design guidelines and recommendations and possible design directions for future projects.

Inclusive Design

When tackling a project of such scale, we should consider how the rich diversity of residents' backgrounds reflects on their needs and values. Thus, I decided to adopt an Inclusive Design approach to guide me through the process. The British Standard Institute (2005) defines Inclusive Design as *'The design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialised design.'*

Stakeholders

In projects where inclusive design is a leading value, it is often the case that we can clearly distinguish three main groups of stakeholders - the people who are responsible for integrating the products, product manufacturers and the final users. Ptoduct manufacturers are beyond the scope of this report. In this project, I focus on the other two groups, namely the demand side of a renovation and the residents who will use the products. From the demand side, two main sub-groups are recognized - one consists of professionals that safeguard residents' interests as project managers, engi-

neering advisors, building managers and the other - from residents who volunteer to represent the rest.

Even though one of the parts of my design is directly targeting the stakeholders who aim to commission a renovation, the results will also be in favour of the residents, who are the end users. They are the direct target group for the other parts of my design. In this project, those are people with visual impairments (VIPs) as well as the wider public. This decision was based on my background in exploring tools for designing for visually impaired while the limited time span of the project prevented me from exploring different kinds of disabilities in detail. However, some of the obtained results are also applicable in other scenarios such as with older people, low-literate users, etc.

Method

This report consists of four main sections, describing the project. The Double Diamond approach (Design Council, 2004) (Fig. 1) correlated with my needs. As initial challenge, I have started with the statement that residents misunderstand the newly introduced systems and interfere with them in undesirable ways. That leads to a decrease in their efficiency and potential health hazards for the residents. As I was provided with the freedom of choosing a specific goal and creating my own path, I spent the first diamond defining it. I started by establishing the main research question and three sub-questions:

In what way could zero energy housing renovations be optimized in terms of matching residents' needs with heating and ventilation systems' functioning with a focus on visually impaired users?

- **What are the functional challenges with the systems currently installed in Reigersbos demo apartment?**
- **Which characteristics of a product make it accessible to visually impaired users?**
- **What are the accessibility limitations of currently installed systems?**

Together with a team of fellow students and our mentor Stella Boess, we have closely studied the connections between the systems in the Reigersbos demo-apartment and the experiences of potential residents through a series of eleven stays at the unit. Next to that, I conducted an in-depth analysis of the needs and wants of users with impaired vision both through literature research and six user interviews.

In the 'Define' phase or as I named it - 'Synthesis', I translated the discovered insights into actionable design guidelines and requirements which I call Design Challenges and Design Fundamentals. They served as main principles in the 'Develop and Deliver' phase. Furthermore, I reflected on the initial goal and defined a sub-problem statement with sub-questions as follows:

- **In what way can we enable stakeholders aiming to commission a renovation to make decisions that improve accessibility?**
- **How to address the identified design challenges in a concept as a whole?**

During the 'Develop' phase, I briefly continued with research on humanity and technology, as some knowledge gaps were identified. In the meantime, I explored various ideas through brainstorming with fellow students and target users. Considering the fact that I wanted to provide immediate value for the stakeholders while still incorporating most of the findings, I chose to develop two deliverables - one short-term oriented design targeting decision makers and one long-term oriented targeting end users. The first is a Booklet with guidelines and recommendations while the second is a set of two concepts, suitable for future development.

During the 'Deliver' phase, I mainly focused on the content of the booklet and the future concepts. The booklet includes summarized information from the research phase, in the form of Challenges, Guidelines and Recommendations for Reigersbos and future zero-energy renovation projects. The Booklet aims to provide the demand side with the tools to take more inclusive decisions that better suit residents' needs.

The Future Vision concept aims to serve as an example how the discovered needs could

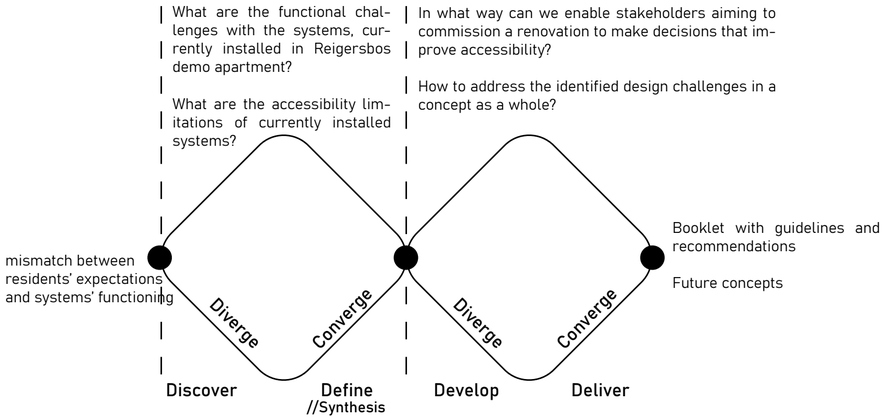
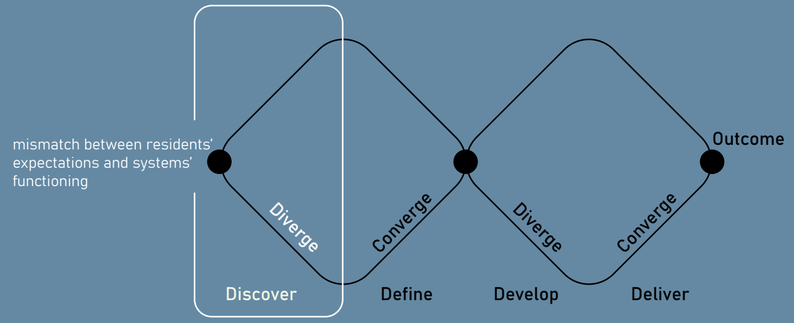


Fig. 1, Double Diamond model, Design Council, 2019



Discover

In what way could zero energy housing renovations be optimized in terms of matching residents' needs with heating and ventilation systems' functioning with a focus on visually impaired users? (Fig.2)

- What are the functional challenges with the systems currently installed in Reigersbos demo apartment?
- Which characteristics of a product make it accessible to visually impaired users?

1.

1.1 REIGERSBOS

The neighbourhood

Reigersbos is located in the Zuidoost district of Amsterdam. (Fig. 3) It is one of 32 ontwikelbuurten (Gemeente Amsterdam, 2022). It includes a big shopping centre and a metro station. The buildings date back to the 1980s and rise 4 floors high with shops occupying the first one. Because of the terraced structure of the blocks, each floor's apartments have different living area and orientation. In 2021, the neighbourhood provided home to around 18 000 inhabitants. The average gross income per year per resident is around 21 200 euros a year which falls under the lower-income neighbourhood in the city. More than 60% have a non-western migration background. (Alle Cijfers, 2021) Currently, 48% of the residents are above the age of 65 (AlleCijfers, 2021).

Considering their social engagement, the residents have formed a strong community through an active home owners' association and the housing corporation Stadsgenoot who represents the tenants. Various entertainment and educational activities are organized in the area like for instance the Los festival.(AlLEvents) At the same time, citizens come together to discuss important issues about the neighbourhood and their living situation which makes them active contributors to the decisions made about the upcoming renovation. (B. Knaapen, personal communication, December, 2021) Therefore, considering their experience of the demo apartment is of crucial importance when making a final decision on the systems that will be implemented in the living units. However, the needs of one specific group are not being taken into account, namely visually impaired residents. Considering the identified gap between them and systems for indoor climate (Leporini, B., Buzzi,M., 2018), I have decided to focus on revealing their needs and applying them in context.

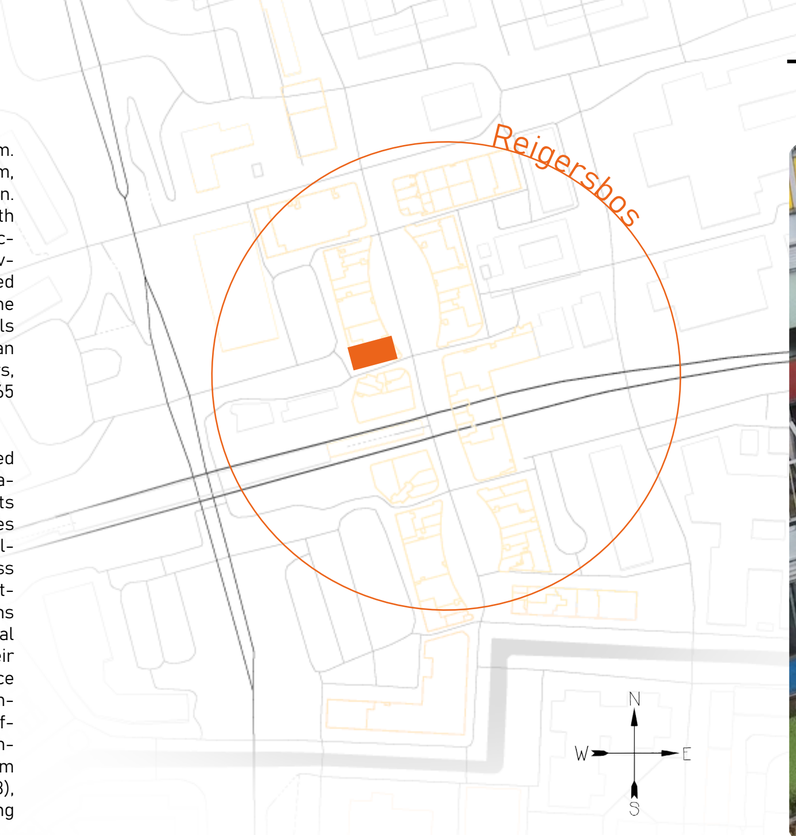


Fig. 3, Reigersbos neighbourhood on the map

The refurbishment

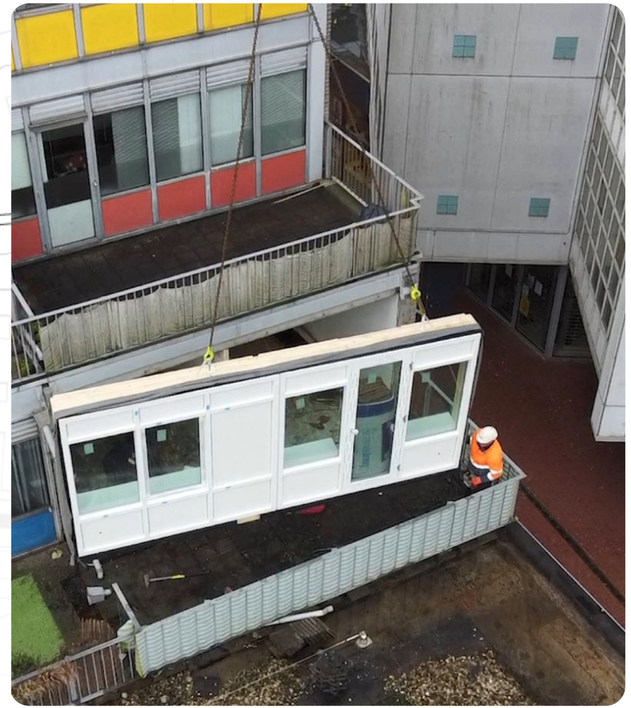


Fig. 4, Reigersbos apartments

The refurbishment of Reigersbos' living units (Fig. 4) is one of the steps towards reaching the zero-energy sustainability goal on Amsterdam's agenda. (Gemeente Amsterdam, 2020) For that aim, all gas technologies are being replaced with electrical ones in order to reduce CO_2 footprint and comply to the increasing energy demand. (Nematchoua, M.K., Nishimwe, A.M., Reiter, S., 2021) These systems mark the beginning of not only a more environmentally sustainable future, but their impact will also reflect positively on the residents' quality of life. The new technologies are expected to improve the comfort and health of residents.

In the specific case of Reigersbos, a heat-pump system is responsible for the heat and warm water supply with convector units taking the place of the old radiators on the facade. A new electric heater is installed in the bathroom. Moreover, a new ventilation system is introduced as well as a new airtight facade. It will contribute to increasing the energy efficiency of the system and thus decreasing energy bills. The new ventilation units are located on the facade where they bring filtered outside air in the living space. In the kitchen, a recirculation hood contributes to cleaner air during cooking.

50% of the costs for the renovation will be covered by a municipal subsidy while the rest of the amount will be provided to the homeowners as a loan which they would pay monthly during the next 30 years. (B. Knaapen, personal communication, February 6, 2022)

Currently, the project is at the stage of creating a definite plan for the refurbishment. The extensive Reigersbos team research together with the results generated through my own part of the project, can contribute to choosing the best fit between technological solutions and user needs.

Main challenges in zero energy renovations

Latest research has thoroughly examined the causes of various issues, emerging among residents as a result of zero-energy renovations. Many suggest that in the core is the misfit between systems' functioning mechanisms and residents' expectations about them. (Becchio, C., et.al, 2018) (Fig. 5) The concerned parties have to be well aware of the actions required for a successful implementation of a new technology. Good understanding of residents' needs is crucial, together with clear initial introduction and sustained support, as a steep learning curve is expected to occur. An improper approach is likely to result in a misfit leading to undesired interactions between the residents and the system as setting it on unrealistic values, turning it off, avoiding maintenance, etc.

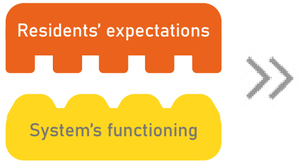


Fig. 5, Zero-energy renovation challenge, undesired scenario

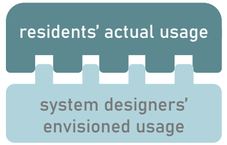


Fig. 6, Desired scenario

UNDESIRABLE SCENARIO

Implementation of new technology	+	Residents unfamiliar with it's working mechanism	=	Misfit between residents' expectation and system's functioning	+	Undesired interactions between the resident and the system
requires:		requires:		might lead to:		might lead to:

- Steep learning curve for the resident
- Initial introduction and training
- Residents do not understand what the system is doing
- Turning off the ventilation system
- Establishment of new habits for the residents
- Sustained support and monitoring
- Setting the heating or ventilation to unrealistic values
- Avoiding maintenance, leading to systems' damage

Addressing values of the residents prior to the final implementation of the technologies, could yield positive results instead. (Boess, 2022c) (Fig. 6) Correctly identifying the user needs' leads to choosing more suitable systems depending on the specific context. In the long-term that brings on one hand the satisfaction of residents and healthier indoor climate, while on the other - more energy efficient systems.

DESIRABLE SCENARIO

Implementation of new technologies with prior user research	+	Choosing more intuitive technologies	=	Match between residents' expectations and system's functioning	+	Residents interfere only when necessary
requires:		requires:		leads to:		

- Small learning curve by the resident
- Initial introduction and training
- Residents understand and trust the system
- Efficiently working systems
- Evolving old habits by the residents
- Sustained support and monitoring
- Less unexpected undesired scenarios
- Improved residents' comfort

The demo apartment

One of the apartments in Reigersbos has been transformed into a demo-apartment where new systems for heating and ventilation are installed. I have built a 3D model for providing context for research and later design. (Fig. 8,9) On Fig. 7 the heating units are marked in red, while the ventilation units are blue. It currently serves on one hand as a place for discussion between residents and the housing association and on the other - for user and system testing.

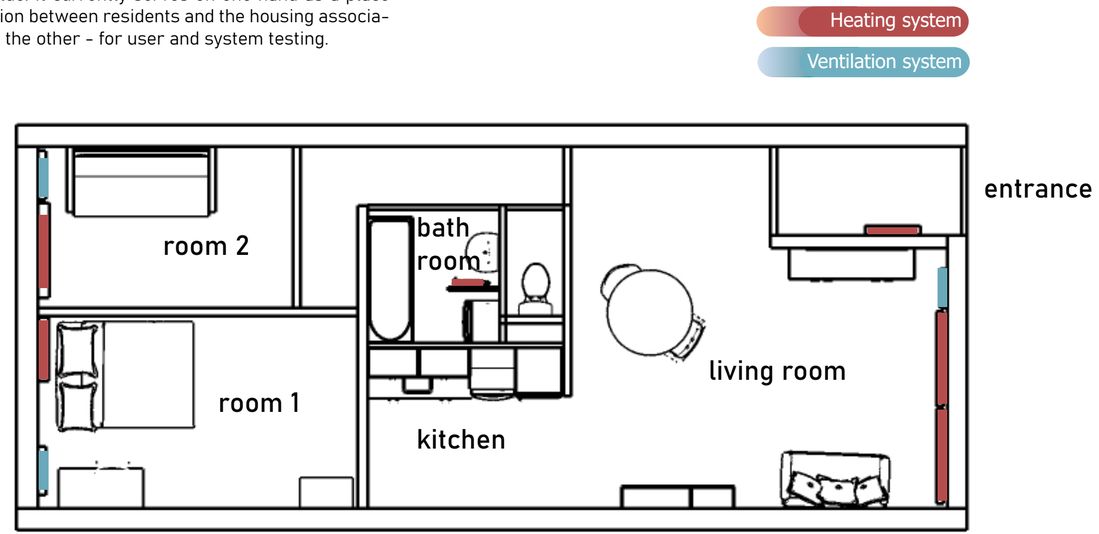


Fig. 7, A drawing of the floorplan of the apartment

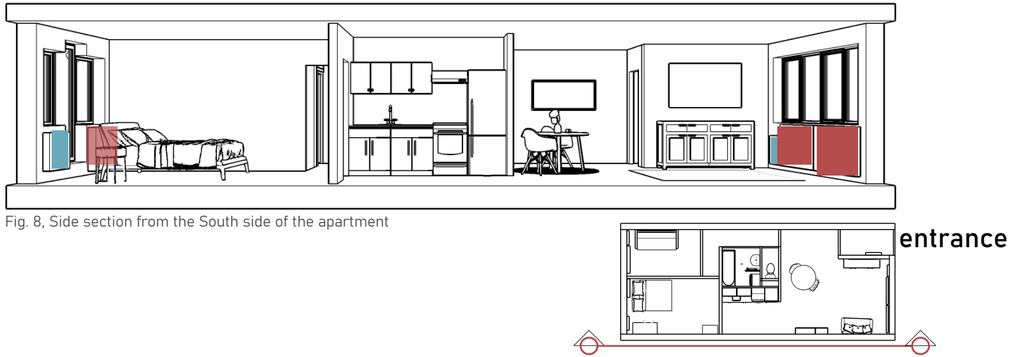


Fig. 8, Side section from the South side of the apartment

Fig. 9, Side section from the North side of the apartment

Method

System analysis

This part of the project is a team work between our mentor Stella Boess and fellow students. The focus lies in the activities that were strictly connected to the Reigesbos neighbourhood. I discuss the results of the user research which we led in the demo-apartment.

Initially, we performed a task analysis of the systems. Four main characteristics of the indoor climate were considered - **temperature, air quality, noise and luminance**. The demo-apartment was equipped with sensors that gathered data for the temperature, CO2 levels and humidity. In order to obtain detailed insights into the user experiences of the apartment's climate comfort, we organised eleven user stays and derived both qualitative and quantitative data which was transformed into practical requirements and recommendations.

As the report emphasizes on the importance of the right match between user and system, this relationship was examined carefully through the extensive user study.

User Research

After investigating the basic working principles of the systems for heating and ventilation, we applied them to the structure of the user questionnaire. The questions were separated into themes for easier analysis and better understanding. We included basic tasks as cooking, sleeping, showering and cleaning so the range of the generated data would be broader.

I played the role of a pilot user. Then I spend 2 days and nights at the apartment, performing the tasks from the questionnaires. This helped us improve it and set the start of official stays. I did not take an active role during the phase of recruiting participants and organising their actual stays.

Eventually, we gathered 18 filled-in interview forms which provided insights into people's experiences of the unit. We carefully analysed them and identified challenges and trends. The qualitative data from the questionnaires was aligned with the quantitative data from the sensors which allowed for more objective conclusions. I will describe further the ones that are in the scope of this project.

Prototype limitations

During the research, we encountered some limitations. For example, during the stays, the heat pump was controlled by the suppliers without our knowledge. That also led to the situation where the heating has been turned off for a couple of days while we were not aware of that. Moreover, the incorrect thermostat controller was mounted on the wall - it was intended for professional use. Furthermore, the ventilation system was not set on the appropriate setting which created high CO2 values and sometimes a lot of noise. Such factors hindered the usability testing of the systems. It should be also taken into account that the heat pump that was chosen for the apartment was designed for constant use. As its application did not correspond to the design, it took a long time for the warm water to come.

