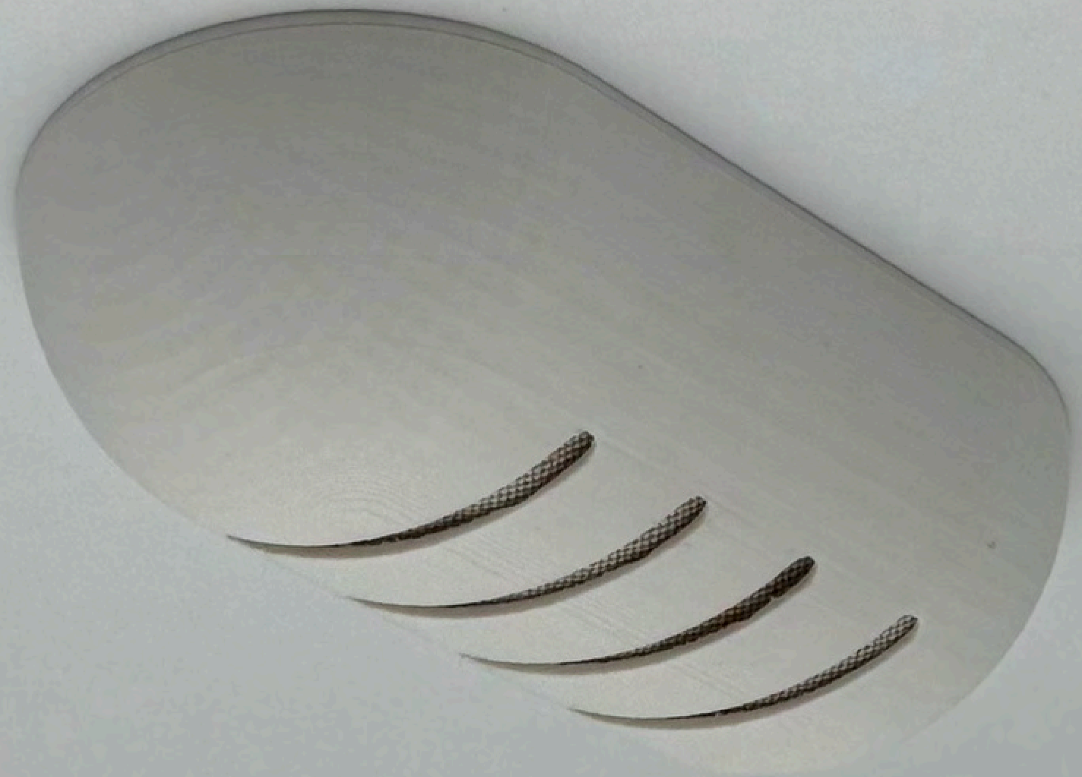
The M.I.C.

A context-aware integrated monitoring system supporting formal caregivers during their nightshifts in dementia care



Final Master Project
Author: Gijs Kooistra
Mentor: Jun Hu

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ABSTRACT

Working the nightshift in a dementia care home is a demanding job, where a small team is responsible for the safety of many residents during the quietest, yet most unpredictable hours. While technology attempts to help, standard tools like cameras or wearable sensors often create more stress by generating false alarms or invoking a feeling of intrusiveness. To address this, this project took a hands-on approach employing User-Centered Design and the double Diamond framework, accompanied by the Consolidated Framework for Implementation Research using field research and shadowing sessions to understand exactly what formal caregivers need to feel supported rather than overwhelmed during their nightshift. The result is the M.I.C. (Microphone Integrated Classification) system, a system that processes sound locally to distinguish between harmless noises and actual emergencies like a fallen resident. By integrating smoothly with the alarm systems formal caregivers already use, the design proves that technology works best when it acts as a silent, helpful tool that filters out the noise so formal caregivers can focus on giving care.

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1.INTRODUCTION

1.1 Formal caregivers in the nightshift

As the global population ages, the demand for long-term dementia care is escalating, placing a great amount pressure on healthcare staff (WHO, 2021). While daytime care is mostly focused on resident engagement and activity, nighttime care is fundamentally about safety and stability. However, this contrast remains a largely underexposed area in design. To the outside observer, a dementia care home at night could appear to be a place of stillness and rest. However, for a formal caregiver (in this case a nurse in a care home) working the nightshift, it is often filled with caution and stress. During the night, a caregiver bears the sole responsibility for the safety of multiple wards with vulnerable residents, operating in an unpredictable and isolated environment (Van Bogaert et al., 2014). The formal caregiver is tasked with a difficult dilemma: they must monitor residents for acute risks, such as dangerous wandering or even falls, while also trying to preserve the homelike atmosphere and dignity of the residents that is central to modern care ethics (Ausserhofer et al., 2016). This tension creates a fundamental mismatch between the capacity of the isolated formal caregiver and the high demands of the nightshift.

1.2 Problem definition

In order for formal caregivers to manage this responsibility, care homes have increasingly turned to assistive technologies. Current solutions in nighttime monitoring are dominated by sound activated alarms, pressure mats, mobile sensors, and wearable devices. While these technologies suggest safety, literature suggests they often deliver unwanted chaos (A. Scott, 2008). Standard sound activated alarms lack contextual awareness, they struggle to differentiate between a resident in distress and a resident coughing in their sleep (Niemeijer et al., 2010). This results in a large number of false positives, that leads to the well-known phenomenon of alarm fatigue, where formal caregivers become desensitised to alarms due to an overwhelming frequency and substantive irrelevance (Cvach, 2012). Furthermore, wearable trackers, while more precise, face significant issues, residents with advanced dementia frequently remove unfamiliar devices, rendering the system useless (Gibson et al., 2015). Therefore, the core problem is not a lack of data, but a lack of relevant data. Current systems greatly increase the cognitive load on the formal caregiver by forcing them to constantly interpret ambiguous signals themselves. Here lies a clear gap in research for a system that can, by itself, filter ordinary noise from acute distress, unburdening formal caregivers rather than overwhelming them.

1.3 Design goal & objectives

This project challenges the widely accepted standard of basic tracking and simple surveillance techniques, by working towards a context-aware, user-centered solution. Instead of a traditional research question, this project is guided by the following design goal:

The goal of this project is to unburden formal caregivers in dementia care homes during their nightshift by developing a novel intervention that helps provide adequate care for their residents.

To achieve this goal, the project is structured around five specific objectives:

1. Understanding the experiences, routines, and challenges of formal caregivers during their nightshift through ethnographic fieldwork.
2. Identifying the important contextual determinants that influence the implementation of new technology in this specific setting.
3. Designing an intervention that actively unburdens formal caregivers.
4. Evaluating the proposed system with the stakeholders and experts.
5. Reflecting on the value of using an implementation framework during the design process.

The project does this by employing a User-Centered Design (UCD) (Abras et al., 2004) approach that is structured within the Double Diamond framework (Design Council, n.d.). This project also utilises the Consolidated Framework for Implementation Research (CFIR) (Damschroder et al., 2009) as an additional tool to ensure the final design is not only functional, but also compatible with the complex context of a care home.

1.4 Report structure

This report documents the journey from identifying the systemic mismatch in nightshift care to the realisation of a context-aware solution. The research begins by framing the design challenge. Here, the Background and Context map out the details of the nightshift in dementia care, highlighting the complex interaction between the context of the care home and the pressures of the nightshift. The solid base from these two chapters is further explored in the Related work section, where a benchmark of current solutions shows the technological and ethical gap that dictates a new approach. Moving from analysis to action, the Methods and Process sections showcase the methodological framework and the iterative design process. These two chapters document how the User-Centered Design approach and the Double Diamond framework work together with other relevant methods and tools to turn the abstract fieldwork into a feasible concept. Afterwards, the Implementation section shows how these findings fit into the final integrated system, further detailing strategies required for real-world adoption. Finally, the report closes with an evaluation in the Discussion, where the design is assessed against its initial goals; a final Conclusion; and a set of opportunities for Future work.

2.BACKGROUND

2.1 Dementia & perceived safety in care homes

Dementia is often discussed in terms of statistics, it being a global crisis projected to affect 139 million people by 2050 (WHO, 2021). However, for a designer, the challenge is not just the volume of cases, but the underlying disruption it causes to the interaction between an individual and their environment. Interpreting sensory information gets harder as cognitive decline progresses, this leaves residents vulnerable in environments that were not designed for their atypical perception. This creates a structural contradiction in care homes, organisations are legally required to provide safety, often leading to a culture of risk aversion. However, as noted in the ethics of care, a "safe" life does not necessarily mean a meaningful one (Niemeijer et al., 2010). The current care model found in dementia care homes has great difficulty balancing this tension: “how do we monitor for safety without taking away from the resident’s freedom.

2.2 Formal caregiver and resident autonomy

While the resident is the focus of the care, the formal caregiver is essentially the ‘operating system’ that keeps the care home running. This role is especially demanding since dementia care staff face higher rates of emotional exhaustion and burnout than almost any other sector in healthcare (Woodhead et al., 2014). On top of that, the workload is not just physical, it is also cognitive. Formal caregivers are constantly prioritising needs under pressure. An important strategy to alleviate this burden is supporting resident autonomy.

Kitwood’s (1997) influential theory of Person-Centered Care argues that maintaining a resident's independence (e.g., going to the toilet alone, no constant check-up’s, etc.) is crucial for their dignity. Moreover, this autonomy is an asset, every task a resident can perform (safely) on their own is a minute of time returned to the caregiver. Therefore, the goal of technology should not be to do everything for the resident, but to leave them in their remaining abilities for formal caregivers to focus on where they are truly needed (IJsselsteijn et al., 2020).

2.3 Problems during the nightshift

While the dayshift is usually physically busy, the nightshift presents a different, more psychological challenge. Preliminary field research indicates this period as a critical pain point in the care setting due to a mismatch between capacity and demand. This lack in capacity pressures means that nightshift staff are stripped to the bare minimum. It is not uncommon for one nurse to manage one or more entire wards, in some cases leading to isolation (as became evident in later observations). This isolation creates what researchers call "vigilance fatigue" (L. D. Scott et al., 2006). During the night, the caregiver’s attentiveness is heightened, and they are constantly aware of potential signs of distress, fearing that they might have missed an acute event (e.g., falls, distressed wandering, extended bathroom use, etc.). In addition to low staff numbers, formal caregivers are also confronted with behavioural complexity in residents.

"Sundowning" (the emerging of heightened agitation, confusion, and wandering during late afternoon and night due to circadian rhythm disruption) affects a significant portion of people with dementia (Volicer et al., 2001). This creates a rather worrying intersection, because the environment is at its most unpredictable exactly when the staff are least equipped to handle it. Still, most innovations are focused on the daytime (activity tables, memory games, etc.). The nightshift remains an innovation void, where formal caregivers have to rely on outdated, uninformative systems providing ambiguous alarms that often raise uncertainty rather than insight.

2.4 Defining the design problem

The situation as described above is not a straightforward problem that can be solved by simply hiring more staff, since they either do not exist or are deemed too expensive due to budget cuts. It is a classic "Wicked Problem" (Rittel & Webber, 1973), a complex social system, with numerous stakeholders, where every solution creates new issues (e.g., placing more cameras would solve safety but violates privacy). The problem is not the lack of skill of the formal caregivers, but an environmental mismatch. The current environment conceals a lot of information that the is incredibly valuable for formal caregivers. The scope of this project, therefore, is to redesign that information flow, creating an innovation that acts as a sensory extension for formal caregivers, an innovation that filters the chaos of a care home by night into clear, actionable choices.

3.CONTEXT

While the Background chapter established the clinical reality of dementia and the nightshift, it is equally, if not more, important to map the contextual reality where this design has got to function. An intervention like this does not exist in a vacuum, it is introduced into a complex ecosystem of stakeholders, structural constraints, and fixed workflows. Because the goal of this project is to create a sustainable integration rather than just a gadget, it is essential to understand the specific environmental pressures and complex context. This chapter analyses this context, distinguishing between the two highly relevant contextual CFIR domains: the Outer Setting (the sociopolitical context) and the Inner Setting (the physical and cultural context of the care home).

3.1 Outer Setting

As mentioned in the CFIR (Damschroder et al., 2009), in order to understand the complex ecosystem surrounding the nightshift, it is essential to look beyond the immediate problem and its potential solution. Rather, the design space is shaped by a complex network of stakeholders (e.g., formal caregivers, residents, family, organisations), each applying a specific pressure on the intervention. As seen in *image 1* (stakeholder map), at the centre of this ecosystem lies the locus of care, the formal caregiver, accompanied by the resident. The formal caregiver acts as the leading trial, if a system does not immediately alleviate their workload, it will be rejected (A. Brown & Seeman, 2015). The resident s an implicit beneficiary, profiting from a good result but often unable to actively interact with the interface, meaning their safety and privacy are relatively passive requirements. Surrounding this core are the most important influencers, most notably the informal caregivers and family members. In dementia care, for some people, the family acts as a substitute for consent regarding the resident (Bravo et al., 2013). Their trust is vital for successful implementation (Arntzen et al., 2014). Here, a delicate balance emerges, for a monitoring system to be ethically viable, family members must be convinced that the technology offers safety and comfort rather than surveillance. Without their consent, implementation is legally and morally impossible. Finally, the holistic outside layer directs the feasibility of any solution. Care organisations and healthcare providers view the intervention through the lens of staff occupation and cost-efficiency, while government bodies define the legal boundaries through strict frameworks like the WZD (Wet zorg en dwang (Ministerie van Volksgezondheid, Welzijn en Sport, 2025)) and GDPR (intersoft consulting, 2024). Consequently, the design must satisfy a difficult double requirement: it has to alleviate enough burden of formal caregiver, be reassuring enough for caring family, and compliant enough for demanding legislators.

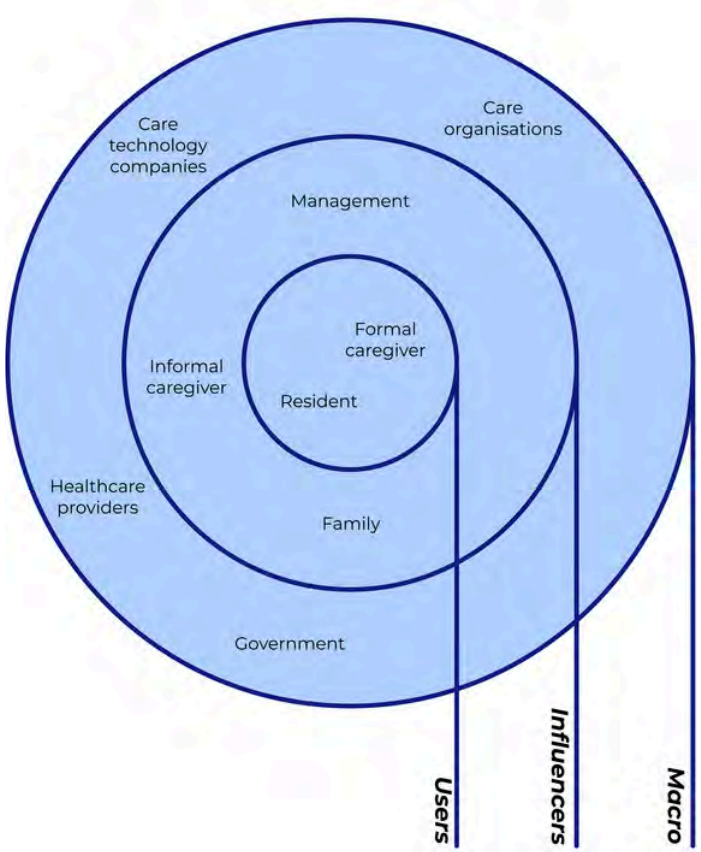

Image 1: *Stakeholder map*

3.2 Inner Setting

The design context is a large-scale institutional care home that houses residents with varying stages of dementia. This environment is defined by a severe mismatch between scale and capacity during the nightshift, at that time a team of three formal caregivers is responsible for over 100 residents distributed across multiple wards and floors.

While every floor includes a central office, the reality of the work is more dynamic. The formal caregivers are rarely stationary; they spend a large amount of their shift running around between floors to answer calls, perform rounds, and manage calamities. This mobile workflow creates a heavy reliance on the existing technological infrastructure to bridge the physical distance. Currently, the infrastructure consists of a fragmented chain of technologies. Input is gathered via Open Care Products (wrist, necklace, and mobile sensors (Open Care Products, n.d.)), which feed input into the VSS Sherpa system that triggers alarms on mobile devices (Axians, 2022). This system also allows the formal caregiver to scroll through several cameras located in certain spots in the hallway. A new design must recognise the already established ecosystem as a somewhat inflexible constraint, the solution must integrate with these systems rather than clash with them. Perhaps the most crucial contextual finding, however, is the Implementation Climate (Damschroder et al., 2009). Observations and expert interviews suggest a conservative climate, where staff prefer to adhere strictly to established workflows. These routines serve as a defence against chaos, but also create a high barrier to entry for innovation. Because the formal caregivers are already cognitively overloaded, there is a low tolerance for learning curves. If a new intervention adds too much friction or uncertainty to their routine, it is likely to be abandoned, regardless of its long-term benefits.

3.3 Context analysis

In order to translate constraints into actionable design requirements, the PACT framework (Benyon, 2014) was utilised (*table 1*). PACT breaks down the domain into People, Activities, Contexts, and Technologies:

Domain	Analysis	Design requirement
Person	Formal caregiver, high cognitive load, high levels of stress, overwhelmed.	The interface must be glanceable. Information can be found by skimming interface. The interface should have no complex menus.
Activity	Classifying alarms, patrolling, crisis response, and comfort care.	The system must distinguish between urgent and non-urgent cases to support rapid decision making.
Context	Mostly silent (aside from HVAC noise from ventilation, etc.), multi-story buildings. Isolated work, fear of mistakes.	The appearance must be tranquil, e.g., no bright lights or loud noises that disturb the sleeping ward. The design must support self-trust and self-reliance in the formal caregiver.
Technology	Reliance on VSS Sherpa and wearables. Potentially poor connection in remote sections of the care home.	The system should seamlessly integrate into the existing ecosystem. The system should employ local processing to avoid reliance on unstable cloud connections.

Table 1: *Pact framework (Benyon, 2014)*

3.4 Conclusion

The analysis of the context reveals an environment sensitive for innovation. The Inner Setting is characterised by cognitive overload, high resident-to-staff ratios, and a technological infrastructure that is seemingly functional but fragmented. Therefore, the core challenge for this project is not just technical, but rather contextual. A successful solution cannot simply be a better sensor, it must be a better assistant. It must fit into the strict workflow of the nightshift without demanding new behaviours or routines from staff who are already operating at maximum capacity.

4.RELATED WORK

In order to design a valid novel innovation, first must be assessed why current solutions are failing to unburden formal caregivers during their nightshift.
The world of assistive technology is vast, ranging from simple panic buttons to complex AI-driven care homes. However, when viewed through the lens of the nightshift, where there are different defining constraints, most existing solutions reveal either significant functional or ethical gaps. This section functions as a benchmark for assessing current solutions and why it is they fail to adequately resolve defining issues of formal caregivers, in doing so revealing the innovation gap that this project aims to fill.

4.1 Benchmark

4.1.1 Wearables and tags

The most universal solution in resident monitoring are wearable devices, typically a wristband, necklace, or clipped tag equipped with accelerometers and GPS. These are the industry standard for fall detection and wandering residents.

- Example: wrist sensor with alarm button (*image 2*), this wrist sensor can send blind alarms to the formal caregiver and prohibits residents from wandering outside their ward if a restriction has been put in place.

While most wearables are technologically excellent, they all suffer from a fundamental user-experience flaw in dementia care: compliance. As noted by Gibson et al. (2015), residents with advanced cognitive decline often fail to understand the purpose of these devices. This leads to residents removing the "foreign object", causing false alarms or, worse, leaving the device on a nightstand while they wander unprotected. Furthermore, the stigma of wearing a "medical tag" can be seen as objectifying, reducing the resident to a patient to be tracked rather than a person living in a home (Gagnon-Roy et al., 2017).