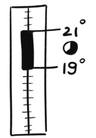
Temperature

Heat pump

This is one of the systems installed in the apartment that is believed to be more eco-friendly than gas. (Verhagen, T.J., van der Voet, E. , Sprecher, B., 2020) This specific heat pump uses the technology of low-temperature heating which means that the system's response to big temperature changes is slower. (D. Sakellari, M. Forse´n, P. Lundqvist, 2006) Therefore, in such case, big heat-loss could result in the system trying to compensate for it by working really hard. However, that increases the usage of electricity and lowers the efficiency of the system. Such undesired heat-loss might occur for instance when windows are left open for long periods of time during cold weather. In order to avoid such situations, residents have to be aware of how the system works and what are the desired and undesired processes that they could initiate with their actions. Efficiently adapting the system to their own needs requires sufficient knowledge and support which could be acquired from the parties responsible for systems' functioning.

Slow system feedback

consequences for the residents
- hard to understand whether the system is working
- confusion why their needs are not met
- climate discomfort
- frustration because they do not know how to reach the desired result



consequences for the system
- being set on unrealistic setting (too high/too low)
- high energy consumption
- failure to keep up with residents' commands
- residents interfere needlessly and decrease the efficiency

Lack of direct warm air stream

consequences for the resident
- unable to identify by touch whether the convector is working or not
- could not receive direct heat supply when feeling cold (hands, feet)
- discomfort

consequences for the system
- receiving unrealistic comands (too high temperature)
- that could lead to inefficiency and energy waste

Consequences for design

Immediate feedback from the system to the residents is recommended as it will enable them to take better informed decisions about the commands they are giving to the system. Detailed information about what actions it is currently executing should also be accessible for optimal feeling of control. This could be presented as visual, auditory, haptic or tactile data. Providing transparency is expected to build trust between the residents and the system which would lead to less interference from their side and more energy efficient system.

Control

The low-heating mechanism does not provide direct tactile feedback like warmth coming out of the heating unit or warm unit itself. That might confuse the users that the system is not currently working, while actually, it is. Such lack of understanding might lead to unrealistic commands from the side of the user which could result in energy loss.

The potential resident would be able to control the heat pump either through an app or a touch thermostat on the wall. Here, I want to register the fact that neither of those options was properly working during the user research. During a meeting with the system providers, it was discovered that the thermostat which was positioned on the wall was intended for professionals.(Fig. 10) However, a similar thermostat interface is available which targets the resident but we did not have the opportunity to investigate it. On the other hand, the app did not connect to the system which was working independently. These obstacles hindered the conclusions concerning the control of the apartment temperature.

Fig. 10, The incorrect thermostat on the wall intended for professional use

A newly developed app for the system (Appendix D)

- some control instruments do not correspond with system's functionality (Fig 11)
- some main rules for accessible interface are not kept (Fig.11)
- lack of option to connect other devices e.g. sensors, triggers, etc.
- does not support residents in keeping track of their energy usage easily
- illogical color usage (Fig. 11)

EXAMPLE:

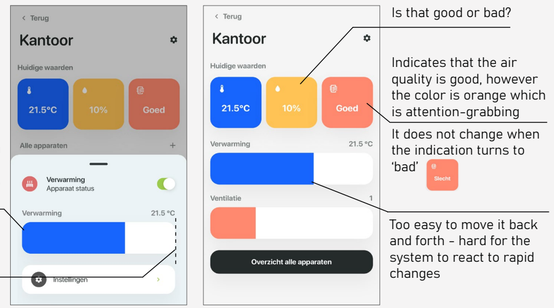


Fig. 11, Evaluation of screens from the app

Bathroom heater

The electric heater which is placed in the bathroom is another important component that influences the temperature in the apartment. This space requires a direct source of heat as it needs to be quickly dried in order to prevent mold growth and contribute to healthy living environment. (Niemeyer, S.M., 2008)

It is a stand-alone element and does not communicate to the heat pump system. It is equipped with its own controller piece on the body, located in the down left corner through which the resident can control it separately. The interface consists of slightly raised buttons and small screen from which the resident could turn it on/off, set the desired temperature or program it.

The two main issues with the bathroom radiator are concerning the controller unit. (Fig. 12) Its position is very uncomfortable while it provides no other option to work with it. Currently, the resident has to bend under the sink in order to be able to reach the buttons. Seeing the screen is even more difficult also because of the angle. Moreover, the buttons are too small to be recognised from too far, as well as the Figures on the screen. Currently, that imposes health hazard on the residents as there is also a high risk of hitting their head on the sink when standing up. (Fig. 13) Wireless control units for electric bathroom heaters are already available on the market. Therefore, I would recommend substituting the current one with one that provides opportunities for connectivity and remote control.

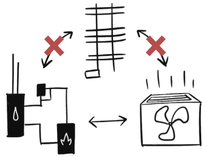
In addition, the unit is not currently communicating to the heat pump and the heating convectors. A more energy efficient solution could be opting for a interconnected heating system. Such decision will also avoid the scenario where the resident has to shower in a cold bathroom because he forgot to turn on the heater. He could also forget turning it off which would lead to needless excessive energy usage because he could not reach the controls to program it when to stop.

Fig. 12, The controller of the electric bathroom heater

Heat pump and electric radiator do not communicate

consequences for the residents :
- harder to operate with it in the most efficient way
- more factors to think about
- discomfort (if the residents forget to turn it on or off)
- inability to control everything remotely

consequences for the systems:
- not synced
- harder to function efficiently
- excessive energy usage if the radiator is put on a high setting and forgotten



Bathroom radiator controller is hard to reach (Fig. 13)

consequences for the resident:
- difficult to control (hard to reach, hard to see)
- the residents might hit their head on the sink
- lack of other control option
- climate discomfort (if the residents could not operate with it as they wish because of it's location)

consequences for the systems:
- left on longer than needed - energy waste
- being set on a wrong setting because of the lack of visibility access

> 'Very low for me, hard to read (knee injury)', Boess, S. (2022b)

Consequences for design

A control hub that unifies the three systems is recommended. Consequently, the user will only have to learn one interface and would be able to interact with the systems more easily and efficiently. Furthermore, this control hub could provide an overview of the apartment and the current processes. This would give the user with valuable information and allow him to take better informed decisions.

Concerning the position of the controller of the bathroom heater, there are two more favourable options. The first one is to choose a radiator with a controller positioned at the top corner. The other possibility is to opt for a controller which provides Wi-Fi connection. (Terma, 2022a) That way, it could not only be programmed and controlled remotely but it could also connect to the other heating system and exchange data, contributing to the house energy efficiency.

This video is part of one my design proposals which is explained in detail in Design Process // Booklet. Here I use it to show the perspective of the resident to the reader in the case with the controller in the bathroom.

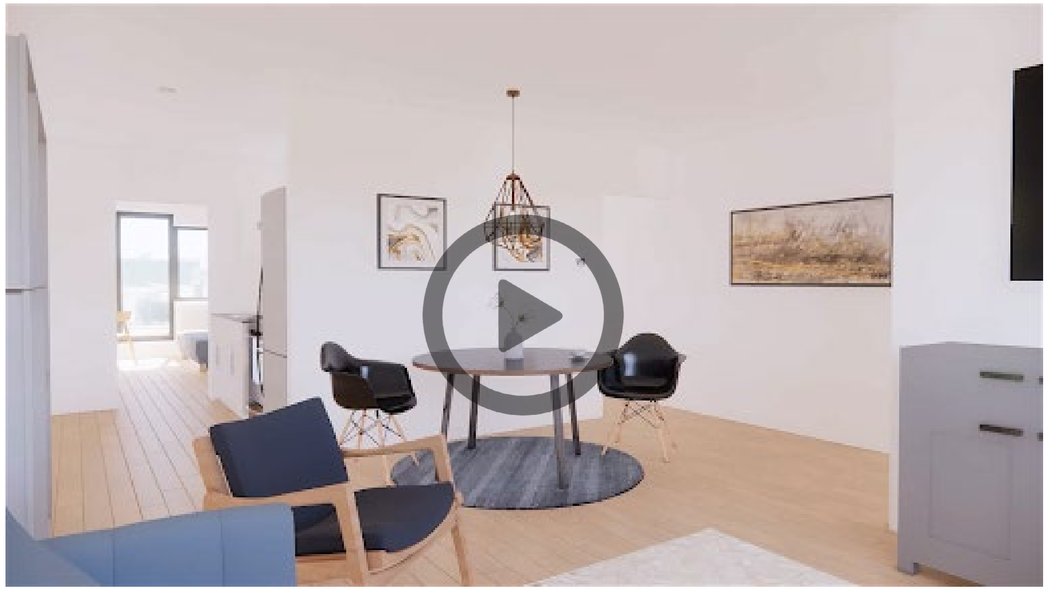


Fig. 13, Video simulation, press the play button to watch

Solar radiation

The factor of solar radiation was shortly examined during the task analysis. However, in the run of the project, I have found that it could have significant influence on the perceived thermal comfort of the residents. (Chinazzo, G., Wienold, J., Andersen, M. , 2019) According to the aforementioned experts, users tend to feel more comfortable at a temperature of 19 degrees with high luminance level, compared to a low one. And the other way around, with higher temperature of 27 degrees, they prefer low luminance levels.

Figures 14, 15 and 16 visualise the light in Reigersbos according to the seasons and time of the day. The only period when there is direct light there, is in June, early morning. Therefore it should be considered how that might influence the perceived thermal comfort of the residents. On the other hand, much light penetrated in the bedroom 1. (Fig. 17)

During the study of the demo-apartment, manually controlled blinds were used to influence the sunlight in the bedroom. This aspect should be carefully considered for future implementation, as the integrity of the new facade should not be compromised. That could complicate the process of finding suitable sun shading products.

Consequences for design

Being aware of the solar radiation in the apartment could mean that stakeholders could choose to integrate such technologies in the renovation which would make use of it in the most efficient way. For example, if automatic blinds are to be installed, they could be programmed in such way that they let the sunlight in to support the heating system or keep it out when it is too hot to avoid overheating. Furthermore, that information has implications on the type of overhang and type of glass.

If such installations are not integrated, the information could be used to advise citizens about the most efficient ways to use the sunlight. For example, let's imagine that it is wintertime. A resident goes out early in the morning for work while it is still dark and forgets to open the curtains. The space then lacks the source of sun heat for the whole day.

Fig. 14, LIght study, Living room, January, 10AM

Fig. 15, Light study, living room, March, 1PM

Fig. 16, LIght study, Living room, June, 7AM

> 'I worked in the bedroom during the most of the day because there was sun in there and it was warmer and brighter than the living room',
> Boess, S. (2022b)

Fig. 17, Video Simulation, Light Study

Air quality

Ventilation units

The ventilation units, that are mounted on the walls, supply the indoors with fresh filtered air. A motor unit that is located inside of the extraction pipes in the ceiling is also a part of the ventilation system. It detects humidity levels and how much air is being extracted. By sending this data to the inlet units, the system successfully maintains a balanced air pressure inside the apartment.

The units are equipped with sensors that track the CO2 levels and are responsible for keeping them within the desired boundaries. Even though the system is meant to work mainly automatically, that was not the case during the research. This was caused by numerous factors, among which the wrong position of the CO2 sensors and some unknown interventions from some experts, influencing the main settings.

While staying at the house, the participants could also change the settings manually. The system provided two types of control - the app and the button on the unit itself. Each unit has one long button which could be pressed at three places (left, middle, right). This is not indicated in any way. By pressing the button, the user can put the power up and down while receiving immediate feedback from the air through the outlet and by looking at the lights. (Fig. 18) However, in case the system does not respond to the given commands accordingly, the user could easily unplug it from the power source. This is not desirable as then the CO2 levels are not under control.

Confusing controls on ventilation units

consequences for the residents :
- difficult to set the system on the desired setting
- a cause for confusion and frustration
- self-doubt if they interact with it 'correctly'
- climate discomfort
- compromised air quality

consequences for the systems:
- undesired changes to some main settings
- hard to function efficiently and autonomously - energy waste
- working unnecessarily (when there is noone at home)

Fig. 18, The controls of the ventilation unit

Consequences for design

The most desirable scenario is that the system works well autonomously and requires minor user interventions. If such are needed, the app should be made more comprehensible and the interface on the unit itself should be improved. More clear and tactile buttons can contribute to that. The interactions between the user and the system have to be fluent so unplugging is avoided.

Concerning the maintenance, the paper filters of the ventilation units have to be cleaned regularly which might pose another issue. When maintenance is performed, the shell of the unit has to be taken away. The controller board that is on the shell is connected to the body only by a soft extension cord as you see in Fig. 19. That connection could be broken really easily. The next step is taking out the paper filter. However, as there is no assigned handle or a place to grab it, the user could damage it by grabbing it incorrectly. (Fig. 20) When cleaning is finished, the shell is put back on. However, the user does not receive any feedback if he has put it back correctly or not. 1 out of 9 participants partly guessed the right way to clean the ventilation unit (Boess, S., 2022b) which confirms the unintuitiveness of the maintenance process.

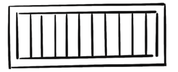

Fig. 19, Incorrect grabbing of the filter of the ventilation unit

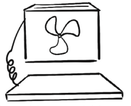

Fig. 20, The cable that connects the unit with the cover

Complicated maintenance is required (cleaning and replacement of the filter)

consequences for the residents :
- fear of damaging the system
- avoiding performing maintenance
- experiencing worse air quality in terms of CO2
- opening the windows more often which could cause excessive energy usage of the heating system

consequences for the systems:
- inefficient working (not filtering well)
- long-term damage
- shorter life-span


filters could be damaged because of the lack of clear indication of a grabbing spot


main cables could be easily detached

Consequences for design

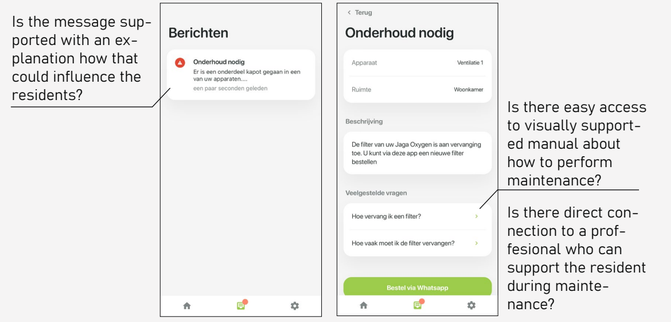


Fig. 21, Screens from the app developed for Reigersbos

The research showed that the ventilation system can cause very disturbing loud noise when trying to lower the CO2 levels. That problem occurs as the system is not working consistently hard enough to balance the levels at all times. Instead, it waits until the CO2 levels rise considerably and only then takes an action that results in a very hard ventilation process which creates an unbearable noise. Furthermore 7 out of 18 participants mentioned that the noise form the heating and the ventilation systems bothered them. (Boess, S., 2022b) It seems that the noise from the air extraction system was the most common cause for complaint.

Loud noise from systems

consequences for the residents :
- disturbance and annoyance
- using the ventilation system less than intended which could lead to high CO2 levels
- health hazards because of the high CO2 level

consequences for the systems:
- might be turned off directly from the plug
- inability to keep up supplying fresh air
- inability to maintain the balanced air pressure inside

> There are some installations that make noise, especially around the bathroom, ventilation at the façade was quiet. , Boess, S. (2022b)

> 'The ventilation hood in the kitchen and bathroom was on for a long time, that was quite loud. Boess, S. (2022b)

> Having the head close to the ventilation is not nice. Nice, clean air, but too cold. Boess, S. (2022b)

The ventilation units at the apartment are bringing air directly from outside, filter it and dispense it inside. During the month of the most user visits from the monitoring period, April, the average temperature was 7.7 °C (Weathertovisit, 2022) . Thus, the air coming in through the ventilation units was considerably colder than the inside air (around 19°C). Several participants mentioned the discomfort that the cold air stream from the ventilation units created. (Fig. 22,23) It made some change their sleeping position (feet towards the window) because of sore muscles caused by the stream. Others mentioned that they felt their feet cold during the day. (Boess, S., 2022b)

Cold air stream from ventilation units

consequences for the residents :
- discomfort in terms of temperature
- sore muscles
- using the ventilation system less than intended which could lead to high CO2 levels
- health hazards because of the high CO2 level

consequences for the systems:
- might be turned off directly from the plug
- inability to keep supplying fresh air
- inability to maintain the balanced air pressure inside

Consequences for design

According to the user feedback, it would be better if the cold air stream is removed. In that case, installing ventilation units which preheat the air before letting it in, is a feasible solution. On the other hand, decreasing the cold air supply will increase the efficiency of the heating system.

Fig.22, Visualisation of a woman sleeping while the cold air stream from the ventilation blows at her head

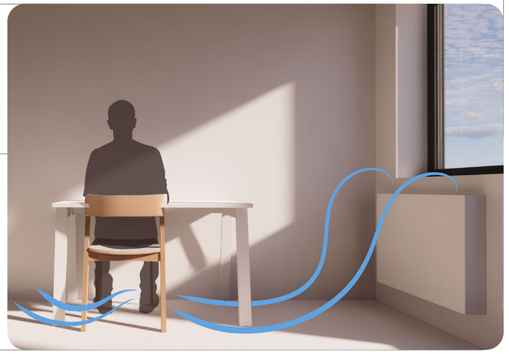


Fig. 23, Visualisation of a person working at the desk while the cold air stream from the ventilation blows at his feet

Air extraction

Air is being extracted from the space through three outlets in total. They are located in the bathroom, in the toilet and in the kitchen. All of them are internally connected to the same motor of the bathroom outlet. Therefore, when the motor in the bathroom works longer, for example after someone took a shower and the humidity rose, more air is automatically being sucked also from the outlets in the toilet and the kitchen which is not desirable because it causes heat loss. (Knaapen, B., personal communication, December, 2022) The resident does not have access to its control mechanism.

On the other hand, as the apartments have an open kitchen plan, a recirculation hood is installed in the kitchen which has become a standard choice in highly energy efficient houses. (Rojas, G., Walker, I.S. and Singer, B.C. 2017) It is positioned above the stove where it decreases the concentration of the NO2 and PM2.5 in the air and disposes it back into the same room. (Jutulstada, A.H.N., Yang, A., Schild, P.G., Chaudhuri, A., Thunshelle, K., 2022) It is controlled separately. More research is required into the characteristics and performance of the installed hood in order to determine its efficiency.

Passive and active cooling is not available at the moment. Various solutions are being considered for the warm months of the year as the temperature inside tends to become unbearable when the building units are exposed to long hours of sun. That is outside of the scope of that project.

Conclusion

Consequences for design

While the main extraction mechanism is automatic, I recommend a manual switch for the extraction in the toilet. A ten minutes delay for automatic turn off could be added so there is no waste of energy. Such decision would improve the comfort of the users.

During the conducted user research, the main issues with the apartment were defined. According to literature, some of them are common for other zero-energy houses as for example the slow response to big changes in temperature of the low-temperature heating system(Leporini, B., Buzzi,M., 2018) Another example is the weird location of some controllers (Rooney, C. et.al., 2017). We observed that the majority of the participants were confused by the controls of the heat pump and the ventilation units. The bathroom radiator was the most understandable, however, some participants pointed out that the position of the controller is too low which makes it inaccessible for them. Moreover, the cold stream from the ventilation unit seemed to cause discomfort when standing close. The expected mismatch between the users' expectation and system's response was confirmed by the data from the user interviews. Nevertheless, we could not draw definite conclusions on the latter as some prototype errors and unpredicted events prevented the users from interacting with the systems freely.

1.2 ACCESSIBILITY

Here starts my individual part of the project. This chapter provides insights about the importance of accessibility in our society. Systems and products that serve in the every-day life of a visually impaired user are discussed on the basis of desk research and user interviews. I focus specifically on smart systems and their control methods and add-ons as this correlates to zero energy renovation projects. Their characteristics are described in detail and summarized into visuals. I also describe how those translate into the practices of each user which they explained during the interviews. Different tools for designing for and with VIPs were tested as well during the sessions.

Why is it important?

How would you feel if that happens to you?

Imagine this scenario:

It is late in the evening, you are sitting on the couch and your halfway through a movie. After it ends, you want to take a shower as always. First, you want to preheat the bathroom. But then you remember - you cannot control the bathroom radiator because it is not accessible to you. Your wife can but she is already asleep. Should you wake her up or should you just go to bed without showering...

Fig. 24, Feelings of a person when being excluded (Appendix B)

While visual impairment is already associated with reduced sense of well-being (Schifferstein, H. N. J., Desmet, P. M. A., 2007), excluding a person from his home environment is highly likely to contribute to that. As one of the main goals of a renovation is to improve residents' comfort and well-being (Gatt, D., Caruana, C., Yousif, C., 2020)(WHO, 2021), provoking such feelings, especially while in the safe space of their home has to be avoided. To respond to these needs, the decision-making process in housing renovations should be driven also by the thought of accessibility next to all other factors. Heylighen & Bianchin (2018) suggest that by addressing usability in context, the needs of more diverse group could be covered. They define it as the extent to which *'agents can convert a resource—in other words, a city, a neighbourhood, a building, a space—into a functioning'*. In one of the official standards 'NEN 17210: Accessibility and usability of the built environment - Functional requirements' it is explicitly stated that it has to be ensured that *'ventilation and heating equipment are operational'* from all kinds of diverse users. That makes designing inclusively not just and option but a requirement which the concerned parties have to comply to.
What accessibility does is not only improving the well-being of

the users. It also has the potential to increase social and environmental sustainability. (Dolores, M., Garrido, P.,2015) When the resident can access the system, not only could he influence his own indoor climate comfort. He is able to understand and know the system and therefore comply to its needs. This is likely to result in better cooperation and more energy efficient system. Having control does not only mean being able to change the temperature setting but also being in control of your own living space, aware of your energy usage and on-going processes.

Even though, I have chosen to focus on residents with visual impairments, many of their needs overlap with those of other user groups, e.g. older people, ones unfamiliar with such technology, etc. Besides, this project is focused on inlcusivity which is defined as 'The design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialised design.' As Microsoft (2016) states, 'accessibility is an attribute, while inclusive design is a method'. In that manner, I aim to design solutions, also desirable for the wider public rather than products strictly directed at VIPs. Therefore, the insights, acquired during that phase could also serve as input for other future projects.

In 2021, WHO argued that then 'at least 2.2 billion people have near or distance vision impairment'. There are four levels of distance visual impairment - mild (below -3.00 diopters), moderate(-3.00 to -6.00), severe(-6.00 to -9.00) and blindness (above 9.00). Then we could assume that all people who wear glasses, experience the effects of visual impairment when being without them. Even though, each case and stage of disability leads to different experiences, people with mild cases could stumble upon the same difficulties in specific situations. For example, when going to the bathroom to take a shower, in many cases we tend to leave our glasses outside. Therefore, we should also take into account that in many scenarios we have a situational compromised vision.

However, many cases of visual impairments are not correctable by standard means as glasses, contact lenses, medication or surgery and as such, they prevent the person from performing everyday activities. Some of the most common causes are Cataract, Diabetic Retinopathy, Macular Degeneration, Retinitis Pigmentosa and Color Blindess. As a result, I categorized 6 types of field of vision for demonstration. (Fig 25.)

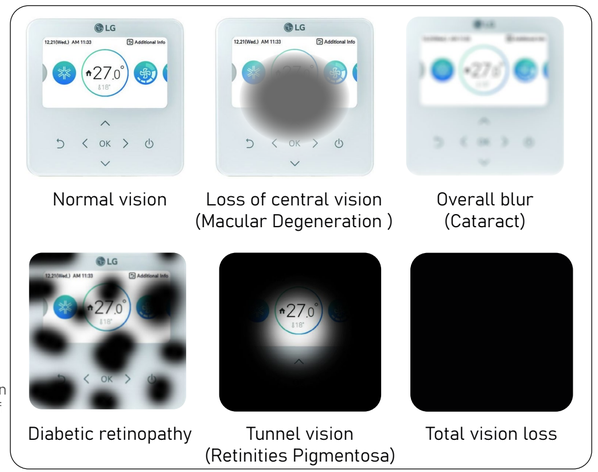


Fig. 25, most common types of visual impairment

Accessibility in products

In this section I discuss the accessibility features of various products. First, I explore the topic of accessibility before focusing specifically on the VIP experience. Hence, my initial desk research includes information about people with different disabilities - from motor disabilities through deafness and loss of hearing to visually impaired. Numerous statements proved true for most cases:

> Ultimately, though, the **smart home excels** at helping people with disabilities live a more **independent lifestyle**.
> Ceriola, R. (2021)

> 'Bring **empowerment, dignity**.'
> NBC News, (2017)

I would like to emphasize on the connection between independence and empowerment. (Leporini, B., Buzzi,M., 2018) Little do we know and pay attention to the mental well-being of people that face such challenges. Prior research (Appendix B) has found that we tend to mostly focus on convenience and practical functionality while the emotional aspect is left behind. However, many target users mention that accessibility also empowers them and brings them a sense of self-worth and confidence. (Kumar, D., 2018) In my previous research, it was discovered that those are some of the main pillars in the framework for emotional well-being. (Appendix B) That is why I would like to underline again how important it is to design inclusively through applying personalized and flexible product features.

Smart systems

Overall, the systems that these people use in their everyday life to control their homes are mostly smart systems like Apple Home Kit, Google Home, Alexa, Hive and other similar devices that they control mostly by voice. (Leporini, B., Buzzi,M., 2018) Furthermore, some emphasised the importance of the simple operation of the system and a good working app that has the function of a basic remote controller. Another interesting feature was 'routines' where the user could access valuable complex information through a single command.

Now, I will discus the topic further with a focus on visually impaired users.

NO ONE SIZE FITS ALL
approach

Products for VIPs

In this section of the report, I would like to describe different devices accessible for VIPs. I used them to learn what are the most important features of the products that VIPs use and the reasons behind them. Most of the following facts are extracted from videos in which users from the target group give first-hand reviews about their own experiences with certain products.

The first object that was valuable for my research was a smartphone with tactile buttons, a new generation, specifically designed for VIPs called BlindShell Classic 2. (Fig. 26) (The Blind Life, Oct 2021) The reviewer said that this time the creators have incorporated the essential features for both users with low vision and no vision. That makes it really accessible and adapted to the user needs.
The next device on the list is a portable magnifier. (Fig 27.) (The Blind Life, May 2021) Many of its features are the same as those of the smartphone.

Fig. 28, NFC add-on (The Blind life, 2021)

Fig. 26, BlindShell Classic 2 (BlindShell, 2022)

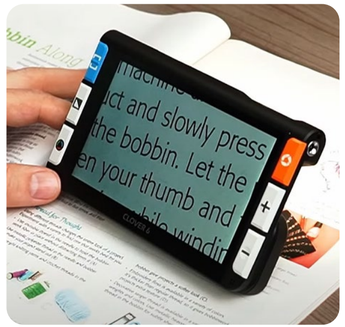


Fig. 27, Portable magnifier (The Blind life, 2021)

Some of the most important features that he had mentioned and which are widely applicable are:

Programmable button on the side - quick launch of apps

vital information on the home screen

easy navigation through the menu with a click of a button

SOS button on the back

high contrast colors

buttons with high tactility

loud speaker

compatible with different visual aids add-ons (Figure 28)

NFC reading function

audio feedback

offline voice dictation

color filters options

shortcut buttons

pocket-sized

Other products, specifically designed for the VI public had very similar characteristics. Thus, we will leave them out for now. Instead, we will discuss the application of those features into a digital product which is designed for the wider public, while many accessibility functions are implemented. Apple is a very good example of that. (The Blind LIfe, Dec 2021) Their list of accessibility settings is long and elaborate. (Fig. 30)

Another device that provides at the same time smart and tactile functions are the Flic smart buttons. (Fig. 29) They are compatible with countless systems and allow the user to assign various functions to each button when programming it through a smart phone. Then, they could be labelled and glued to different spots.

Fig. 29, Flic 2 (Flic, 2022)

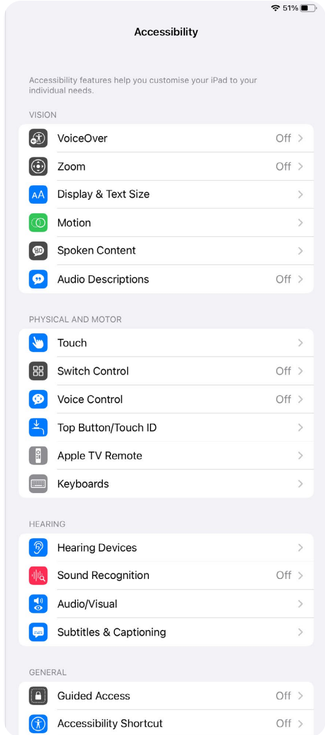


Fig. 30, iOS accessibility menu

voice over

bold text

zoom in option

chimes

customizable tactile interactions to control the touch-screen

audio description option

adjust light sensitivity
siri

Kitchen context

After listing those requirements for the accessibility, I would like to discuss other pain points that are connected with people's vital functions as eating and therefore cooking. One of the new alternatives to gas stoves that are applied in zero-energy renovations, are the electrical induction hobs. However, the old fashioned tactile knobs are replaced by a touch control panel. This technology is inaccessible for VIPs. Having only flat touch buttons, it is impossible for people who do not see to indicate where they should touch. Therefore, that kind of new kitchen appliance is not suitable for this target group. Any kind of sound feedback is also lacking, which means that users could not even learn how to use it over time.

Imagine not being able to use your own kitchen safely and comfortably. Unfortunately, many VI users experience that daily. As they do not feel abled enough to use their kitchen appliances safely, they just do not cook. (The Blind Life Live, Oct 2021) However, that is not only more expensive which is an important factor for a target group with an almost 80% unemployment rate (The Blind life, 2018) but also it is unhealthy.

Therefore, many VIPs have invented their own tricks for a more accessible kitchen. Also during the course 'Inclusive Design', it became clear that they have adapted most of their kitchen utilities. During the desk research, some more interesting adaptations were discovered. Some users are applying bump dots on the almost flat push buttons in order to be able to remember which one is for what. In some cases, that might also help them using a touch panel, but then each button has to be assigned with only one function, so it does not work with multifunctional buttons. (The Blind Life, Mar 2021) Another important function is sound feedback. That is how they know if they have pressed the right button and if it is on the right setting. Moreover, when you control something only by voice, it is of crucial importance to receive audio feedback. There has to be a confirmation that the command is accepted. For instance, Google Home and Amazon Eco are some examples for good voice control functions as they always send voice feedback when they have received a command or performed an action.

At the same time, not all accessible devices have to be smart. VIPs also use different talking devices as for instance a kitchen scale (The Blind Life, Mar 2021) or a thermometer. Furthermore, some companies have developed ways to adapt existing devices by making them more accessible. One example are the talking knobs of Iris Huys.(Fig. 31) An advantage is that they could be attached to already existing kitchen appliances. However, the price of 569 Euros for 2 knobs seems too high for this target group. The affordability issue will be further elaborated on.

Fig 31,Talking oven knobs (Iris Huys, 2022)

Smart systems

In this section I will discuss the functionalities that smart home systems provide with a focus on indoor climate. While keeping in mind the diversity of existing devices, I have picked two smart thermostats to describe in more detail, as I believe that they incorporate many of the features that I find important for the goals of the project. Those are namely Ecobee (Fig. 33) and Google Nest third generation (Fig. 32). We will discuss their overlapping qualities and then their unique features.

Both systems have a touch control interface and a built-in voice control function. Only the most important information is available on the screen which in this case are the degrees. Moreover, they are compatible with other softwares such as Amazon and Google assistance which provides another option for voice control through an app. Moreover, that provides the user with the option to control his home from distance which could lead to better comfort and energy saving. He also has the opportunity to connect other smart devices as well. For instance, a presence sensor could detect if someone is in the room and sends commands accordingly. That particular feature is believed to save energy because the system is not working when there is no one at home. However, that is one out of tons of possibilities to make your home smarter which will be elaborated in one of the user interviews below.

Nevertheless, it became clear that many times those systems do not work as intended in terms of efficiency. Even though they are said to be smart and to control the energy usage in the most energy efficient way, this is not always the case. Some users mentioned that they needed many trials and errors in order to find out what are the best settings for their particular home and heating system.

> 'I learned the hard way that I should not trust the smart thermostats decision-making'. Smart Home Solver,(2021)

He further explains that the process of discovering has been long and complicated as it has involved gathering information from many additional sensors. (Smart Home Solver, 2021) Here comes the problem that few people are that technically experienced and engaged with the energy usage of their house and level of sustainability. Therefore, if you are not one of them, it is highly likely that you will leave the smart system to run by itself, negligent of the processes that are happening in the back. Of course, that would not cause a problem if the system is properly developed in the first place.

On the other hand, the Nest thermostat is said to have a better learning mechanism. Moreover, it incorporates some useful features in the Google home application. It allows you to make different schedules so it learns what is your daily routine. Moreover, the user can check how much energy he has used, when and for what.(Tech with Brett, 2020) That creates transparency and builds trust between the user and the system.

Fig 32, Nest, learning thermostat (Google, 2022)

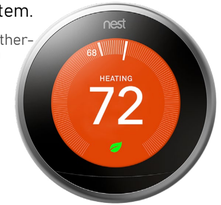


Fig 33, Ecobee3 lite thermostat (Ecobee, 2022)

Affordability

So far, we have observed a positive tendency that big companies try to excel in digital accessibility. However, that is not the case with the rest of the products. A recent study argues that even though modern home appliances bring advantages to our every day lives, 'due to the lack of accessibility support from the manufacturers and designers, a considerable number of people in need of accessibility support have been ignored'. (Lee, J.H., et. al. , 2021) They also add that the most recent innovations actually could be more difficult to use for these groups than old-fashioned products. A simple example are the hobs controlled only by touch.

On the other hand, there have been many developments in the products specifically designed for VIPs. This is especially because their needs are closely studied while they are becoming more involved in the process. (The Blind Life, Oct 2021) Unfortunately, most of those products are still in the high price range. While one of the reasons for that is the high-end technology inside, another is that the demand for assistive devices is too little. As the total costs for R&D, manufacturing and marketing have to be split between the demand, the market price stays high. (The Blind life, 2018) Considering that VIPs have one of the highest unemployment rates - around 80%, many times those products turn out to be unaffordable for the target group.

In order to support them in getting the devices they need, many assistive services have been established. They can provide some technologies, especially if the users need them for employment or education. There are also different grants, crowd-sourcing platforms and second-hand devices available for VIPs. Still, many of these devices stay out of the reach of the ones who need them.

In the coming years, it is expected that the demand for assistive technologies will increase when Generation Z, which has been brought up with technology, grows older. They are the ones more likely to use it when their vision worsens with age while the baby boomers who are not used to such devices are less likely to want to learn in their later years. If that prediction proves correct, the prices are expected to go down too. (The Blind life, 2018)

Tools for designing for VIPs

One of the initial goals of the project was to investigate what kind of methods are developed for helping designers to create inclusive products. The most common ones are in the form of official international guidelines and requirements - some about how to design spaces and products (NEN-EN 17210) while others focus on digital accessibility. (Graham T., Goncalves, A., 2017)(EN 301549).

The simulation glasses (Fig 34) on the other hand are an educational tool that allows people with a regular vision to gain a critical understanding of the challenges that visually impaired people face every day in various activities. They are useful when designing for visually impaired users. It has been proven that the empathy and creativity of people with regular vision increase significantly after a simulation session with the glasses. (Raviselvam, S., Hölttä-Otto, K., Wood, K.L., 2016) Silverman (2015) advises to perform such simulations under the guidance of a professional as otherwise it could result into negative effects. Different pairs are developed in order to mimic a wide range of visual impairments.

An app called 'I have low vision' is also a tool that shows different types and stages of visual impairments in real-life. It could be used on a phone or in VR. (I have low vision, 2022) Websites, imitating different types of color blindness also exist. (Colblindor, 2021)

In rare cases, I could find tools or methods for co-creation with the users. Numerous were proposed for organizing physical workshops with this user group. Some included providing accessible information pamphlets and questionnaires written in Braille, different means of documenting results like talking rather than writing. Audio cues were also applied in some cases. A very interesting tool that was presented at a symposium was 'BlindPad' which was a device that could physically create various 3D shapes. It could be used for orientation in different locations or shape learning for children. (Living Innovation - EU Project H2020) Other tactile means like Lego were also among the used tools because they allow VIPs to express their ideas physically.

Fig 34, Cambridge Simulation Glasses, Inclusive Design Toolkit

During one of the interviews, I tested whether it is efficient to present information to visually impaired through embroidery. (ZSK, 2020) I embroidered the floor plan of the demo-apartment on a piece of paper with bright colors so I could provide them with some context. (Fig 35) I made a second iteration (Fig 36) on a thicker paper and narrower stitching as the first one was not sturdy enough. I used bright colors because some VIPs could be able to distinguish them. That was not true in the case.

Another reason to use the embroidery method was to show in advance that I have some understanding of the topic as is happened to be difficult to discover the latent needs of the users during a first-time conversation. As those participants were very easy-going and open, I cannot determine if the tool contributed to the insights they gave.

Still, the interviewees could easily understand the floor plan and explain what kind of rooms there were. With enthusiasm, they confirmed that this is good way to present accessible information.

Fig. 35, First iteration of embroidered floor plan

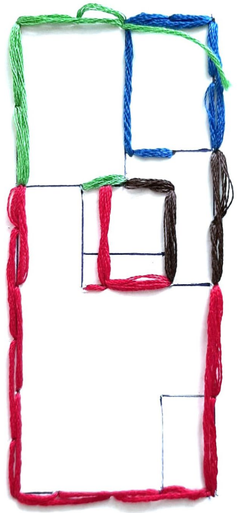
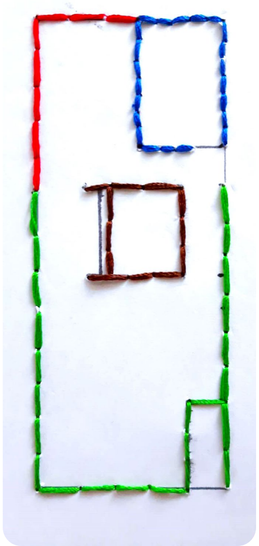


Fig. 36, Second iteration of embroidered floorplan



User interviews

As a way to evaluate the findings from the desk research and expand the gathered data for the design phase, I conducted 6 qualitative open-ended user interviews. In order to obtain more diverse insights, I have recruited participants from different nationalities and backgrounds. One was a Bulgarian (Expert user 1), completely blind as a result of losing his vision 20 years ago. He was an expert in accessibility and coaches other visually impaired people how to use digital applications. Moreover, he is an active contributor in creating accessible recommendations for the institutions responsible for voting machines. (BNR, 2021) Two of the other interviewees (Expert user 2, 3) were also experts in the field, visually impaired themselves. They were also coaches of other VIPs.

The other three participants were regular users, one of which fully blind (Regular user 2), one able to slighlty distinguish light and bright colors (Regular user 3) and one with overall blurred vision and night blindness (Regular user 1).

Five were employed and one was retired (Regular user 1). Three of interviews took place in real life and three were led online. One of the real-life interviews was combined with a filed study. The data contributed to answering one of the research sub-questions:

- **What are the accessibility limitations of currently installed systems?**

In order to assess the accessibility during the interviews, I wanted to understand to what extent 'agents can convert a resource ... into a functioning' (Heylighen, A., & Bianchin, M. (2018)

Story-telling was the main tool I used to explain in detail about the systems in Reigersbos and their interfaces - functionalities and controls. Then I asked the participants to imagine how they would perform specific tasks as for example changing the temperature setting. That approach helped identifying the possible accessibility limitations of the systems while also uncovering additional accessibility requirements.

Striving to discover the latent needs of the users, I asked them to talk about their habits, the products they liked using and the obstacles they meet in their everyday life. (Appendix C) The focus of the discussion mainly laid on the indoor climate and interaction controls. The two of the interviewees who were coaching visually impaired people how to use various technologies, shared valuable insights about common user behaviours observed in their practice.

Field research & reguar user 1

The company Visio has established a Living Experience Lab in Apeldoorn which is a room with all kinds of integrated smart systems. Currently, it serves as a showroom for the residents of the unit. There they could test different technologies and decide which ones are the most suitable for them. During my visit there, one of their clients made a demonstration of how she interacts with all the smart systems there. She also narrated her experience which provided a valuable layer of insights.

Moreover, one of the staff members was also present and he explained how all the smart systems are actually being set in the first place and how are they all controlled and connected.