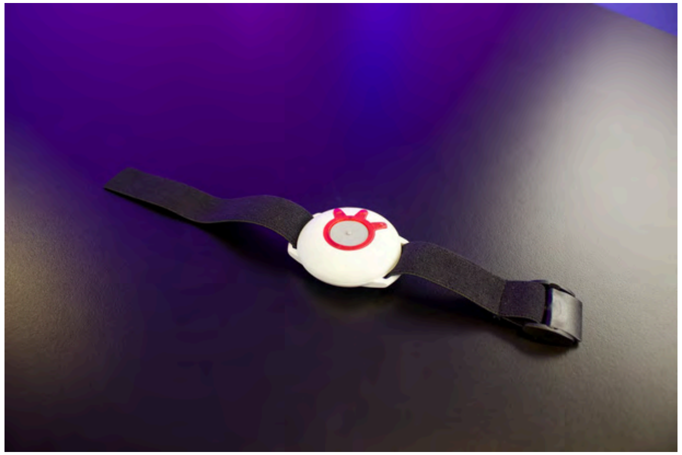

Image 2: *Wrist sensor (Open Care Products, n.d.)*

4.1.2 Lifestyle monitoring

To avoid compliance issues of wearables, some solutions have shifted towards environmental sensing or "lifestyle monitoring." These systems use a network of passive infrared motion sensors to track daily routines.

- Example: Sensara, this system is an example of preventative technology, it employs radar sensor to analyse long-term behaviour in order to predict health decline and behavioral patterns (Sensara, 2024).
- Example: Momo Bedsense, this system exists of a matrass sensor that measures movement in residents, predicting if they are about to get out of bed or are already out of bed (Momo Medical, n.d.) and also analysing long-term data to assess behavioural patterns (*image 3*).

Tiersen et al. (2021) argues that, yes, multi-sensor fusion is excellent for creating a complete overview of a resident's health over time. But, for the acute needs that a nightshift requires, these systems fail to provide required data. Sensara, for example, is designed to spot trends. It is less effective at sudden, acute event detection. A formal caregiver during the nightshift does not only need to know a resident's walking trend, but they also need to know, within seconds, if a resident has fallen.

Image 3: *Momo bedsense (Momo Medical, n.d.)*

4.1.3 Visual surveillance

When immediate certainty is required, care homes often resort to the most intrusive option, namely cameras or continuous audio streaming (e.g., baby monitors, planted microphones, etc.).

- Example: CCTV systems, streaming live visual input to connected applications.

This approach represents the most direct conflict between safety and privacy. A recent scoping review by Van Gaans-Riteco et al. (2025) highlights that while families often prioritise safety, residents (and ethicists) prioritise privacy and dignity. Placing cameras in bedrooms or bathrooms, where most nighttime falls occur, is often ethically inappropriate. Moreover, continuous video monitoring gets problematic instantly due to necessary GDPR compliance (Barnoviciu et al., 2019). Yes, radar systems would get rid of these privacy concerns due to their ability to recognise points and position rather than images. But this is what also makes them inferior to audio, for example, because they lack the in-depth context on what this position means.

4.1.4 Auditory surveillance

While visual monitoring is often rejected due to privacy concerns, care facilities have the option to turn to auditory surveillance. This approach ranges from low-tech solutions, such as simple intercoms, to more high-tech sound event detection systems that use microphones to assess decibel levels in resident rooms.

- Example: sound event detection systems like CLB, alarming the formal caregiver and opening a listening channel when the volume in a room exceeds the set threshold (CLB, n.d.).

Much like wearables and other mobile sensors, these existing systems give an alarm when a certain threshold is met, however, these give no subsequent information regarding the severity or contents of the alarm itself. Moreover, continuous audio monitors solve the visual privacy issue but create a new issue, information overload. Streaming every cough and snore to the caregiver directly contributes to the alarm fatigue (Cvach, 2012). This highlights that listening alone is not the solution. The challenge is not capturing sound, but interpreting it (locally) without recording it.

4.2 Conclusion

The table *below* summarises the benchmark of relevant existing solutions.

Approach	Benchmark example	Focus	Weakness for current context
Wearables	Wrist sensors	Location & tracking	Compliance, residents remove them due to confusion or discomfort (Gibson et al., 2015).
Lifestyle monitoring	Sensara Momo bedsense	Health trends & behavioural patterns	Works for prevention, but lacks immediate context for acute events like falls.
Video surveillance	CCTV	Visibility	Intrusive privacy violation in resident bedrooms (Van Gaans-Riteco et al., 2025)
Auditory surveillance	(CLB) sound event detection	Sound monitoring	Records private speech or triggers false alarms from trivial sounds.
Social robotics	Paro & Pepper	Social engagement	Only used for possible prevention of agitation (Van Huêt, 2025).

Table 2: *Benchmark summary*

By analysing these categories, a clear gap emerges, there is currently no system that checks all the required boxes: non-intrusive (no wearables), privacy-preserving (no cameras), real-time (immediate detection), and context-aware (filtering irrelevant noise).

5.METHODS

The review of related work in the previous chapter identified a significant gap, current technologies often fail not due to a lack of technical feasibility, but due to a misalignment with the complex workflow of the nightshift. To address this challenge, a linear approach is insufficient. Instead, this project employs a hybrid methodology that combines the systemic foundation of the Double Diamond framework (Design Council, n.d.) with the iterative thoroughness of User-Centered Design with the added integration of implementation science. This chapter outlines the methodological framework used to structure the project, showcasing the reasoning behind the UCD approach, highlighting the interpretation of the Double Diamond framework and the integration of the CFIR as a central design tool.

5.1 UCD approach

At its core, this project follows a UCD approach. UCD is defined by the active involvement of stakeholders at multiple stages of the design process to ensure that the final product meets their needs and capabilities (Abras et al., 2004). By placing the caregiver's experience at the centre of the challenge, the project moves away from creating a technical solution because it is possible, and moves to "demand-pull" creating the solution because it is needed.

5.2 The Double Diamond framework

To structure this UCD approach, the project employs the Double Diamond framework developed by the Design Council. This model maps the design process into four distinct phases, alternating between divergent thinking and convergent thinking.

The design process structure is as follows:

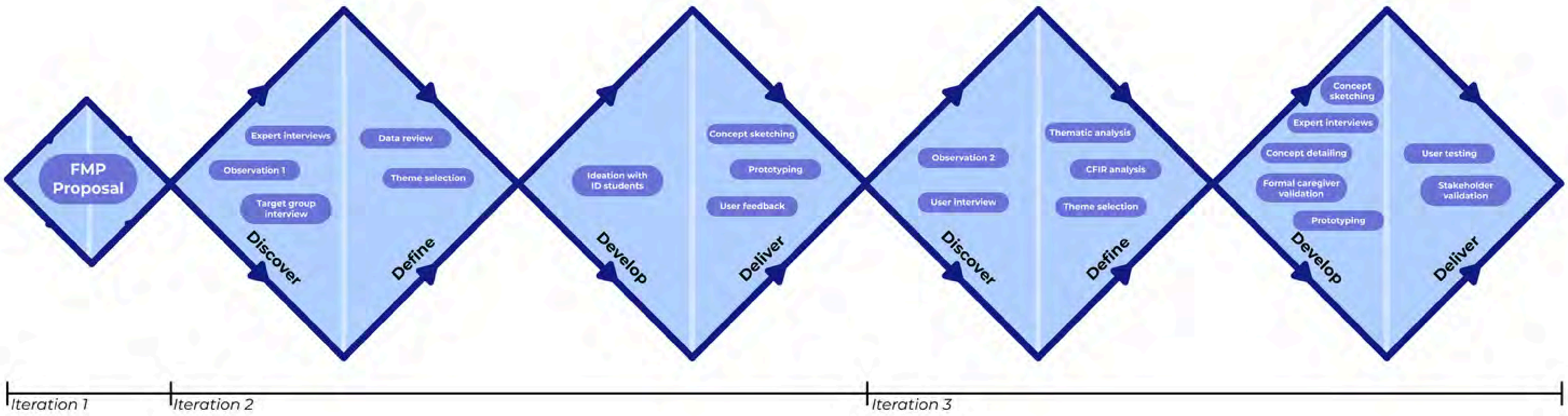

Image 4: *Design process overview*

5.3 Implementation science

In order to mitigate the implementation gap, where many technologies fail due to organisational misalignment, this project integrates the CFIR. Unlike individual focused models (e.g., Technology acceptance model, or TAM (Davis, 1989)) or after process evaluative tools (e.g., Reach Effectiveness Adoption Implementation Maintenance framework, or RE-AIM (RE-AIM, n.d.); The Nonadoption, Abandonment, Scale-up, Spread, and Sustainability, or NASSS (Greenhalgh et al., 2017)), CFIR provides a comprehensive categorisation of systemic barriers, such as Inner Setting workflows and Outer Setting regulations. By applying this framework during the design phase, the project proactively identifies and addresses organisational constraints. In the process, CFIR was used not only as an evaluation tool, but also as a generative design constraint, e.g., pre-emptively removing ideas that conflicted with the 'Inner Setting' before they were even drawn up. This predictive approach ensures that technical decisions are aligned with the complex context of a care home.

6.DESIGN PROCESS

This section discusses the two main iterations of this project. The Design process ensues the initial foundation of the proposal phase.

6.1 Second iteration

Where the initial proposal phase (Appendix 1) generated a clear strategic direction (specifically, the focus on supporting the formal caregivers in order to ultimately improve resident care), this following phase is dedicated to the thorough investigation of caregiver needs, operational struggles, and the potential for technological unburdening.

6.1.1 Discover

In order to jumpstart the project and establish an empathetic baseline, a simulation of a resident experience was done. A Virtual Reality simulation showing early and late stages of dementia (*image 5*) was utilised. The main objective of this immersion was to bridge the gap between the designer's perspective and the lived reality of a resident with dementia. In UCD, understanding the cognitive and emotional state of important stakeholders is highly important (McDonagh-Philp & Lebbon, 2000), this experience provided a better understanding of the confusion and distress often experienced by residents, moving beyond theoretical knowledge to embodied empathy.

Following this individual immersion, the project moved to the field at the community centre 'de Meerpaal'. There, an activity was joined that had been designed for individuals with dementia and their spouses, assisting a PhD candidate with their current user study. This activity was driven by the need to orient the research within the social dynamics of care. It allowed for the observation of interactions not only between the researcher and those with dementia but also the dynamics between residents with dementia and their spouses. This participatory observation offered valuable insights into the manifestation of dementia and the precarious nature of interaction that is required to preserve the resident's comfort and dignity.