My first observation was that the space integrated many of the smart systems that I have researched online in real life as for example Google Home. As smart radiator knobs were connected to it, the resident could control the heating with a simple voice command. (Fig. 37

Different routines were programmed through the app which could be activated not only by voice but also by just pressing a single button. (Fig. 37) A morning routine and a back home routine are some examples. There were sensors on the windows, doors and even on the drawers that could be used as triggers. (Fig. 37) A presence sensor was also installed. (Fig. 37)

I noticed that the client sometimes had problems guessing the exact right command in terms of choosing the specific sentence that the system would recognize. Nevertheless, more often than not, the voice control function worked pretty well. Furthermore, it always gave audio feedback when receiving a command. The interviewee said that she mainly uses Google Home at her own place for finding recipes and she mentioned that she really likes how patient it is with her - it waited until she could prepare all the ingredients before going further. Concerning the stove, she said that she prefers physical knobs rather than voice control. She added that she used small stickers in order to indicate where she has to put the pots on the stove. In terms of affordability, she mentioned that the Google Mini is a very affordable solution for her and her brother who still have some vision left.

- **Google Mini is affordable**
- **commands her thermostat with voice**
- **sometimes has difficulties with finding the right voice commands**
- **prefers stoves with buttons and knobs**
- **likes how patient Google is with her**

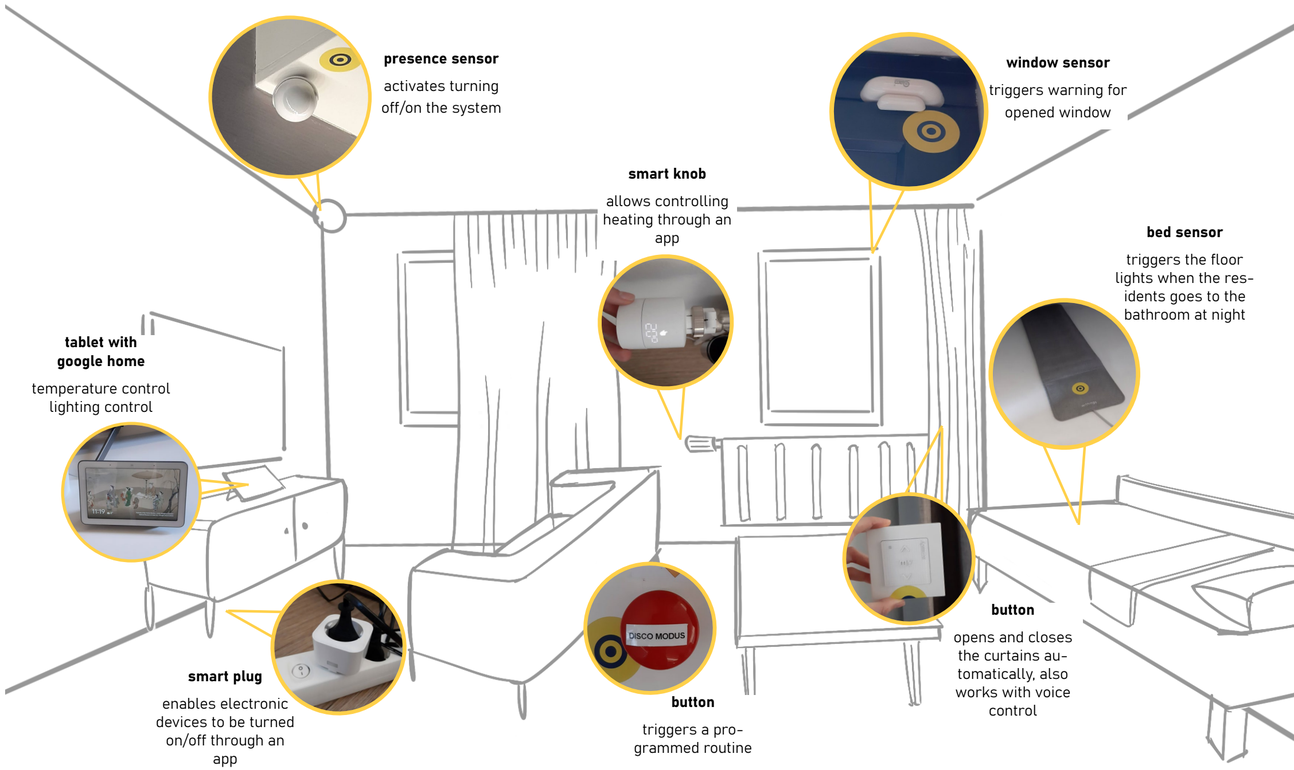


Fig.37, Diagram of the smart systems in Vsisio Living Lab

Expert user 1/ Bulgaria

One of the Bulgarian interviewees who is completely blind is an active contributor to the Bulgarian community of visually impaired people. After I explained what are the systems at the demo apartment and how they are controlled, he replied that it seems impossible to him to control the main thermostat unit because of the flat touch buttons. Then, he described his experience with his personal ventilation units which are also inaccessible as the buttons are small and unclear. Furthermore, whatever he presses, the system makes the same sound which according to him is useless. He misses well ergonomically designed tactile buttons as well as adequate audio feedback. Moreover, he mentions that many people lose their vision as a result of diabetes, which also worsens the touch perception in the tips of their fingers and they would benefit best from audio feedback. Currently, he finds a solution in the mobile application through which he could control those units separately. However, he finds it hard to program it for different days of the week and therefore he mentioned the importance of following the standards and rules for building a truly accessible app.

According to him, the more control options a device has, the more accessible it becomes. He believes that combining voice control with physical buttons could cover the biggest audience. However, he does not trust smart systems completely because of questionable privacy. When he buys products, he always chooses the ones with physical buttons. Moreover, he mentions that he already has too many things to remember and prefers to have straightforward interactions with the devices he uses. He also commented on the price of the smart systems. By pointing out the high percentage of unemployment among the target group, almost 90% in Bulgaria, he underlines the unaffordability of those systems budget-wise.

needs ergonomical tactile buttons

requires adequate audio feedback

diabetes worsens the touch perception of fingers

highly appreciates truly accessible apps

recommends to follow standards and rules

a combination of voice control and physical buttons is desired

doubts in privacy policy

always chooses the product with physical buttons

straight-forward interactions

high price range

they already have too many things to remember

Expert user 2/ Visio

This user is an employee at Visio, where he conducts different trainings of VIPs. He, himself suffers from Macular Degeneration and does not see in the centre but only in the periphery. That causes him problems mainly when it gets darker so proper lighting is one of his priorities. That is the reason why he has installed smart lights everywhere in his home. It was interesting that he mentioned that he has a 'love-hate' relationship with light because when it is too bright, it bothers him. He has installed blinds on the inside and outside in order to be able to prevent the sun from shedding too much light inside. The blinds are not automatic yet but he would like them to be.

Concerning the heating, he has a smart thermostat 'Tado' for some of his radiators. He controls it with voice commands and finds that it functions pretty well. It is clear that he is very much involved with new technologies and smart systems and is eager to learn how to interact with them properly. Therefore, he said that he dreams of a house with smart systems installed everywhere so he could control everything by voice. He uses an iPhone which has very accessible applications of the smart systems that he is currently using. Creating different schedules is one of the things that he does in order to make his everyday life easier. Furthermore, he understands well the compatibility of the systems and he upgrades them step by step because they are quite expensive. He confirms that there is indeed a learning curve in the usage of such systems. However, he mentions that if you do it little by little, that curve is not that steep and if you are motivated, you could easily learn the main commands. Currently, he uses also a smart coffee machine and washing machine which he finds very handy.

Concerning the ventilation system, as he lives in a building from the 70s, where central ventilation system is not installed, he is using the windows for a supply of fresh air. His home is also equipped with air conditioning because in the summer it becomes too hot inside and he has to take care of the climate comfort of his pets as well. He does not use the air conditioning for warming up because he says that the heat from the radiators is more consistent. Moreover, they react to commands fast enough and he could feel the increase in temperature almost immediately. He has floor heating also installed and he mentions that it feels very comfortable on your feet.

He is very independent and has always been. He always conducts extensive research before buying devices which most of the time guarantees their accessibility afterwards. For instance, he would like to replace the gas stove with an induction one. Nevertheless, he is still researching which ones provide the best usability and he hesitates between buying one with voice control and one that is equipped with physical knobs. He worries that maybe the one with voice control will need an app in order to function well and he does not want to be interrupted while he is cooking and having to look at his phone.

He has also trained many elderly to interact with such systems. He noticed that the level of education played an important role in their desire to learn. 'The ones that were motivated have achieved remarkable success, he says. On the other hand, some of the people still preferred a simple interaction with one button with must-have audible feedback. That is why he suggested the invention of add-ons for different smart systems.

The idea of one unified transparent smart system that would show him what and when the house is doing fitted him. He added that he would also like to see what the water usage is.

smart lighting is very important for him

bright light bothers him

tech expert

wants to turn everything at home smart

upgrades step by step because of high prices

the learning curve of smart systems is not that steep

likes the schedule function

always does extensive research before buying a device

some of his trainees still prefer one button interaction

audio feedback is a must

suggested creating add-ons

some simple tasks require a lot of energy

Expert user 3 / Visio

As an employee at Visio this interviewee tteaches visually impaired users from the age of 8 to 89 how to use smart devices. He still has some remaining vision. In his job, he notices that most people do not know anything about smart technologies. Most of them feel anxious about them because they have to be regularly updated and maintained. Even though he mentions that the speed of learning is different depending on motivation, lifestyle and stage of life, he says that overall younger people are less anxious and do pick it up faster. They tend to think more about the profits rather than the problems that might occur.

In his home he has smart lighting and smart thermostat Tado which he controls by voice and also physical buttons. He noticed that people are getting too used to automation. An example he gave was how people were asking if the phone calendar sends notifications for appointments as if the paper calendar did send some. He believes that a combination of smart devices and regular things is needed.

Keeping track of his energy usage motivates him to see that he spends less with every month. Concerning the cooking experience, he uses induction stove with buttons. He notes that a smart stove always needs a stable wi-fi and adds that there will always be market for knobs.

The smart lighting system has to be reset at least once a month which might cause a problem for some users. Many of the other smart systems also have distortions and require different actions in order to keep functioning. That might be very frustrating for users, especially when manufacturers are not transparent about those. He proposes that companies provide troubleshooting videos on the internet.

He believes that too much automation is also bad. He compares our future to the Wall-e movie, an analogy which I really liked and even used in my vision in the next chapter. Moreover, he mentions that good ideas always meet resistance in the beginning. According to him, instant gratification does not give the best products.

He believes that the device should help people when needed only and suggests to give them options rather than only solutions, a system that communicates with you. Another option that he mentions is to connect the indoor climate with the outdoors because for instance 20 degrees inside in the summer feel differently than 20 degrees in the winter while he mentions that everybody have a different experience.

youngsters pick up technology faster

people are too used to automation

recommends a combination of smart devices and regular things

there will be always market for knobs

smart systems have to be reset often

frustration is caused by unexpected system errors

companies have to be transparent about possible issues

Regular users 2,3

One of the interviews was led with two users simultaneously - a man and a woman who worked at a blind-fold restaurant. I discovered that could be a good approach as they were friends which created a safe space for free sharing of thoughts and ideas. That resulted into more in-depth insights and proved how different their experience was as the woman still had some remaining sight, while the man was completely blind.

They both said that they mainly relied on accessible applications. When he couldn't access something, he used the help of a friend or the app 'Be my eyes' (Be My Eyes, 2022). At the moment, they preferred older electric appliances because of the physical buttons. She mentioned that she recently encountered the problem of not being able to find a built-in oven with physical knobs. The only available ones were too expensive, she added. He labelled his hobs with stickers so he could use them. He emphasizes on the fact that *'there is a big difference between a product being usable and a product being accessible - it needs to be intuitive to use instead of needing adaptations'.*

In the future, they would like to have all of their appliances automated and controlled by voice. When I asked if they would not feel bored then, they replied that they would just

He owned an automated vacuum cleaner and mentioned that even though it was advertised as completely autonomous, this is only the case under certain circumstances. For example, you have to make sure that the floor is free from cables and that there are not spots where it can get stuck. He was disappointed that he could not leave it alone while he is away but has to keep an eye on it and provide help when needed. What he encountered is a problem with transparency about the actual functionality of the product.

As she still can distinguish bright and dark, lighting is very important to her. In comparison with other users, she wanted everything to be very bright.

want be able to talk to all the appliances

cannot imagine not being able to open a window

use 'Be my eyes' or the help of a friend

lack of transparency about products functionality

what will be the influence on kids health when being brought up in such sterile climate

there is a big difference between a product being usable and a product being accessible - it needs to be intuitive to use instead of needing adaptations

lighting is essential

she prefers to have super warm indoor climate, she does not want to put on extra clothes

Summary // smart systems

On the basis of the desk research of accessible systems and the following user evaluation, the main advantages and disadvantages of smart systems were defined. (Fig. 38) Some of the characteristics are neither pluses nor minuses as for instance the app support. When accessible, it serves as great means of interaction and control. Nonetheless, some users mentioned that they do not completely trust the privacy policies and would rather not use it. Voice control was another functionality, triggering mixed opinions. While adding an accessibility layer to each device, it could be frustrating and confusing when the user cannot guess the exact command. Self-learning mechanisms also were found misleading sometimes. Even though being advertised as highly autonomous, more often than not they needed an initial manual adjustment tailored to the specific space. Only then, they can provide efficient autonomous experience for the resident.

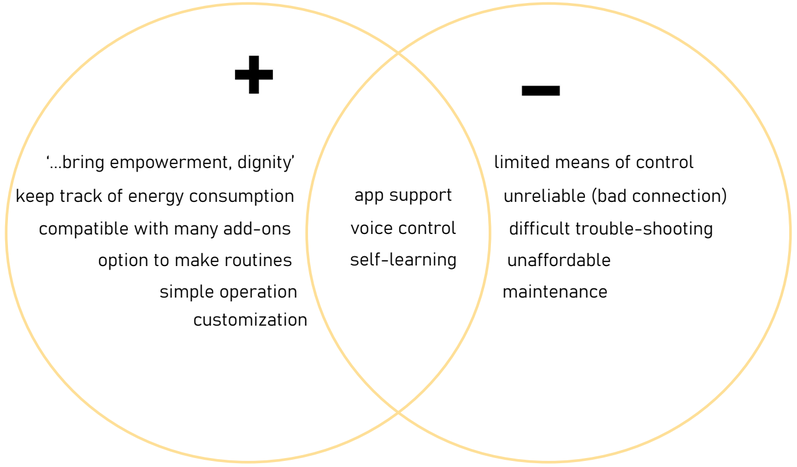


Fig. 38, Summary of the characteristics of smart systems connected to accessibility and heating systems

Summary // accessibility requirements

- AUDIO FEEDBACK
- LOUD ENOUGH VOICE OVER
- TRULY TACTILE PHYSICAL CONTROLS
- CUSTOMIZABLE INTERACTIONS
- SIMPLE INTERACTIONS
- SHORTCUT BUTTONS
- STURDINESS
- AFFORDABILITY

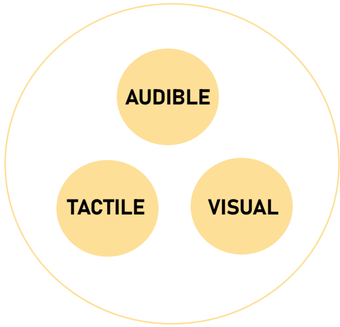


Fig. 39, Summary of the required means of control

DIGITAL INTERFACE

- HIGH CONTRAST COLORS
- ZOOM IN OPTION
- COLOR FILTERS
- MOST IMPORTANT INFORMATION ON SCREEN
- CLEAR SEMANTIC STRUCTURE

The rest of the accessibility requirements, described during the research were sythesized. That way they are more comprehensible for people to use. They are later included in one of my design proposals.

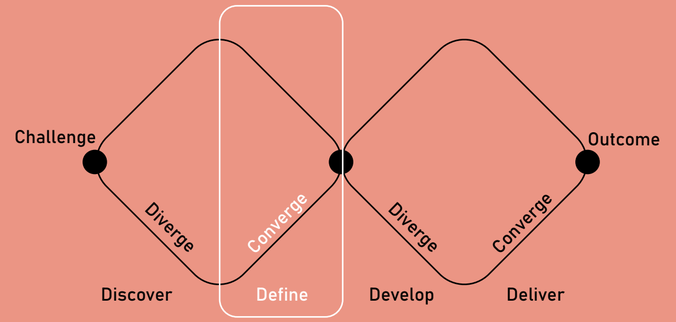
Conclusion

This section provided an extensive overview of the needs of visually impaired users and how are they being embodied in products. The user interviews confirmed many of the insights, discovered during the desk research, and expanded on them. Good examples of accessible products, also appealing for the wider public, were discussed. While some are still too expensive, others are more affordable and positively contributing to the users' well-being by bringing them independence and empowerment.

One of the most important takeaways is that when striving to develop an accessible product, the best strategy is to apply a participatory approach where you involve VIPs in the process. Otherwise, they mention, there are many products that are designed for them which they do not really need or use. This is as a result from them not being able to give their opinion and contribution to the process.

Furthermore, the users that I interviewed, as well the literature review, confirmed that one-size-fits-all approach is implausible for users with disabilities. (Bichard,J., Coleman,R., Langdon, P., 2007) Every person's disability is different, everyone has learned to tackle it in their own way. Therefore, a personal approach is one of the most important things to keep in mind when designing for this target group.

The main insights from the chapter were summarized so they could be applied into the next phase of the project where accessibility and zero-energy renovations come together.



Define

- What are the accessibility limitations of systems currently installed in Reigersbos?

2.

2.1 ACCESSIBILITY IN REIGERSBOS

In this section I apply the layer of accessibility on the systems in Reigersbos. By performing an accessibility assessment while following specific guidelines, I manage to identify the accessibility limitations that might arise during usage in terms of control, feedback and maintenance, etc.

Accessibility evaluation

In order to assess the accessibility systems in Reigersbos also according to official standards, I have sorted out a number of requirements from **'NEN 17210: Accessibility and usability of the built environment - Functional requirements'**. They cover the main aspects of the living environment that are influenced by housing renovations. Then, on the basis of my prior desk research and user interviews, I provide a detailed analysis of each requirement. The decision-makers in renovations such as Reigersbos have to be aware of the need to comply with such requirements. Experts in the field of accessibility stress the importance of applying those into projects that will be used from wide variety of users. (Expert user 2) Otherwise, users could be unintentionally excluded from being able to interact with the surrounding environment.

> I was staying at a brand new hotel, where I could **not even use the elevator myself**. Gladly, I was with my wife.
> Expert user 2

Requirements
1. Accommodate to limited sensory abilities (in that case visual impairment)
2. Access equipments and facilities
3. Operate equipments and facilities
4. Access and understand information via multiple senses (e.g. signage, apps)
5. General ICT usability and accessibility
6. Natural lighting

Questions to ask:

1. Do the choices of technology accommodate residents with impaired vision?

2. Do visually impaired residents have free access to the chosen technology?

3. Are visually impaired users able to operate with the chosen technology freely?

4. Does each selected technology provide three options for interaction (visual, audible and tactile) ?

5. Does the digital interface provide accessible features for visually impaired residents?

6. What amount of natural lighing penetrates the living space?

Question 1,2,3

The first three questions are vital. I have closely examined each system at the demo apartment on the basis of the accessibility requirements that I have defined earlier during the research phase. By explaining the working mechanisms and interfaces of the systems to VIPs during the user interviews, I could determine the level of accessibility of each technology. During the open-ended interviews, I asked users to imagine possible scenarios and on the basis of their own experiences, they identified possible limitations and additional issues that might arise.

Heat pump

Currently, the heating system installed in the demo-apartment provides one option for control - an application which is still in developing phase. I had the opportunity to evaluate screenshots from it but not its functionality. That leads to another important accessibility standard - EN 301549 for digital accessibility. One of the stated requirements is that '*at least one mode of operation that does not require vision should be provided*'. In that case, the app should be compatible with the screen reading software of a smartphone, so the user can have its content read out loud. To be possible for the software to recognize the buttons in the app, they have to be labelled correctly. Therefore, the app has to be designed and programmed accessibly on the first place.

Another requirement is '*provide a visual mode of operation that does not require user perception of color*'. When applying different color filters simulating different visual impairments, on the screens of the app, I concluded that overall the readability is insufficient as the contrast of some elements is too low. (Fig. 40)

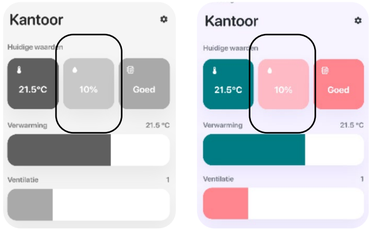


Fig. 40, Color blindness simulation on the Reigersbos app, (Colblindor, 2021)

In combination with the app, it is envisioned that the system will be controlled also through a thermostat on the wall. However, as an effect of a prototype mistake, the currently installed thermostat had a screen interface designed for professional technicians. That prevented its usability testing. Nevertheless, the same manufacturer provides the same thermostat with a screen interface designed for regular users. (Fig. 41) That allowed me

Fig. 41, Thermostat controller (LG, 2021)

to evaluate the identical parts of the product as the buttons. Having completely flat touch buttons makes it extremely hard for VIP to interact with it. Such user would have the option to adapt it into a usable device by labelling it with bump dots. However, Regular User 2 emphasized that:

> **There is a big difference between a product being usable and a product being accessible - it needs to be intuitive to use instead of needing adaptations.**

The same requirements as for the app are valid for the screen of the thermostat. I did not evaluate it as the 'user' version was not available to me.

Even in case that the app is fully accessible, 4 out of 6 interviewees stated that they would feel more comfortable in terms of reliability if the system provides three options of control - app, voice control and tactile control. Such intervention would allow them to act in unexpected situations as for example if the network breaks down. According to the standard ISO 21542: *'Information in audible, visual, tactile and simple language formats should be provided where possible ... visual information to be supplemented by audible information plus tactile information where appropriate...'*. In the case of Reigersbos, such options are not available. Furthermore, direct heat feedback is lacking which prevents the user from identifying even in a tactile manner if the system is working.

Bathroom radiator

Concerning the radiator that is in the bathroom, it has tactile buttons. and a simple small display. However, they are hard to reach because of the low position level and the sink. During the interviews, VIPs commented that even though they would be able to feel the buttons, again the lack of voice feedback, would prevent them from knowing on which temperature setting they have put the device. Moreover, they thought that the buttons are too small and lacking any embossment or indication which one is for what. Furthermore, because of the lack of audio feedback, the function of programming the heater would also be inaccessible. The same is valid for the display as it is too small and lacking contrast.

When I was in the apartment, I also used the simulation glasses set. (Fig. 42) It mimics cataracts, vision degeneration because of diabetes and tunnel vision. From the pictures, it becomes clear how inaccessible the controller unit becomes when you have a compromised vision and no other option to interact with it. (Fig. 43)

Fig. 42, Simulation glasses set I used

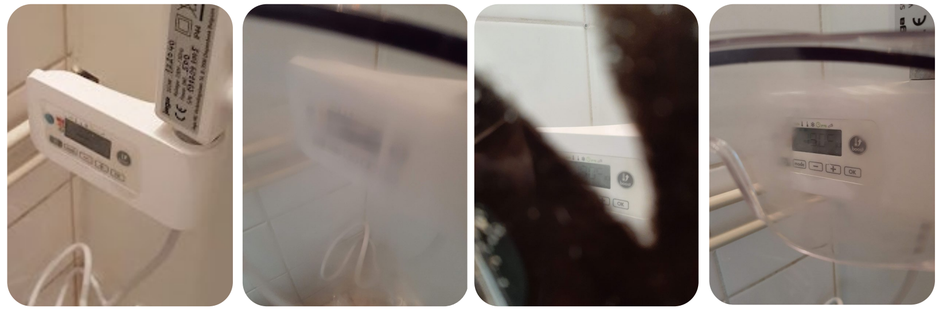


Fig. 43, Simulation glasses applied on the bathroom radiator controller- normal vision, catarcts, diabetes, tunnel vision

Fig. 44, Simulation glasses applied on the ventilation controllers - normal vision, catarcts, diabetes, tunnel vision

Ventilation units

The ventilation system provides tactile control button on each unit. However, it is not labelled, does not have embossment and gives the same audio feedback when it is pressed. According to the user interviews, that is impossible for visually impaired residents to control. ISO 21542 states that *'embossment, has to be min. rise of 0.8 mm, preferred is 1mm to 1.5mm'*. There are light indicators to show the power it was set on but they are too small. (Fig. 44)

The units require complicated maintenance of filters. As that could be especially frustrating for visually impaired users to handle, they have to rely on professional maintenance. Designing simple maintenance process does not only favour users but also companies as it could decrease support expenses.

Air extraction

The recirculation hood in the kitchen is equipped with accessible tactile controllers. One aspect that could be improved is the physical shape of the hood. One user pointed out that he prefers rounded corners as it is safer.

The main air extraction unit is out of reach for the user to control as it is integrated in the extract pipes. (Knaapen, B., personal communication, December, 2022) The noise that it creates could be disturbing for the residents as some people who stayed at the apartment shared. (Boess,S., 2022b) Having low or no vision, VIPs rely mainly on their other senses. Thus, they are using their hearing to orientate and identify what is going on around them. Some even mention that *'your hearing develops so much as you almost got an x-ray vision'*. (UPROXX Studio, 2016) One of the most surprising findings was that some VIPs have learned how to navigate through passive and active echolocation. Passive echolocation means that they are using the sounds that are already in the environment to determine what are they surrounded by. The active echolocation, on the other hand, means that the person is emitting some sound and waits for the wave to come back.(Be smart, 2019) Then, they could envision their surrounding in 3D with amazing accuracy (BBC Earth, 2014) - 'image the world acoustically'. (UPROXX Studio, 2016)

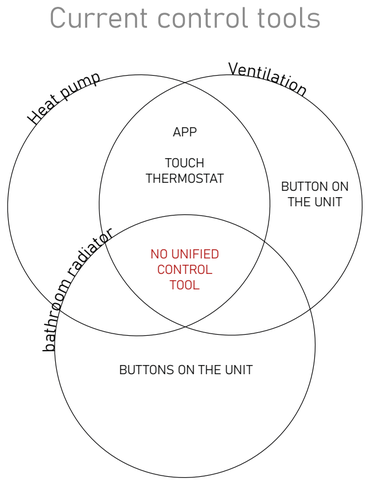
Having that information, we should consider two scenarios:

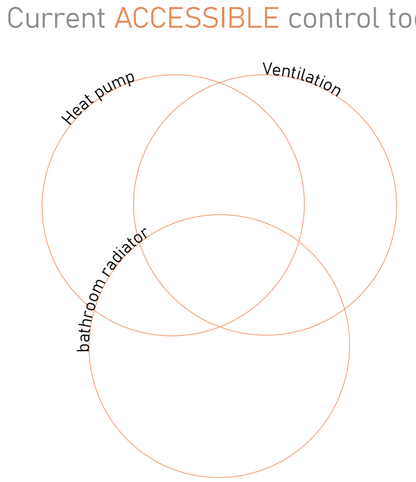
1. Being able to identify what is the system is doing at all times.

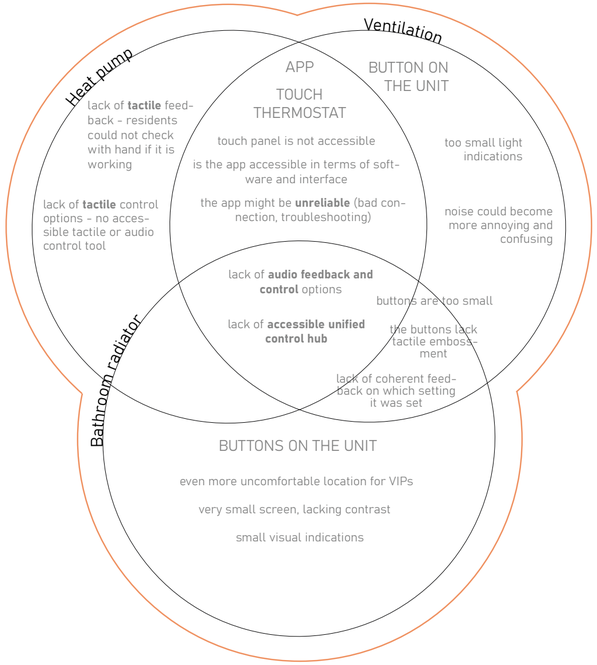
2. Have a constant noise disruption that the user not only finds more disturbing because he/she is more sensitive to sound but also hinders his/her sense of orientation.

I would like to stress the importance of this aspect. Still, more research is needed in order to suggest possible solutions which is out of the scope of this project.

Summary







From the research, it becomes clear that accessible smart thermostats and electric heater controllers do already exist. Some of the ones mentioned earlier are not only more suitable for people with visual impairments but also for the rest of the residents because of their broad functionality and compatibility. However, they are not being implemented in the current renovations. That indicates that there is an unaddressed need for connecting the right systems to the right scenarios. That could be achieved through careful investigation of systems available on the market and connecting them to users' needs.

Fig. 45, Diagram of the accessibility limitations in Reigersbos

Design challenges

In order to respond to that gap, I have summarized the gathered knowledge and translated it to Design Challenges and Design Fundamentals. The Design Challenges highlight the main problems that need to be solved while the Design Fundamentals serve as criteria to evaluate concepts.

DC 1 Provide comfortable indoor climate

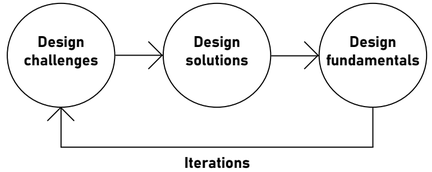
Having a good indoor climate is important for the user's well-being. Considering the low-temperature heating technology, the product has to be the means through which the user will create a comfortable home ambience and could even help him excel in that by giving advices and recommendations.

DC 2 Accessible interaction controls

The system has to be equipped with controls that are accessible both for VIPs and the wider public. The best combination of controls has to be chosen for the specific case. The previous section will be used as reference.

DC 3 Provide a feeling of control

Some users feel like smart systems are taking the control away from them while executing actions that they are not aware of. I still want to give the user opportunity to say the final word for all processes and the opportunity to keep track of them.



DC 4 Provide options for customisation

In order to provide the target group with more options, customization is key. They have to be able to choose their preferred interactions.

DC 5 Balance between automation and activity

I want the product to be balanced between full automation and physical interaction.

DC 6 Affordability price-wise

It is important that the product is not too expensive because VIPs are mostly unemployed and they cannot afford too expensive devices.

DC 7 Reliable system

The device has to be reliable because VIPs would have difficulties doing troubleshooting themselves. Moreover, if one control option becomes disabled, another one should be available. For instance, if the wi-fi breaks down and the voice control becomes unavailable, another interaction option should be provided.

Design fundamentals

By combining the accessibility research with the zero-energy renovation research, the following Design Fundamentals were formed. They serve as a set of requirements that guide us in the selection and design of suitable systems for accessible zero-energy renovations.

Design for accessibility

Inclusion is one of the main goals of this project. Therefore it is crucial that the designed solution is accessible to VIPs while also desirable for the wider public.

Design for trust

When leaving the control of your home to a smart system, you should definitely trust it. The user has to be sure that it is indeed executing the desired commands at the right time and he should be able to check that at any given moment. It is also desired that possible bugs are envisioned and being transparent about.

Design for low-maintenance

As the bigger part of VIPs usually need assistance for tasks that are not performed often, low maintenance products are preferred. Not only they need to ask for help more rarely but for them that also means a more reliable product.

Design for simplicity

Certain commands have to be executed with as little actions as possible. Moreover, the interactions should be natural and familiar. Only vital information should be presented, unless additional information is explicitly asked for. Simple interactions are in the core of accessible interactions. Simplicity in terms of maintenance is also desired.

Design for adaptability

Each visually impaired user has different needs and habits. Some want more automation while others prefer to do things the old way and I want to give them the option to choose. Therefore, it is very important that the product is adaptable.

Design for robustness

The product has to be solid both in terms of physical characteristics and software. Reliability and easy troubleshooting are required.

How to apply them

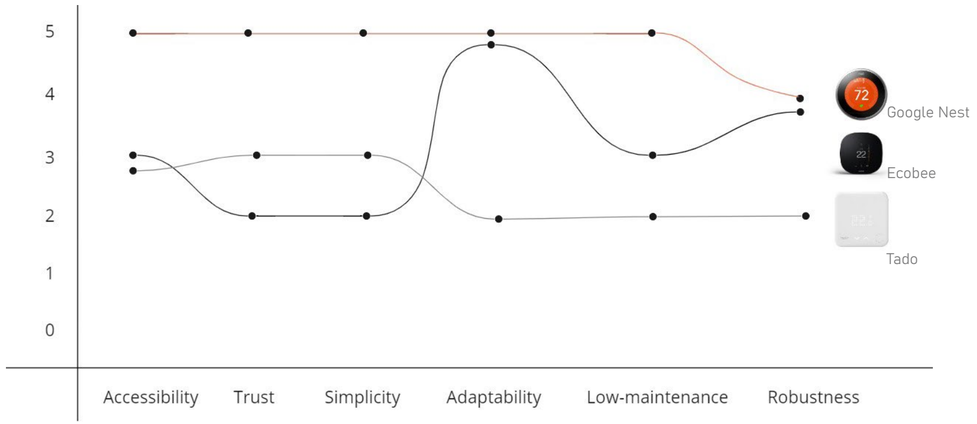
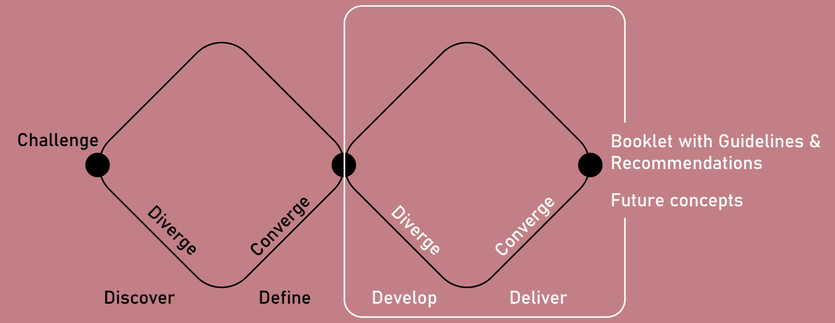


Fig 46, Example of the application of the Design Fundamentals

This is an example on how the Design Fundamentals could be used. By creating an evaluation matrix on their basis, different products can be compared, so the most suitable one for the case is chosen.



Develop & Deliver

- In what way can we enable stakeholders aiming to commission a renovation to make decisions that improve accessibility?
- How to address the identified design challenges in a concept as a whole?

  How to improve the communication between the system and the user in terms of understanding, control and functionality in the future?

3.

3.1 DESIGN SPACE

While the project aimed to provide immediate value, it also strived to make use of as many of the findings from the research as possible. That resulted into creating two design directions - a short-term and a long-term oriented one. On that basis, two sub-questions emerged:

- **In what way can we enable stakeholders aiming to commission a renovation to make decisions that improve accessibility?**
- **How to address the identified design challenges in a concept as a whole?**

The two questions are targetting two different groups as defined earlier.

Target group 1

Those are the people responsible for choosing the products and systems in a renovation such as project managers, engineer advisors, resident volunteers, etc. Therefore, the solution has to be easily understandable by people with diverse occupations and backgrounds. It also has to be simple and time-efficient as usually in such projects there is no space for wasting time. I want to achieve the biggest improvement as possible at the cost of as little effort as possible from the target group. The solution has to lower the threshold for decision-makers to pay attention to the accessibility aspect of the project. It also needs to be motivating and revealing the value of such intervention.

Target group 2

On the other hand, the second question aims to find a solution which is intended for the end users. They could be visually impaired or not, as one of the main requirements for the solution is to be inclusive and appealing to both them and the wider user group. I used the accessibility requirements, the Design Challenges and the Design Fundamentals as quidelines and requirements for the idea generation phase and later during the selection process.

I led brainstorming sessions both on my own, with the users and experts, and with fellow students. (Appendix I) By clustering and combining ideas, three main concepts were defined. First, I will elaborate on the design of the Booklet which answers the first sub-questions and targets the decision-makers. Then I will describe the design of the to Future concepts which target the end users.

3.2 DESIGN PROCESS // Booklet

- **In what way can we enable stakeholders aiming to commission a renovation to make decisions that improve accessibility?**

I first started brainstorming about the first design question. Having already researched many tools for designing for VIPs made me aware of the existing gaps. Most of the tools were targeting only one aspect of accessibility - for example the simulation glasses could give an idea of what it is like to have a compromised vision. However, additional explanation is require in order to be able to translate the data from the experience into usable information. On the other hand, official accessibility standards which are around 300-page documents each, required a lot of time to be carefully read and studied. In most big scale projects as housing renovations, time is limited and should be used efficiently. There are also many websites that share insights about accessibility but again, there is the same time barrier. Someone has to take the time to search for the relevant ones which means filtering a lot of information. Therefore, the solution needed to be simple, straight-forward, easily comprehensible and accessible. This way, the threshold of using it would be lower and the likeliness of people applying it would increase. As expert user *' I am stunned that such information exists but is not being spread and applied.'*

Another issue with online materials is that they require self-initiative on the first place in order to be found. And people tend to miss such 'special cases' unless they have experienced the problem first hand. (Expert user 2)Thus, the product also needed to be able to trigger empathy so it could motivate people.(Toi, M., & Batson, C. D., 1982) I knew that the awareness about the topic has to be increased.

On the other hand, I needed a way to stress the issues with Reigersbos demo-apartment so they could be fixed now and avoided in future renovations.

I thought about the ways that could be achieved. One of the main ideas that emerged after talks with experts, was defining guidelines, requirements and recommendations - clear and concrete. They could be created and applied fast, leading to immediate results. Some forms of communicating information in fast and understandable manner that I considered were info-graphics, posters, drawings and models. The poster that I created for a conference in Amsterdam (Appendix E) gave me some initial directions of how I could proceed.

Fig. 47, Brainstorming

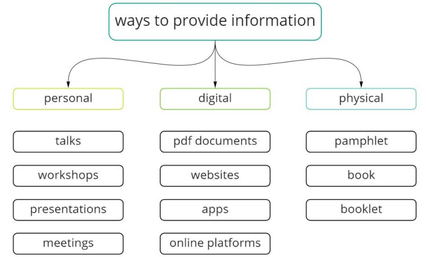


Fig. 48, Brainstorming

Then, I brainstormed about different ways of providing information. (Fig 48) Eventually, a combination of all three is desired as being the strongest approach.

The current design incorporates the selected information in the form of a physical and digital booklet. A pamphlet was too short to deliver the message while a book was too long. The physical copy could be more comfortable for some (Jansen, F., 2021), while the digital one is more easy to access and distribute. Next to that, the booklet refers to different tools, one of which is the app 'I have low vision' which simulates different kinds and stages of visual impairment in real time. It can also be experienced in VR. That approach could help project managers to take on a new perspective and make better informed decisions when it comes to selecting the right systems.

For bigger engagement and extra dimension of interaction, the videos introduced earlier are implemented in an AR app. (Fig. 49) They were designed for the aims of the booklet to trigger empathy with the residents and engage the reader. One of the reasons for choosing specifically an AR was that I wanted a more untraditional way to support the booklet. I thought that such addition could draw more interest to it.

Nonetheless, personal communication is always preferred as being more convincing. (Community Tool Box, 2022) Therefore, even though it is not currently incorporated into the concept, I recommend including it in the long term. For example, workshops with exercises and presentations where the booklet is introduced could be organised. Such intervention could considerably expand the application of such tool for inclusivity. One of the users mentioned that *'This knowledge should be included in the education of people responsible for making such decisions as architects, project managers, system engineers.'* Furthermore, some of the tools proposed in the booklet, as for example the ones simulating visual impairment, are more efficient when applied with the guidance of a professional. Then they could result in a richer and more valuable experience. (Silverman, A.M., 2015)

Concerning the content, based on my research, I concluded that it would be very valuable if I could show people how to make an accessibility evaluation of already existing products. Then, those, responsible for taking decisions in a renovation would have the opportunity to take better informed decisions, which are matching the needs of users for the specific case. During the research, it was discovered that the product suppliers are often unaware of the accessible features that a product provides and thus fail to communicate that to the clients. This is why I translated my process of accessibility evaluation of Reigersbos into concrete steps to be performed by non-designers. Through several iterations, I shaped them in the form of a basic tool-kit for investigating the accessibility of systems' both physical and digital characteristics. In some cases, the result of the evaluation could be that several different products are suitable. Thus, I present the 'Design Fundamentals' evaluation matrix. It incorporates 6 general requirements that a product should fulfil in order to succeed in the context.