These observations with industry and organisational perspectives through two expert interviews (Appendix 2). The first interview involved the digital solutions manager and product owner of 'Slim incontinentiemateriaal' at ABENA (Appendix 3), a healthcare products company. The rationale for this interview was to gain a commercial perspective on development and implementation, specifically regarding how industry leaders assess and validate the problems they want to solve. This interview revealed significant pain points in the implementation process. A key finding was that the value of a product is second to its system integration, ensuring sustained use remains the most problematic hurdle. The second expert interview was conducted with the regional innovation manager of Vitalis, a care home organisation (Appendix 4). This shifted the focus from product development to organisational adoption. The goal was to understand the specific mechanisms that care organisations use to implement innovations, and to identify where organisational structures create tension for formal caregivers. This interview highlighted the nightshift as a critical pain point, both as an operational aspect and for the well-being of the formal caregivers involved. Furthermore, it was established that behavioural change is one of the main drivers of adoption, with non-intrusive innovations showing a much higher success rate. The second interviewee also noted that resident well-being heavily links to a sense of autonomy and self-reliance, people feel happier when they are not subjected to constant checks. Finally, the interviewee pointed toward Artificial Intelligence as a necessary new direction to combat current and predicted staff shortages (Jevšnik & Krilić, 2023).

Image 5: *Still from 'VR into dementia' (IJsfontein, n.d.)*

To conclude the discovery phase, a formal observation of a nightshift was performed. This involved shadowing a formal caregiver (Ferguson, 2016) because a lot of information is perceived to be implicit and would be neglected in an interview, utilising ethnographic field notes in order to capture a holistic view (Phillippi & Lauderdale, 2017), and concluding with a semi-structured interview to discover potentially omitted factors (Ruslin et al., 2022). The motivation was to witness the challenges of the nightshift first-hand. It was hypothesised that many operational problems are underreported because they are considered "routine", rather than identified as solvable issues, hence the observational approach to retrieve information. While the CFIR was initially selected as a template for notetaking (Appendix 5), it proved too static for real-time observation, hindering the natural flow of data collection by forcing immediate categorisation. The ethnographic field notes (Appendix 6) revealed that the specific location (a small care home) was atypical; residents were in early dementia stages, and the physical load was lower than anticipated, a fact confirmed by the caregiver during the subsequent interview.

6.1.2 Define

The start of the definition phase was to synthesise the raw observational data into relevant design themes. In order to go from observation to ideation, a collaborative analysis was performed with other Industrial Design students. Through reviewing the ethnographic field notes, in combination with the formal caregiver's input, the data was analysed to identify relevant patterns. This review resulted in the identification of the three most relevant themes, which served as the foundation for the subsequent ideation phase. The identified themes were 'Restlessness in the night', 'From day to night', and 'Autonomy among residents'.

6.1.3 Develop

The development phase focused on diverging in order to explore a variety of potential solutions based on the defined themes. To facilitate creative output, an ideation session was organised with two other Industrial Design students. This session combined the Round-Robin and Lotus Blossom brainstorming techniques (Shen et al., 2016) into one template for each direction (Appendix 7). The use of these structured creativity tools was intentional, they were selected to jumpstart the ideation process and generate a high volume of distinct directions in a compressed timeframe, preventing fixation on the first available solution. Following a dot-voting round and elaborate discussion, three distinct idea directions emerged (*image 6*) (Appendix 8). However, a critical reflection on these themes revealed a scope gap.

Two of the three directions ('Restlessness in the night' and 'Autonomy among residents') saw ideas that relied heavily on the cooperation with a resident. To adhere strictly to the project's scope, prioritising the formal caregiver, a decision was made to filter the results. Only the concepts that placed focus on formal caregivers were selected for further conceptualisation.

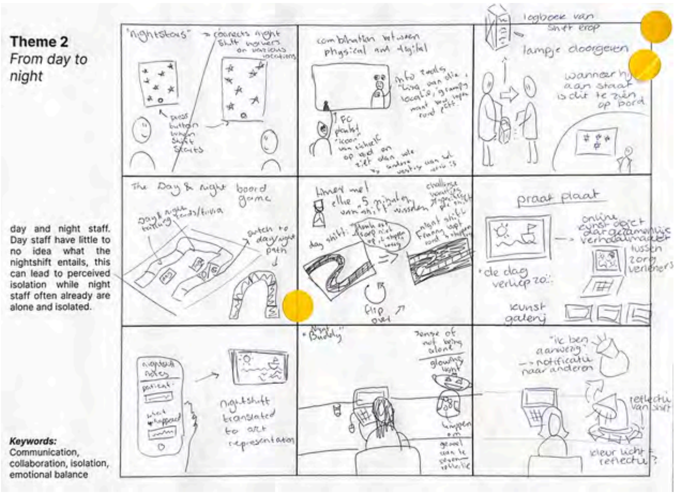

Image 6: *Brainstorm results theme 2*

6.1.4 Deliver

The final phase of this iteration focused on manifesting the selected directions into tangible prototypes for user feedback. The three selected idea directions were initially explored through sketching (Appendix 9). Sketching was employed not only as a representation tool, but as a method of inquiring mechanical and logical feasibility of the ideas. This resulted in three distinct concepts that were translated into mid-fidelity prototypes using 3D-printing, laser cutting, and painting (Appendix 10). The first concept sees a carried artefact that through a consistent format accompanied by a subtle gesture, facilitates a more mindful transferring from the dayshift to the nightshift (*image 7*). The second concept highlights remote collaboration in order to decrease perceived isolation during the nightshift, it does this through showcasing which other formal caregivers are working a nightshift as well (*image 8*). The last concept facilitates immersion into both types of shifts, when the timer strikes 5 minutes, part of the boardgame flips over to reveal the day or nightshift with corresponding challenge cards (*image 9*). The reasoning for creating physical prototypes was made up of two parts. In the first place it tested the physical potential of the solutions, and secondly, to create a provotype (provocative prototype) that would serve as a communication tool during the next contact moment with a formal caregiver. During a second observation session, the three mid-fidelity prototypes were reviewed with a formal caregiver.

The objective was to evaluate their underlying principles, rather than their aesthetic finish. This session produced detailed feedback, with the first two concepts deemed overly intrusive and challenging to integrate into routine, and the "boardgame" concept emerging as the clear favourite due to its empathic and reflective nature (Appendix 11). To conclude the second iteration, it was decided to take a step back and generate new contextual insights regarding the nightshift due to the lack of relevance emerging from this iteration. The next step should be, again, radical divergence, bringing over only the insights found during empathising, foundational knowledge of the problem from experts, and the well-liked "boardgame" concept from the second iteration.

Image 7: *Transfer artefact concept*

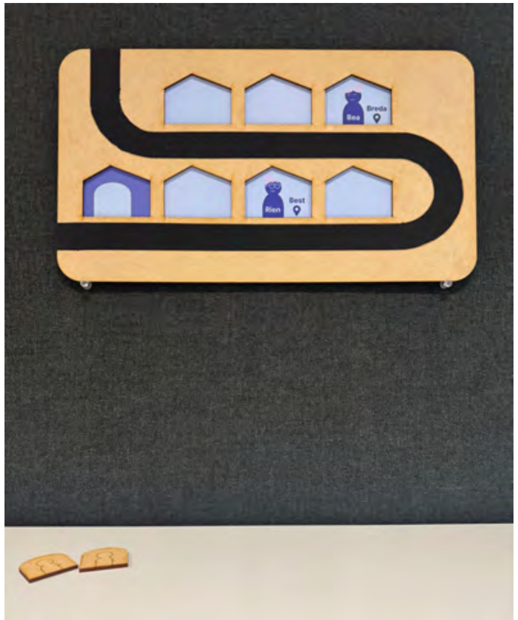

Image 8: *Home wall concept*

Image 9: *Day-to-nightshift boardgame concept*

6.2 Third iteration

The third and final iteration addressed the delicate tension between providing adequate care and maintaining resident safety and privacy. This phase built upon the insights from the previous iteration and concludes the design process with a final concept and validation.

6.2.1 Discover

In order to obtain a representative view of the nightshift, a second observation was performed in a different, larger more typical care home. The previous observation, while informative, lacked the acute stress and cognitive load that is typical of an average nightshift, rendering it an insufficient context for the final solution. Once again, a formal caregiver was being shadowed during their nightshift, collecting ethnographic notes (Appendix 12), learning about current systems and technologies (*image 10*), and conducting a semi-structured interview. Learning from the friction encountered with the CFIR template in the previous iteration, the notetaking approach was adjusted. A clearer template was adopted (only note-taking, no categorisation), allowing for unrestricted ethnographical fieldwork during the session, leaving a structured analysis for after the observation.

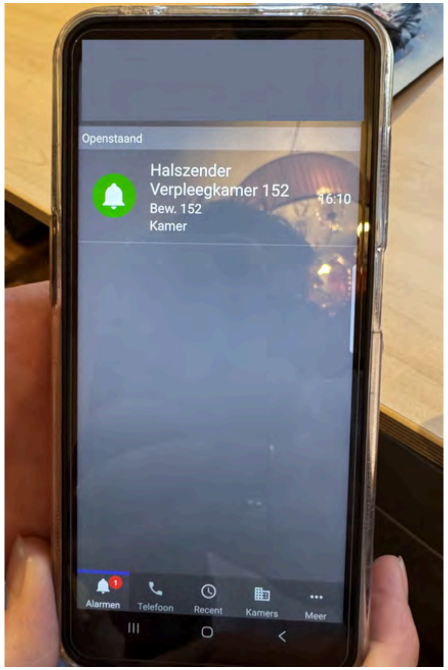

Image 10: *Currently used VSS Sherpa application*

6.2.2 Define

To start off the analysis on the observational data, a latent inductive thematic analysis was performed on the collected ethnographical notes (Braun & Clarke, 2006). This method was chosen to uncover the underlying meaning of the formal caregivers' actions and frustrations, rather than just their statements. This resulted in the identification of eight distinct themes ('Technical difficulties', 'Hindering environment', 'Emotional connection/exhaustion', Multiplicity of tasks, '(Whereabouts of) wandering residents', '(Whereabouts of) wandering residents', 'Communication between working personnel', 'Physical challenges', and 'Turbulent transfer') (*image 11*) (Appendix 13). Afterwards, a semantic deductive thematic analysis was done on these eight themes using the CFIR (Appendix 14). Through mapping the themes in CFIR domains, the analysis highlighted which design directions were organisationally feasible and where the barriers lay (Damschroder et al., 2009). The mapping revealed that the majority of barriers existed within the "Inner Setting" (the internal structural and cultural context of the care home), as can be seen in *image 12* (overview of domains). This insight was crucial, because it suggested that the design intervention needed to function independently and be compatible with current caregiver routines to bypass these barriers. This hypothesis was later validated during an expert interview with an innovation manager at Anna Zorg. Afterwards, the three most promising themes were selected for further development:

- Empathy for the nightshift: Taken from the boardgame concept and validated by the second observation.
- Adequate tracking of residents: Emerging from the observation of wasted time on routine checks and the multiplicity of tasks.
- Mindful transfer: Emerging from observations regarding information loss and lack of uniformity during shift changes.