All the information in the booklet is based on the conducted desk research and user interviews, some of which was presented in the first chapter of this report.

As with this booklet I am aiming towards immediate contribution, I also provide a list of advice with specific recommendations both for zero-energy renovations as a whole and also for the specific Reigersbos case. Considering the conducted research, I believe that their timely implementation will improve the results of the renovation considerably in terms of systems' energy efficiency and residents' comfort.

As many of the detected issues are also typical for other zero-energy renovations, the booklet is designed in a way that it could be also used for other projects except from Reigersbos. The content is separated accordingly.

In the future, recommendations for other types of disabilities could be added to the booklet so it becomes a united tool for accessible zero-energy renovations.

The app that complements the current form of the booklet opens room for countless future possibilities. (Expert from The Green Hub) (Fig. 49) It can be downloaded from the QR code and tested on Pages 23 and 25. In the short term, the interactions with the systems installed in a demo-apartment could be integrated in the app so some tests could be performed remotely. Then, those could turn into a VR version allowing more thorough experience, more accurate conclusions and boost in inclusivity. (Fig. 50) Current rendering softwares as Enscape already provide the opportunity to experience a 3D model in VR.

I will now present some content from the booklet and then I will discuss the two future concepts in more details.

Reigersbos AR
educational

Fig. 49, AR app

Google Play

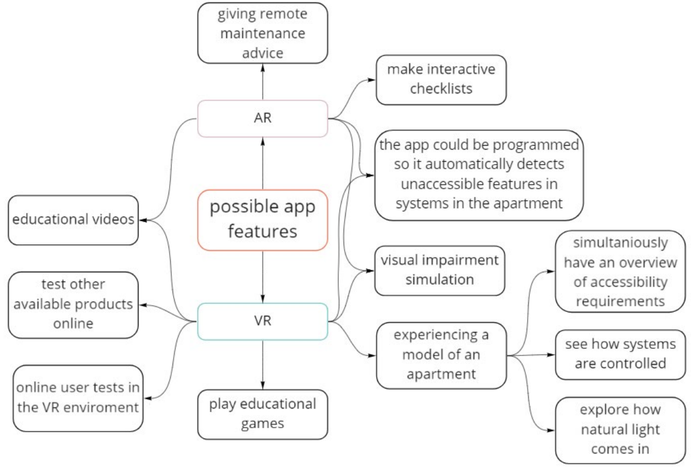


Fig. 50, Future possibilities, brainstorm

3.3 BOOKLET

The booklet addresses the issue that in current renovations the systems do not always fit the needs of the users. Furthermore, often inclusivity is not being taken into account which leads to unintended exclusion of residents.

This manual suggests basic guidelines, presented as step by step actions. Following them will lead to more inclusive decisions that meet residents' needs. This will not only increase their satisfaction and comfort rates, but could also decrease the expenses for support and maintenance after a renovation. Therefore, this solutions favours both project developers and residents.

The whole booklet can be found in Appendix H.

Fig. 51, Booklet cover

Structure

MAIN CHALLENGES

The first section is an overview of the main challenges in zero-energy renovations. It provides the reader with context. Then it presents a summary of the specific challenges with the systems in Reigersbos in terms of functionality and accessibility. The latter is targeting decision-makers involved in Reigersbos renovation. You can find the challenges explained in the beginning of this report.

GUIDELINES

One of the main goals of the booklet it to enable non-designers to take decisions tailored to the needs of VIPs next to all other users. This chapter includes a step by step explanation on how to apply a human-centered design approach in the process of renovations. The guidelines are based on the principles that I used to evaluate the accessibility of the systems in Reigersbos. I structured them in a comprehensive manner so they are easy to understand and follow. They can also be applied on other renovation cases. Some of the visuals that are present in the actual booklet were left out now as they are available in other sections of the report.

RECOMMENDATIONS

Particular points of action are proposed, both for zero-energy renovations as a whole and also for the case of Reigesbos in specific. They suggest immediate solutions to existing problems and presents the advantages of each recommendation.

FUTURE STEPS

In conclusion, several future steps are proposed.

GUIDELINES

How to perform an accessibility evaluation?

(with focus on visually impaired users)

Fill in the 'NEN 17210' checklist of functional requirements for accessibility and usability of the built environment according to the choice of technology for the specific case.

Requirements	SYSTEM	YES/NO	Comments
1.Access and operate equipments and facilities			
2. Access and understand information via multiple senses (e.g. signage, apps)			
3. General ICT usability and accessibility			
4. Natural lighting			

Please find a biger, detachable version of the checklist on Page 41 (of the Booklet). (Appendix H)

Questions to ask:

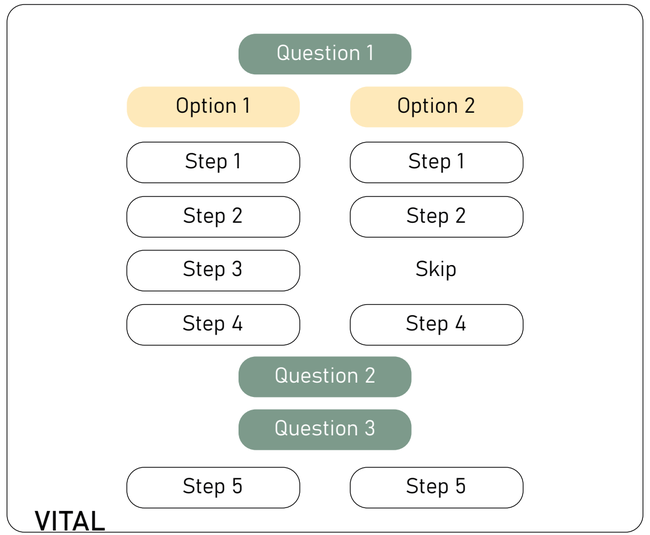
1. Do visually impaired residents can access and operate the chosen technology freely?

2. Does each selected technology provide at least two out of three options for interaction (visual, audible and tactile) ?

3. Does the digital interface provide accessible features for visually impaired residents?

4. What amount of natural lighting penetrates the living space?

How accessible are the systems?



Fill in the accessible checklist

This page provides a step by step approach on how to conduct user testing.

Question 1

Option 1: **Facilitate user tests with visually impaired users**.

Step 1: Define specific testing objectives depending on the case.

Map all the systems that are or will be installed in the demo-house. Then, for each system, list all the interactions which the user should be able to complete, e.g. turn on/off, set the temperature high/low, set a routine, etc.

Suggestion// First start with the functions that are vital for the resident. Try to list at least 5. Then continue with the ones that are of lower priority. Try to put yourself in the shoes of the user. You can use either the app that simulates low vision on Page 7 or the Simulation Glasses method. Then act out an imaginative scenario in order to come up with more possible interactions.

Step 2: Create a plan.

Where will the user testing take place? How long will it last? Would you recruit participants to stay at the apartment overnight or would you invite them only for a shorter period of time? Write a task scenario - what actions would you exactly ask them to perform and in what order? Prepare materials to keep track of the results. Think about what answers are you looking for specifically. You will most probably be interested in the process as well as the final results. Create a questionnaire for the interview which will take place after the testing.

Suggestion// Plan how long the user test would take - maybe it could be a usability user test of around 1 hour. For an in-depth user test you might need to recruit participants to stay overnight. Take into account that staying overnight would require more time for preparation. Decide how you will record the results - would you do it yourself, or would you involve another person to help you with that. Do you intend to record videos, or would you be only taking notes? If the person stays overnight, would you ask them to document anything themselves while there? When all this is ready, perform a pilot user test..

Step 3: Recruit participants.

Partner up with associations and companies involved with visually impaired users (e.g. Koninklijke Vision, Envision, WOON!, etc.) Provide information about the study in accessible manner - Braille print, audio, contrast colors, large text.

Suggestion// Recruit a minimum of 10 participants. Make sure that you have well explained the goals of the study and what will be required from them - in terms of actions and time. Decide how you would compensate them for their time - you could grant them giftcards for example.

Step 4: Conduct the test

Depending on the context, you can refer to the explanation of Question 2 and/or 3 for accessibility requirements. Reflect on each user test and if needed, make changes to the following ones.

Step 5: Analyse the results and fill in the checklist from Page 40

Look at all findings and think what they mean for the project. If any problems emerged, think what kind of solutions could be applied. You can evaluate them with the Design Fundamentals on Page 32.

Option 2:

Simulate visual impairment.

Step 1: Choose a tool which could assists you in simulating a visual impairment.

- Simulation glasses are proven to enhance designer's empathy and creativity.
- You could tie your eyes with a scarf.
- In case you wear glasses, obstruct the view of each lens with tape or paper.
- Get plastic safety glasses and paint them or scratch them.
- You could also use the guide by Erin Ringwald on how to make your own Simulation Glasses (eHow, UK)

Step 2: Follow the above procedure from 'Option 2' while skipping 'Step 3'.

Question 2. By using the provided graph, assess to what extent each selected technology provides three different options for interaction. According to ISO 21542: 'Information in audible, visual, tactile and simple language formats should be provided where possible ... **visual information to be supplemented by audible information plus tactile information where appropriate....**'[3]

Audible

commands
feedforward
feedback
questions

Tactile

big clear buttons
air stream
embossment, min. rise of 0.8 mm, preferred is 1mm to 1.5mm (ISO 21542)
sliders
vibration
hot & cold
texture

Visual

light signals
accessible digital interface
text and color mapping
contrast

OTHER ACCESSIBILITY FEATURES TO KEEP IN MIND

solid
loud speakers
audio cues

offline voice dictation
NFC reading function
compatible with different visual add-ons

easy navigation (with a click of a button)
intuitive

big buttons - electrical switches should have large push plates to prevent accidental operation[3]
truly tactile buttons

This page provides guidelines on how to perform a digital accessibility check.

Question 3. Evaluate all digital interfaces on the basis of the provided criteria for digital accessibility **EN 30154** [4]

What? Provide at least one mode of operation that does not require vision

How?
- well formed semantic structure
- audio and tactile user interfaces

What? Provide features that enable users to make better use of their limited vision

How?
- magnification, reduction of required field of vision and control of contrast, brightness and intensity

What? Provide a visual mode of operation that does not require user perception of color

How?
- provision of additional methods of distinguishing between the features

Please fill in the checklist. A bigger, detachable version can be found on Page 42.

Requirements	**YES/NO**
Accessibility setting on the main screen	
Voice over	
Zoom in option	
Color filters	
Most important information on screen	
High contrast colors	

This page provides guidelines on how to perform a light study.

Question 6. Create a light study of the space using a 3D software in order to predict the movement of natural light in the space This has implications for the thermal comfort of the residents. It is also and important factor for VIPs. It stimulates their brain. This study also has implications for decisions on the light throughout of window panes, overhang and type of glass.

Step 1: Create a model of the space that you would like to examine in SketchUp.

Step 2: Import the correct geo-location and sync the orientation of your model.

Step 3: Turn on the shadows feature in SketchUp and explore how the light comes into the space throughout different times of the day and the year.

Suggestion// For a more realistic feeling, you can use the rendering software 'Enscape'.

Step 4: Make conclusions about how the thermal comfort could be influenced and what kind of means are the most suitable to control natural lighting in the specific case.

Additional question: How to measure the psychological well-being of the residents ? (being one of the goals of the renovation)

This evaluation tool serves to include the emotional layer in the project. The 'Well-being calculator' is a matrix, incorporating the most important criteria for the well-being of disabled users. This is a method that aims to translate the needs of the users in a scalable form. Give a grade to each criterion in order to compare different products.

Well-being calculator

CRITERIA	GRADE	NOTES
ACHIEVEMENT	1 — 10	
MEANING	1 — 10	
SELF-ACCEPTANCE	1 — 10	
AUTONOMY	1 — 10	Example // Peter can control the heating all by himself.
PERSONAL GROWTH	1 — 10	
SAFETY	1 — 10	
SOCIAL INCLUSIVENESS	1 — 10	

Important note

Please, take into account that in that kind of user evaluations, it is recommended to use the services of a professional, such as a Design Researcher for example. Their expertise will contribute to obtaining richer and more valuable results for your project. (Boess, S., 2022a) (Boess, S., 2022c)

RECOMMENDATIONS

RECOMMENDATIONS // General

One unified system to control all heating and ventilation units in the apartment (including the electric bathroom radiator)

Advantages

- more energy efficient systems
- less components for residents to learn and be aware of
- better control of the humidity in the bathroom
- allows residents to connect other devices and sensors
- provides better control
- better connectivity

Provide three control options of each system (tactile, audible, visual, on the basis of the above guidelines)

Advantages

- more reliable system
- more accessible system

Provide immediate feedback (audible, tactile, visual, on the basis of the above guidelines)

Advantages

- more energy efficient system because users would interfere less when they know what the system is doing
- more accessible system

Provide air recirculation hood in the renovation package, one with rounded edges

Advantages

- better fit to the other systems
- easier for the residents
- safer

Choose ventilation units that preheat the air

Advantages

- more energy efficient heating system because warm air comes in
- better comfort for the users because of the lack of cold

Collaborate with companies that are transparent about envisioned issues and troubleshooting

Provide an accessible troubleshooting manual - use clearly legible fonts and symbols with good visual contrast, standardized symbols; provide tactile and audible formats [7]

Implement a function (app) so users could make basic diagnostics themselves

Advantages

- allows taking better informed decisions
- the residents will perform maintenance more easily
- less interventions will be needed from professionals
- lower maintenance costs both for the user and the company
- better functioning of the system
- better reliability
- trust

RECOMMENDATIONS
// Reigersbos specific

Install balanced heating and ventilation system when possible

Advantages

- decreased heat loss
- highly automated
- better comfort for the resident
- more energy efficient

Include a reminder signal for residents to close the windows on time

Advantages

- more energy efficient heating system because there is no uncontrolled cold air inlet
- more energy efficient ventilation system because there is no uncontrolled unfiltered air inlet

Install automatic blinds

Advantages

- improved comfort for the users
- more energy efficiency system when the sun contributes to warming up the space
- better control of natural lighting

Change the position of the CO2 sensor of the ventilation system

Advantages

- better air quality (because of the more accurate data)

Choose an electric unit for the bathroom equipped with a controller at the top and/or one that has a wireless control option

Advantages

- easier access and control
- safer

Provide a manual control option for the air extraction in the toilet

Advantages

- better comfort for the residents
- include auto turn off function after 10 minutes

Evaluation & Conclusion

In order to evaluate the application and content of the booklet, I led 7 open-ended user interviews. Two of them were with Expert users 2 and 3 from the initial user interviews. I created an accessible format of the booklet by transferring only the text in Word so they could access it through screen readers. (Appendix F) 'InDesign' did provide certain features for accessible design as well but I did not manage to put them in good use. The screen reader read out loud everything in a different order than desired. I have sent the document a couple of days before our meeting so they could take as much time as they need to explore it.

They assessed the content of the booklet from the viewpoint of VIPs on several criteria such as completeness, quality and clarity. Both interviewees were pleased with the guidelines and recommendation sections which they defined as *'practical, implementable, understandable, good quality and elaborate'*. Expert user 2 even mentioned:

> **Such guidelines are very much needed. I hope that they will use them!**
> Expert user 2

Expert user 3 suggested some ways to motivate people to use it by triggering empathy as adding a link to an app that simulates different types and stages of visual impairments in real time. I found the 'I have low vision' app which could be used in VR too and linked it to the booklet. It could enable the user of the booklet experience a simulation of a visual impairment. He also noted that it might be useful to add some kind of quote on the cover to attract interest and also through discussion helped me simplify some of the guidelines.

One of the other user evaluations was with a sighted colleague of Expert 2 and 3. As he is also involved in advocating for the needs of visually impaired, he delivered valuable feedback. He advised me to make the official standards bolder and make clear that the people responsible for the renovations should comply to them and be up to date. A very practical advice was to add a clickable link to the videos which was missing in the draft version. Another important remark was that he missed clarification who is target reader and how can he benefit from it. Therefore, I added an extra page with short explanation. (Appendix G)

I also spoke again to Regular user 2 and 3 from the initial interviews. As I only had the booklet in English, I summarised the information vocally at our real-life meeting. They also thought that it does cover he basic principles of accessibility and did not have any other remarks. That could be in result of the fact that they did not have the opportunity to look at it beforehand and think about the content.

The evaluation with other two interviewees was conducted in a combined interview. One of the participants was a target user, namely a project manager for Reigersbos while the other one was an ICT specialist from the Green Hub Amsterdam. On one hand, the latter provided interesting insights like confirming that the AR app makes it more appealing to read. On the other, his presence shifted the focus from the target user and some misunderstandings occurred that slightly hindered some aspects of the booklet evaluation such as its context of use. It is to be used during the process of renovation. However, because of the remote work-setting, I did not have the opportunity to create that scenario in a more realistic way than using story-telling.

Overall, the project manager said that a thing as the booklet is *'very needed'* and valuable. He gave some advice on how to improve it in terms of comprehensiveness. For example, he mentioned that I need to add a clear explanation about who is it for. He also advised me to create a flowchart on the steps that the user is expected to undertake so they do not get lost in the process. (Appendix G)

Concerning the application of the booklet, Boess. S. (2022c) also argues that more tools are needed for the planning and then

decision-making phase as doing an evaluation post occupancy is too late. She also emphasizes on the fact that such interventions needs to be easy to adopt. During the evaluation Expert user 3 mentioned that the recommendations seem *'implementable'* and *'practical'*.

In order to make it applicable to more cases, I separated the Reigersbos' challenges and recommendations from the General ones. Then, it becomes usable also to people who are not involved in the case of Reigersbos. Appenix (G)

To sum up, the booklet was accepted very positively. Except from several small remarks, all interviewees found the content very elaborate, understandable and applicable which were among the main requirements. As one of the shortcomings of the evaluation was that it was not tested in the projected setting, that could be performed in the future.

3.4 DESIGN PROCESS // Future concepts

- **How to address the identified design challenges in a concept as a whole?**

During the first diamond, I did some preliminary brainstorming with users and fellow friends. At that moment, I could not find application of those ideas. One of the main problems that I identified was that good accessible products already do exist but are not being applied in the right cases. This is why, only when I came up with the booklet which addresses this issue, I felt the need to also explore possible future concepts. They would embody the other main findings of the research, so I could depict which functionalities and characteristics are valued from both visually impaired and the wider public.

Before going back to the early generated ideas, I expanded on the research I made. My goal was to detect one urgent specific issue to design for. That is why I looked into the details of heat-pump mechanisms, their replacements and zero-energy housing renovations generally. On the other hand, I read more articles about the habits and needs of visually impaired users, how they clean, what they like doing at home, modifications and adaptations they create.(Cliona R., et. al., 2017) (Stevens-Ratchford , R., Krause, A., 2004) The bathroom could pose health hazards, for example because of the low radiator controller, next to other issues. However, after further research, it became clear that there are already solutions for that too. For instance, there are controllers that either provide wireless control through an app (Terma, 2022a) or ones with very tactile buttons.(Terma, 2022b) I did not find a product that I personally wanted to re-design and I made the decision to instead explore several different ideas. They could be valuable for future development and could serve as an inspiration to people who tackle the topic further. Still, some of the insights of this research were incorporated in the booklet's recommendations section.

In order to expand on the preliminary ideas, I organised another online brainstorming session with 5 fellow students. The sub-question that we explored was:

- **How to improve the communication between the system and the user in terms of understanding, control and functionality in the future?**

Prior to the meeting, I sent them a short informational pamphlet where I asked them to complete one small home exercise. They had to blind-fold themselves and interact with their heating system. It proved the point that most of the installed thermostats are currently not accessible. On the other hand, it helped them to think also from the perspective of a visually impaired user which lead to richer ideas. (Appendix I) Except from the insightful results, it was also a new learning experience for me organising such session. I used different techniques as for example brain-writing and collage making.

I then added the preliminary ideas and clustered them into 4 main categories with most of the ideas concentrated in 'Physical feedback' and 'Automated systems'. (Appendix I) The fact that nowadays automation is taking over our tasks with high rate bothers me and causes struggles with my vision as a designer. In order to try to solve that, I decided to apply the method 'Vision in Design'. Then, in order to obtain more information before making decisions, I conducted a brief research into the topic of Human & Technology.

Vision in product design

Deconstruction

Context

- Inclusive Design is a topic in the present agenda
- VIPs need accessible products to control their home climate
- The systems in Reigersbos are not accessible
- Smart home systems provide VIPs with independence
- Many VIPs live by themselves
- Smart systems have high compatibility with many devices
- Many smart home systems are too expensive for this target group
- Little information is available on the internet about the level of accessibility (Molly Burke, 2022)
- Staff in stores for home appliances is rarely familiar with the accessibility level of a device (Molly Burke, 2022)

Interaction

- VIPs prefer to have the opportunity to interact with a device in 3 different ways
- Voice control, accessible app and tactile control are desired
- Touch control is almost impossible to use for VIPs
- Adaptability and customizability are highly desirable
- Most smart systems require pre-use training
- The option to control a device physically gives VIPs a sense of reliability
- Younger users are less anxious when learning how to use the systems
- There is a trend for touch interactions while physical ones are forgotten
- The inability to control a device leads to frustration

Product

- Smart home systems are mostly accessible through voice control
- Manufacturers are not being honest about the problems that might occur and therefore do not give possible options for repairment
- Most of the products are not designed inclusively
- Products specifically designed for VIPs are very expensive
- Most users do not like to use products that look differently as they want to feel 'normal'
- Some users find smart home systems unreliable because bluetooth, wi-fi and troubleshooting issues

Vision

I used to believe that the automation in our everyday activities is unnecessary. We don't have to put any effort in order to complete some tasks and most of the time the action is done for you by only pushing a button. That made me feel like we are losing the charm of real life and its little struggles. But I have never thought that for some users, those are big struggles which could lead to exhaustion and frustration, disability and exclusion. So far, as sad as it may sound, I have never looked at it from the point of the people who actually need those simple automations in order to lead a more qualitative life. I am grateful that I now tackle this problem which humbles my strong views and provides me with a new perspective on design.

Nevertheless, I still do not argue that we have to automate everything. As one of my favourite writers says:

'What would happen with people when machines start doing their job? The person has become human through labour, while the machine that he creates will take his place not only in physical but also in mental labour. If not everyone - at least most.... What will people do without work? How will they develop? Will they become more human?', Nikolay Haytov

As this question truly bothered me for years now, I could not continue without learning more about it. As this is a matter of no wrong or right, I will present the statements that I chose to believe in and which helped me move forward not only with the project but also with my development as a person and a designer as a whole.

Experts argue that technology allows us to share ideas faster, to create more, collaborate and evolve and opens up new opportunities. Those things I already knew, but what made me start agreeing were the following quotes next to many similar arguments, extracted from the talks of different experts:

> We are becoming more human than we've ever been because **the things that we used to worry about is being taken care of**.
> We move from survival into thriving.
> Sanei, J.(2019)

> In the war of automation, I bet on humans.
> Hand, E. (2020)

> **The choice if we let technology to impact our life in positive or negative way is ours**!
> Killebrew, M. (2015)

Build the best teams of people and machines - 'Human-technology teamwork', Don Norman

On the basis of the acquired knowledge, I could continue my idea generation process with clearer goal. That made me remove my Design Challenge 5 - Balance between automation and activity. I still do believe that we have to keep that balance in our life. Nevertheless, I think that home heating and ventilation should not take up too much of our time and attention and therefore, the more autonomous it is - the better. Then, the residents will have more free time to enjoy their time at home in more qualitative ways. Of course, it is still desirable that they have control over it when demanded. Furthermore, it was important to also incorporate a physical interaction into my concept.

Going back to the idea generation phase, based on the idea clusters and research, I identified two main directions that I wanted to explore. The first one was products that are physically detached from the house as different add-ons to the already existing systems. The second - products that are integrated in the house as parts of the ventilation or heating systems. Then, by combining ideas, I created two separate concepts that were solving most of the defined Design Challenges and were compying to the Design Fundamentals. That will be explained in the next section, under each concept. I also used design sketching to develop the ideas. (Appendix I) I also drew inspiration from the talk of Jinsop Lee (2013) who talked about designing for all 5 senses - smell, touch, sight, sound, taste.

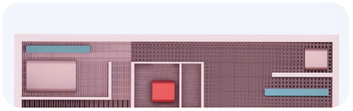
General

DESIGN DIRECTIONS

PRODUCTS PHYSICALLY DETACHED FROM THE HOUSE

- for control
- for informing
- for receiving feedback

Tactimap



PRODUCTS INTEGRATED IN THE HOUSE

- for sensing
- for emitting
- for receiving

Breathing Walls

TACTIMAP

Context

Tactimap is a concept of a portable 3D model of the living space which serves as an informational tool for the resident. It integrates all heating and ventilation units and through them provides tactile feedback about the current setting of the systems. Tactimap allows the resident to easily understand what the system is doing at each specific moment in all separate rooms. If it heats up, the elements will become warm, otherwise they will stay cool, analogical to old school radiators. On the other hand, when the ventilation is working, an element will rise up - if not, it will stay flat.

This concept is inspired by the issue with the lack of warm air stream from low-temperature convectors. Informing the residents about the systems' state will decrease the amount of undesired interactions between them and the system. For example, when the resident feels cold, he could think that the system is not working which would make him increase the temperature setting. This leads to needless energy consumption. While when the resident is aware that the system is already working, he is more likely to put some extra clothes on and wait for the space to warm up without causing excessive energy usage.

Fig. 52, Tactimap put in the context of the living space

Future potential

Another issue that Tactimap addresses is that residents have the tendency to forget windows open for too long. As many users mention that they *'enjoy having contact with the outside (sound, smell)'*, (Boess, 2022b) the option to open a window cannot be removed. However, during the winter, such uncontrolled inlet of cold air for longer periods of time is highly undesirable. Therefore, a light indicator is integrated in the product which reminds the residents to close the windows on time. (Fig. 53) This contributes to the energy efficiency of the system and the comfort of the user. Auditory feedback could also be incorporated.

For determing the 'Desirability' of the concept, an online questionnaire was created. It included questions for desired functions. Some of the answers are included below while the reset are discusses in the next paragraph.

In the future control function could be implemented to the product as many users pointed that as a desirable function. *'Controlling lights, lock and unlock doors, actually everything that I can control in a living environment.'*, a respondent from the online questionnaire. (Appendix J) For example, double tap on a heating unit could mean 'Increase the temperature by half a degree'. (Fig. 54) In that manner, the basic functions of the system could be incorporated into the elements of the model which would expand its application and value. The expert from The Green Hub noted that it could also be used to show when maintenance is needed and immediately send signals to User Support or alert the resident when there is something wrong with the system.

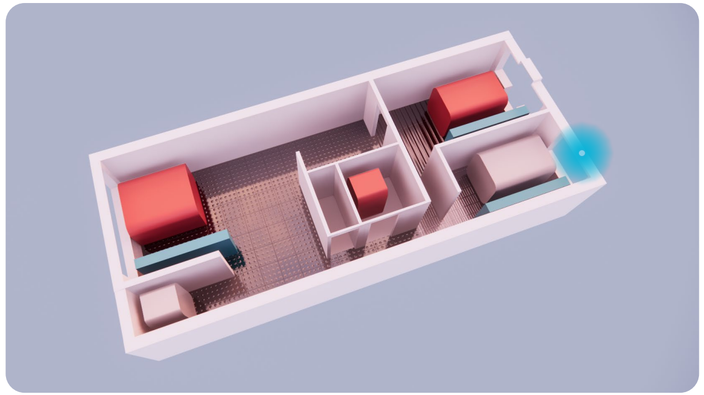


Fig. 53, A 3D model of Tactimap in perspective where the LED for reminding to close the windows is visible

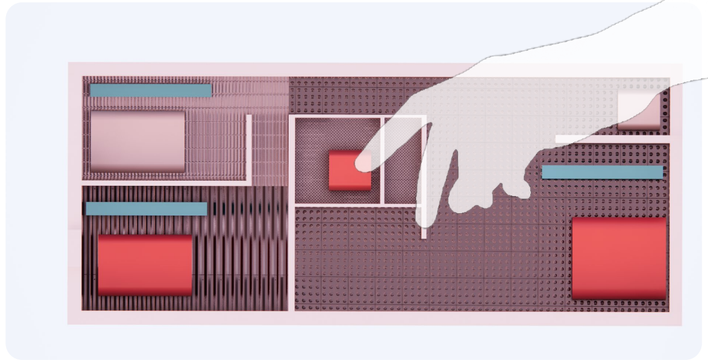


Fig. 54, Top view of Tactimap where the different floor textures are visible

Many of the respondents said that they would like to have an app in addition to that model. There they would like to get informed about their energy usage. This was pointed out as a desired function from several participants in the research. They pointed out that such information would help them to learn how to control their home more efficiently and adapt with time.*' It would be nice to be able to show statistic of how your indoor temperature changes depending on the outside weather for a period of time. For example daily, weekly, yearly. If the user then compares how he/she experienced the indoor comfort in relation to the weather one can learn how to use the heating and ventilation system more efficiently by adjusting it to the weather forecast in the future.'* a respondent from the online questionnaire (Appendix J)

Tactimap could be very useful in scenarios of multy-storey dwellings. (Fig. 55)When a person needs to check whether the heating in one of the rooms on the other floor is working, he can just check the Tactimap element. That could be specifically valuable for older people and people with motor disabilities. If it is applied to such case, then some kind of physical connection would be useful for reliable stacking. (Fig. 56)

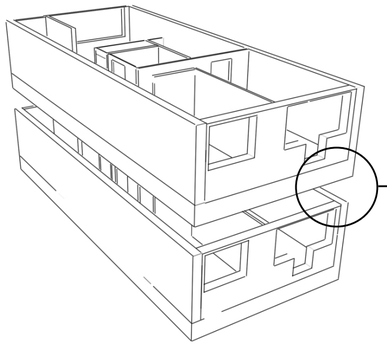


Fig. 55, A concept for possible stacking of several Tactimap s

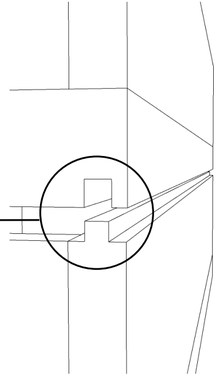


Fig. 56, A close up of possible joint structure for the product

Desirability

When interviewing the users for the booklet evaluation, I also asked them about the future concepts. In addition, I prepared the online questionnaire that I mentioned earlier. I included a short explanation and visuals of the ideas. It was targeting the end users from the wider public. I received 10 responses from people at the age between 24 and 36 (Appendix J). To the real-life interview with Regular User 2 and 3, I brought a simple prototype to give them some context. (Fig. 57) Regular user 2 said that the model provides nice context.

8 out of 17 participants explicitly said that they would use such product. The rest had mixed opinions on it- many of them said that an app would be more useful to them. (Appendix J) However, Expert User 3 noted that having a 3D representation in any form, different than a screen, is very useful as people process the information much better that way. He proposed a hologram. Another interesting remark was that it looked 'luxurious' and 'exclusive'. The project manager said that it could be more useful for creating a block of apartments for keeping an overview of them rather than having it for personal use.

Fig. 57, Physical low-fi prototype of Tactimap used during user evaluation

Fig. 58, Regular User 2 exporing the model of Tactimap

This product is envisioned as an add-on to already existing heating and ventilation systems. They have to communicate to each other and have a unified control unit. In that case, they can send data to the Tactimap which would translate it into tactile information.

After conducting a TRL analysis (Appendix K), the weakest point of the concept from technical perspective turned out to be the heating element. It seems that there are many trials with devices incorporating Peltier elements (Fig. 59) that seek to provide thermal feedback. (Ueda, Y., Ishii, C, 2016)(Benali-Khoujal, et.al., 2003) (Ranasinghe, N, Yi-Luen Do, E., 2016) Thermoelectric devices could also be an option as argued from Kim, S. et.al. who applied the technology to a VR glove. However, that aspect still requires further research which is beyond the scope of the project.

The other components are already existing parts. For more efficient production of the housing, five most common floor plans could be selected and produced. Creating a box joint design of the walls could provide additional customizability. (Fig. 60)

However, for the value it provides, it might be a too costly product which does not fit the affordability challenge.

Fig. 59, Peltier element

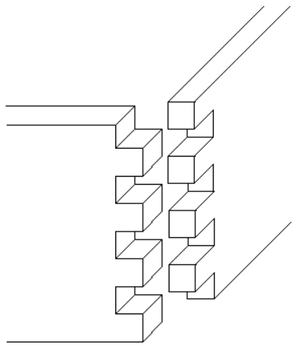


Fig. 60,Possbile joint structure for better adaptability and customizability

Design Challenges

DC 1 Provide comfortable indoor climate
By knowing the system better, the resident can control it better which leads to more comfortable indoor climate.

DC 2 Accessible interaction controls
The physical 3D model and the thermal feedback allows people with visual impairments to interact with the product freely.

DC 3 Provide a feeling of control
Being constantly aware of the actions that the system performs enables timely intervention from the resident when necessary.

DC 4 Provide options for customisation
An add-on is what give you the opportunity to customize your main control system.

DC 5 Balance between automation and activity
I excluded this Design Challenge for the case

DC 6 Affordability price-wise
This is one of the expected issues with the product - that it would bot be very affordable because of the technologies it needs to integrate

DC 7 Reliable system
This could make the main system more reliable as this adds another way to check the information that you have on the thermostat.

Design Fundamentals

Trust
When the residents know what the system is doing, they seem to have more trust in it.

Accessibility
The 3D model and the tactile thermal feedback are what provide great accessibility.

Simplicity
The interactions with the product are pretty straight-forward. You can just touch it and receive information.

Adaptability
As an add-on, the concept could serve to adapt the main control system to your needs.

Robustness
The product could be pretty sturdy and robust because of the tick walls. It also could call maintenance faster through the app and that way it becomes more reliable.

*Both, the DC and the DF are assessed on the basis of future possibilities for development.

BREATHING WALLS

Context

'Breathing Walls' is a concept of an interactive cover for a built-in convector heater. The openings for air inlet provide thermal and light feedback, so the resident could immediately understand what the system is doing. This could bring both physical and mental comfort to the user. Physical because of the direct heat and light ambience and mental because he is always aware of the system's actions and therefore calm that it is working towards achieving his preferences.

Fig. 61, 'Breathing Walls' concept

Future potential

Can you imagine not having the opportunity to experience the feeling of touching the warm radiator, after a cold day outside, never again? 'Breathing Walls' has the potential to tackle one of the big drawbacks of low-temperature heating - the lack of direct warm source. (Fig. 63) The technology of built in the wall convectors already exists. Some even have a fresh air supply function integrated. After the talk with the project manager, I dare to suggest that those systems are the future. Therefore, an interactive cover could fit very well to this vision. A tactile control function could also be incorporated on the cover itself. Another advantage is that when the openings are on the wall, rather than on the window sill, it is less likely for the residents to obstruct them.

Some users mentioned that it would be nice if the system colud detect when they are coming close so it could provide heat feedback only then as it is more efficient. Furthermore, a couple of respondents mentioned that they would like to choose the shape of the holes themselves. (Fig. 62)

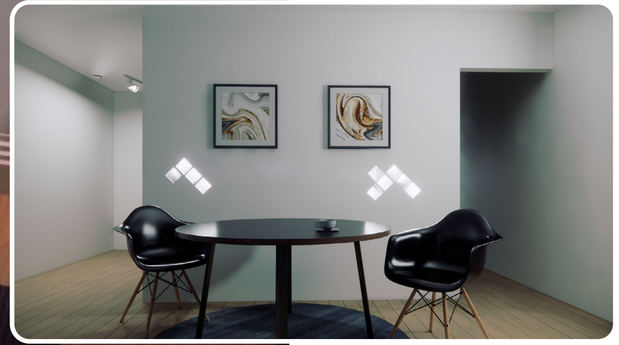


Fig. 62, Exploration of the possible shapes of 'Breathing Walls'

Fig.63, The user enjoying the heat feedback from 'Breathing Walls' openings

Desirability

In order to evaluate the desirability of the 'Breathing Walls' concept, the same method was used as for the 'Tactimap'.

Overall, this idea was very much liked from the majority of the users. Most of them said that it looks very aesthetical and that *'it can even be considered art'*, a respondent form the online questionnaire. (Appendix J) Furthermore, the majority found it a lot more modern than the current grill openings. The ambient lighting was also very highly appreciated. One respondent also mentioned: *'I would like to try such a system. It seems like it will help me understand the heating system better which will then help me use it in a better and more efficient way and perhaps will ultimately improve my indoor comfort.'*

However, the users did not seem to pay much attention to the other value that I added to the product, the thermal feedback. I assume that this is because, as far as I am concerned, non of them had experienced a low-temperature heating system. Therefore, even though I explained the issue with the lack of heat stream it seems that they still did not take it into account. This is a limitation of the study.

Regular user 3 said that the low-fi prototype provides nice context. He could not understand the idea only by an explanation. After he explored the prototype, it became more clear. Therefore, as simple as they may seem, such prototypes could bring value when designing for VIPs.

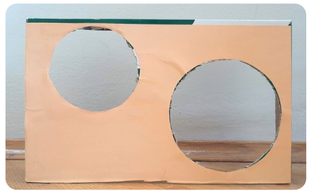


Fig. 64, Low-fi prototype of the concept 'Breathing Walls'

Fig. 65, Regular user 3 exploring the prototype for context

Feasibility

The process of creating a TRL analysis (Appendix K) helped me determine the feasibility of the concept. On the basis of my brief research, I decided that the most feasible way would be to use a convector that is built in a wall. (Fig. 66, 67) (Daikin, 2021) The project manager that I interviewed also confirmed that it is possible. However, he mentioned that for the case of Reigersbos, it would be better to be integrated in the new facade. He argued that it would take too much valuable space if it is integrated in the wall.

Basically, the part that is re-designed is the cover of the convector. Most of the components are available for direct use. The only aspects that scored a 7 on the TRL are the cover itself and the infrared foil that will provide warmth. I could not find covers with openings for the air in another shape than the grills. Therefore, this is something that still has to be developed and manufactured. It is also questionable if the best solution for the heat feedback is the infrared technology. Therefore, if this concept would be developed further, those are the two components that require more attention. That is outside the scope of my project.

Fig. 66, A standard wall built-in convector with cover (Daikin, 2022)

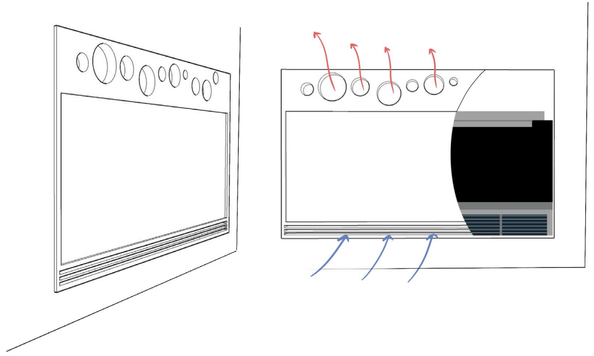


Fig. 67, Proposal for the new 'Breathing Walls' interactive cover

Design Challenges

DC 1 Provide comfortable indoor climate
This is one of the strongest points of the design. It solves the problem with the lack of direct heat feedback and provides comfort when sitting close to it.

DC 2 Accessible interaction controls
In the future, such could be incorporated.

DC 3 Provide a feeling of control
The system provides tactile and light feedback which allows residents to understand what the system is doing at the moment which increases the feeling of control.

DC 4 Provide options for customisation
The panels could come in different shapes and the lighting feedback could also be programmed depending on the preferences of the user.

DC 5 Balance between automation and activity
I excluded this Design Challenge for the case

DC 6 Affordability price-wise
I assume that the value that the product creates can be balanced with the production price. Furthermore, it seems that there could be big demand for such intervention.

DC 7 Reliable system
Overall, the system becomes more reliable this way, because the resident knows that it is working towards reaching his temperature preferences.

Design Fundamentals

Trust
When the residents know what the system is doing, they seem to have more trust in it.

Accessibity
The thermal feedback and the ambient lighting provide an easier way for visually impaired to determine whether it is working. This is the case also for people with lower literacy, elderly, ones that do not know the language, etc.

Simplicity
The interactions that are envisioned for now are very simple and just as with 'Tactimap', the user just has to touch it in order to receive information.

Adaptability
The users can program the type of heat feedback they receive and if any. They can also control the type ot lighting - changing colors, dimming option.