Unravelling these themes resulted in the foundation of the setup for the co-creation session.

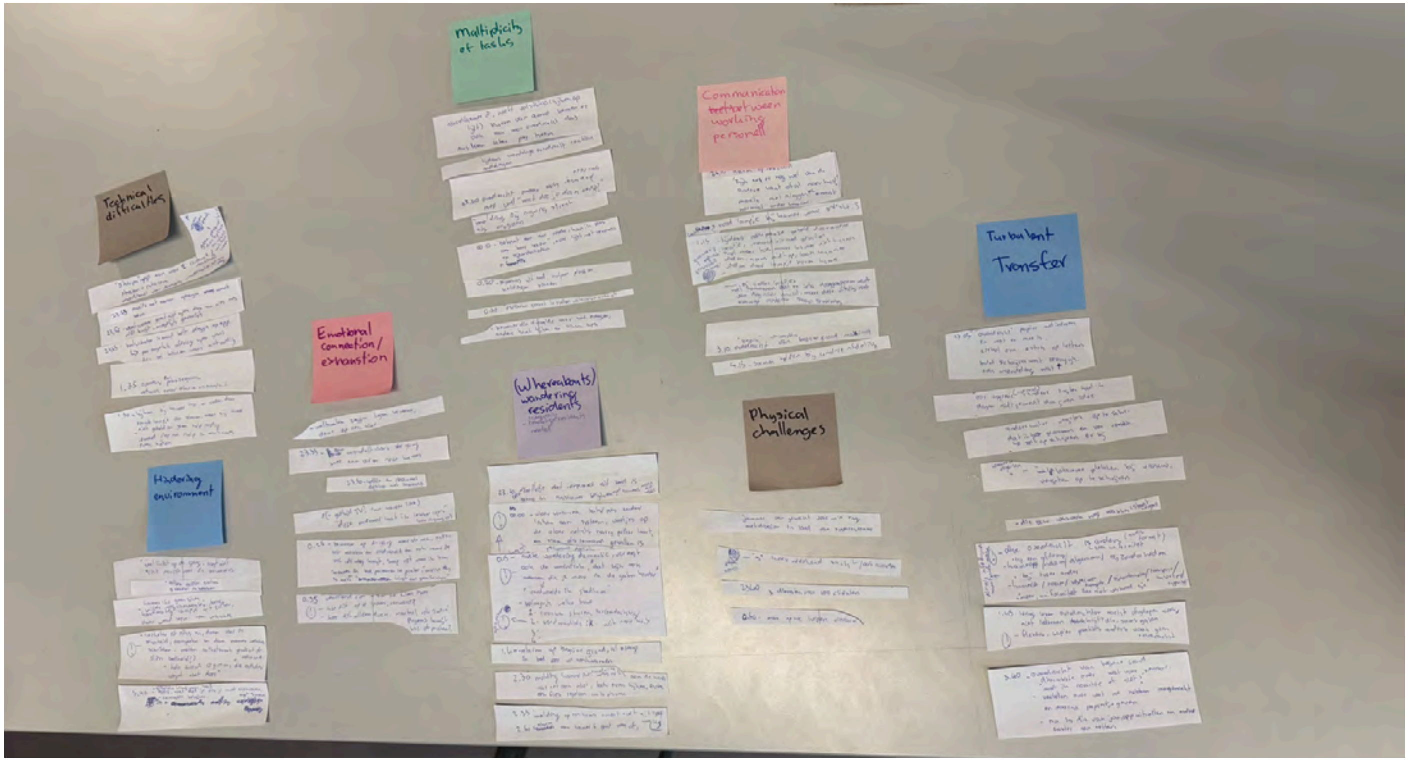

Image 11: *Thematic analysis of ethnographical field notes taken during observation 2*

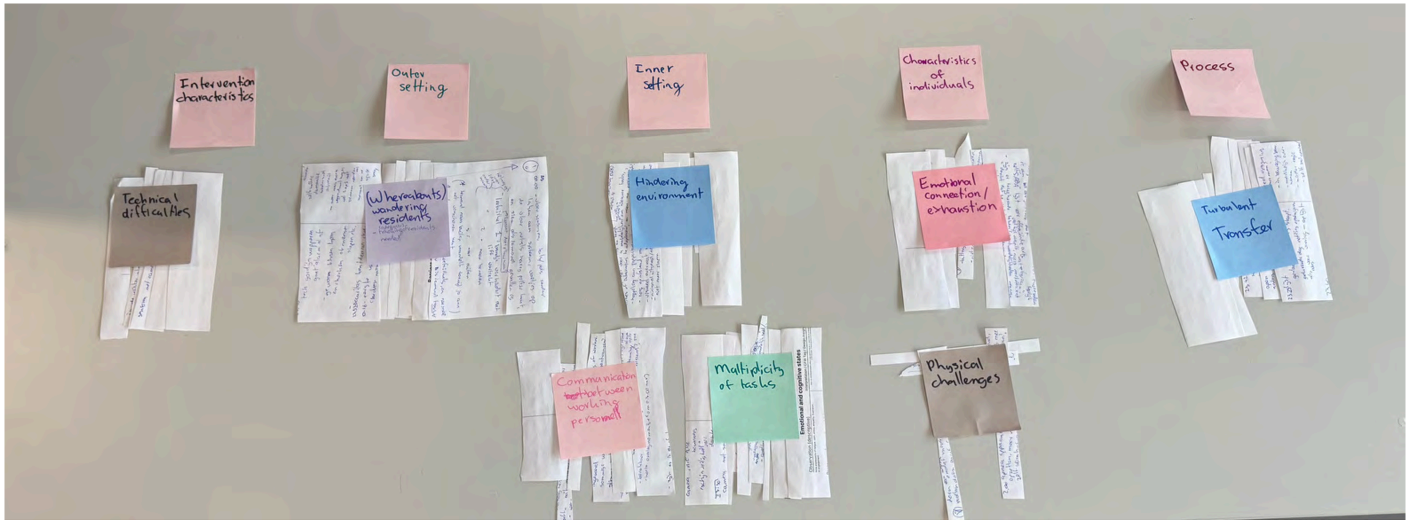

Image 12: *Thematic analysis of themes in CFIR domains*

6.2.3 Develop

The development phase moved towards participatory design, involving stakeholders directly in the creation of the solution. A co-creation session (Sanders & Stappers, 2008) was performed with three formal caregivers in order to receive input directly from the target group (*image 13*). The session was structured in three parts (Appendix 15): introduction, dissection of themes through pain points (Appendix 16), and visual ideation. Recognising that ideation is notoriously difficult for non-designers, particularly in healthcare contexts (Gustavsson & Andersson, 2017; Karloopia & Agrawal, 2024), specific facilitation tools were employed. "Prompt cards" (*image 14&15*) (Appendix 17) were used to trigger idea generation. Also, participants were constrained to drawing or creating for the first three minutes of each theme, to avoid them simply writing down their ideas. This constraint was imposed to avoid analytical barriers and encourage visual and intuitive problem-solving. In a complex context like dementia care, receiving direct, unfiltered input from the target group is essential to avoid assumptions. The session yielded new insights into workflow bottlenecks (e.g., shift transfer moments, missing residents) and validated the relevance of the selected themes (participants expressed explicit agreement with stated challenges) (Appendix 18&19). After dot voting and discussion, one idea stood out significantly: a new method for context-aware resident tracking and adequate visualisation.

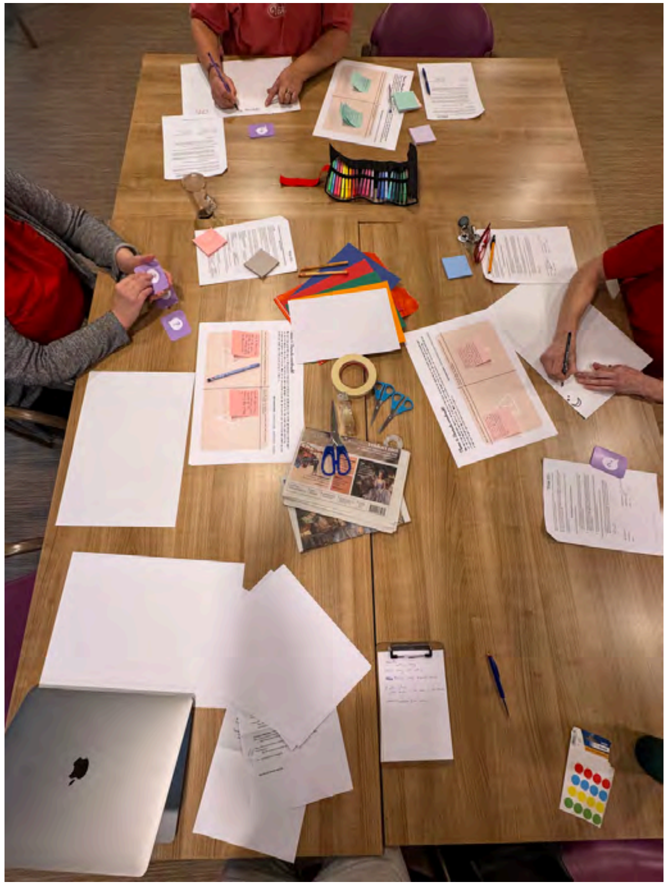

Image 13: *Co-creation session*

Image 14: *Prompt cards*

Image 15: *Prompt cards in use during session*

Following the co-creation session a brief ideation phase was completed to refine the "context-aware tracking" direction through sketching (Appendix 20). This final divergence was necessary to explore the technical manifestation of the concept. The result was a feasibility-impact matrix that identified two clear best ideas that had their key features combined in a concept equipped for detailed development (*image 17*) (Appendix 21).

During the concept development phase, external expertise was gathered to ensure technical and commercial viability. A product developer from the care technology company Aumens was consulted to provide guidance on implementation challenges and requirements (e.g., subsidy requirements, Technology Readiness Level (TRL), legal requirements) (Appendix 22). This step was vital to ground the academic concept in a market reality. Simultaneously, an interview with a data engineer at KPMG provided the foundation for the technical aspect of the final concept, emphasising the importance of processing power, power over ethernet, and a potential neural processing unit (Appendix 23). Once the manifestation was defined, an expert validation was conducted with a formal caregiver (Appendix 24). This final loop filtered out redundant features and confirm the value and relevance of the proposed functions before final prototyping.

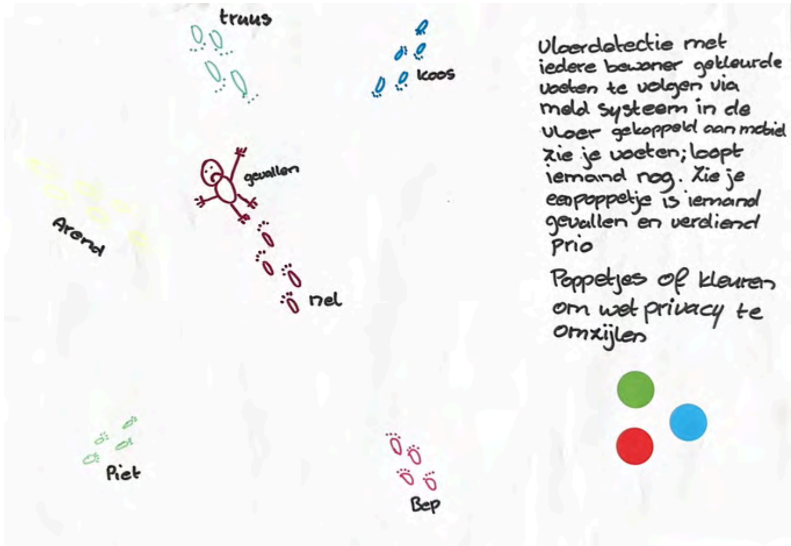

Image 16: *Co-creation session idea that led to final concept*

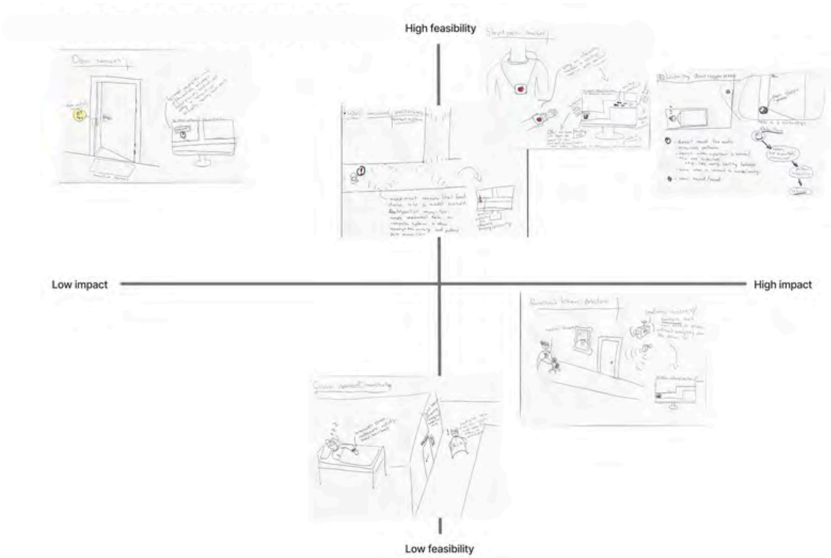

Image 17: *Feasibility-impact matrix*

6.2.4 Deliver

The final delivery phase focused on the realisation, testing, and multi-stakeholder validation of the M.I.C. system.

FINAL DESIGN: The M.I.C.

The project resulted in the design of a context-aware integrated monitoring system named 'The M.I.C.' (Microphone Integrated Classification system), that supports formal caregivers during their nightshifts in dementia care by prioritising and contextualising alarms. The system aims to reduce cognitive load and uncertainty of context by giving formal caregivers relevant insights into which resident needs help most urgent, where, and why.

System architecture

The system consists of a distributed network of ceiling-mounted microphones installed throughout each ward. In the hallways, microphones are placed approximately every eight meters to ensure sufficient spatial resolution for tracking movement and activity. Each hallway microphone array is part of a local cluster, with one microphone per ward that contains an edge-processing unit (*image 18*). In resident bedrooms, each microphone contains its own dedicated processing chip to allow fully local processing. All microphones use a 4-mic omnidirectional microphone array to capture sounds from multiple directions (Seeed Studio, n.d.).

The edge processing is enabled through the FRDM i.MX 8M Plus development board (Mouser & NXP, n.d.), allowing real-time analysis directly on the device. This way the system, preserves privacy by avoiding raw audio storage or streaming explained more thorough in Appendix 25.

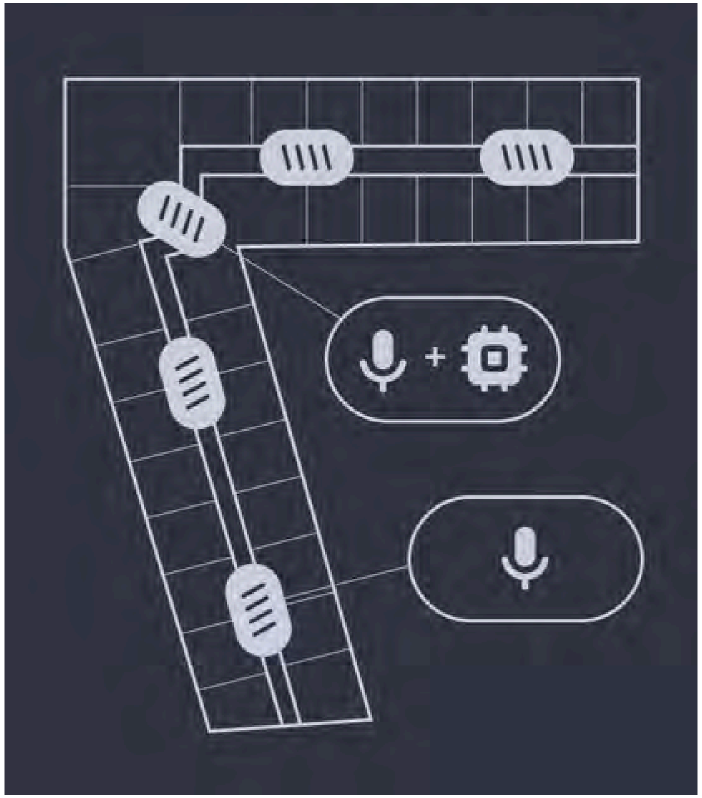

Image 18: *Microphone architecture hallway mics*

Measurements and modules

Using audio analysis, the system performs a set of measurements and classifications that establish the current status of residents:

- Approximate location of a resident (up to 3 meters (Khan et al., 2025))
- Walking direction
- Differentiation between casual walking and distressed wandering
- Fall detection
- Identification of residents (displayed through room number for privacy)
- Detection of single versus multiple people in a space
- In bed or out of bed
- Sleeping or wake state
- Prolonged bathroom occupancy

Each of these measurements is performed by a combination of modules such as sound source localisation, gait detection, and fall impact detection. A detailed technical explanation of these modules is provided in (Appendix 26). Acoustic events are detected using low-level machine learning (Vaibhavi, 2022), these features are classified using convolutional neural networks (Ceolini et al., 2019; Ordóñez & Roggen, 2016), while a higher-level large language model reasoning layer (Ouyang & Srivastava, 2024) combines these signals into context-aware and meaningful alarms for the formal caregivers.

Alarm contextualisation
The system introduces the new 'Fall detected', 'Wandering resident with fall risk', and 'Unusually long bathroom visit' alarms. In addition to generating new alarms, the system also contextualises existing alarm. For example, when a resident pushes their wrist sensor, the interface now provides contextual information such as the resident's location (*image 19*), activity (*image 20*), and status (*image 21*). This context allows formal caregivers to evaluate urgency before physically visiting the resident. All measurements are translated into a clear, minimal interface (Appendix 27) which is a redesign of the current Sherpa application (Axians, 2022). The system is not designed to replace the judgements formal caregivers make, but rather to support rapid decision making by ranking alarms based on urgency and providing context to the alarms.

Image 19: *Resident location*

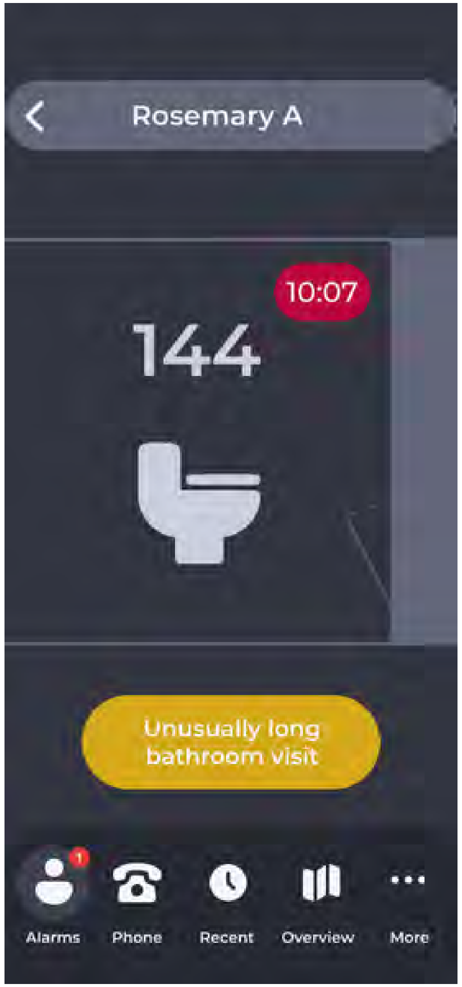

Image 20: *Bathroom activity*

Image 21: *Sleeping status*

6.2.5 Prototyping

A functional prototype was developed to demonstrate the technical viability of the concept (Appendix 28). Due to the complexity of machine learning integration, the prototype focused on specific core functionalities. The hardware setup consisted of a ceiling tile with the 3D-printed prototype mounted on it (*image 22*), equipped with a microphone on a breadboard, and a Raspberry Pi 3 Model B, to collect audio data. This data was processed via a p5.js editor (Appendix 29) running a Teachable Machine (a convolutional neural network that compares audio input to predetermined classes (Carney et al., 2020)) sound classification analysis. The output was visualised on a screen encased in a 3D-printed housing, simulating the formal caregiver's mobile interface (*image 23*). When an object was dropped, the code triggered a "Fall detected" alarm that was displayed on the screen. Additionally, the user interface was prototyped in Figma to visualise the user experience flow. This prototyping approach served to demonstrate programming and prototyping competence while also providing a high-fidelity visual application interface for user testing.

Image 22: *3D-printed shell on wooden ceiling tile*

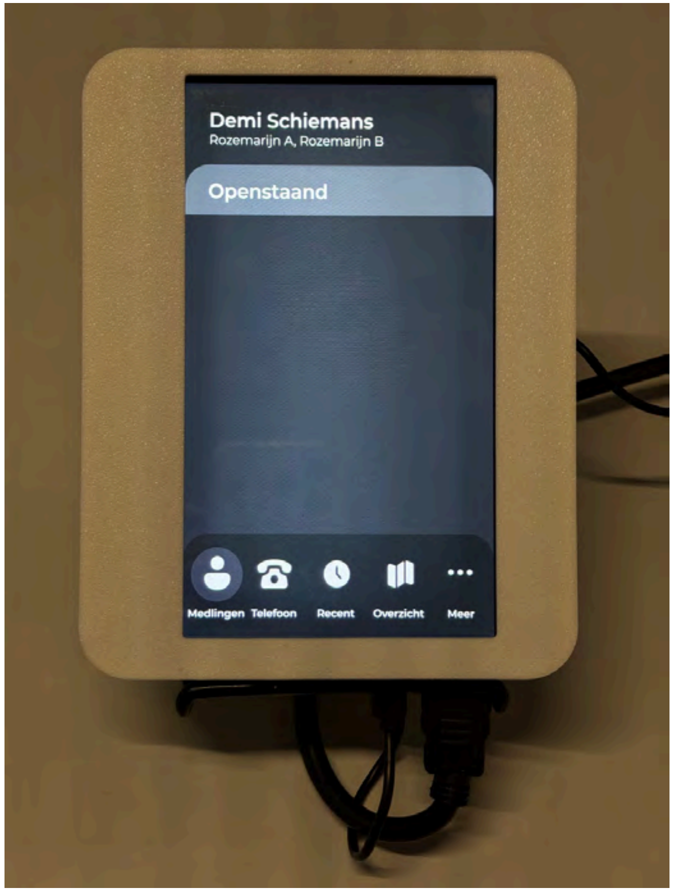

Image 23: *Prototype screen with application*

6.2.6 User testing

Due to the constraints of caregiver schedules and limited number of applicants, a single in-depth user test was arranged. To ensure this opportunity was optimally used, a pilot test was conducted with an industrial design student (Shakir & Ur Rahman, 2022). This pilot test resulted in useful modifications to the application flow, for example, removing confusing elements and unclear task flows before the actual evaluation.

The primary user test was then conducted on-site with a formal caregiver. The session made use of navigation-based tasks, asking the user to navigate the application, and react to four distinct scenarios (Appendix 30&31). Following this, the caregiver was asked to rank a set of alarms by priority (*image 24*). This prioritisation exercise was crucial to understand the formal caregiver's priority in new and existing alarms, resulting in a newly justified prioritisation classification (Appendix 32). Given the highly contextual and complex nature of the formal caregiver's environment, qualitative data was collected during the final user test in order to gain a deep, nuanced understanding of the workflow integration and the design's alignment with the current system, an insight into user experience and clinical feasibility that quantitative data are unable to provide in such a small sample within a sensitive care setting (Rørtveit et al., 2020; Tenny et al., 2022). The test confirmed the concept's validity, the caregiver deemed the system efficient and non-intrusive. A significant finding was the user's immediate trust in the system, alarms from the M.I.C. were treated with the same seriousness as existing systems.

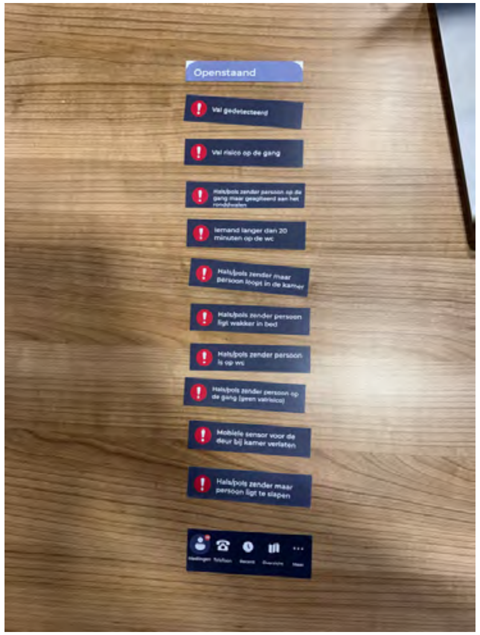

Image 24: *User test ranked alarms*

6.2.7 Stakeholder validation

Given the limited sample size of the user test (N=1), a strategy of triangulation was applied to validate the design through other critical stakeholders and thus diversify input. An interview was conducted with a product developer at Aumens (Appendix 22). This step was taken to assess the concept's technical feasibility against current market competitors and insurance requirements (factors often overlooked in academic designs but critical for real-world viability). The developer confirmed the structural soundness of the idea and highlighted that its non-intrusive nature would lower barriers to integration. Another interview with an innovation manager at Anna Zorg was conducted to evaluate the potential for implementation within a different organisational structure (Appendix 33). This was done to test the "transferability" of the concept, ensuring it wasn't biased toward the specific workflows of the previously observed care home. The interviewee confirmed that the M.I.C. meets the critical criteria of being labour-saving and increasing well-being (2 out of three key criteria, the other one being moneysaving), predicting a high chance of organisational adoption due to its ability to hook onto existing systems with minimal routine disruption. Two interviews were conducted with two individuals who had family members in dementia care, one of whom was also an informal caregiver (Appendix 34). This validation was essential because residents with dementia cannot always fully consent to or comprehend new innovations. Family members act as substitutes, and their acceptance is a prerequisite for an ethical implementation. Both interviewees confirmed they would want the M.I.C. system used, showing great trust in the system and the potential for better care due to reduced caregiver workload. Finally, two user tests were conducted (Appendix 35) with non-formal caregivers (one in their 20s, one in their 60s). This was done to diversify user experience input and test the tangibility and intuitive nature of the interface without having to rely on one opinion. While some initial familiarisation was required, both participants navigated the user and task flow smoothly, with one suggesting visual updates (e.g., a 'check'-icon) that were incorporated in the final design of the interface.

7.IMPLEMENTATION

As noted in the foundational text of the CFIR, stakeholders in a receiving organisation often have a "socially constructed perception" of evidence that differs significantly from expert ratings, and it is this local perception that determines implementation effectiveness (Damschroder et al., 2009). This insight serves as the guiding principle for this chapter. This chapter addresses the contextual challenges mapped in Chapter 3. Context. It outlines the strategy for transitioning the M.I.C. system from a design concept to a sustainable intervention, distinguishing between the technical readiness and the organisational integration required for an adequate fit.

7.1 Technical implementation

Currently, the M.I.C. system is estimated to be at Technology Readiness Level (TRL) 3, applicability has been tested on an experimental basis and Proof of Principle has been effectively validated (RVO, n.d.). The technical architecture is also the main method for ensuring legal compliance. A major barrier identified in the context analysis was the rigid legal framework surrounding surveillance, specifically the GDPR and the WZD (Wet zorg en dwang). Under the WZD, care interventions are bound by the principle of proportionality, meaning the least restrictive measure must always be chosen (Ministerie van Volksgezondheid, Welzijn en Sport, 2025). Where camera monitoring is often deemed disproportionate due to visual intrusion, and standard audio streaming violates the confidentiality of private conversations, the M.I.C. system offers a legally viable alternative. Because the system utilises edge computing, no audio data ever leaves the device, it transmits only metadata (through power over ethernet cables), such as a "Fall Detected" signal. This architectural choice classifies the system not as a surveillance tool but as a sensor, significantly lowering the legal threshold for implementation compared to video-based competitors.

7.2 Organisational integration

Technical readiness is pointless if the stakeholders perceive the innovation negatively. Therefore, the integration strategy focuses on aligning the system with the existing mental models and workflows of the care home. As was established in the validation phase, the formal caregivers are convinced of the system's value, but to prevent implementation fatigue, the system must not add a new interface to the already overly crowded routine. Therefore, the M.I.C. system is designed to feed directly into the existing Sherpa ecosystem rather than functioning as a standalone application. This means the caregiver's routine remains basically identical, they still consult the Sherpa interface for alarms, but the quality of the information is enriched and contextualised. Instead of a generic sensor alarm, they receive specific context, such as the high urgency of a fall alert, resulting in better prioritisation without requiring behavior change. While the system is technically private, the perception of privacy among family members could prove to be a critical hurdle. To address this, the implementation plan includes a transparent communication strategy that frames the device not as a recording device that stores data, but as a digital listening system that processes sound, only listening when this is required. Mitigating the privacy hurdle, this is manifested in the form of a presentation for stakeholders expressing concerns during initial deployment, where the system and especially its principles are thoroughly explained (Lenhart et al., 2023).

7.3 Macro context implementation

For healthcare providers and subsidy providers, the ultimate adoption decision is financial. The business case for the M.I.C. system is built on two principles: burnout prevention through lowered workload and cost prevention of medical expenses. The context analysis revealed a workforce operating at maximum cognitive load, where high stress directly correlates with sick leave and turnover (Willard-Grace et al., 2019). By filtering out a large number of false alarms, such as accidental presses or incorrectly labelled movement by mobile sensors, the system directly lowers this cognitive burden. If this reduction prevents even one caregiver per facility from burning out annually, the system will eventually effectively pay for itself through the avoidance of workforce turnover. Furthermore, falls are among the most expensive events in long-term care, often leading to hospitalisation and increased care dependency. Unlike passive motion sensors that detect a fall only after it has occurred, the M.I.C. system's ability to detect fall risk residents, allows for preventative intervention. By generating a response before the fall occurs, the system reduces the direct medical costs associated with trauma care. This dual benefit aligns perfectly with the WLZ (Wet langdurige zorg), specifically regarding funds allocated for "Quality of Life" and "Labor Saving Innovations" (Ministerie van Volksgezondheid, Welzijn en Sport, 2023). Since the M.I.C. system addresses both resident safety and caregiver workload, it is a good candidate for these subsidies, lowering the expense barrier for care organisations. However, in order to legitimise these claims, concrete numbers should be presented.

In conclusion, this chapter has outlined the path from a validated design concept to a potentially viable healthcare product. By addressing the technical requirements of privacy local processing provides, the organisational needs for seamless workflow integration, and the financial reality of cost-saving funding, the implementation plan answers the specific constraints of the "Inner Setting" identified in Chapter 3 'Context'.

8.DISCUSSION

8.1 Design principles for complex care contexts
Beyond the manifestation of the M.I.C. system, this project generated a set of generalised design principles. These principles serve as prerequisites for future designers attempting to innovate within the sensitive context of institutional dementia care.

Operational principle
The most critical finding from the context analysis is that the implementation climate is fatigued. Therefore, a new system cannot demand new behaviours.

- Minimal behavioural change: The design must hook onto existing routines rather than create new ones.
- Seamless integration: The system must function independently but communicate seamlessly with existing systems.
- Clearly communicated incentive: The "Why" must be immediately clear. The system must prove within the first shift that it saves time and unburdens users, rather than just adding data.

Interaction principle
Because the user is operating under high stress and cognitive overload, the interface must respect their limited (cognitive) capability.

- Glanceability: Information must be able to be retrieved by skimming an interface. There should be no complex menus or deep navigation flows.
- Prioritisation over detection: It is not enough to detect an event; the system must assign it a value or urgency to support rapid decision making.
- Support for self-reliance: The design should not replace the user's judgment but validate it.

Environment principle
The design must respect the resident's home and the sensory sensitivity of dementia.

- Non-intrusive innovation: The hardware must blend into the environment. There should be no bright status lights or sudden mechanical noises that could trigger a sundowning episode or disturb the resting residents.
- Zero-effort compliance: As identified in the Related work, the system must not rely on the resident to wear, charge, or accept a device. It must function regardless of their active compliance.

Technical principle
Finally, in a domain where users cannot always give informed consent themselves, privacy must be integral, not just policy based.

- Local processing: To avoid reliance on unstable cloud connections, mitigate privacy risks and avoid surveillance fears, data processing must happen locally.
- Transparency: The nature, details, and workings of the system must be communicated in a clear and transparent manner.

8.2 Limitations

This section reflects on the specific constraints of the audio classification logic, the acoustic variability of the resident, and the ecological validity of the testing process.

As dementia progresses, many residents develop a shuffling gait, characterised by sliding feet and irregular rhythm rather than clear steps. There is a risk that the current algorithm, optimised for standard walking, might fail to diversify this shuffling from agitated shuffling movement, potentially misinterpreting resident status. Future iterations must therefore rely on training data specifically collected from specific populations to capture these subtle acoustic signatures.

This challenge of gait detection is further complicated by the variable nature of the resident's footwear. The current detection logic relies on the acoustic impact of footwear on flooring (Mughal et al., 2025) to identify movement, calculate location and resident identification. However, the reality of the nightshift is that residents frequently wander in socks or bare feet. In a shoeless scenario, the acoustic footprint of a resident drops significantly, changing from a sharp percussive sound to a soft, frictional shuffle. This creates two problems, first, the risk of false negatives (missing the movement entirely), and secondly, the loss of identification. If the system relies on the unique sound of a footstep to identify who is walking, it may fail when that sound is dampened. Consequently, the system's reliance on identification through room exits, remains a critical failsafe.

Apart from the resident, the environment itself presents as a significant variable as well. While the large language model uses advanced filtering to isolate relevant sound data, the acoustic complexity of an institutional building cannot be fully simulated. Care homes are filled with regular sounds like HVAC noise, rattling of a passing cleaning cart, or the clanking of old plumbing. While the model may achieve high accuracy in a controlled test, unforeseeable sounds in the real world (such as a television playing in a resident's room or a loud thunderstorm) could still trigger the classification threshold. Even a minimal false positive rate can re-introduce the very alarm fatigue the system attempts to avoid. Therefore, the calibration is a functional necessity in order to mitigate these outliers.

It is also necessary to reflect on the scope of the project context. The entire design process, from the initial ethnographic shadowing to the final testing, was conducted within a single care organisation at a specific location. While this provided deep insight into that specific ecosystem, it limits the generalisability of the results. Care homes vary drastically in their Inner Setting. A facility with carpeted floors, for instance, would render initial acoustic training data useless compared to the linoleum floors of the current care home. Consequently, the current design is optimised for a specific type of institutional care, its transferability other contexts remain unproven without broader testing. It is suggested that diverse care homes, different care organisations, and possibly further care contexts are explored in order to assess if the system functions in alternate care settings.

Finally, the validation of the system rests heavily on a Wizard of Oz type testing and simulated scenarios. While this is a standard and accepted method for prototyping innovations, it lacks long-term and technical validity. The user test measured the formal caregiver's response to the interface and the concept over a period of minutes, not months. The Hawthorne Effect, where subjects modify their behavior because they know they are being observed (Sedgwick & Greenwood, 2015), possibly influenced the positive results during observation and user testing. It is not yet known how the system performs during a real crisis at 3 AM when the caregiver is fatigued and the researcher is absent. The long-term effects on workflow, whether formal caregivers truly trust the system enough to stop patrolling or whether they ignore it, can only be validated through a longitudinal pilot study in a live operational environment.

8.3 Future work

To bridge the gap between a promising academic prototype and a deployable healthcare product, the system must undergo several distinct developments. This section outlines the strategic plan for future iterations, focusing on product refinement, technical integration, and longitudinal validation.

An immediate priority for the next iteration is a rebranding of the system. During user testing, a semantic conflict was highlighted. The formal caregiver pointed out that the acronym "M.I.C." is already used in their workflow and stands for "Melding Incident Cliënt" (Client Incident Report). Introducing a device with the same name creates immediate confusion and potential communication errors during a crisis. A new name must be developed that is distinct, empathetic, and reflective of the system's supportive role.

The current shell is a rapid prototype designed to hold the current prototype hardware. The next phase of hardware design must focus on design for actual manufacturing. The shell requires redesigning to accommodate the specific dimensions of the final printed circuit board and the NXP i.MX 8M Plus chipset. Furthermore, given the decision to run edge AI processing locally, heat management is a concern. The new shell must integrate passive cooling, while blending seamlessly into the ceiling of a homelike environment without looking like an industrial device.

Currently, the choice of the NXP i.MX 8M Plus chipset relies heavily on external expert consultation regarding the necessary processing power for real-time audio classification. An in-depth hardware review is required to verify if this specification is in fact optimal. It is possible the system is currently over-engineered for its specific task. Future work should investigate if a lighter, more cost-effective system on module could achieve the same results, lowering the cost for large-scale adoption.

A detailed technical plan must be executed to build the integration bridge between the M.I.C. system and device, and the Sherpa server and system. This involves moving towards a fully integrated protocol where the audio device triggers specific event codes directly on the formal caregiver’s mobile device.

As discussed in the Discussion, every care home has a unique acoustic fingerprint (e.g., HVAC noise, etc.). Future software should include a setup phase where the device is calibrated to the empty room for a certain period of time in order to establish a baseline, ensuring that the large language model adapts to the specific environment rather than relying on a generic threshold.

In order to further mitigate the perception of privacy, a physical or digital privacy switch should be implemented. This feature would allow family members or staff to temporarily disable the monitoring during visits, care moments or alarm fatigue. Giving users the ability to temporarily turn the system off could restore a feeling agency and trust.

Finally, the most critical step for future work is moving the system to TRL 7: demonstration in an operational environment. A longitudinal pilot study is required to evaluate the system's impact over time. Short-term user tests cannot capture the "Hawthorne Effect" or the gradual buildup of trust. This pilot study should focus on technical sustainability, workflow impact, system retention, and scalability (testing the system in different facilities to understand what is required to extrapolate these results to other care organisations). Through this real-world testing the M.I.C. system can transition from a well-intentioned design concept to a reliable standard of care.

9.CONCLUSION

9.1 Final design

The central objective of this project was to address the "wicked problem" of the nightshift in dementia care, a domain characterised by a critical mismatch between high resident vulnerability and low caregiver capacity. The design goal sought a way to prioritise acute needs without increasing the cognitive load on the staff or violating the privacy of the resident.

The final result of this goal is the M.I.C. (Microphone Integrated Classification) system.

The M.I.C. is a privacy-preserving, decision support system designed specifically for a nighttime care environment. Unlike traditional acoustic monitoring, which acts as a passive funnel for noise, the M.I.C. functions as an active filter. It is an intelligent system that continuously listens to the acoustic environment but only speaks when necessary.

Technologically, the system utilises edge processing to process audio data locally within the resident's room or hallway. By employing machine learning models trained on specific sound events, it distinguishes between environmental background noise, passive resident behaviour, and acute distress signals. Crucially, it translates this complex data into a revised interface for the formal caregiver. It integrates with the existing Sherpa system workflow to deliver prioritised alerts.

This solution is the result of a comprehensive design process, grounded in a User-Centered Design approach, with two iterations based on the Double Diamond framework, and enhanced by the CFIR. From the initial uncertainty identified during ethnographic observation to the collecting of direct user input during co-creation sessions, the design was shaped by the active involvement of formal caregivers, care experts, and family members. This participatory approach ensured that the final system is not only a technological demonstration, but a validated response to the struggles of a care home.

9.2 Final conclusion

The M.I.C. system demonstrates that the future of care technology does not lie in more sensors, but in smarter interpretation. By shifting the focus from surveillance to context, and from cloud to edge, this design offers a solution that keeps dignity with the resident and autonomy with the caregiver. It proves that when designed with intent, a design can brilliantly facilitate adequate care for the right person.

10.ACKNOWLEDGEMENTS

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