Robustness
The design would be durable and not easily breakable.

*Both, the DC and the DF are assessed on the basis of future possibilities for development.

Conclusion

From the three concepts, it seems that the 'Booklet' and the 'Breathing Walls' have better potential for success. The first could be integrated immediately, while the second seems promising for further development. 'Breathing Walls' scored high on desirability, both by VIPs and the wider public. The 'Tactimap' provided some interesting insights but the majority of the respondents said that they would prefer an app instead. That might be indeed a more feasible option because I assume that the value could not balance the price.

The 'Booklet' evaluation confirmed that it does fill a gap for human-centered tools in zero-energy renovations. One of the target users mentioned that it is a 'much needed' thing. Furthermore, VIPs found the content very elaborate and covering their basic needs. Still, an evaluation in real scenario could bring very valuable insights for improvement.

I can conclude that both the 'Booklet' and the 'Breathing Walls' are worth exploring further. I would not recommend the same for 'Tactimap' or at least not in the same context.

4. Conclusion

Conclusion

This report expands on the existing knowledge on one hand of zero energy housing renovations and on the other - of Inclusive design. It intertwines them in 3 final products - a Booklet with Design Guidelines and recommendations for more accessible renovations and two future concepts - 'Tactimap' and 'Breathing Walls'. The last two embody the main insights of the research and combine it with my personal design vision.

By applying the obtained knowledge about accessibility to the case study of Reigersbos, the need of a more accessible approach to the renovation process was confirmed. One of the main conclusions of the research was that currently there are more inclusive heating and ventilation systems on the market but they are not applied in the case.

As a result, the Booklet was created. Its main goal is to support the stakeholders responsible for choosing the installed systems through the decision-making process. On the basis of literature research and interviews with users, it can be suggested that it would be a successful inclusive design tool in zero-energy housing renovations. The structure and clarity were iterated on through several user evaluations, one of which with a target user. The visually impaired interviewees assessed the content as very *'elaborate'* and *'understandable'* and the recommendations were defined as *'implementable'*.

The AR app that was built to provide interactive context and to trigger interest, opens space for many future possibilities for building inclusive tools. Overall, it can be concluded that such intervention as the Booklet has a promising potential for improving the outcomes of zero-energy renovations.

The two future concepts serve as means of inspiration and future direction for designers who would tackle this topic further. They illustrate how could the needs of visually impaired be translated to inclusive products that fit zero-energy houses. Based on the user evaluation and technical research, 'Tactimap', a 3D model, providing thermal feedback, was an interesting exploration of an add-on product. Its main function was to inform the residents about systems' state. However, it had an unsatisfactory outcome from the desirability evaluation. Furthermore, it did not comply to one of the important for an add-on Design Challenges - 'Affordability Price-wise'. That led to the conclusion that the idea is not worth exploring furhter in the same context.

'Breathing Walls', the interactive convector cover, on the other hand, showed promising potential for future development. It was very desirable concept for the users. Furthermore, after a brief research, I can suggest that it is also a feasible solution to built in terms of technology. I would advise that it is worth looking further into.

Overall, the project provides a new perspective on renovation projects and suggests a practical way to deal with the identified challenges. It expands on the field of inclusive design tools while also incorporating an innovative take on future products tailored to users' needs.

Limitations

While the project yielded valuable results, it also encountered some limitations. One of the bigger ones was the fact that the project was executed mostly remotely which prevented me from doing a real-life evaluation of the booklet. Its projected use is during a process of renovation. The evaluation phase was also during the period of the summer holidays and finding target users for the booklet was a big hassle. That resulted into it's usability being evaluated with only one target user. The current conclusions are mainly based on assumptions. However, I believe that I have a stable foundation built on talks to users and experts and also literature research which allows me to argue that the tool can be successful.

Another limitation is connected directly to the Rigersbos study. As explained, many of the systems were not set correctly ,so their real usability could be hardly tested. Therefore, the results could be different if the prototype effects were not present. Furthermore, eventually residents will live there constantly, while the current participants stayed only for a couple of nights. While residing the unit for longer periods, different challenges might emerge.

As I was not there physically, I could not invite a VIP to the apartment to make a real-life evaluation. During the remote user interviews with VIPs, after I explained what are the controls of the systems, the interviewees did not hesitate about whether or not they would be able to interact with them. They just knew. An aspect that was questionable was the app developed for Reigersbos. They said that it should be tested for accessibility but that was not done as I did not have access to it.

Considering the evaluation of the future concepts, I discovered that for most users, imagining a context could be very hard. For example, none of them has experienced the effect of low-temperature heating system. That led to the impression that they do not take this factor into consideration even though I explained it initially.

Future steps

I see a couple of immediate steps that I would like to undertake if I was to continue with the project. The first one would be printing the booklet and going with it to the target users in real-life so I could receive more feedback. I suppose that another iteration concerning the proposed steps might be needed afterwards. When that is done, I would like to see it applied to the Reigersbos renovation. As the well-being calculator is something that has not been applied before, the outcomes from it could also be very interesting. If positive, the booklet could be applied to other zero-energy renovations as well.

In order to draw people's attention to the topic of inclusivity, a couple of real life presentations could raise the awareness and present the booklet. An educational video about the booklet could also be created for introducing it to big amount of people in an efficient manner.

As already mentioned, the app also provides a lot of room for integrating a wide range of functionalities. They could make the process of accessibility evaluation easier and more efficient. Software developers will need to collaborate with professional researchers and designers in order to integrate the most suitable functionalities.

The future concept of the interactive convector cover 'Breathing Walls' is also worth the exploration. I would be interested in creating prototypes and continuing the research testing in order to determine if it could turn into a mass-produced product.

Reflection

Even though this project has been a real challenge, I have managed to prove to myself that perseverance and patience do pay off. The process was at the same time a huge learning experience and an affirmation of the skills I have gained throughout my studies. It was a very rewarding experience to see how everything came together at the end.

While I used to prefer a more hands-on approach in the past, during my graduation, I believe that I considerably developed as a researcher. Now, that I have skills from both approaches, I feel more confident as a designer. I also expanded my knowledge about zero energy renovations, accessibility and Inclusive Design which I would like to tackle also in my future job.

There were moments when I felt stuck. During those, I kept performing some small tasks, hoping that the inspiration will come. At the end, I could recognize how each of them more or less contributed to the final result. When I was hesitating how I should continue, I learned to search for help so I could move forward.

Doing the project mainly remotely was surely a difficult task as many times I missed having the chance to go to some fellow student and discuss my ideas. Furthermore, I would have loved doing more prototyping and real-life interviews and evaluation. However, sometimes we cannot control the circumstances.

I learned the hard way that in such cases, we have to strive to take the most out of the situation and take advantage of the positive sides, rather than feeling sorry. In my case, one of the things that working remotely gave me was the opportunity to do a more in-depth research and improve my analytical skills.

Another important learning point was to not try solving all the problems at once. Many times that prevented me from making decisions which held be behind. Through developing the Future Concepts, I learned to identify the positive characteristics of different concepts and how they could be used for exploration, research and finding future possibilities.

My main motivations during the project were the fact that I worked on a real case which could improve people's lives and that I could contribute to the inclusiveness of our society. I am satisfied with the end result which I would love seeing come to life.

Acknowledgements

I would like to thank all the people involded in the project, especially my three supervisors - Stella, Tomasz and Juliette. Thank you all for supporting and motivating me at the times when I needed it the most. Without you, i might have given up. Thank you also for being critical and gently pushing me to do my best. Stella, thank you for sharing your rich knowledge and providing me with so many valuable connections. Tomasz, I am grateful that you gave me a fresh perspective on the process and made me zoom out and reflect. Juliette, your valuable feedback, connections and positive attitude are highly appreciated!

I am also thankful to all the experts outside TU Delft who took the time to discuss my project and share their expertise. It contributed to a more qualitative final result.

Furthermore, all the meetings with users were very valuable for me. I appreciate your willingness to share all your knowledge and ideas during several sessions. Your friendliness stays with me.

Thank you also to my friends who were willing to think with me, helped me order my thoughts and motivated me .

I enjoyed every talk with all of you! I am grateful that I had this opportunity to work with such good and intelligent people and I couldn't be more honest!

And lastly, I want to thank my family and relatives. Thank you for your huge support during that time which helped me move on.

Thank you!

References

AlleCijfers, 'Informatie buurt Reigersbos Zuid', Retrieved from: https://allecijfers.nl/buurt/reigersbos-zuid-amsterdam/

allevent.in, 'Festival Los in Reigersbos 2019', Retrieved from: https://allevents.in/amsterdam/festival-los-in-reigersbos-2019/200017565602347

Basic Electronics 27 – cells and batteries, Engineers Garage, Retrieved from: https://www.engineersgarage.com/basic-electronics-27-cells-batteries/,

BBC Earth, 2014, 'Blind Man Uses Echolocation', [Video], YouTube, https://www.youtube.com/watch?v=2IKT2akh0Ng

Be My Eyes, 2022, 'Bringing sight to blind and low-vision people' Retrieved from: https://www.bemyeyes.com/

Be smart, 2019, 'How Blind People See With Sound... feat. Molly Burke!', [Video], YouTube, https://www.youtube.com/watch?v=08smCjKWNL0

Becchio, C., Bertoncini, M., Boggio, A., Bottero, M., Corgnati, S.P., Dell'Anna, F., 2018, 'The Impact of Users' Lifestyle in Zero-Energy and Emission Buildings: An Application of Cost-Benefit Analysis', New Metropolitan Perspectives

Benali-Khoujal, et.al., 2003, Thermal feedback model for virtual reality

Bichard,J., Coleman,R., Langdon, P., 2007, 'Does My Stigma Look Big in This? Considering Acceptability and Desirability in the Inclusive Design of Technology Products', International Conference on Universal Access in Human-Computer Interaction

BlindShell Classic 2, BlindShell, 2022, Retrieved from: https://www.blindshell.com/?gclid=Cj0KCQjwr4eYBhDrARIsANPywCgHPL7e4wQ_cffVCsZYaK0pmFmHRyih2BOcaMrd5rZcMGX-oNj3grcaAukzEALw_wcB

BNR (Bulgarian National Radio), 2021, 'Негослав Събев предлага чрез софтуер да се улесни гласуването на хората със слабо зрение', Retrieved from: https://bnr.bg/horizont/post/101556515/negoslav-sabev-predlaga-chrez-softuer-da se-ulesni-glasuvaneto-na-horata-sas-slabo-zrenie

Boess, S., 2022a, Let's Get Sociotechnical: A Design Perspective on Zero Energy Renovations', Urban Planning, (ISSN: 2183–7635) 2022, Volume 7, Issue 2, Pages 97–107 https://doi.org/10.17645/up.v7i2.5107

Boess, S. U. 2022b, Draft Report for the Reigersbos apartment – evaluation of usability and circularity. Report for the Municipality of Amsterdam, unpublished

Boess, S.U. 2022c, The role of design in renovation concepts. Report from subproject 2.4. Accessed at https://btic.nu/iebb-consortium/

Ceriola, R. 2021, NYTimes, 'These Smart Home Devices Can Enhance Independence for People With Disabilities and Mobility Needs', Retrieved

from: https://www.nytimes.com/wirecutter/reviews/best-assistive-smart-home-technology-for-disabled/

Chinazzo, G., Wienold, J., Andersen, M. , 2019, 'Daylight affects human thermal perception', Scientific reports

Cliona R., et. al., 2017, 'Living Independently: Exploring the Experiences of Visually Impaired People Living in Age-Related and Lifetime Housing Through Qualitative Synthesis', The center for health design'

Community Tool Box, 2022, 'Section 2. Using Principles of Persuasion', Chapter 6, Retrieved from: https://ctb.ku.edu/en/table-of-contents/participation/promoting-interest/principles-of-persuasion/main

D. Sakellari, M. Forse´n, P. Lundqvist, 2006, 'Investigating control strategies for a domestic low-temperature heat pump heating system, international Journal of refrigeration

Daikin, 2021, Daikin Altherma HPC Heat pump convectors A fresh approach to comfort

Dolores, M., Garrido, P.,2015, 'Social sustainability through accessibility and equity',

Ecobee, 2022, Ecobee3 lite, Retrieved from: https://www.ecobee.com/en-us/smart-thermostats/smart-wifi-thermostat/

eHow, UK, Erin Ringwald, 'How to make impairement goggles'

EN 301549, 2021, 'Accessibility requirements for ICT products and services', ETSI, Harmonised European Standard,

Flic, 2022, 'SImply Life', Retrieved from: https://flic.io/

Gatt, D., Caruana, C., Yousif, C., 2020, 'Building Energy Renovation and Smart Integration of Renewables in a Social Housing Block Toward Nearly-Zero Energy Status',

Gemeente Amsterdam 2020, 'Strategy for Climate Adaptation Amsterdam', Gemeente Amsterdam

Google, 2022, Nest Learning Thermosat, Retrieved from: https://store.google.com/nl/product/nest_learning_thermostat_3rd_gen?hl=nl

Graham T., Goncalves, A., 2017, Smashing Magazine, 'Stop Designing For Only 85% Of Users: Nailing Accessibility In Design', Retrieved from: https://www.smashingmagazine.com/2017/10/nailing-accessibility-design/

Heylighen, A., & Bianchin, M. (2018). Building justice: How to overcome the inclusive design paradox? Built Environment, 44(1), 23–35

I have low vision, 2022, Retrieved from: https://www.tengobajavision.com/en/

Iris Huys, 2021, Feelware spraakuitvoer voor kookplaat en oven, Retrieved from: https://irishuys.nl/product/feelware-spraakuitvoer/?cn-reloaded=1

ISO 21542, 2021, 'Building construction — Accessibility and usability of the built environment'

Jansen, F., 2021, Renovating with Residents: A more inclusive process to help residents shape the sustainable renovation of their apartments

Jutulstada, A.H.N., Yang, A., Schild, P.G., Chaudhuri, A., Thunshelle, K., 2022, Clima 2022, Rotterdam

Killebrew, M., 2015, 'How social Technology makes us more human/Michelle Killebrew' [Video] YouTube, https://www.youtube.com/watch?v=pIH-FAOzJZjM&t=42s

Kim, S. , et.al, 2020, Thermal display glove for interacting with virtual reality
Kumar, D., 2018, 'EMPOWERMENT THROUGH ACCESSIBILITY: AN ANALYTICAL REVIEW OF DISABILITY POLICIES IN INDIA', Impact Journals

L, Jinsop, 2013, 'Design for all 5 senses/Jinsop Lee/TED Talks' [Video] YouTube, https://www.youtube.com/watch?v=N6wjC0sxD2o
Lee, J.H., et. al. , 2021, A Persona-Based Approach for Identifying Accessibility Issues in Elderly and Disabled Users' Interaction with Home Appliances

Leporini, B., Buzzi,M., 2018, 'Home Automation for an Independent Living: Investigating the Needs of Visually Impaired People', W4A '18: Proceedings of the 15th International Web for All Conference

Life Noggin, 2016, 'How do blind people perceive the world?', [Video] YouTube, https://www.youtube.com/watch?v=SIJDlnd9G0g

Living Innovation - EU Project H2020, 2021, 'How to include people with blindness or low vision in innovation'[Video] YouTube https://www.youtube.com/watch?v=UAvITEhxLJc

Microsoft, 2016, Inclusive MIcrosoft Design

Molly Burke, 2022, 'The (emotional) Journey to Finding Accessible Kitchen Appliances!'[Video] YouTube https://www.youtube.com/watch?v=20z13X-J9aPA

NBC News, 2017, 'Smart Homes Are Game Changer for People With Disabilities' [Video] YouTube https://www.youtube.com/watch?v=4s9vCFkmabs

Nematchoua, M.K., Nishimwe, A.M., Reiter, S., 2021, Towards nearly zero-energy residential neighbourhoods in the European Union: A case study, Renewable and Sustainable Energy Reviews

NEN-EN 17210, 'Accessibility and usability of the built environment - Functional requirements', January 2021, ICS 91.040.01

Niemeyer, S.M., 2008, 'Identifying Moisture and Mold Sources in Houses', NebGuide
product experience and personal wellbeing', Ergonomics

Neilsen Norman Group, 2022, 'Human Technology Teamwork: The Role of Machines and Humans in Good UX Design (Don Norman)', Retrieved from: https://www.nngroup.com/videos/human-technology-teamwork/

Ranasinghe, N, Yi-Luen Do, E., 2016, Virtual Sweet: Simulating Sweet Sensation Using Thermal Stimulation on the Tip of the Tongue

Raviselvam, S., Hölttä-Otto, K., Wood, K.L., 2016, User extreme conditions to enhance designer emphaty and creativity: applications using visual impairement

Residential Kitchen Range Hoods for use in High Energy Efficient Housing. Proc. AIVC Conference 2017

Rojas, G., Walker, I.S. and Singer, B.C. 2017. Comparing Extracting and Recirculating residential kitchen range hoods for the use in high energy efficient housing. Berkeley Lab

Rooney, C. et.al., 2017, 'Living Independently: Exploring the Experiences of Visually Impaired People Living in Age Related and Lifetime Housing Through Qualitative Synthesis', National Library of Medicine

Sanei, J., 2019, 'Is technology making us lazy and less intelligent?' [Video] YouTube, https://www.youtube.com/watch?v=upXih6h7fjY

Schifferstein, H. N. J., Desmet, P. M. A., 2007, 'The effects of sensory impairments on roduct experience and personal wellbeing', January 2008 Ergonomics 50(12):2026-48

Silverman, A.M., 2015, The Perils of Playing Blind: Problems with Blindness
Simulation and a Better Way to Teach about Blindness, Journal of Blindness Innovation and Research

Smart Home Solver, 2021, 'Smart Thermostats: what I WISH I knew earlier...', [Video], YouTube, https://www.youtube.com/watch?v=S6rl1Sbasrw

Steve Krug, 2013, Don't Make Me Think, Revisited: A Common Sense Approach to Web Usability

Stevens-Ratchford , R., Krause, A., 2004, 'Visually Impaired Older Adults and Home-Based Leisure Activities: The Effects of Person-Environment Congruence'

Tech with Brett, 2020, 'Everything the 2020 Nest Thermostat Can Do', [Video] YouTube https://www.youtube.com/watch?v=X7lb9aykSRs

Terma, 2022a, Heating element Moa blue, Retrieved from: https://en.termaheat.com/grzalka/moa-blue

Terma, 2022b, Heating element KTX 2, Retrieved from: https://en.termaheat.com/grzalka/ktx-2

The Blind life, 2018, 'Why Is Assistive Technology So Expensive?' ,[Video] YouTube https://www.youtube.com/watch?v=zNvzVJIQix4

The Blind Life, 2021, 'Apple Watch Accessibility - Part 2'[Video] YouTube https://www.youtube.com/watch?v=q7jee7Ib_58

The Blind Life, 2021, 'BlindShell Classic 2 - The Most Accessible Phone Just Got Better!' [Video] YouTube https://www.youtube.com/watch?v=5r9V_UsJ6ng

The Blind Life, 2021, 'Clover "Looky" 6 HD - Portable Handheld Digital Magnifier' [Video] YouTube https://youtu.be/OWZHqDiQD58

The Blind Life, 2021, 'My Accessible Kitchen Tour', [Video] YouTube https://www.youtube.com/watch?v=DqFowyOaMX0

The Blind Life, 2021, 'VIP's In The Kitchen! Cooking Gadgets, Tips & Tricks, How To's', [Vidoe] YouTube, https://www.youtube.com/watch?v=LjqipAaX-KU4
The Green HUb Amsterdam, Retrieved from: https://www.circ.energy/en/cases/the-green-hub-amsterdam

Toi, M., & Batson, C. D. (1982). More evidence that empathy is a source of altruistic motivation. Journal of Personality and Social Psychology, 43(2), 281–292. https://doi.org/10.1037/0022-3514.43.2.281

Ueda, Y., Ishii, C, 2016, Development of a feedback device of temperature sensation for a myoelectric prosthetic hand by using Peltier element

UPROXX Studio, 2016, 'Blind man's "superpower" lets him bike, skate and navigate the world', [Video], Youtube, https://www.youtube.com/watch?v=EFvH7NF4MSw

Verhagen, T.J., van der Voet, E. , Sprecher, B., 2020'Alternatives for natural-gas-based heating systems: A quantitative GIS-based analysis of climate impacts and financial feasibility', Journal of industrial ecology

WHO, 2021, Blindness and vision impairment, Retreived from: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment