Fulfilling connectedness in Critically Ill Patients in the Intensive Care Unit through a Personalised Soundscape System

Master Graduation Project
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EXECUTIVE SUMMARY

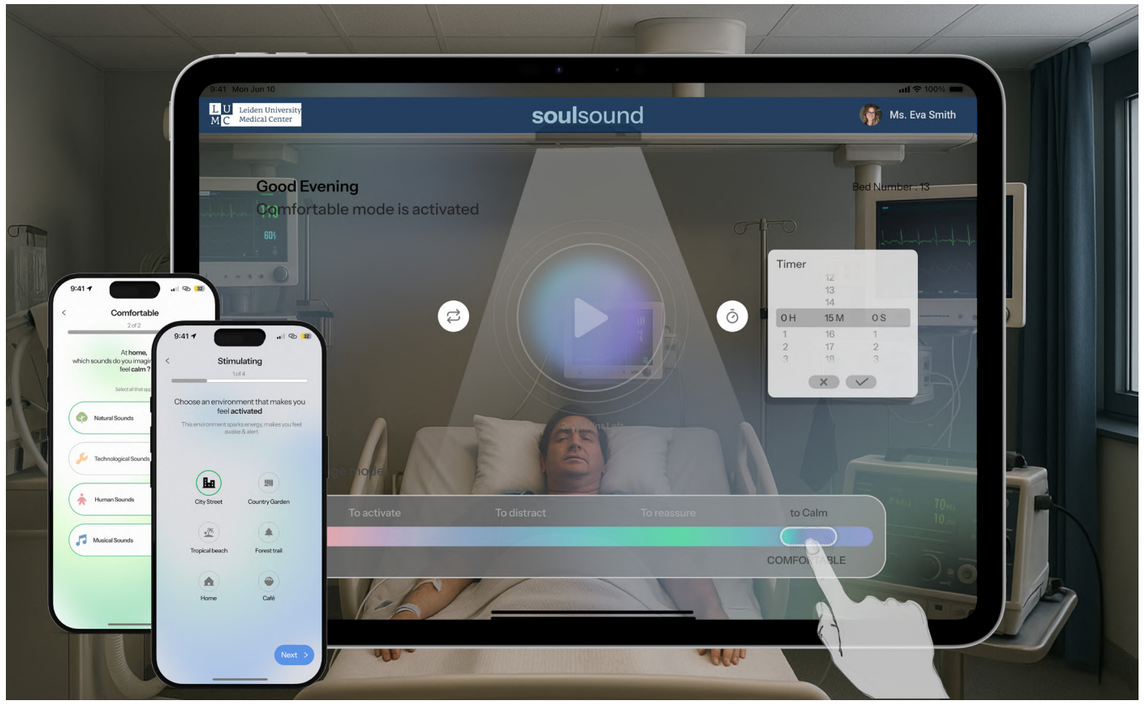
In critical care environments, patients are surrounded by an abundance of unwanted sounds from the medical alarms and equipments that often lead to heightened stress, confusion and psychological discomfort. This graduation project explores how the acoustic environment of the Adult Intensive Care Unit (ICU) can be reimagined to support the critically ill patients using a soundscape system. The context of this project is the Leiden University Medical Centre (LUMC) and the stakeholders considered in this project along with the patients are the healthcare providers and loved ones.

Existing literature and field studies reveal that while sound is a vital component for healthcare professionals (HCP) to monitor patient status, it is often a source of disruption and emotional strain for patients and their loved ones. The project identifies a gap in current interventions, which largely focus on reducing noise rather than enhancing the patient's experience. A soundscape is defined as the acoustic environment as perceived or experienced and/or understood by a person or people, in context (ISO 12913, 2014). The current acoustic environment has been outlined through a context study, along with its impact on key stakeholders. This provided a clear understanding how the current ICU soundscape hinders the emotional well - being of the patients. A multi-method research approach was conducted, including contextual observations at LUMC, interviews with healthcare providers, and a review of ICU patient experiences to identify the affected psychological needs of patients.

From these insights, a detailed patient journey map was created, highlighting critical moments where the auditory environment could support or hinder well-being. Through a thorough understanding of the journey map , four unfulfilled psychological needs were identified - Lack of autonomy , relatedness, security and comfort. Following literature, these unfulfilled psychological human needs can be fulfilled by providing the right sonic ambience at the right moment. A need for connectedness with the outside world through these sonic ambiences was investigated to be fulfilled to meet the identified fundamental needs. Literature explores how need based sonic ambiences should be tested for their functional role i.e to comfort, to distract during long stretches of time without visitation or spontaneous breathing trails etc. Connectedness to environment became a facet to explore as a design direction which was further explored in the event based journey map of the patient through different times of the day and modes for sonic ambiences which could fulfil the desired functions. These findings underlined the importance of a personalized approach to creating meaningful soundscapes within the ICU. By mapping out key moments of interaction, the framework for the system was outlined detailing when and how each stakeholder would be engaged. Implementation touchpoints were identified as: patients pre-admission, loved ones at the beginning of the ICU stay, and healthcare providers throughout the admission, who would be responsible for tailoring and adjusting the sonic experience. This multi-stakeholder approach became essential for integrating the system into the complex ICU environment.

Several mobile and tablet based prototypes were created to conduct usability tests with fellow students to test the engagement on the app and how easily sounds are selected based on contextual cues related to specific given environments leading to the most intuitive methods to be implemented in the real world setting.

The resulting design, SoulSound, is a soundscape system integrated into the ICU room to deliver personalized auditory experiences. The system includes an interface for input collection by patients, family members, or HCPs and dynamically adjusts sound based on changing needs throughout the day. Four key sonic functions were defined: calming, distracting, activating, and reassuring. These roles help support patients during moments of loneliness, discomfort, or procedural stress, waking up or sleeping times of the day. Usability testing with design students validated the concept's interaction model, while expert evaluation highlighted practical challenges and ethical considerations. Positive responses from participants indicated that personalized sound could serve as a subtle yet powerful tool to support mental well-being during ICU admission by reducing stress and meaningfully involving loved ones and HCPs in the care journey. However, concerns were raised regarding system credibility and integration into clinical workflows, leading to a set of recommendations for future research. The feedback and insights gathered from these tests resulted in recommendations for future research. Finally an overall reflection on the study concluded the research.



ACKNOWLEDGEMENTS

Designing for a sensitive context as the Intensive Care Unit introduced me to the world of caregiving and proved to be the best way to end my masters journey at the Faculty of Industrial Design Engineering at TU Delft. The journey from February to August 2024 has been one of deep learning, challenge, and growth, both as a designer and as a person.

I would like to express my heartfelt gratitude to my Chair, Elif Özcan Vieira, for her unwavering guidance with the right questions, and sharp insights that continuously pushed me to think critically and grow beyond the obvious in the field of sound which was very new to me. To me mentor, Ela I am grateful to your indepth knowledge and ability to give insights and directions in whatever i presented throughout our meetings. The journey would not have been thorough without you. In addition I would like to extend my gratitude toward my external mentor from Leiden University Medical Centre, Floor for her prompt help and medical guidance throughout the project. The entire project would not have shaped the way it has without your interest and expertise.

I am deeply thankful to all the researchers, designers, healthcare professionals, students, and former ICU patient who contributed to this project through creative facilitation sessions, interviews, surveys, and usability tests. Your perspectives, openness, and participation were central to shaping this thesis. To my family Mom, Dad , my sister Mitali and my Granddad - your constant support, love, and belief in me have been my strongest foundation. To my friends, both near and far, and to everyone in Delft who stood by me thank you for being my cheerleaders, and late-night motivation.

This project has been a collective effort, and I am deeply grateful to everyone who has been a part of it. With immense pride, I present to you my thesis - "Fulfilling connectedness in Critically Ill Patients in the Intensive Care Unit through a Personalised Soundscape System".

Avanti

TABLE OF CONTENT

01

INTRODUCTION

This chapter establishes the foundation of the master thesis by defining the context and need for a personalised soundscape system within an intensive care environment. It outlines the project scope, formulates the main research objectives, and presents the overarching research question. These elements are based on the gaps identified in existing research on sound-based interventions in the ICU.

1.1 GENERAL INTRODUCTION

1.1.1 THE CONTEXT

In 1858, Florence Nightingale said that "Unnecessary noise is the cruelest absence of care which can be inflicted upon either the sick or the well" (Nightingale, 1858). Due to the critical health status of these patients, they need constant and careful monitoring and life support in specifically equipped rooms. Automated mechanical ventilators, patient monitoring systems, and many other advanced medical technologies are essential in this effort (Kelly et al., 2014). Healthcare outcomes of patients have improved much owing to these innovations (Vincent & Singer, 2010). However, this development also established an environment centered around technical rather than human aspects of care (Velasco Bueno & La Calle, 2020). This shift is particularly evident in the acoustic environment, with continuous streams of sounds provided by medical devices contributing to sound levels that far exceed internationally recognized safety standards (Darbyshire & Duncan Young, 2022; Johansson et al., 2012). ICU patients spend increasing amounts of time awake during their stay due to trends towards lighter sedation (Vincent et al., 2016). Many patients are therefore conscious of these sounds during their stay, often perceiving them as unwanted and therefore consider them as noise. The constant noise of alarms, medical equipment and conversations can contribute to increased stress levels of patients, confusion, sleep disturbance and annoyance, which hinders the healing process. However, studies have shown the importance of the auditory stimuli within the soundscape, particularly for HCPs because it contains valuable information regarding the patient's condition (Oleksy & Schlesinger, 2018; Fatima et al., 2016). HCPs are dependent on equipment and patient sounds and need these auditory stimuli to provide patient care.

1.1.2 CURRENT HOSPITAL SOUNDSCAPE INTERVENTIONS :

Soundscape interventions have shown to significantly reduce sound levels in hospitals and improve the comfort of both patient and care staff (Delaney et al., 2019; Luetz et al., 2019; Vreman et al., 2023). Hospitals are increasingly aware of the importance of providing people-centered care environments in ICUs (Özcan et al., 2020; Rodriguez-Ruiz et al., 2025), introducing soundscape interventions at three different levels: (Fig 1) at the source, along the path (i.e., between source and receiver), or at the receiver (Bush-Vishniac & Ryherd, 2023). At the source, improvements focus on developing measures to reduce medical alarm noise, (Philips Healthcare, 2024; SASICU Project, 2023), implementing quiet-time protocols, and introducing staff-focused noise awareness tools (Jun et al., 2021; Lu et al., 2023; Spagnol et al., 2023; Özcan et al., 2021). Architectural solutions along the noise path, such as private, well acoustically insulated ICU rooms and sound-absorbing materials, significantly reduce sound transmission (Özcan et al., 2024; Luetz et al., 2016). At the receiver level, protective measures like earplugs and noise-cancelling headphones are common (Elbaz et al., 2017). Introducing new and positive sounds in the ICU can be a good solution to optimize the current ICU soundscape overall. Reintroducing pleasant natural sounds and music has therapeutic effects aligned with biophilic design principles (Özcan et al., 2023). For example, birdsong integration helps alleviate psychological stress (Saadatmand et al., 2015), and personalized playlists reduce opioid intake and delirium incidence (Khan et al., 2017).

Needs are essential for human well being and shaping positive experiences. Activities or environments that feel enjoyable or meaningful often fulfil one or more fundamental needs (Desmet & Fokkinga, 2020). An example of the need is comfort i.e having an easy, simple and relaxing life rather than experiencing strain, difficulty or overstimulation. In user experience research, the fulfilment of fundamental needs has been associated with positive user experiences, leading to positive emotions, and enhanced psychological well-being (Milyavskaya & Koestner, 2011) unfulfilled or frustrated fundamental needs have been linked to negative user experiences, stress and negative emotional responses (Deci & Ryan, 2000). This need centric soundscape approach remains unexplored in ICU soundscape design. This project focusses on designing a soundscape system in the ICU to help patients get out of the isolated state and feel emotional connectedness through sound by fulfilling the underlying psychological needs. The aim is to transform the ICU space at the receiver level i.e the patient by adding positive sounds to reduce the stress and anxiety caused by unwanted sounds.

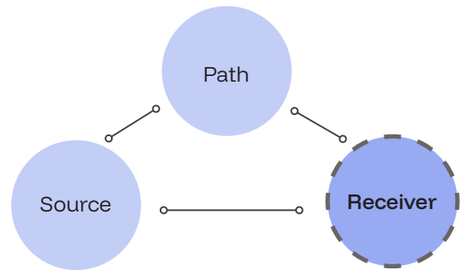


Fig 1: Sound Intervention classification by Bush-Vishniac & Ryherd et al. (2023)

1.2 PROJECT SCOPE

1.1.3 AIM AND RESEARCH QUESTION

The aim of this master thesis is to explore the psychological and emotional challenges faced by ICU patients. This includes investigating the sound related influences that create negative experiences for the patient. By identifying the specific needs and preferences of patients in ICU , and exploring the role of family members, healthcare providers and the patient himself, the study aims to design and validate a soundscape system that enhances connectedness during moments of vulnerability experienced by patients.

This research is important as it tackles a key element of patient care in ICUs - managing stress through sound. By enhancing the soundscape, the design system has the potential to reduce patient stress, contribute to better recovery, and possibly shorten ICU stays. It could also offer valuable insights and guidelines for creating more supportive and advanced ICU environments in the future.

On the basis of the aim , the following research question (RQ) is created which is further used to guide the design process in this project.

MAIN RESEARCH QUESTION (RQ):

How might we create a system in the Adult ICU that enhances connectedness in critically ill patients using personalised soundscapes during their stay?

This project is a collaboration between Delft Univsersity of Technology , members of the Critical Alarms Lab at the Faculty of Industrial Design Engineering (IDE). The key stakeholder of the project as an external collaborator is the Leiden University Medical Centre (LUMC) at Leiden, the Netherlands.
Fig. 2 shows the positioning of this project as guided by the existing research of the CAL in sound -driven design. The main opportunity in this project is to design sound experiences and facilitate the outcome through a product - service concept on an implementable basis.

Target Group :
Adult ICU at LUMC

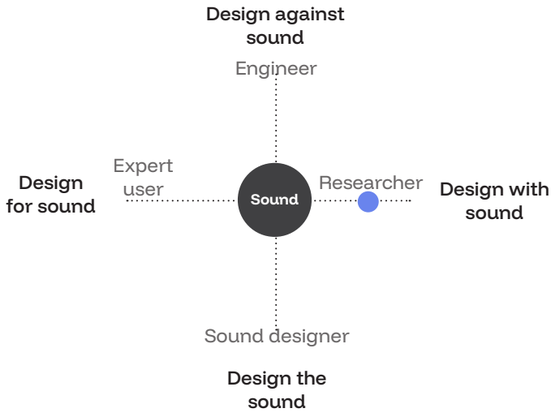


Fig 2: Sound Driven Design framework of Monache et al. (2022)

1.3 PROJECT APPROACH

Research Phase

Discovery - In this phase, the ICU at LUMC will serve as the primary context for conducting field observations and gaining in-depth insights into patient experiences, with valuable input from healthcare professionals. The goal is to build a deeper understanding of the challenges identified in the literature by exploring them from multiple perspectives within the actual environment.

Define - In this phase, insights gathered during the discovery phase are translated into a clear problem statement, which serves as a foundation for defining the design goal and initiating the human-centred design process. Alongside the design goal, the design vision are established, forming a starting point for developing the intervention. Fig. 3 gives an impression of the approach.

Design Phase

Develop - In this phase , a wide range of solutions are explored which forms the creative stage of the process. These ideas are formed into concepts which are evaluated primarily based on their usability and potential to meet user needs.This phase also includes critiquing ideas on the desirability, feasibility and viability (What Is Human-Centered Design? | HBS Online, 2020).

Deliver - The delivery phase focuses on refining the most promising ideas that most effectively address the defined problem at the start of the process. This stage involves multiple rounds of testing with stakeholders and participants to ensure the design's effectiveness and relevance. The final solution is shaped by insights gathered throughout the research and design phases, ensuring it aligns with the principles of human-centered design (HCD).

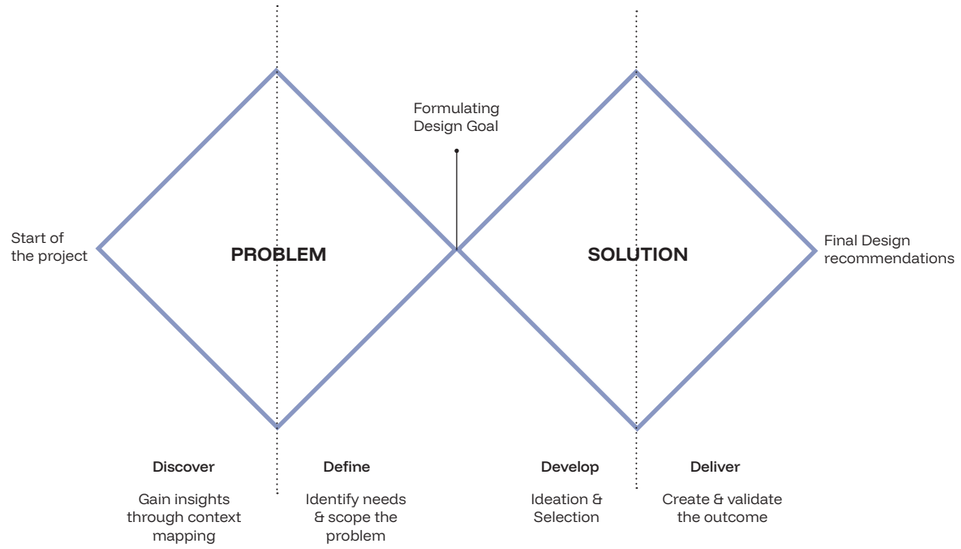


Fig 3 : Double diamomd approach used in the project (Kochanowska et al., 2021).

OVERVIEW OF METHODOLOGY

	SCOPING OF LITERATURE	PROBLEM ANALYSIS	DEFINING THE NEED	DESIGN EXPLORATION	DESIGN DEVELOPMENT	DESIGN EVALUATION
	OVERARCHING RESEARCH QUESTION **How might we create a system in the Adult ICU that enhances connectedness in critically ill patients using personalised soundscapes during their stay?**	**SUB RQ 1** How do ICU environmental conditions contribute to unfulfilled psychological needs in critically ill patients? **SUB RQ 2** At which points during the ICU journey do these unfulfilled needs occur and how do they impact the overall experience?	**SUB RQ 3** How can we address connectedness through sound and personalise the system to meet the underlying psychological needs in ICU patients ?	**Interaction with sounds** Facilitation of the soundscape system in ICU set up **Designing sounds** Strategies for new soundscape compositions	**Usability testing** (App flow) **Usability testing** (Experiencing sound compositions)	
HOW ? Methods & activities	**Literature study & Desk research** Current sound conditions in the ICU , physical and psychological effects, interventions , sound mitigation behaviours, ICU layout and types of sounds, ICU stakeholders and how sound conditions affect them, Negative experiences , isolation in ICU , sound influences	**Semi structured interviews** **Online survey for HCP**	**Literature on connectedness** **Sound preference survey** Defining aspects & fundamental needs associated with connectedness Categorization of sounds under identified needs	**Design explorations** Creative brainstorming session Self exploration System outlining Conceptualisation	**Concept development** Storyboards Final user interfaces Hardware components	Desirability . feasibility and viability Concept evaluation
WHAT? Outcome	**Defining RQ 1 and RQ 2** With the help of gaps in the current literature and interventions , an overarching research was defined to further investigate and come up with sub research questions 1 /2 .	**Environmental condition and experiences contributing to psychological distress in ICU** With the help of patient experience literature and HCP interviews and questionnaire responses , factors contributing to stress and anxiety were defined and sound related influences were studied in detail. **With the help of a patient journey map , a typical day of the patient was looked at to identify vulnerable moments in the day** Distinct moments where psychological needs are affected were defined to scope down.	**Aspects of connectedness were discovered from survey analysis** Relatednes, comfort , security and stimulation were scoped down as needs to be taken ahead **Soundscape elements and types** On the basis of the categorized sounds corresponding to the aspects of connectedness , types and sounds were defined to be used further for ideation.	**Design Goal** **Design characteristics** **Current and desired interaction** To achieve the design characterisics , a desired interaction was developed that outlines how the patient will be interacting with the system **Design outcome** A soundscape system that addresses different functions throughout the day by providing sound ambiences.	**Implementation in ICU setting** **Positioning in ICU journey of the patient and loved one** **Final dashboard designs to show sound implementation**	**Expert Interviews** **Final design recommendations** **Discussion** **Limitation** **Further Research Directions**

02

INTENSIVE CARE

This chapter provides a detailed overview of the Intensive Care Unit (ICU) context in which the design intervention is situated. It outlines the various stressors commonly experienced by ICU patients to build a foundation of literature to start context mapping in the hospital context. In addition, the chapter offers a brief insight into the role of sound within the ICU environment and introduces the key stakeholders involved, with a particular focus on practices and roles specific to the Netherlands. This chapter concludes with an introduction to the Soundscape definition in the ICU and how it affects the key stakeholders. It further explores the relationship between sound and psychological need fulfillment.

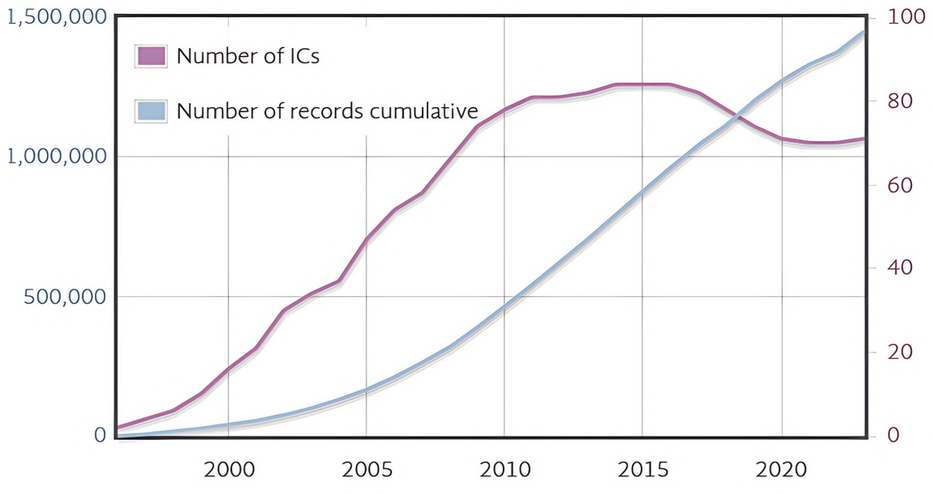


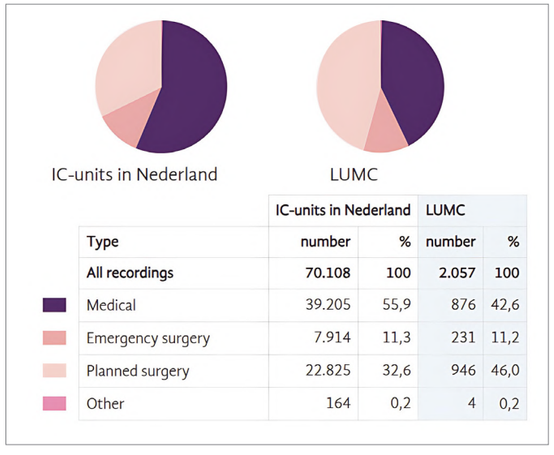
Fig 4 : Graph showing number of increasing IC admissions in the Netherlands (Stichting NICE, 2023)

2.1 INTENSIVE CARE IN THE NETHERLANDS

The Intensive Care Units (ICUs) in the Netherlands are specialized hospital departments that provide intensive treatment and monitoring to patients with life-threatening conditions requiring life support and those at extremely high risk of organ failure and death (Ervin et al., 2018). These units are equipped with advanced medical technology and staffed by multidisciplinary teams, including intensivists, specialized nurses, and various therapists, all trained to manage complex and critical health issues. In the Netherlands, ICUs play a crucial role in the healthcare system. According to data from the National Intensive Care Evaluation (NICE) foundation (fig 4) , since 2016, all Dutch ICUs participate in this quality registry, with approximately 75,000 new ICU admissions added annually (Stichting NICE, 2023).

2.1.1 ICU ADMISSIONS

Patients are admitted to the ICU for various reasons, including major surgical procedures, severe infections, respiratory failure, or traumatic injuries. The primary goal of ICU admission is to provide continuous monitoring and advanced medical interventions to stabilize patients during critical phases of their illness or recovery. In the Netherlands, ICU admissions are divided into three categories: elective-surgical, medical (non-surgical), and emergency-surgical (Stichting NICE, 2023). The decision to admit a patient to the ICU is based on the severity of their condition and the need for specialized care that cannot be provided in general hospital wards.



Type	IC-units in Nederland number	%	LUMC number	%
All recordings	70.108	100	2.057	100
Medical	39.205	55,9	876	42,6
Emergency surgery	7.914	11,3	231	11,2
Planned surgery	22.825	32,6	946	46,0
Other	164	0,2	4	0,2

Fig 5 : Percentage wise distribution of the IC units in the Netherlands (Stichting NICE, 2023)

Medical (Non-surgical) Admissions:

These involve patients with acute medical conditions requiring intensive monitoring and therapy. In 2023, medical admissions accounted for 55.1% of all ICU admissions in the Netherlands (Fig 5). Common diagnoses in this category include:

Pneumonia: 12.8% of medical ICU admissions
Sepsis: 8.9%
Cardiac Arrest: 8.2%
Overdose (medication, drugs, etc.): 8.1%

Surgical Admissions:

Patients undergoing major surgical procedures may require postoperative intensive care. Surgical admissions are further categorized into:

1.Planned (Elective) Surgical Admissions:

These are scheduled surgeries where postoperative ICU care is anticipated. In 2023, planned surgical admissions comprised 32.9% of ICU admissions (Fig 5). Common procedures leading to planned surgical ICU admissions include:

Cardiac Surgery (e.g., Coronary Artery Bypass Grafting or Valve Replacement): 34.6% of surgical ICU admissions
Aneurysm Surgery: 8.1%
Thoracotomy: 4.9%
Carotid Endarterectomy: 4.4%

2. Emergency Surgical Admissions:

These involve urgent, unplanned surgeries due to acute conditions such as trauma or complications requiring immediate intervention. In 2023, emergency surgical admissions accounted for 11.7% of ICU admissions (Fig 5). Other Admissions: This category includes patients admitted for reasons not classified under medical or surgical admissions, accounting for 0.3% of ICU admissions in 2023.

This project focusses on both planned and emergency admissions recognizing the importance of addressing the unique needs and treatment responses of all patients (including both female and male patients) in all different scenarios.

2.1.2 TYPES OF ICU PATIENT STRESSORS

Operating 24/7, the ICU is characterized by constant activity, including medical procedures, patient admissions, diagnostics, and surgeries. Routine care, such as administering medications and hygiene tasks, takes place throughout the day and night, while staff frequently co-ordinate care and families visit to support patients. These activities paired with the advanced medical technologies that the ICU utilizes for patient care are essential for sustaining life but also contribute to the ICU's highly stimulating and complex atmosphere adding to its technologically dynamic nature (Elbaz et al., 2017b; Martinez et al., 2022; Younis et al., 2019).

Factors that impact the physical and psychological health and well-being of patients are as follows -

Environmental Stressors :

Artificial lighting, while crucial for performing medical tasks around the clock, interferes with the natural light-dark cycle, contributing to circadian misalignment in ICU patients (Elbaz et al., 2017c; Ma et al., 2024). Additionally, the noisy nature is one of the notable characteristics of the ICU environment. A combination of monitor alarms, equipment sounds, staff communications, and external noises generates a persistent soundscape that exceeds recommended noise levels. This auditory chaos, coupled with continuous artificial lighting, significantly impacts patients, leading to disruptions in sleep, heightened stress levels, and delayed recovery (Younis et al., 2019 ; Martinez et al., 2022).Constant noise and movement triggers sympathetic nervous system activation, leading to elevated cortisol levels, increased anxiety, and emotional exhaustion. Unpredictable loud noises, particularly alarms, intensify stress responses, leaving patients feeling helpless and vulnerable (Younis et al., 2019 ; Martinez et al., 2022).

Sleep disturbances such as shortened sleep duration, fragmented sleep, or altered sleep architecture can severely affect both physical and mental health (Telias & Wilcox, 2019a). ICU patients often experience more daytime sleep, with fragmented sleep cycles dominated by N1 and N2 stages, while slow-wave sleep (SWS) and REM sleep are significantly reduced. Frequent arousals lead to poor sleep continuity, and many ICU survivors report sleep disturbances persisting for weeks or months (Telias & Wilcox, 2019c).

Psychological Stressors :

The absence of natural light cycles, disconnection with nature (outside world) and lack of meaningful interactions throughout the day isolates patients, weakening their sense of connectedness (Tronstad et al., 2020). Patients often experience a loss of control over their surroundings and personal autonomy, leading to feelings of helplessness & anxiety. The separation from family and reliance on healthcare professionals for basic needs further contribute to psychological distress. Sleep deprivation and resulting fatigue common in ICUs due to environmental factors like noise and light, exacerbates stress and can lead to delirium. These combined factors increase the risk of developing mental health disorders such as depression, anxiety, and post-traumatic stress disorder (PTSD) during and after the ICU stay (Novaes et al., 1997).

Physiological Stressors:

One of the primary stressors is pain, which may arise from the underlying medical condition, surgical interventions, or the presence of invasive devices such as tubes and catheters. Studies have identified pain as a major physical stressor in ICU patients (Novaes et al., 1997). The use of mechanical ventilation and the insertion of tubes in the nose or mouth are also significant stressors. Patients often find these interventions uncomfortable and distressing, contributing to their overall stress levels (Novaes et al., 1997). Prolonged bed rest can lead to muscle weakness and physical deconditioning, complicating recovery and rehabilitation efforts.

2.2 ROLE OF SOUND IN ICU

ICU noise levels frequently exceed WHO's recommended 30 dB at night, often ranging between 53–80 dB, with peaks above 80 dBA during critical care (Martinez et al., 2022). Elbaz et al. (2017) mentions noise levels were generally higher during the day compared to the night with median noise level in ICU rooms being 72.2 dBC (Fig 5). Major noise sources include medical equipment (cardiac monitors, ventilators, infusion pumps, alarms) and clinical activities (rounds, shift changes, patient admissions, morning care). Alarms, particularly disruptive, exceed 77 dBA and significantly disturb sleep (Elbaz et al., 2017). ICU noise levels are rising annually by ~0.38 dB (day) and ~0.42 dBA (night) (Darbyshire & Young, 2013).

Excessive noise negatively impacts health and recovery, contributing to sleep disturbances, cardiovascular stress, cognitive decline, and emotional dysregulation. Both patients and caregivers rank noise as one of the most distressing aspects of the ICU environment (Darbyshire & Young, 2013). Sleep deprivation caused by noise leads to fragmented and poor-quality sleep, reducing slow-wave sleep (SWS) and rapid eye movement (REM) sleep, both crucial for physical repair, memory consolidation, and emotional stability (Martinez et al., 2022; Elbaz et al., 2017). The persistent background noise in ICUs often matches or exceeds normal conversation levels (50–55 dBA), keeping the stress response active. This triggers sympathetic nervous system activation, leading to elevated cortisol levels, increased anxiety, and emotional exhaustion. Unpredictable loud noises, particularly alarms, intensify stress responses, leaving patients feeling helpless and vulnerable. Chronic noise exposure increases the risk of anxiety, depression, and post-traumatic stress disorder (PTSD), further slowing recovery and diminishing long-term quality of life (Elbaz et al., 2017).

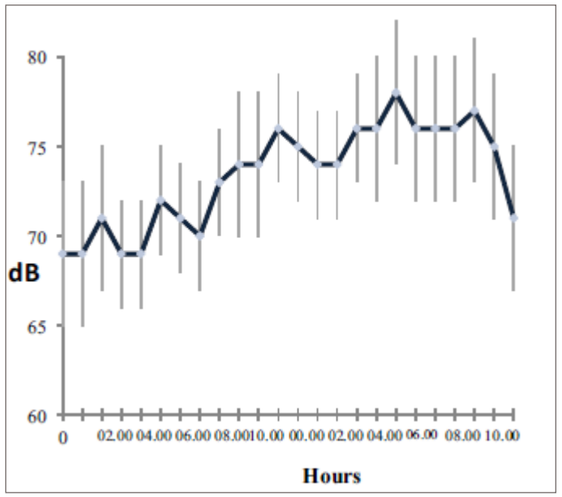


Fig 6 : The average dBC level every 10 s during the 24-h period recorded in an ICU (Elbaz et al., 2017).

2.3 ICU STAKEHOLDERS

In the context of healthcare , understanding the roles and perspectives of all key stakeholders is essential, especially those centered on improving patient experiences and outcomes in the intensive care units (ICU).

2.3.1 KEY STAKEHOLDERS

Healthcare professionals (HCPs), ICU patients and their loved ones are recognized as 'key stakeholders' in the intensive care setting. Each of these groups shares the common objective of achieving optimal care in the ICU, but their individual contributions toward this goal vary as depicted in Fig 7.

ICU patients:

These patients are the primary focus of the research study. They navigate the complex nature of critical illnesses, dealing with both physical and emotional challenges during their ICU stay. Understanding their experiences and specific needs is crucial to developing tailored interventions that provide them with the appropriate support and enhance their recovery process in the ICU environment.

Healthcare providers:

Intensive Care Physicians : Intensive Care Physicians are the primary caregivers responsible for diagnosing and treating critically ill patients in the ICU. They develop treatment plans and oversee the implementation of critical care interventions. Surgeons may also be involved depending on the patient's condition, performing necessary surgeries and procedures.
Critical Care Nurses: Nurses in the ICU work closely with the intensive care physicians to administer treatments, monitor patients' progress, and manage the side effects of treatments. They provide essential support and education to patients and their families, helping them understand the treatment process and make informed decisions about their care. Their role is vital in ensuring the day-to-day well-being of ICU patients, offering both medical and emotional support.

Family members & friends:

Family members and close friends play a pivotal role in enhancing the well-being of patients in the Intensive Care Unit. Their involvement can significantly contribute to the overall care and recovery process. Family members often understand the patient's preferences and values better than anyone else.

Fig 7 :Key stakeholders of the ICU context

2.3.2 ROLES AND ECOSYSTEM

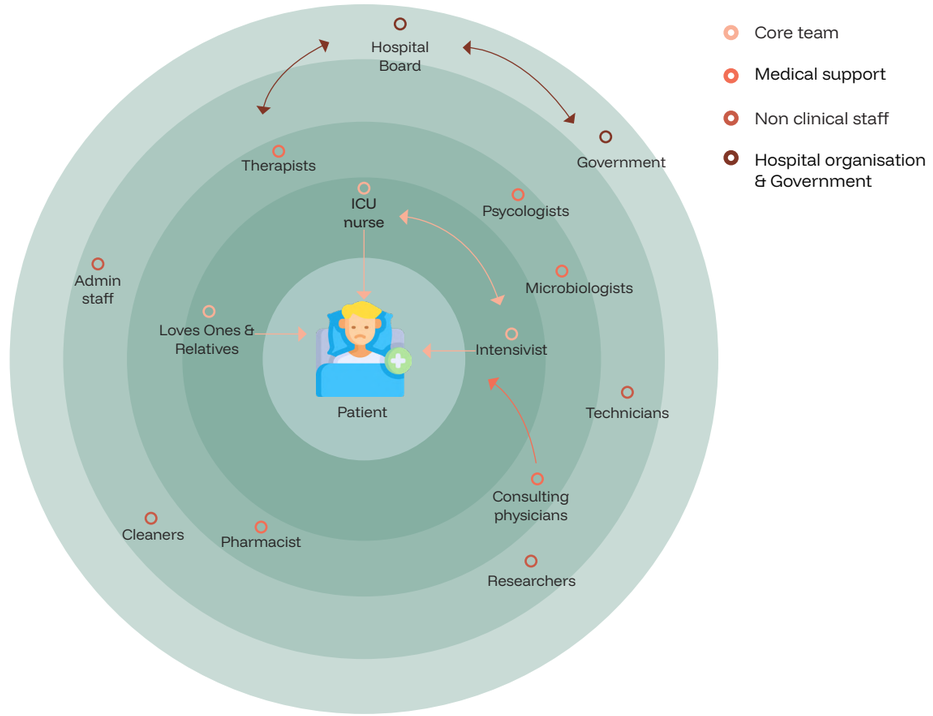


Fig 8 : Ecosystem of the ICU stakeholders

The value exchange shown in form of an ecosystem diagram in the above Fig. 8 is used to make some design decisions and will be taken into account in the intervention.

- Central to this project are the critically ill ICU patients for whom the intervention will be designed for as they will be the most impacted with the impact.

- The main handling and control over the system will be done by the HCPs. This decision is based on the HCPs' expert knowledge and their ability to assess and respond to medical needs effectively, ensuring that the system is used optimally and safely.

- Family members and friends are also crucial stakeholders. Although they are not the primary focus of the end experience of the system , their insights will be taken into account and designed what could benefit them in the care context as well.

2.4 SOUNDSCAPE DEFINITION

“ A Soundscape is an acoustic environment as perceived or experienced and/or understood by a person or people , in context “ (ISO 12913 , 2024).

2.4.1 THE TERM SOUNDSCAPE

The term ‘Soundscape’ came to light in a study of music in the 1970s through the work of a Canadian composer R.M. Schafer (Schafer, 1977). He defined the term ‘soundscape’ as “an environment of sound (or sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society”.

Soundscape perception considers sound as a holistic experience, encompassing natural, human, and technological sounds (ISO 12913-2:2018). Research suggests that sounds are rarely perceived in isolation but as part of a broader ecosystem. This ecosystem comprises various objects, people, and natural or artificial sources that produce sound, creating a dynamic acoustic environment. Soundscapes are thus understood as the interaction between these sound sources, the physical environment, and the psychological and physiological characteristics of the listener. (Özcan et al., 2022b). Soundscape research emphasizes the relationship between the acoustic environment and human health, particularly in sensitive settings such as ICUs. It distinguishes between unwanted noise and beneficial sounds that can be utilized as resources to enhance recovery and well-being (Louwers et al., 2024).

Psychological impact:

Soundscapes impact humans psychologically influencing their emotions and well-being. Natural soundscapes are often associated with a calming effect on people similar to that of natural landscapes (Cerwén et al., 2016; Franco et al., 2017). Their effectiveness can be seen in how they help reduce stress, as research has shown that listening to nature sounds can slow heart rate, ease anxiety, and create a calming effect (Alvarsson et al., 2010; Diette et al., 2003).
In contrast, harsh, industrial noises such as traffic or construction sounds can heighten stress and anxiety, leading to discomfort. The sounds that fill our environments affect our mental functions too. In busy urban centres, where the soundscape is dominated by continuous traffic noise, there is a risk of cognitive overload. Behaviourally, the characteristics of a soundscape can drive changes in our actions and interactions within a space. Noisy environments often lead people to alter their routines or paths to avoid the discomfort of loud sounds, whereas more pleasant acoustic environments can foster social interactions and encourage people to linger. By understanding the concept of soundscapes, we gain a deeper understanding of how sound influences people and the role it plays in our lives (Bilen & Can, 2021).

Music in critical care :

Literature highlights the use of music in critical care settings and documents it thoroughly. Music therapy has positively influenced patients in critical healthcare settings by reducing anxiety, relieving pain and improving overall wellbeing (Bradt & Dileo, 2014; Chou & Özcan Vieira, 2020; Dalli et al., 2022). Through methods such as personalised audio messages from family, traditional music and bedside radio , it has been understood that these apraoches in music therapy have provided a sense of familiarity as a psychological factor (Dalli et al., 2022b).

Additionally , especially in intensive care, the greatest benefits are observed with classical music, particularly compositions by Bach, Mozart, or Italian composers, as well as meditation music (Trappe, 2012). These genres are associated with a reduced need for sedative medication and a lower perception of pain, making them valuable non-pharmacological interventions in critical care settings (Aghaie et al., 2013; Çalışkan et al., 2023). Moreover, the emotional and cognitive power of music, especially songs from a patient’s youth or meaningful past, has been found to enhance mood, boost motivation and vitality, and encourage social interaction, which are essential factors for psychological recovery (Mateu-Capell et al., 2018). The ability of music to trigger memory and emotion underscores its therapeutic potential in promoting holistic care in the ICU.

While considering these benefits , this project does use music therapy at the core but sound compositions which can be tailored to the specific needs of patients and highly contextual to environments personal to individuals studied by Louwers, Pont, Gommers, et al. (2024a).

While music can be beneficial , it can an overhwhelming effect on the patients especially when it is generic and does not allign with the need of the day or the clinical atmosphere (Bradt et al., 2013). Meaningfully designed sound compositions can not only seamlessly blend in with the atmosphere but also be linked with environments or places close to the individual. Thus , this project explores how curated sound compostions can have an effect on the well - being.

2.4.2 IMPACT OF ICU SOUNDSCAPE ON STAKEHOLDERS

This section takes into account the impact on the stakeholders of the acoustic environment The various sound sources combined have an influence on the patient , family members and HCP staff differently in the way they perceive it. This section outlines the experiences and impact on the stakeholders outlined in the literature essential to be considered for the further direction.

Patients

“THE WAKEFULNESS TURNS INTO A NIGHTMARE. SUDDENLY I AM LYING IN AN IMPOSSIBLE PLACE, IN AN IMPOSSIBLE BED, WITH LOTS OF NOISE, BELLS AND WHISTLES.”
(wijzijnMEO, 2024).

The advances in critical care have led to increasingly favorable odds for patients to survive their stay on intensive care units (Kelly et al., 2014), but they may develop long-term psychological, physical and cognitive problems that persist after discharge (Geense et al., 2021). Psychological impairments such as post-traumatic stress disorder and anxiety are partially attributable to the environmental conditions of ICUs (Darbyshire et al., 2019). The main modifiable factors among the environmental disruptors are sound (50.4%) and light (45.3%), making them primary targets for intervention (Martinez et al., 2022). In fact, patients, healthcare providers and relatives rate hearing alarms, medical device sounds, and sounds produced by other patients as particularly stressful (Krampe et al., 2021). These stressors turn ICUs into a hostile acoustic environment for both caregiver and patient. Patients suffer from disturbed sleep-wake rhythms (Dawson & Johansson, 2020), potentially resulting in increased incidence and severity of delirium. (Novaes et al., 1997).

Like healthy individuals, ICU patients listen with intent (Tuuri & Eerola, 2012) to their auditory environment for cues that fulfill their needs for reassurance, safety, and information (Özcan et al., 2018; Van Den Bosch et al., 2018). Louwers et al. (2025) studies that sounds makes patients feel alert all the time while it a also a source of orientation. Infact , some patients expressed that they liked listening to music as it was the only source of distraction from the pain while some felt the generic radio music did not comfort them which takes us to understanding how personal preferences are important when it comes to need fulfilment. Besides psychological impact , the ICU sounds have shown to affect patients physically as they may experience unknown , loud and unoredictable sounds leading to an increase in blood pressure levels and heart rate (Nilson et al., 2005).

HCP

“WE TRY TO MINIMIZE IT , BUT WE CANNOT DO MUCH ABOUT IT. ”
(VAN HOUWELINGEN, 2022)

ICU’s noisy environment profoundly impacts healthcare staff, leading to alarm fatigue, a condition characterized by clinicians becoming overwhelmed and less responsive to alarms due to their excessive frequency. This phenomenon contributes to frustration, elevated stress levels, and diminished patient safety (Sanz-Segura et al., 2019). Persistent noise exposure can impair cognitive performance among nurses, hindering their ability to effectively prioritize critical tasks and respond promptly, thereby reducing teamwork effectiveness and increasing workplace stress (Maidl-Putz et al., 2014).

Research indicates that designers have explored various strategies for alarm management to mitigate the negative impacts of ICU noise. Potential solutions to alarm fatigue include organizational and educational interventions aimed primarily at reducing unnecessary noise and improving alarm handling practices. However, these approaches predominantly focus on noise reduction and often overlook the potential benefits of integrating positive soundscapes. Incorporating intentionally designed soundscapes could significantly benefit the healthcare staff as well.

Loved ones

“THE CONSTANT NOISE WAS TOO MUCH; ALL I COULD THINK ABOUT WAS WHETHER MY FATHER WAS OKAY.”
(VAN HOUWELINGEN, 2022).

The ICU is never quite with constant beeps and mechanical sounds from machines making the sound environment overly stimulating even for the family members. This excessive auditory stimulation can heighten loved ones’ anxiety, leading them to become more concerned about the patient’s condition (Kok, 2024).

Moreover, this continuous exposure contributes to feelings of isolation and disconnection as family members leave the ICU, increasing their sense of helplessness and undermining their confidence and hope. Ultimately, these intimidating sounds create a profound lack of comfort, affecting the emotional bond and sense of familiarity between patients, their loved ones, the environment and their homes (Kok, 2024).

2.4.3 SOUND & NEED FULFILMENT

Understanding what fundamental needs are fulfilled or affected by the perception of sounds is important when designing soundscapes for a critical space like ICU.

Fundamental Human Needs

Sound connects our physical and psychological world, bridging the outer physical world with our inner emotional one through vibrations (Bennett, 2019). Deci and Ryan (2000) proposed that psychological needs form the basic nutriments for an individual's growth, integrity, and well-being, and that the fulfilment of these needs is an ongoing source of meaning and pleasure (Deci & Ryan, 2000). The implementation of needs as a basis for design can support a systematic approach to design for positive experiences and subjective well-being (Desmet et al., 2001; Desmet & Hekkert, 2007).

Cross-cultural studies into needs and subjective well-being have shown that certain needs are universal and exist regardless of cultural differences, and that the fulfilment of fundamental human needs contributes to subjective wellbeing, provided that each need is fulfilled to some extent (Tay & Diener, 2011). Building on the Maslow (1943) theory , Desmet and Fokkinga (2020) introduced a typology of thirteen fundamental needs for human-centered design consisting of : the need for Autonomy, Beauty, Comfort, Community, Competence, Fitness, Impact, Morality, Purpose, Recognition, Relatedness, Security, and Stimulation (Fig 9). This typology provides a structured approach to understanding fundamental human needs and sub needs and gives opportunities to fuflfil them through design. In the context of this project , this typology can be used for not just for need identification but also to categorize sounds and create a framework for the perceived quality of the cerated soundscapes in the intervention.

How does sound leave needs unfulfilled in ICU patients?

ICU patients often experience negative interactions with their environment, particularly related to sound, which highlights a deeper issue: the failure to fulfill certain fundamental human needs. Although noise reduction has traditionally been the focus of ICU sound interventions, its impact on outcomes meaningful to patients remains uncertain (Kim et al., 2021; Luetz et al., 2019; Delaney et al., 2019). Recent research by Louwers et al. (2024) highlights the potential of personalized soundscapes, tailored to individual psychological and emotional profiles, to enhance patient well-being. Their work suggests that sound can go beyond being a source of disturbance and instead become a tool for meeting deeper psychological needs. Yet, in their qualitative study (Louwers, Pont, Gommers, et al., 2024b), patients in single-occupancy ICU rooms described the auditory environment as monotonous, unfamiliar, alienating, and at times distressing feelings that often heightened their sense of isolation and discomfort. These insights resonate with findings from Kim et al. (2024), who, through a mixed-method study, identified nine key contributors to negative ICU experiences: hopelessness, dependency, trauma, lack of distraction, loneliness and disconnection, loss of dignity, physical discomfort, illness-related exhaustion, and difficulty sleeping in a noisy environment. These recurring themes underscore the need to address fundamental human needs such as connection, autonomy, dignity, and the pursuit of self-fulfillment that are often overlooked in conventional ICU design, especially in terms of sound. Moreover, the European Environment Agency (2020) reiterates that environmental noise remains a significant public health concern across Europe. Collectively, this body of research indicates a clear opportunity to rethink ICU soundscapes not just to control noise, but to actively support the psychological well-being of patients through intentional and personalized auditory design.

Fig 9 : Overview of the fundamental needs typology (Desmet & Fokkinga, 2020).

03

CONTEXT STUDY

This chapter introduces the context of the project, situated within the Leiden University Medical Centre (LUMC), and provides an overview of the relevant equipment and ICU floor plan to support spatial understanding of the setting. Through a combination of qualitative and quantitative research methods used to assess the sounds, it offers a detailed representation of the auditory environment within the ICU.

Fig 10 : Entrance of the Leiden Unversity Medical Centre

3.1 LEIDEN UNIVERSITY MEDICAL CENTRE (LUMC)

3.1.1 THE ICU ENVIRONMENT

This project specifically focusses on the Adult ICU at Leiden University Medical Centre in Leiden, the Netherlands. (fig 10 and 11)
Leiden University Medical Center (LUMC), is a prominent academic hospital affiliated with Leiden University. Established in 1996 through the merger of the university hospital and the medical faculty, LUMC integrates patient care, research and education under one roof. The center offers a comprehensive range of medical specialties and serves as a tertiary referral center for the northern part of South Holland. Specialized units within LUMC include ophthalmology, neurosurgery, cardiothoracic surgery, neonatal and pediatric surgery and intensive care, pediatric oncology, orthopedic medicine, biliary surgery, rheumatology, and a Level I trauma center. The Intensive Care Department at LUMC provides specialized treatment and care for patients experiencing potentially life-threatening issues affecting vital bodily functions such as respiration, heart rate, and blood pressure. Admissions to the Intensive Care Unit (ICU) can be planned, for instance, following major surgery, or unplanned, resulting from emergencies like accidents or acute severe conditions. The ICU is equipped with advanced medical technology and staffed by specialized healthcare professionals, including intensivists and intensive care nurses, ensuring the delivery of high-quality care to critically ill patients. LUMC is committed to continuous improvement in patient care through participation in various internal and external quality research projects, improvement initiatives, and registration systems. The institution engages in ongoing studies to enhance future patient care, adhering to strict privacy regulations to protect patient information.

Additionally, LUMC offers a range of educational programs, including bachelor's and master's degrees in Medicine and Biomedical Sciences, as well as specialized training for healthcare professionals. Afdeling Intensive Care | LUMC, n.d.).

The ICU environment at LUMC is laid out to optimize patient care and staff efficiency (Fig 12). Key areas include isolated rooms for individual patient care, which are essential for preventing cross-infection and ensuring patient privacy. The design of the ICU also features nurse stations that allow for effective monitoring and quick access to each patient. LUMC's ICU aims to provide a healing environment with reduced noise levels and controlled lighting to mimic natural cycles, enhancing patient recovery. However, despite the efforts to reduce stress levels, the reality is that stress remains a significant concern for patients (Afdeling Intensive Care | LUMC, n.d.).

Fig 11 : Corridor of the ICU wing at LUMC

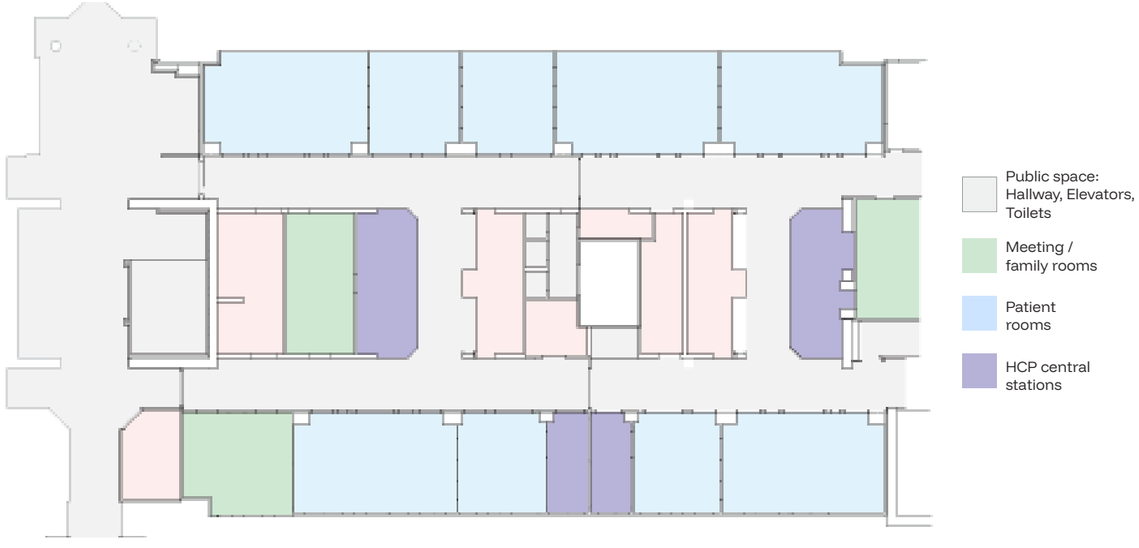


Fig 12 : Floor plan of the LUMC ICU wing

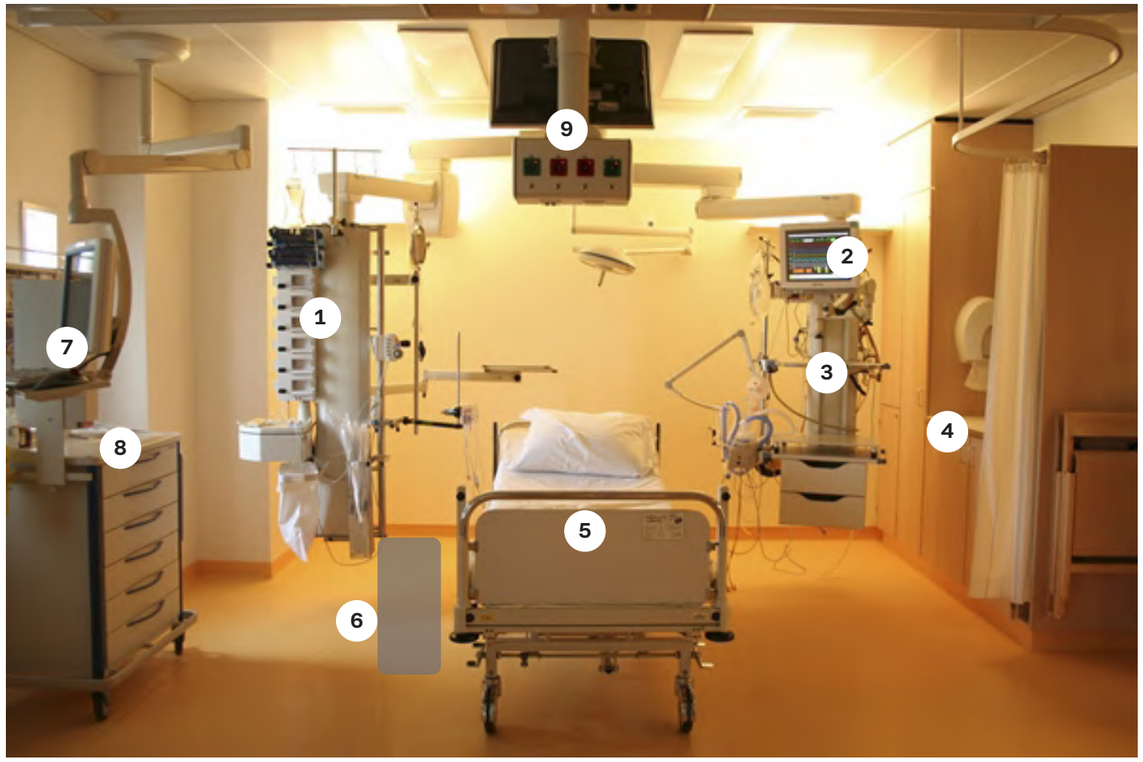


Fig 13 : ICU box from HCP perspective

Fig 14 : ICU box from patient point of view

3.1.2 ROOM LAYOUT AND EQUIPMENT

Fig 13 and 14 give an impression of the interior of the patient room from the point of view of what HCP sees and from what the patient sees respectively.

The ICU room is equipped with suitable medical equipments for the treatment required by the patient and some product aimed for personal care and comfort like television (9) and pictures from family members.

One of the most prominent elements in the ICU room is the intensive care bed, (5) which is equipped with electrical outlets and digital connections to support advanced medical care. The mattress is adjustable, allowing for various patient positions to aid in comfort and treatment. Beside the bed, a syringe pump (1) is typically present to administer precise doses of medication. This pump is programmed to alert healthcare professionals when it is nearly empty or if medication is not being delivered correctly. Another key piece of equipment is the dialysis machine,(6) if the patient needs) used to filter toxins from the blood when a patient's kidneys are not functioning. This device requires a central line, a tube placed near the heart and secured to the skin to ensure stability. The ventilator(3) is another essential device in the room, helping patients breathe by delivering oxygen or air directly into the lungs through a tube inserted into the mouth. It also triggers alarms when it detects sudden or abnormal changes in breathing patterns.

All patient vital signs such as heart rate, blood pressure, and respiration rate are continuously monitored and displayed on a central screen within the room. (2) This monitoring system is crucial for identifying any deviations that may require immediate attention.Other than this , there is a monitor and desk with all supplies that the nurse needs present in the room. (7) & (8) .

3.2 SOUND ASSESSMENTS AT LUMC

3.2.1 SET-UP AND METHOD

This context study was conducted at LUMC with the aim to make observations not just sound related but also understand behaviors in the ICU related to the events taking place. Both unstructured and structured sound observations were conducted. This allowed the researcher to absorb all the information without any predeterminations.

Unstructured Observations

- Observing as HCP:

This activity was conducted through shadowing the nurses to be a part of their routine activities and make observations.

- Observing as a non - participant

As a non-participant observer , the researcher like a fly on the wall observed the environment , heard sounds and responses taking place.

Structured Observations

- Sound Catalogue :

A sound event observation technique has been used to describe the frequency/occurrences of different sound events as can be perceived by the patient's point-of view. A pre-estimation was done on the different possible sound sources/sound types by earlier observation. The observer would be present inside an ICU room next to a patient, so the observer would be exposed to same sounds as a patient would be including monitor, ventilator or infusion pump sounds. The observer's presence should not be intrusive for the patient. Therefore, the observation only took place where the patient was unconscious or asleep. Table 1 shows the possible sound sources used to determine the occurence of sounds.

Mechanical sound	Electric amplified/ generated sound	Human activity	Human body	Nature sound
Air/ Ventilation Machines Liquid sounds Mechanical impact (sound between product parts)	Red , yellow, blue alarms Pump beeps/ alarms Ventilator alarms Phone ringing/ notification Television/ Radio/ Music	Walking Movement Sound of Moving/ pushing trolly/ container Moving plastic bags Opening/ Closing doors	Non-verbal/ Non-vocal (clapping, sneezing) Non-verbal/ Vocal Patient related Verbal/Vocal Medical discussion	Weather/ Nature Animal sounds

Table 1 : Sound types for observation

- Sound level measurements :

To gain an understanding of sound pressure levels within a typical ICU environment, a SoundEar decibel meter was employed to measure the variations. A simulated setup was arranged inside the ICU, wherein typical auditory elements such as monitor alarms, ventilator sounds, and equipment beeps were activated at intervals to replicate realistic conditions. Simultaneously, the hallway environment immediately outside the ICU room was left in its natural state, capturing ambient background noise. The researcher conducted measurements both inside the room and in the hallway, systematically transitioning between the two spaces to record fluctuations in sound pressure levels and observe the contrast.

3.2.2 RESULTS

Qualitative Insights :

Observing the ICU from the point of view of the HCP in the shadowing process made the researcher understand how alert the HCP's have to be to respond to events in the ICU. During the shadowing , it was also observed that there is a lot of co-operation between nurses to ensure the promptness in patient care delivery. Sound of alarms play a big role for them in terms of receiving important information about the patients while it also causes them fatigue. Another important observation that made was about how the nurses react to different patient needs in terms of providing them with a different stimuli like switching on the TV or playing music they like which gives an insight that nurses are a major contributor to personalise care to patients.

Observations also included experiencing the acoustic environment from the patients' perspective, specifically noting how centrally positioned they are within the room. The sounds appeared directed toward the patients, creating a heightened sense of continuous alertness. This was experienced by the researcher herself while noting the sound events.

Quantitative Insights

- Frequency and types of sounds

The data collected consisted of distinct sound events occurring within the ICU environment. These sound events were recorded in 5-minute intervals, focusing on the nature and frequency of auditory occurrences across various ICU units during daytime hours. Sound observations were systematically conducted over 69

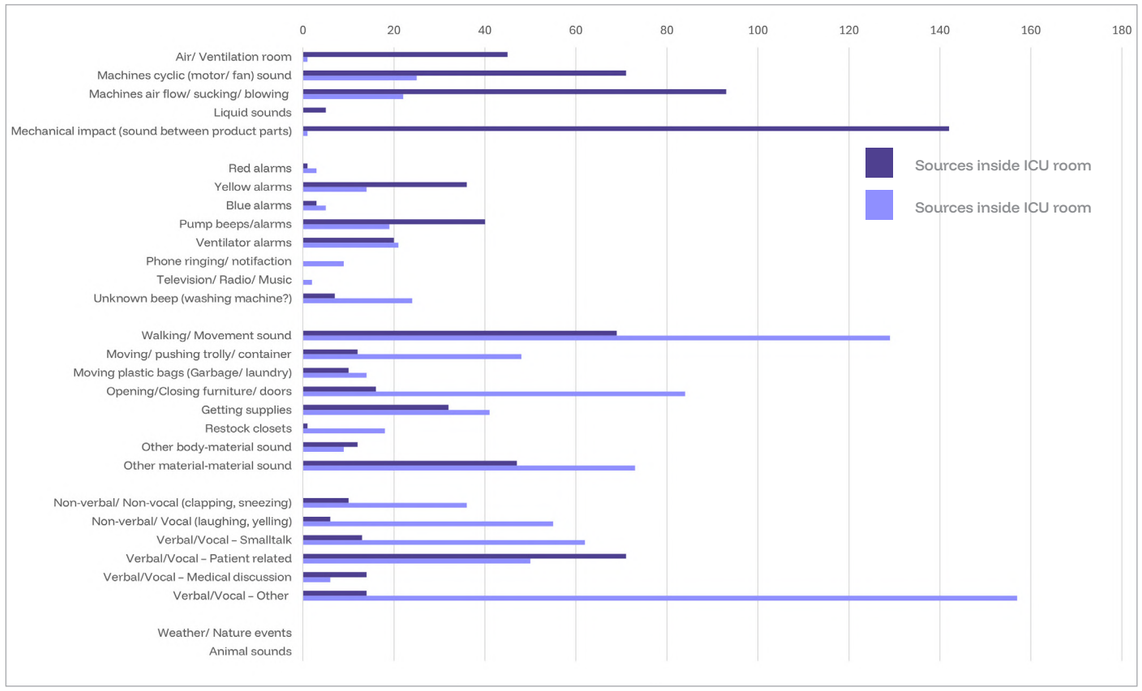


Fig 15: Sound type frequency occurence in the ICU according to the source of the sound

separate 5-minute intervals, totaling 345 minutes of data. During each interval, unique sound events were identified and counted. Continuous or ongoing sounds were recorded only once per interval to reflect their less disruptive nature in the overall acoustic landscape, despite their significant contribution to the background sound environment. In contrast, discrete and separate sound occurrences within each interval were individually noted. This approach was chosen to more accurately represent how sounds of different durations impact the perceived atmosphere. Observations were carried out across ICU Units 1/2, 3/4, and 5, and spanned various times between 8:00 a.m. and 8:00 p.m. While the sessions were not all conducted on the same day, they captured a representative range of routine daytime activities in these intensive care units.

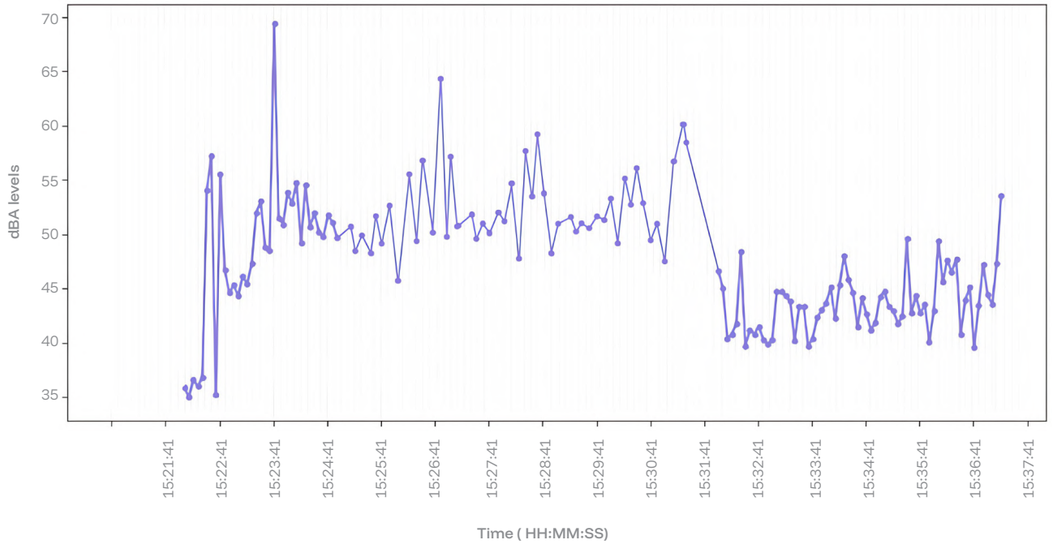
Fig 15 clearly depicts sound frequencies categorized by their source, either from inside or outside the ICU room. Key observations include:

Inside the ICU room :
The dominant sounds originate primarily from mechanical sources, particularly the "Mechanical impact (sound between product parts)" category, which shows the highest occurrence among all internal sounds. Additionally, sounds related to machines like cyclic motors, ventilation, and airflows are frequently noted, highlighting that these are mostly continuous, persistent background noises.

Outside the ICU room
Human-generated sounds are predominant here, especially "Walking/Movement sound", "Verbal/ Vocal - Other", "Opening/Closing furniture/doors," and "Moving plastic bags (Garbage/Laundry)." These sounds significantly surpass the frequency of inside human-generated noise, indicating that human activity outside the ICU rooms heavily contributes to the overall acoustic environment.

Alarms :
Alarm sounds are relatively infrequent compared to mechanical and human-generated sounds. However, this infrequency does not accurately represent their disruptive impact. While fewer alarm events are recorded, their prolonged duration and varying intensity significantly affect how intrusive they are perceived. For example, pump alarms, though fewer in number, were notably more intrusive and disturbing due to their loudness and persistence, compared to quieter alarms such as yellow alarms.

Fig 16 : Measurement of Sound Pressure Levels (dBA) in the ICU Environment



- Sound pressure levels

The graph (fig 16) shows fluctuating sound pressure levels (in dB) recorded at an interval of 20 mins in a in an ICU room, where clinical alarms were artificially simulated to mimic a realistic scenario of the ICU soundscape. Notably, during the period where alarms and equipment sounds were active in the room, sound levels peaked at nearly 70 dBA, indicating a sharp increase. Overall, the dB levels ranged approximately from 35 dBA to 70 dBA, showing significant variability likely caused by intermittent beeps, alarms, background equipment noise, people walking outside or other surrounding activity.

After 15:31:41, a noticeable drop and stabilization in sound levels is observed, reflecting the transition from inside the ICU room to the hallway environment. This section illustrates a quieter ambient condition, with values generally remaining lower and showing less abrupt fluctuation, suggesting a clear acoustic contrast between the patient room and surrounding corridor.

3.3 SOUNDSCAPE OF ICU

As a result of the insights gained from the context study at Leiden ,the acoustic environment is visualized in Fig 17. The following sound sources are present in the ICU with different listeners.

1. Medical Equipements :
Various types of medical equipments present in the ICU ike Cardiac monitors, Ventilators and infusion pumps produce a variety of alarms and beeps along with mechanical sounds which are important for monitoring.

2. Nurse Actvity :
HCP activites include medical conversations, assessments and important procedures. Along with this there is ambient noise create by various human acitivities.

3. Sounds from patient :
Some types of sounds come from the patient himself like calling out names of loved, expressing pain and sometimes shouting. These generally comes from the discomfort they want to express.

4. Environmental Sounds :
Sounds like distant chatter , sometimes sounds coming from the air conditioning system as well as sounds coming from the window contribute to the overall noise level of the room. These also include noise from other patients, emergencies or visitors from other patients.

5. Visitors :
The soundscape is noticeably affected by the presence of visitors, who engage in conversations with patients and healthcare professionals, offering emotional comfort and support. Although these interactions positively influence the patients' mental well-being, they simultaneously add to the overall ambient noise level in the environment.

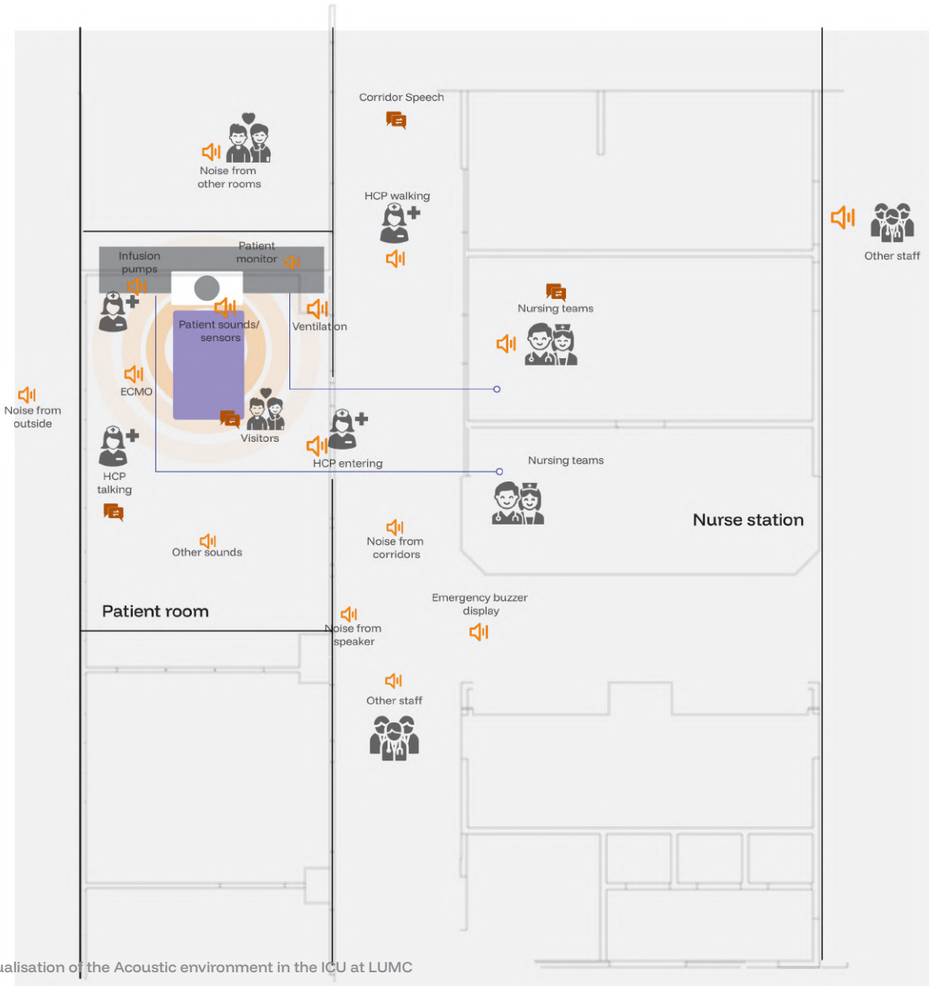


Fig 17 : Visualisation of the Acoustic environment in the ICU at LUMC

04

MAPPING THE NEED

This chapter establishes the foundation for the design goal by examining patient concerns in the Intensive Care Unit (ICU) with a focus on unmet psychological needs. Sub research questions are presented which guides the study. Using an event journey map, the study investigates when these needs arise and identifies potential triggers within the ICU environment. The chapter also introduces and defines the concept of connectedness as a key psychological need, supported by insights from a targeted survey that explores how this need is perceived and potentially fulfilled through sound.

4.1 DEFINING SUB-RESEARCH QUESTIONS

Empirical research was essential to accurately map the needs of ICU patients and was structured around three sub-research questions. These questions will help guide our next steps and ensure our design decisions stay focused on addressing the most important issues. By answering these questions, we can create designs that better align with the project's goals and effectively meet user needs.

SUB RQ 1:

How do ICU environmental conditions contribute to unfulfilled psychological needs in critically ill patients?

This question aims to explore the various elements within the intensive care environment that may lead to feelings of isolation and disconnection among patients. To thoroughly investigate this, patient experiences will be closely studied across different stages of their ICU journey, capturing their emotional responses and identifying key moments of vulnerability. Insights from healthcare professionals (HCPs) will also be gathered to gain a deeper and more comprehensive perspective on patient interactions, challenges, and care practices.

This sub-research question is addressed in Section 4.2.

SUB RQ 2:

At which points during the ICU journey do these unfulfilled needs occur and how do they impact the overall experience?

This question mainly focusses on the timeline of a patient journey and when do the needs occur. The focus will also be on understanding what the specific events are that have an impact on the journey contrubuting to a negative experience.

This sub-research question is addressed in Section 4.3

SUB RQ 3:

How can we address connectedness through sound to meet the unfulfilled psychological needs of ICU patients ?

This question aims to explore how individuals perceive connectedness and identify which psychological needs are most closely associated with it. By examining preferred sound types in relation to these needs, the research seeks to inform how such insights can be applied in future design explorations towards personalisation.

This sub-research question is addressed in Section 4.4

4.2 PATIENT EXPERIENCES

SUB- RQ1:

How do ICU environmental conditions contribute to unfulfilled psychological needs in critically ill patients?

4.2.1 PATIENT PERSPECTIVES

Method :

This section explores patient experiences from both patient and HCP perspectives to answer the above mentioned sub research question which guides the study. The research has been done using three different resources to get an expansive and comparative understanding of the patient needs very significant for the project : Graduation thesis of a PHD canditate from TU Delft , patient blogs and systematic analysis from scientific literature. A qualitative thematic analysis has been done to learn in depth about the moments of negative and positive experiences later leading to identifying the barriers to the sense of connectedness from both patient and HCP perspectives following the approach outlined by Braun & Clarke (2006). This method consists of identifying, analyzing & reporting patterns in data. Using a lot of quotes and analysis from the resources used, patient data was extracted and collected into various clusters. For the HCP perspective, quotes from interviews and the survey results were analysed to identify themes connected to the patient perspectives.

Fig 18 : Themes emerged as a result of the analysis of the patient perspective

4.2.2 RESULTS

Fig 18 shows the themes emerged after analyzing patient perspectives. These themes have been distrubuted in three segments namely experiences ,psychological impacts and sounds related needs to understand whether they concern the internal or external factors in the ICU environment. The themes from segments experiences and psychological impact have emerged from the patient blogs while the Sound related needs from pre-existing gradutation thesis.The themes are explain as followed :

Overall Experiences

The Experiences cluster reflects the multifaceted nature of patient encounters in the Intensive Care Unit capturing the perceptual challenges of they endure.

Sensory Sensitivity:
This theme mentions the psychological effects on patients caused by the environmental stimuli like unwanted stimuli and noise from the medical equipments which heightens the feelings of anxiety and stress.

Decreased autonomy:

This theme outlines the patient's diminished sense of autonomy, rooting from physical dependency and the inability to control one's surroundings, often resulting in feelings of helplessness and a shattered sense of self.

Visual associations :

This theme is defined as the way the patient keeps a record of the passing of time in the ICU. These include both physical and mental cues like looking at the clock or passing people outside the window.

Overall ambience:

This theme is defined as the characteristics of the environment and the events that have an impact on the patient related to sleep wake cycles , nursing care and the overall atmosphere.

2. Psychological impact

This theme mentions the psychological effects on patients in response to the environmental events around them like feeling lonely in the evening or restlessness due to sleep disruptions. These aspects reflect the internal psychological strain placed on patients who often face long periods of sedation, physical immobility, and restricted communication.
Disorientation upon waking up, feeling disconnected from the outside feeling abondoned and lonely to name a few. This theme specifically outlines the vulnerability moments in the ICU journey.

3. Sound related needs

The Sound-related Needs theme clearly describes what patients need in terms of sound and communication within the Intensive Care Unit, emphasizing how sound can function both as a stressor and as a potential therapeutic tool.

Orientation through sound :
This theme describes how patients rely on recognizable auditory cues to make sense of their ICU environment, influencing their sense of safety and emotional state.

Coping with disruptions:
This theme captures how intrusive and frequent auditory disturbances causes wakefulness.

Auditory support:

This theme mentions how hearing sounds of human presence, particularly staff voices and movements, reassures ICU patients by reducing isolation and enhancing perceived safety.

Variation:
This theme defines the limited diversity and repetitive nature of ICU sounds perceived negatively by the patient.

Association with sounds:

This theme defines the perception of sounds by linking them to familiar or imagined sources causing both negative and positive effects.

Communication:

This theme reflects ICU patients' sense of isolation, dependency, and fear when unable to reliably communicate with staff resulting in uncertainty, panic, and heightened reliance.

4.2.3 HCP PERSPECTIVES

As direct interviews with ICU patients were not possible due to institutional restrictions, the patient experience at LUMC ICU was explored through insights from nurses and doctors. This was facilitated by the supervisor's professional network within LUMC.

Method used :
An online questionnaire, created using Qualtrics.com, was used to collect insights consisting of a combination of closed and open-ended questions. It was distributed to ICU nurses via email, using the supervisor's professional network to ensure targeted and relevant participation. A semi structured interview followed the survey which was conducted in person at the hospital with a consent form. Four nurses participated in the interviews.

Participants :
A total of 50 nurses and doctors participated in the questionnaire. The survey was divided into two main sections. The first focused on the current sound environment in the ICU, exploring the types of sounds present and how they are experienced. The second section addressed the emotional impact of the ICU on patients, aiming to identify key triggers for emotional highs and lows. The questionnaire concluded with questions about possible sound-based interventions, inviting participants to share their thoughts on what types of sounds could positively support patients during their ICU stay.

	Male	Female	Neutral
Participants	18	31	1
Years of experience & profession	ICU nurse and doctor 2 - 30 years of experience		

Table 2 : Demographic data of the participants

4.2.4 RESULTS

The results from the HCP perspectives are drawn from the insights recorded from the online survey and the semi structured interview session.

The results have been presented in six distinct categories :

Challenges in the ICU

A - Current sound stressors
B - Experiences around sound conditions
C - Moments of vulnerability of patients in the ICU

Opportunities in the ICU

D - Potential new sound based interventions
E - Sound that can create a healing environment
F - Control over the environment

A - Current sound stressors

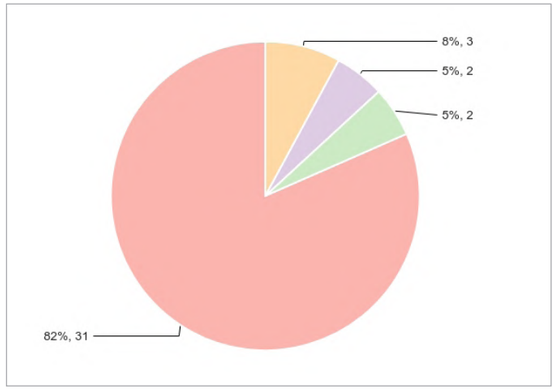


Fig 19 : Sounds causing most distress to patients

This pie chart (fig 19) illustrates which types of sounds ICU staff believe cause the most distress to patients, based on 49 responses. A significant 81.63% (40 respondents) identified alarm/machine sounds as the most distressing, making it by far the leading source of auditory discomfort in the ICU. In contrast, 10.20% pointed to sounds from other patients, while only 4.08% each selected corridor noises and sounds from emergencies. This data highlights a clear concern around the constant and intrusive presence of machine and alarm sounds, suggesting that addressing these specific noises could greatly improve patient comfort and emotional well-being in ICU settings.

B - Experiences around sound conditions

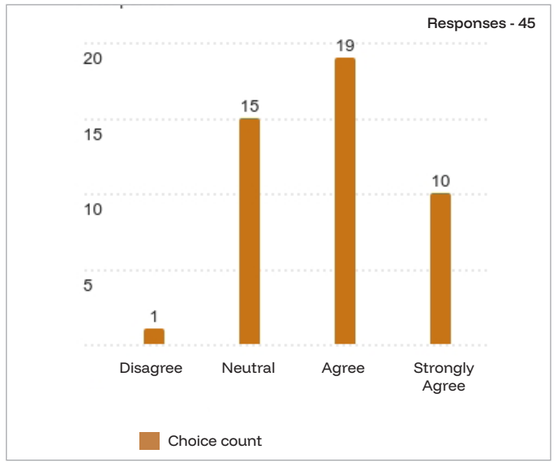


Fig 20 : Percentage count on Agitation Caused by Noise in ICU

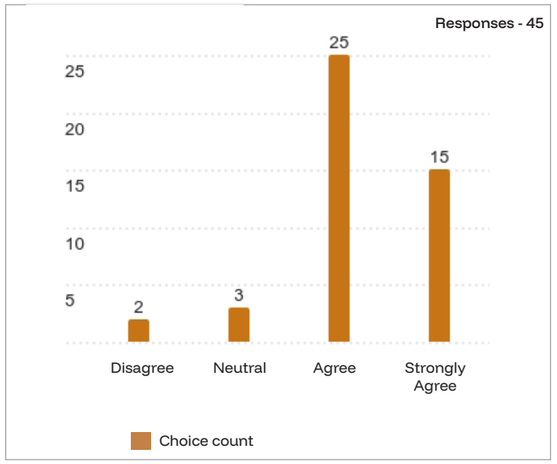


Fig 21 : Percentage count on Sleep Disturbance Due to ICU Sounds

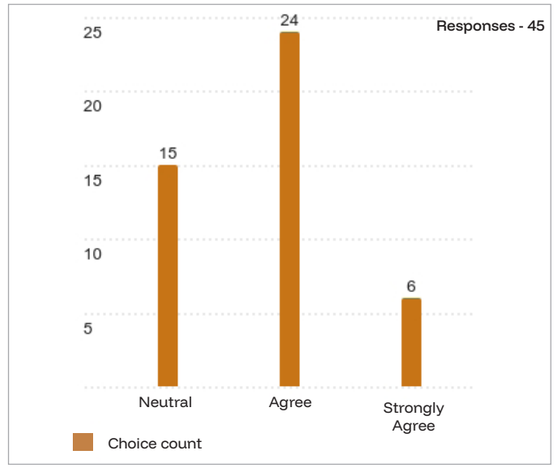


Fig 22 : Percentage count on Impact of Soothing Sounds on Emotional Well-Being

The survey responses highlight a strong consensus among healthcare staff regarding the negative impact of ICU sounds on patients. A significant majority agree that ICU sounds disturb patients' sleep, (fig 21) pointing to noise as a key barrier to rest and recovery. Additionally, 29 out of 45 observed that patients often display confusion or agitation in noisy environments,(fig 20) further emphasizing how disruptive sound can affect mental and emotional stability. This aligns with previous findings linking noise to increased stress, disorientation, and emotional distress. Encouragingly, 30 out of 45 respondents believe that soothing sounds could benefit patients' emotional well-being,(fig 22) suggesting openness toward sound-based interventions as a potential solution to counterbalance the negative effects of the existing soundscape.These findings also highlight that the healthcare is aware of this situation in the ICU according to how many are in agreements of the negative effects of sounds in ICU which sets a good foundation to think of future interventions and benefit the hospital staff as well.

C - Moments of vulnerability within ICU patients

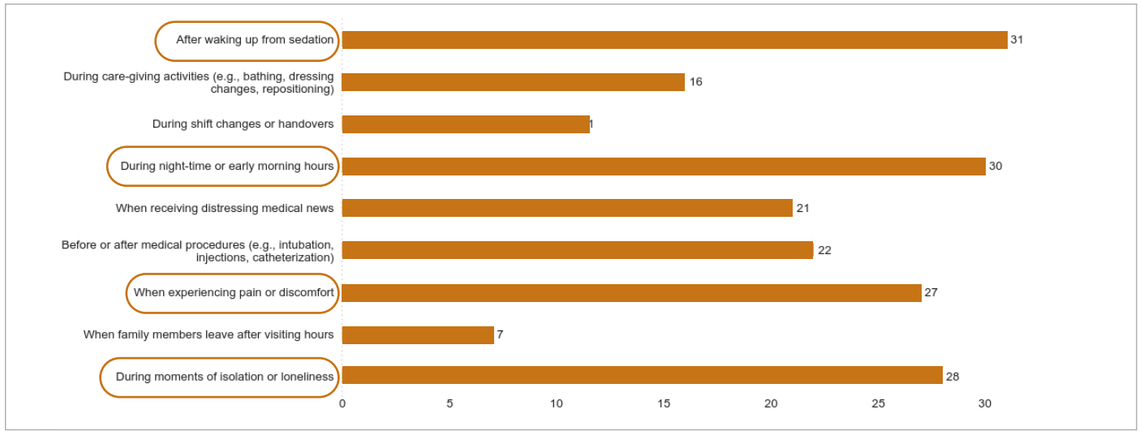


Fig 23: Percentage count on specific times when patients seem vulnerable

The above chart (Fig. 23) presents the responses of 44 healthcare professionals including doctors, intensivists, and nurses who were asked to identify specific times during their shifts when patients seem particularly sensitive or vulnerable. The respondents could select multiple answers. Focus points of vulnerability according the responses include waking up from sedation , night-time hours , times of experiencing pain and discomfort post operation or during mobilization and periods of isolation. These moments suggest critical periods essential to be taken under consideration for the intervention.

These findings support and validate our earlier insights from the literature review, providing practical, real-world evidence about the current ICU sound conditions. They highlight how the existing acoustic environment contributes to emotional distress and psychological issues for patients. These insights lay a solid foundation for clearly defining the problem statement, helping us pinpoint key triggers and effectively narrow the project's scope. The highlighted moments in the chart show the most ratings identified as focus points to be taken ahead.

D - Potential new sound based Interventions

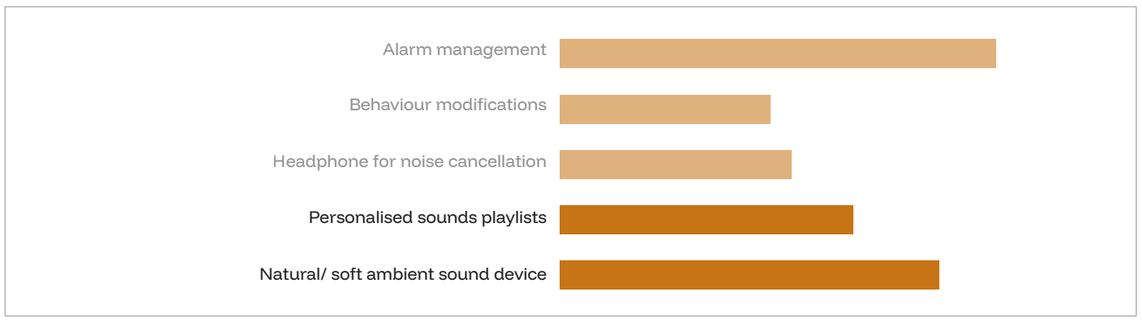


Fig 24: Results of potential new sound based intervention

Fig 24 presents the outcomes of a survey assessing the potential of various sound-based interventions within the ICU context stated by the healthcare providers. Among the proposed strategies, alarm management received the highest preference from participants, followed by the use of a natural or soft ambient sound device and personalised sound playlists. Although alarm mitigation was rated as the most impactful intervention, it falls outside the core scope and direction of the current project, which prioritizes enhancing patient well-being and emotional connectedness through sound, rather than addressing clinical alarm systems. Other options, such as behaviour modifications and the use of headphones for noise cancellation, were comparatively less favored. Notably, interventions that introduce soothing or personally meaningful auditory environments such as nature-based sounds or familiar music demonstrated strong potential for patient-centered application.

E - Sound that can create a healing environment

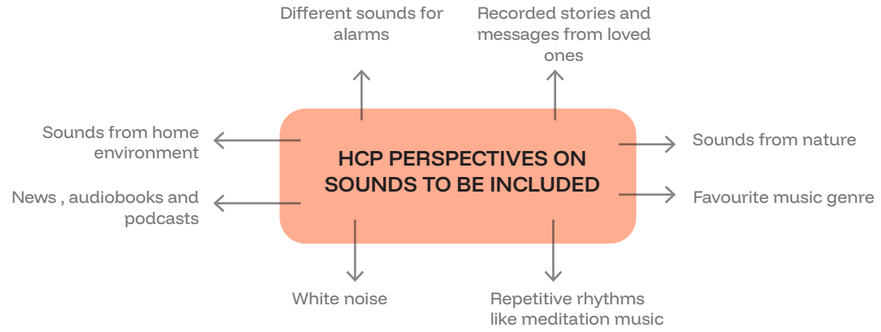


Fig 25: Results of sounds for patients

When healthcare professionals (HCPs) were asked about the types of sounds they believe could enhance comfort and familiarity for ICU patients, a diverse range of suggestions emerged, as illustrated in Figure 25. The responses highlighted the importance of both emotional resonance and environmental familiarity. HCPs identified recorded stories or messages from loved ones, sounds from home environments, and favourite music genres as particularly meaningful, due to their potential to evoke positive memories and reinforce personal identity. Additionally, sounds from nature and repetitive rhythms such as meditation music were considered beneficial for promoting calm and reducing stress. Other suggested inclusions were news, audiobooks, and podcasts to support cognitive engagement, white noise for masking disruptive stimuli, and different sounds for alarms to reduce startle responses and increase recognizability.

F - Control over the environment

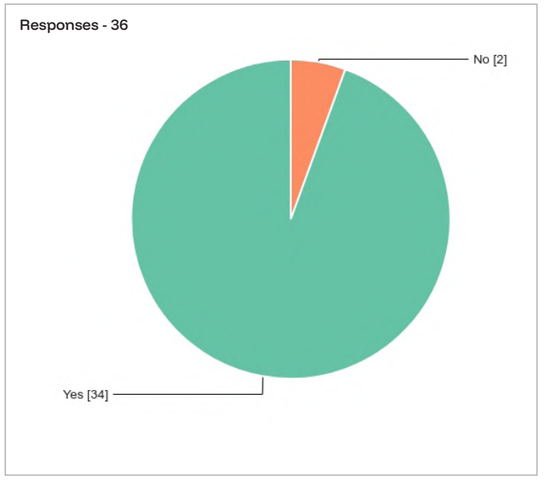


Fig 26: Results of Support for Patient Choice in Sound Preference whether they can have a control or not.

According to the responses from HCP , an ideal sound intervention should allow both patients and staff to have a control. The most effective system also would be when the patient can select sounds to his/her liking from a library. This result strongly reinforces the importance of personalization in auditory interventions, suggesting that granting patients agency in shaping their sound environment is both desirable and feasible from a healthcare provider's perspective. It was also stated through the survey and interviews that the family members often suggest music genres for their loved ones and are often eager to contribute to support them in all ways possible. This suggests that in the situation of an emergency surgery or when the patient is not in the state to give preferences , loved ones can contribute and help build a library of sounds for the patient.

4.2.5 DISCUSSION

"WHEN I'M AWAKE I HEAR THE STRANGEST CONVERSATIONS, MY HEARING IS EXTRA SHARP."
EX ICU PATIENT

"THE EVENING WAS APPROACHING AND VISITING HOURS WERE COMING TO AN END. MY BROTHER AND SISTERS SAID GOODBYE AND WENT HOME. IT WAS GETTING QUIETER AND QUIETER ON THE WARD."
EX ICU PATIENT

The patient experiences in the ICU revealed several recurring psychological and sensory challenges. Feelings of loneliness, fear, and emotional disconnection were common often exacerbated by a lack of meaningful interactions and the absence of family. Patients described the ICU soundscape as monotonous, unpredictable, and disruptive, with alarms, machinery, and unrecognizable noises contributing to anxiety, restlessness, and sleep disturbances. At the same time, certain sounds such as footsteps, staff voices, or familiar tones offered moments of reassurance, and a sense of presence. The lack of control over the surrounding environment, particularly the sounds, emerged as a key factor linked to disempowerment. These insights take us to identifying the barriers to a positive experience leading to unfulfilled fundamental needs.

IDENTIFIED BARRIERS TO A POSITIVE ICU EXPERIENCE FOR PATIENTS:

After reviewing the patient and HCP clusters from the data analysis , negative experiences were further analysed to be identified as 'Challenges or barriers" to a positive ICU experience for a patient during his stay.
Challenges like Sensory sensitivity , physical discomfort ,powerlessness ,prospects of future compiled together formed these negative experiences leading to unfulfilled psychological needs.
These findings are examined concerning the fundamental human needs, using the detailed typology of Fundamental Human Needs for Human-Centered Design (Huang et al., 2023).
As a result of the analysis concerning the fundamental needs and negative experiences groups , the following fundamental human needs are considered as being unfulfilled in the ICU, resulting in the following four barriers to a positive ICU experience:

1. Lack of comfort
2. Lack of relatedness
3. Lack of security
4. Lack of autonomy
5. lack of stimulation

Limitation :

It is essential to recognize that the insights summarized and presented in this study leading to identifying the unfulfilled fundamental needs as a result are shaped by the researcher's own perspective. This subjectivity can be both beneficial and limiting. On the positive side, designers bring valuable skills in translating complex, often ambiguous data into meaningful research outcomes. Their ability to interpret can uncover patterns and relationships that a strictly objective lens might miss. Moreover, qualitative research relies heavily on interpretative skills, which designers are particularly well-equipped with, allowing them to extract deeper insights that aren't immediately apparent in the raw data.

Overall, this study has some important limitations to consider. Firstly, the researcher's interpretations may be influenced by personal biases, orginating from prior experiences or assumptions. To reduce this risk, it is aimed to present the iterative process with maximum transparency. Secondly , the data analyzed from the patient perspectives is taken from websites on the internet and thesis projects presenting a wide range of sources while HCP perspectives are taken from interviews only from the context of this project. As a result, the data analyzed may not fully represent the broad range of experiences found across various ICU contexts and may some inconsistencies.

4.2.6 CONCLUSION

The study revealed insights into the barriers of a positive ICU experience for a patient from both the patient perspectives and the HCPs too. By linking these challenges to fundamental needs , five unfulfilled needs were identified based on the researcher's interpretations which were Lack of comfort, Lack of relatedness , Lack of security , Lack of autonomy and Lack of stimulation.

Our research summarizes that the sound environment of the ICU can be altered by fulfilling the needs of the patients and by identifying when it is most in need during the day as it was clear that the needs and smotional triggers can be varying according to the different events happening. Furthermore, the study expresses the need for patient-centered approaches in ICU settings. By understanding the patient perspectives, designers can develop interventions that can improve the overall stay of patients in ICUs. This can potentially reduce stress and improve the recovery of patients.

ANSWER TO SUB- RQ1:

How do ICU environmental conditions contribute to unfulfilled psychological needs in critically ill patients?

Patients in the ICU often experience feelings of loneliness, sensory sensitivity ,physical discomfort and fear which results into unfulfilled psychological needs like lack of autonomy , relatedness, comfort , security and stimulation.

4.3 PATIENT JOURNEY IN THE ICU

SUB- RQ2:

At which points during the ICU journey do these unfulfilled needs occur and how do they impact the overall experience?

4.3.1 USER PERSONAS

A user persona is a composite character that encapsulates data gathered and synthesized from user research (Fraser, 2012). Based on the insights gathered from interviews with healthcare professionals (HCPs), this research has resulted in a set of detailed user personas. Three distinct personas have been developed to represent typical ICU patients, as they will be the direct users of the proposed intervention (Fig 27) . Understanding these different patient types is crucial to ensure the intervention effectively addresses their diverse needs. Additionally, another persona has been created to represent healthcare professionals who will interact with and manage the product. These user personas will be utilized to create journey maps that specifically address and provide insights into the second sub-research question.

Patient persona :

The three patient personas Patient A , B and C represent diverse ICU patient experiences, highlighting varied emotional states, frustrations and reasons for admission. Each persona reflects specific challenges related to isolation, anxiety and the need for meaningful connections, guiding targeted interventions to enhance emotional comfort and patient well-being.

HCP Persona:

The healthcare professional persona, represented by nurse and intensivist, highlights the dedication, empathy, and patient-centric approach of ICU staff. Their challenges include managing stressful ICU environments and balancing care delivery with patient comfort. They rely heavily on sound from alarms as a part of the monitoring process while trying to keep interactions with patients their top priority.

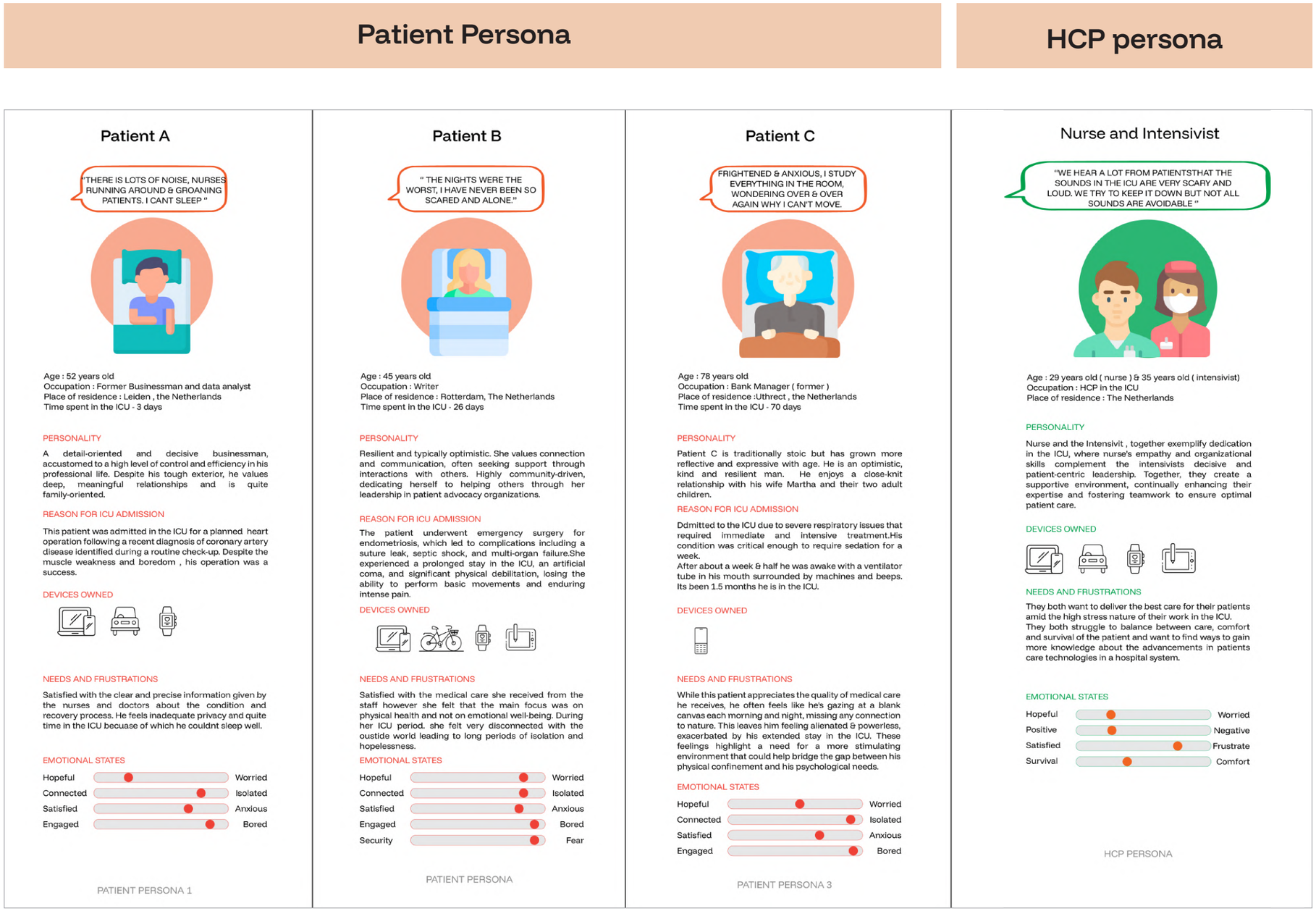


Fig 27 :Patient and HCP persona

4.3.2 USER JOURNEY MAP

Patient mapping or patient journey, a tool used to visualize the patient journey, is beneficial in understanding the patient's experience with healthcare. It highlights what contributes to good care and what does not from the patient's perspective. By viewing the journey from the patient's perspective, the effectiveness and efficiency of care can be improved by eliminating ineffective or unnecessary treatments (Sassen, 2023).The insights from the HCP interviews combined with the unstructured observations at LUMC lead to event specific patient journey map.

This map takes into account all patient interactions with events in the ICU right from morning care to specialists visits. These events define specific needs and frustrations leading to unfulfilled psychological needs as the starting point to understanding which are the event we most need to cater to. The journey map allows to target specific times of the day to focus on several important moments for intervention.

Figure 28 illustrates the event-specific patient journey map, spanning from morning to night. This timeline aligns with the structured shift patterns followed by healthcare professionals at LUMC. Each shift change introduces a new nurse, following a standardized handover protocol in which one nurse updates the next about the patient's condition and care requirements. These transitions influence not only the continuity of care but also the nature and tone of interactions throughout the day. As a result, the events mapped in the ICU journey take into account these shift changes, providing a realistic and context-aware understanding of the patient experience.

The primary objective of the journey map was to identify the evolving psychological needs of ICU patients and to pinpoint moments during the day when patients are physically alone, with limited interaction from nurses or loved ones. Insights gathered through interviews revealed that these needs are not static; rather, they are dynamic and vary significantly across individuals. Both observations and qualitative data indicate that emotional states and psychological needs fluctuate in response to specific events occurring within the ICU.
Along the events taking place , this journey map highlights the unfulfilled needs and identifies which out of the 13 fundamental needs need to be taken care of.

While the journey map provides a general framework to guide design interventions across a typical day, it is important to acknowledge the variability and unpredictability of the ICU environment. No two days are alike, and unexpected developments can shift the patient's experience dramatically. Therefore, the design approach must remain flexible and adaptive, taking into account the diverse and shifting nature of each patient's needs.

Given the high degree of individual variability in when and why certain needs go unmet, it is crucial that the proposed intervention be tailored to each patient. This calls for a personalized approach, one that incorporates direct feedback from patients regarding their perceived needs and emotional states. Only by integrating such feedback can the system effectively respond to individual experiences and ensure that relevant needs are addressed in a meaningful way.

Additionally, it is important to note that the current study focuses solely on daytime experiences and does not encompass night shift observations. Any conclusions drawn about nighttime conditions are therefore based on the researcher's interpretations and second-hand knowledge. This limitation highlights the need for further research to explore patient experiences and psychological states during night shifts, which may differ significantly from those observed during the day.

The event-specific patient journey map offers valuable insights into the changing emotional and psychological needs of ICU patients throughout the day. By identifying key moments especially times when patients are alone it helps highlight when feelings of isolation are most likely to occur. While the map serves as a helpful guide for designing supportive interventions, it's important to remember that each patient's experience is different and can change quickly. This makes personalization essential.

By taking a more focused approach to understanding the changing aspects of mental states we can build a strong foundation for addressing these feelings and ultimately create a more positive and supportive atmosphere for the patient.

ANSWER TO SUB- RQ2:

At which points during the ICU journey do these unfulfilled needs occur and how do they impact the overall experience?

Unfulfilled needs that contribute to a negative ICU experience arise at various points throughout the day, often triggered by specific events in the ICU environment. These needs vary significantly from one patient to another, depending on individual circumstances and how each patient responds to their surroundings.

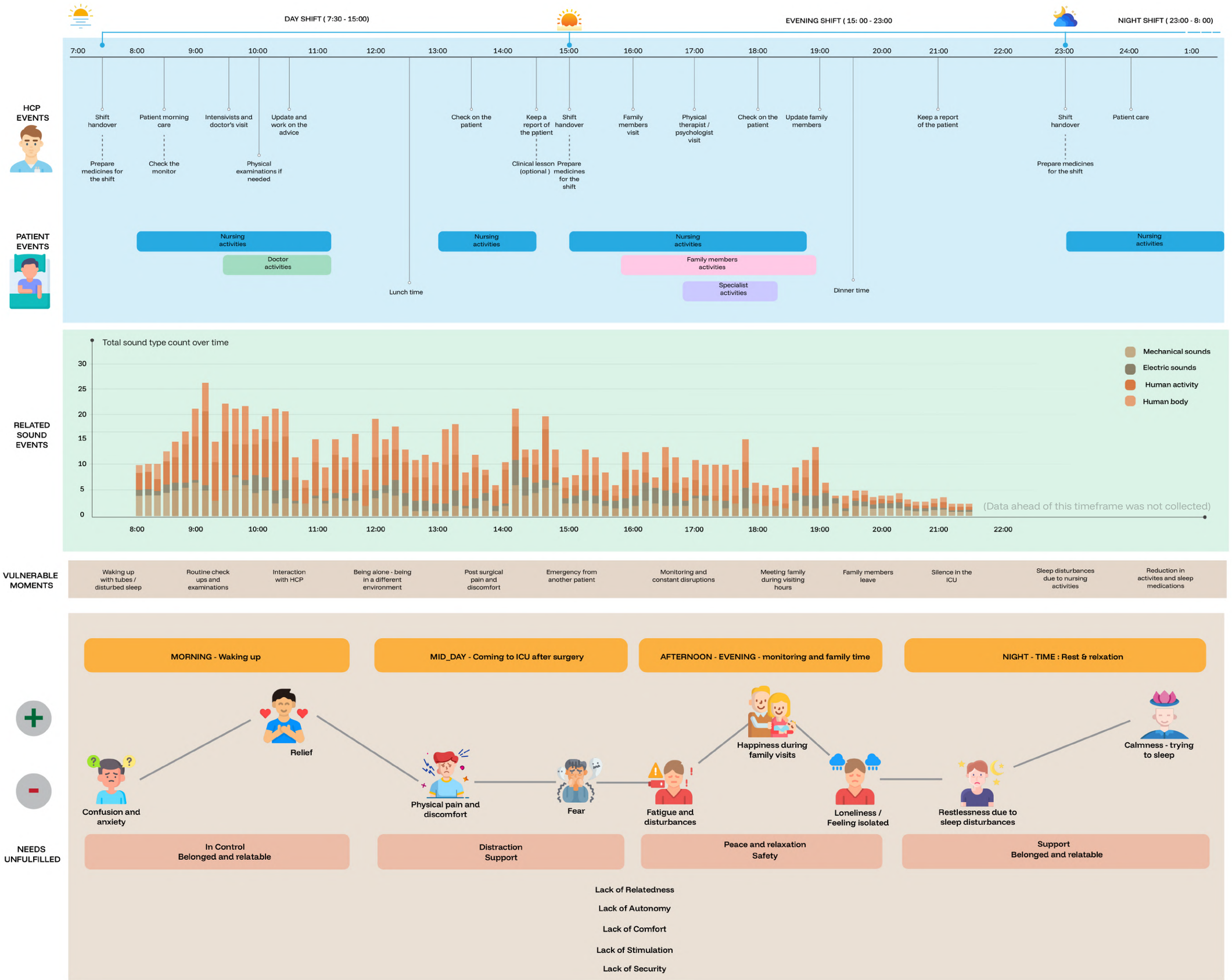


Fig 28: Patient journey map

4.4 THE NEED FOR CONNECTEDNESS

Drawing upon the unmet psychological needs identified in the ICU, the theoretical foundation of connectedness as a core human need encompassing fundamental dimensions such as relatedness, belonging, and emotional security resonates strongly with the patient experiences described earlier. By drawing on these perspectives and anchoring them in the qualitative accounts of ICU patients, this research identifies connectedness as a vital yet often unmet need in critical care one that can be potentially supported using positive auditory stimulation.

Importance of connectedness :

Edward Hallowell, MD, published a book, Connect (1999) that focuses on how and why we need connection in our lives. Dr Hallowell, a psychiatrist who has written extensively on the power of connection and has successfully used it as an intervention, defines connection as "feeling a part of something larger than yourself, feeling close to another person or group, feeling a part of an environment. In the context of ICU , this research explores how the sense of connectedness can be extended beyond whats currently explored or limited to by understanding how deeper ties to the outside world can help support and enhance well-being. Connectedness plays a significant role in shaping overall well-being and personal development. Research by Pritchard et al. (2019) highlights that a strong connection to nature is closely linked to enhanced well-being both hedonic (pleasure-based) and eudaimonic (meaning-based). This connection not only brings a sense of calm and presence but also supports personal growth and psychological health by fostering a deeper relationship with the environment. Additionally, foundational psychological theories have long emphasized the importance of social connectedness. Abraham Maslow, in his "Hierarchy of Needs," identified "love and belongingness" as essential for human fulfillment. Similarly, the Self-Determination Theory developed by Edward Deci and Richard Ryan (2000) underscores relatedness the need to feel socially connected to others as one of the three core psychological needs. These findings suggest that connectedness is multifaceted and can be experienced through various dimensions, highlighting the need for further research to better understand the depths.

Connectedness in the ICU

In the context of an Intensive Care Unit (ICU), research highlights several factors that significantly influence patients' well-being, one of the most critical being the sense of connectedness. Social disconnection, driven by barriers such as isolation and limited communication, has been shown to negatively impact recovery. ICU environments, however, often present conditions that are inherently isolating and disorienting. Constant alarms, sedation, and the absence of familiar cues can lead to overstimulation and confusion. Moreover, the lack of exposure to natural light cycles, minimal contact with nature or the outside world, and the absence of meaningful interactions throughout the day further compound feelings of isolation (Tronstad et al., 2020). Given that the need for connectedness is a fundamental part of the human needs, addressing it should be considered essential in the design and operation of ICU environments.

4.4.1 UNDERSTANDING CONNECTEDNESS THROUGH SURVEY

Recognizing the vital need for ICU patients to feel connected through various underlying facets , the research explores how sound, as an auditory stimulus, can help fulfill this need and support the strengthening of the fundamental needs identified. This led to an investigation into the role of sound in fostering a sense of connectedness within the ICU environment. A survey was conducted to understand individuals' perceptions of connectedness through sound, providing valuable insights into how auditory experiences can bridge emotional gaps. These findings serve as a foundation for designing meaningful, need-driven soundscapes and identifying the most effective ways to deliver them, with the goal of enhancing patient well-being during critical care.

Mapping needs & sound preferences

This section focusses on the survey and results obtained from a sound preference survey. This survey was conducted to answer sub-question 3. It takes into account the personalisation of the sounds to be used in the future intervention identified in previous sections. The goal of this survey was to understand individual sound preferences related to the need of connectedness. The research question which guided this study :

SUB- RQ 3 :

How can we address connectedness through sound and personalise the system to meet the underlying psychological needs in ICU patients ?

Method used :
In future interventions, a system consisting of various types of sound compositions will be utilized tailored to specific connectedness-related needs. To achieve this, a targeted survey was necessary to explore how connectedness is perceived through sound and to identify the specific needs associated with it.

Participants :
A total of 28 participants were involved in this survey. These participants were recruited through the researchers personal network and mainly whatsapp groups. These paticipants comprised of students and working professionals as healthy indviduals. Table 3 outlines the demographic data of the participants who participated in this study.

	Male	Female
Participants	9	19
Age range	20 - 35 years	

Table 3 : Demographic data of the participants

SURVEY DESIGN :
The survey was divided into 2 sections :

1. a. Perception of connectedness
In this part of the survey , participants were asked to share their understanding of the sense of connectedness in key words.

1. b. Fundamental Need Fulfilment
Participants were asked to select one or more needs that they associated most strongly with the sense of connectedness. They were provided with a list of nine fundamental needs, along with clear definitions, to help them make an informed selection. This exercise aimed to identify the overarching needs linked to connectedness, allowing future interventions to effectively target and strengthen need fulfilment through particular sounds.

2. Sound preference
Participants were asked to share their sound preferences as an imagined environment and sound types for each selected need.

DATA ANALYSIS

After collecting the responses, the data was analyzed in 3 steps :

- Find commonalities and group ideas of 'connectedness' into links and key words associating with the further analysis into need fulfilment.
- Analyze which of the nine fundamental needs received the highest number of selections to identify key areas of focus for future interventions.
- Lastly , determine , which types of sounds resonate closely with the associated needs.

4.4.2 RESULTS

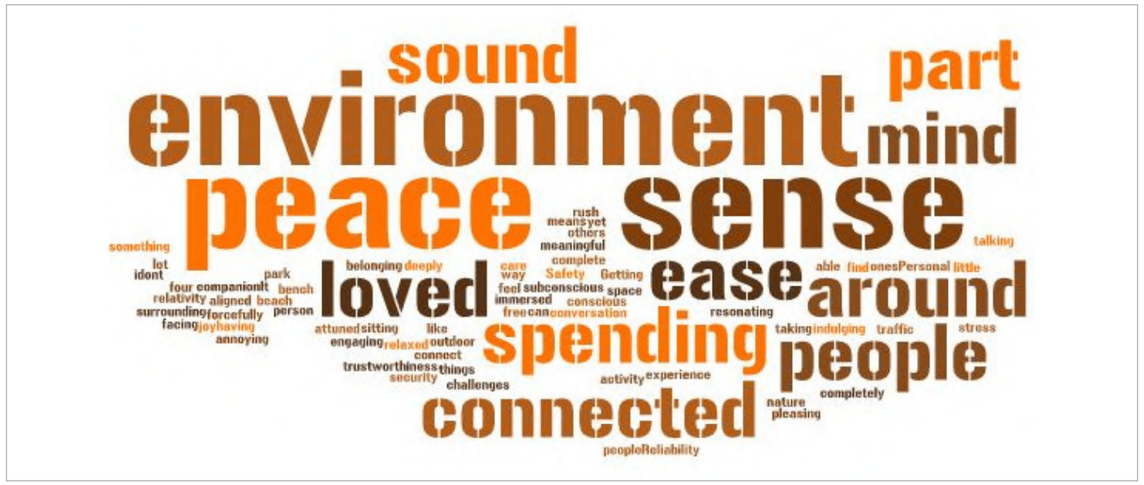


Fig 29 : Word cloud representing emotional association with connectedness

Perception of connectedness

As the first part of the survey, participants were asked to briefly describe what connectedness meant to them, without focusing on the context of critical care, which was introduced only at the beginning of the survey. Their responses were later analyzed in two separate sections. The first section focused entirely on the emotional and psychological states or specific feelings participants associated with the sense of connectedness.

This word cloud in Fig 29 captures the emotional associations people link with the feeling of connectedness. Prominent words like ”environment,” “peace,” “sense,” “loved,” and ”connected” suggest that being connected is deeply tied to feeling emotionally safe, mentally at ease, and surrounded by meaningful people or spaces. Words such as ”sound,” “ease,” “mind,” and ”people” reflect how sensory experiences, especially through sound and presence, contribute to this emotional state. The presence of terms like ”spending,” “around,” and ”part” also indicate that connectedness often involves shared time, space, and experiences. Overall, the word cloud highlights that connectedness is not just social, but also environmental and emotional, grounded in calm, familiarity, and a sense of belonging.

Connectedness was mentioned closely with an environment, often described through personal imagery and atmosphere. Participants spoke of being alone on a park bench, at the beach, or surrounded by nature, where the sound of birds or rustling leaves brought a sense of peace. These environments weren’t just backdrops but active contributors to the feeling of connectedness, evoking calmness, presence, and belonging. Through references to weather , environment , sounds and events happening , connectedness emerged as something deeply rooted in one’s surroundings , a picture of an atmosphere that takes one back to an experience where one feels part of the moment rather than isolated from it.

Defining connectedness facets :

From the survey analysis , it was understood that connectedness meant being fully immersed in a surroundings being physically there or not. It embodies a sense of belonging, the ability to feel part of something meaningful & the joy that arises from that emotional resonance. Through a lot of quotes it was understood that connectedness carried personal memories, an environment that one could link to and feel like a part. This aligns with our previous insight about sound influences on psychological needs of patients in ICU & how they associate certain sounds with environments tracking them back to memories.

“I WOULD SAY CONNECTEDNESS IS WHEN YOU FEEL AS IF YOU ARE A PART OF THE SURROUNDINGS INSTEAD OF JUST AN OBSERVER”
PARTICIPANT 1

“CONNECTEDNESS FOR ME IS TO FEEL BELONGED AND RELATED, NOT BEING DISTANCED FROM SOMETHING. ”
PARTICIPANT 5

“LISTENING TO THE SOUND OF RAIN EVEN WHEN THE CURTAIN IS SHUT MAKES ME FEEL LIKE I AM CONNECTED WITH OUTSIDE. ”
PARTICIPANT 8

- Connecting to outside world :

One key aspect of connectedness that emerged from the responses was the feeling of being deeply in tune with one’s surroundings especially in nature or calming environments. Participants often described moments where they felt a strong sense of belonging simply by being present in a space, even without interacting with others. This form of connectedness extended beyond physical presence; it was also experienced through imagination of a particular environment or cherished memories from home.

- Connecting to loved ones :

Another key aspect that emerged from the responses was the type of connectedness that comes from your relationships with others. It’s when you feel supported, loved, and truly heard. Whether it’s talking to a close friend, being near a loved one, or just knowing someone is there for you, these moments create a sense of belonging and emotional safety. It’s not just about being together, but feeling understood and cared for.

- Connecting to yourself :

Participants described this experience as feeling emotionally grounded, calm, and clear-headed. It’s a moment where you’re not just thinking or feeling you’re in tune with yourself on a deeper level. This connection can also bring up a sense of familiarity, like déjà vu or a gentle reconnection with personal memories or states of being. You might be physically alone, but you don’t feel lonely. Instead, there is a quiet sense of comfort, clarity, and emotional balance. You find a sense of home in yourself.

Needs associated with connectedness

The chart (Fig 30) displays the results of a survey that asked participants which needs most contribute to their feelings of connectedness building on research conducted by Louwers (2022b). The results highlight that ‘Relatedness’ was the most frequently associated need, chosen by 71.4% of the participants, while ‘Security’ and ‘Comfort’ were also significant, selected by 53.6% and 57.1% of the participants, respectively, suggesting that feelings of safety and ease are crucial. ‘Stimulation’ among the other selected needs was also rated higher among others. This understanding allows to selectively focus on these specific needs, exploring sounds that effectively fulfill them. By targeting the most frequently selected needs, future efforts in terms of the sound intervention can be more directed and potentially more impactful in enhancing feelings of connectedness.

Interestingly, these identified needs closely align with those previously recognized by the researcher as lacking within the ICU environment, based on both patient and healthcare professional data analyses. This convergence reinforces the relevance of these needs in contributing to a sense of connectedness, validating their potential as key targets for design interventions aimed at enhancing patient well-being.

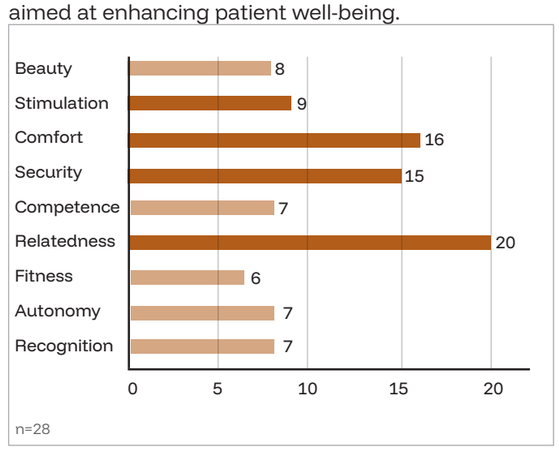


Figure 30 : Percentages indicating the proportion of participants selecting each need that related most with connectedness

Sound preferences for connectedness

To narrow the focus of the project and design soundscapes that foster a sense of connectedness, the top four emotional needs—**Relatedness, Security, Stimulation and Comfort** were selected based on their highest ratings, Figure 30. The following section presents the results and key insights specifically related to these needs. After identifying their most important needs, participants were asked to reflect more deeply through a series of guided questions. These questions explored three main aspects for each need: the imagined environment, the types of events occurring in that environment, and the sounds associated with those events.

	Environment	Events	Sounds
Security	A quite corner in my bedroom	I am sitting on a comfortable seat , there is light chatter	Voices of people, talking , laughter , soft ambient hum
Comfort	Serene, natural environment bathed in warm sunlight and i am i am sitting on soft grass	People are chilling with a drink, there is a waterfall and birds chirping	Sipping sound, waterfall and birds chirping
Relatedness	I am at home with my wife and children having breakfast and talking about life on a sunday morning	Kids running around, soft laughter , sun is shining and mild air is flowing	Conversations , kids voices, air flowing
Stimulation	Vibrant city market early in the morning	Vendors chatting announcing fresh produce , people passing by , there is music in the nearby cafe	Clinking of cups and plates, music , people shouting , footsteps

Table 4 : Examples of participant responses for imagined environments

The results from table 4 confirm the findings that soundscapes can be designed to fulfil psychological needs and each need is associated with specific types of sounds. Louwers (2022a) and Louwers (2024a) found that different needs are associated with distinct sound categories (Human, Natural, Musical, Technological). Human sounds (e.g., voices, footsteps) were the most universally linked across needs, while natural and musical elements varied more by context .

These findings also go in line with table 4. To inform the next stage of design exploration, these results will be considered as a foundation for understanding the need for connectedness and will guide the development process.

4.4.3 DISCUSSION

This study explored connectedness and how individuals perceive this need. Three facets of connectedness emerged from the survey responses : connectedness to environment , to oneself and to loved ones. Participants were also asked if this need resonated with the fundamental needs. The survey responses reveal that the sense of connectedness is most strongly associated with personal sound memories or meaningful activities tied to an environment directly aligning with the fulfillment of needs such as Relatedness, Comfort, Stimulation and Security. In order to understand the co -relation between needs and sounds, the participants were asked to mention their preferred sounds for each need. Human and nature sounds emerged as a more neutral and universally accepted element, appearing consistently across various need categories. These sound components offer valuable insight and serve as a foundational resource for exploring and shaping potential design directions.

4.4.4 CONCLUSION

This study support the use of psychological needs as a starting point for designing sound interventions for enhancing connectedness in ICU patients. This contrasts with traditional approaches that focus solely on noise reduction or decibel limits.

The study investigated personal sound preferences in relation to various fundamental needs, revealing that personalized sound categorization is essential for achieving complete fulfillment of these needs.

The results further demonstrated the effectiveness of using a questionnaire format to capture individual sound preferences, thereby supporting the approach of tailoring soundscapes to individuals.

Overall, the findings indicate that designing soundscapes to facilitate positive experiences is closely linked to the specific context of each need. The data gathered suggest that different sound categories can be strategically combined to create soundscapes suitable for ICU environments, aimed at enhancing patient comfort and promoting connectedness. The questionnaire method successfully gathered highly personalized and detailed insights, proving to be a valuable tool for informing future design interventions.

ANSWER TO SUB RQ-3 :

How can we address connectedness through sound to meet the unfulfilled psychological needs of ICU patients ?

Connectedness is perceived mainly via feelings of Relatedness, Security, Comfort, and Stimulation suggesting that personalized soundscapes incorporating nature sounds, familiar human voices, sounds evoking memories can be seamlessly integrated into ICU settings to evoke a sense of connectedness to the outside world and loved ones, even in their physical absence.

05

DESIGN EXPLORATION

This chapter presents the design goal formed by the problem statement established and forms the foundation of the ideation process. Further on it presents the results from the co-creation brainstorming session. These results come together to a design direction which will be further conceptualised in the coming chapter.

5.1 DESIGN GOAL

This section presents the aim and the design brief formed with the help of the problem statement previousy established.

5.1.1 PROBLEM STATEMENT

Patients in the ICU experience a sense of disconnection due to an unfamiliar environment and unwanted sounds which significantly compounds feelings of isolation and stress resulting in an unhealthy experience.

The following insights are obtained through the research explained in the previous chapters which are going to be used in the design explorations.

Context :

Amidst the advanced care offered to sick patients in the ICU , the bright lights, unstimulating sounds and an impersonal setting contribute to anxiety and stress. Stripped of the comfort and warmth of their home, patients often experience a profound sense of isolation not only from their loved ones, but also from the outside world. The lack of meaningful sensory input in this sterile setting can further intensify feelings of loneliness, boredom, and emotional distress. Given these challenges, there is a growing need for thoughtful interventions that can enrich the ICU environment.

5.1.2 DESIGN QUESTION

Following the 5W and 1H method , the following design question was formulated for the ideation session.

To design a system for the Adult ICU that fulfils the sense of connectedness within critically ill patients through a supportive sound environment during their stay.

To conclude, this question guides the development of solutions that aim to enhance emotional well-being by fostering mental connectedness and creating a psychologically supportive environment for patients.

Connectedness facets addressed :

According to the research and insights gathered in the previous section , it is established that the sense of connectedness is multi - faceted and is perceived is many different ways. In order to fulfil this holistically, the ideation will begin to cater to the following facets of connectedness :

1. Connection with an environment
2. Connection with loved ones
3. Connection with oneself

5.2 IDEATION

5.2.1 CO- CREATION SESSION

Method

The co - creation session took place at the Faculty of Industrial Design Engineering at TU Delft which involved five participants as a resource group. The session lasted one hour and 30 mins. It started with an introduction and the participants signed the consent form before they were asked to start ideating. The session was structured according to the guidelines from Heijne et al. (2019). The researcher made sure every participant understood the aim of the research and was aware of the possible risks and possibilities. The session focused on the possible solutions to enhance connectedness in ICU patients to reduce stress and promote a healing environment.

Results

Detailed results from the ideation session are shown in Appendix. Fig 32 shows an impression of the clustering phase. The researcher let the participants form themes themselves and put them into various clusters according to the ideas.

Discussion

Fig 31 illustrates the results from the co-creation session conducted. This session explored a lot of ideas aimed at designing a sound based system as a sensory support to provide a relief from the current sound situation in the ICU as it was emphasized strongly in the introduction by the researcher and came up as a problem for the research group to work on. The participants were familiarized with the context with lots of photos and existing sounds from the ICU which helped them emphathize with the patients.

Ideas addressed the connectedness facets taking into account the contribution of the nurses and loved ones but also keeping in mind giving a control to the patient as well. The group also came up with ways to personalise the system using a more narrative based approach to sounds to evoke positive sound memories. It was clear that the patients wont be completely in control with the system and so the loved ones can provide preferences to build a sound library by adding sounds which the patient is familiar with. It was also clear that a collaborative space should be facilitated to create a sound library which mixes different sounds and initiates relevant soundscapes. Regarding the methods of implementation , a lot of ideas came up which explored using speaker, soft controls and using other senses like visual aids.

Conclusion

While the concept of fostering connectedness through sound was positively received, the need for deeper exploration into personalization became clear. The session provided valuable criteria for further investigation; however, specific facets of connectedness require additional examination. Particularly, developing a comprehensive strategy for personalized soundscapes, aimed at enhancing the specific dimensions of emotional connectedness identified in previous research, is essential.

Overall, the session delivered significant insights to guide future design directions. A key takeaway is the critical importance of prioritizing widely accepted concepts for integration within the ICU environment. Adopting this pragmatic approach will help ensure feasibility and effective implementation, even if it necessitates temporarily setting aside more novel or experimental ideas.

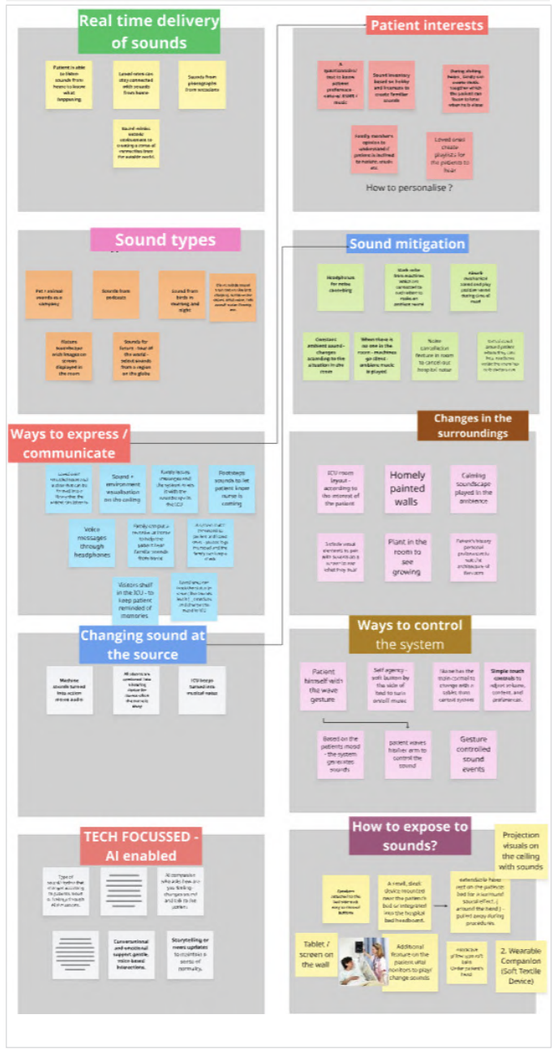


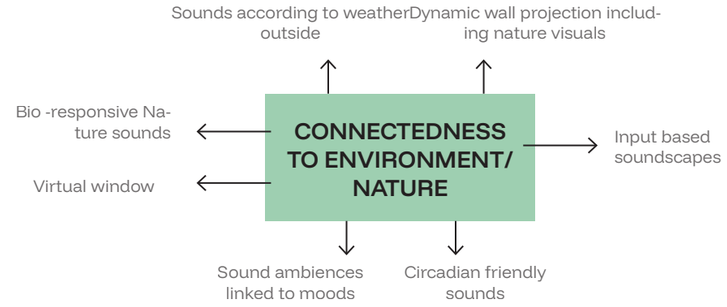
Fig 31 : Impression of the analysis and reflections from the co-creation session

Figure 32 : Creative session held with IDe students

5.2.2 SELF EXPLORATIONS

Building on the connectedness-related needs identified in earlier stages combined with insights from nurse interviews, the researcher began exploring sound-based experiences that align with different facets of connectedness. The goal was to understand how the ideal interaction with sounds is understood in the sound system. Fig 33 visualises it facet by facet and tries to understand how sound plays a role in different types of connectedness.

The exploration led to the realization that the facets of connectedness could serve as a strategic foundation for generating inputs for a sound focussed system. Building on this insight, the next step involved translating these conceptual inputs into an actionable approach. This included developing a comprehensive visualization of the soundscape system as a whole, integrating the various components and their relation with design characteristics of the system.



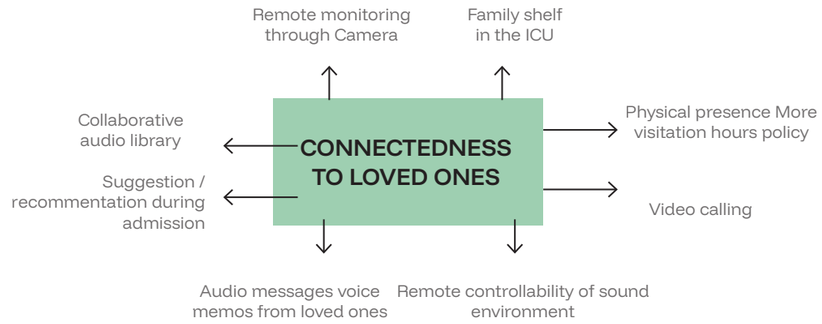


Fig 33 :Overview of the ideas from all three directions

5.3 IDEA SELECTION

The insights from the co-creation session combined with the self exploration exercise led to multiple perspectives for the design intervention. This section focusses on the idea selection method 'Plus , Minus , Interesting' (PMI) to discover which direction was the more feasible to be conceptualised.

Method:

The PMI method is a creative and critical thinking strategy used to evaluate ideas on the basis of their positives, negatives and whats interesting (Sharma & Priyamvada, 2017).This allows designers to compare different directions and identify elements which can be taken ahead .

Results:

Table 5 provides an overview of the results from PMI method. As highlighted in fig 32 , the three ideas related to the connectedness facets identified were explored and used in the PMI method to highlight the positives and negatives to consider the strongest elements.

Discussion

The PMI method provided valuable insights into the strengths and weaknesses of the ideas. After discussion with the project supervisors, connectedness with environment i.e idea 1 was the most promising idea especially when it could also take elements from idea 2 and 3.

Idea 1 takes into account connecting patients to an environment through soundscapes which can directly connect sounds through preferences. Idea 2 explores the connectedness with loved ones which offers a string emotional impact and high level of personalisation but also may impact negatively. Idea 3 explores connectedness with oneself and this is taking sound to its maximum power to help patients to meditate , journal etc which offers less personalisation but easy integration in the ICU.

Conclusion

Idea 1 is identified as the most promising idea which balances personalisation and inputs from patients to create sounds according to environments. By connecting patients to environment through sounds , connectedness to loved ones and oneself can also be considered to be fulfilled by integrating the strengths.

	PLUS	MINUS	INTERESTING
DIRECTION 1	The input from patients about sounds they like can be translated in real time to create soundscape to connect them to environments.	Moderate emotional impact compared to other directions.	It offers an opportunity to covers the other facets of connectedness by exposing relevant sounds. It shows a potential to also influence the staff by a pleasant environment .
DIRECTION 2	Explores connectedness in its real sense as it finds ways to connect family with patients in times of needs which makes it emotionally rich and provides depth.	This idea may harm the emotional well being if right type of stimuli is not used while it also increases dependancy on loved ones.	The social dynamic it introduces offers a unique layer of emotional connection that could extend support beyond the patient to family members.
DIRECTION 3	This approach requires minimal external involvement, integrates easily into the ICU context, and supports internal comfort and reflection.	It falls short in personalization and emotional resonance, and its content may not sustain long-term value as effectively.	Its introspective nature suggests potential value even for patients with limited awareness, offering a calm internal space amid clinical chaos.

Table 5 : Overview of the results from PMI method from 3 main ideas

5.4 IDEA BUILDING

5.4.1 REFINED DESIGN QUESTION

To design a system for the Adult ICU that fulfills a sense of connectedness with environments within critically ill patients using personalised soundscapes during moments of vulnerability.

The above mentioned design brief was synthesized as a result of the creative session as well as the self exploration session to categorize ideas in the "Connectedness to environment" and use as the guiding point for the system flow and conceptualization. Fig 34 shows a glimpse of the categories of ideas generated to enhance the connection with outside through a sound intervention.

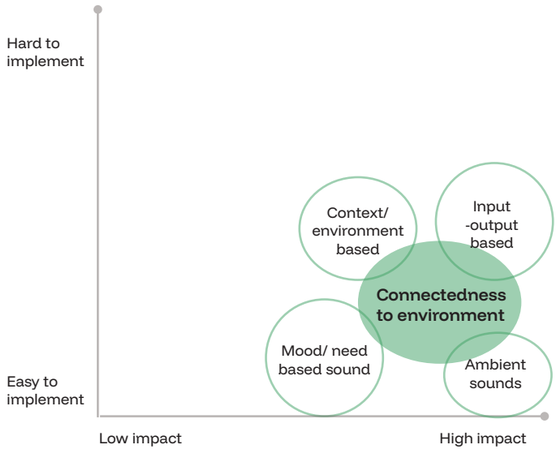


Fig 34 : C-box Mapping of Ideas for 'Connectedness to Environment' Selected for Concept Development

5.4.2 SYSTEM DESIGN

After looking at the ideas plotted through the matrix, it became evident that the design intervention would benefit from an input–output system approach - one that aligns with the complexities of the ICU environment and the needs of its multiple stakeholders. This section explains this approach and outlines the components necessary within this system.

Balaji (2021) refers to a system as: "a collection of components whose performances are interrelated. Invariably, the product of an engineering enterprise is a system". In designing the sound-based intervention for personalization, a central question guided the development of the system: how can the interaction between all stakeholders be effectively designed to achieve the desired outcome ? Establishing the right mode of interaction was essential to ensure the system functions seamlessly within the ICU context. It is also important to be explicit about the input that goes in the system and what type of output is produced.

Input :

After learning from the co creation session and the self explorations , it became important to involve the HCPs and the loved ones in this system although the primary benefit of the intervention was for the patient. The right platform for this input and the timing are important aspects to be considered.

System :

Central to the goal of this intervention is the soundscape exposure to the patients at the right time. For this to be achieved, the internal processing of the input demands a specialised system which produces the output personalised to each patient. Data acquisition becomes an important part in this system to function effectively.

Output :

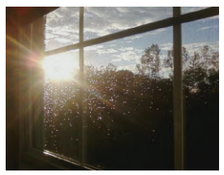
The output of the system is a personalized soundscape, tailored for each patient after their input is processed. As explored in Chapter 4, different sound components that support a sense of connectedness can be used to build this input as a profile profile.

5.4.3 INTERACTION VISIONS

According to Pasman et al. (2011), an interaction vision is a design technique used to express the intended qualities of interaction between a user and a product such as the mood, feelings, or experience that the designer wants to evoke during that interaction. It helps designers by offering a creative and experience-centered starting point, allowing them to focus not just on product functionality but on the emotional and experiential impact of the design. Fig 35 illustrates the interaction vision considering the role of all stakeholders and will be used in the conceptualisation .

Patient interaction

It should feel like the warmth of the sun rays after a rainy day.



Interaction qualities

- Passive
- Spontaneous
- Heartwarming

Loved one interaction

It should feel like warming up a meal ready to be served

Interaction qualities

- Subtle
- indirect

HCP interaction

It should feel like watering the garden on a relaxing day

Interaction qualities

- Comforting
- Instinctive

Fig 35 : Intercation vision for all stakeholders

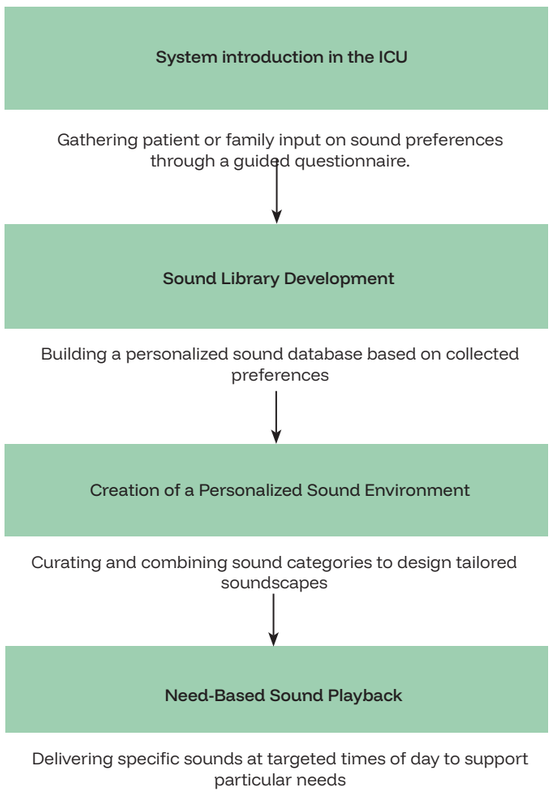
5.4.4 CONCLUSION

The design exploration phase began with a clearly defined design brief and an initial co-creation session with students, where a wide range of ideas were generated. These early concepts addressed both the receiver level such as connecting patients to nature, family, and preferred environments and the source level, including strategies like silencing or mitigating alarm sounds. While these directions were valuable, they remained broad and lacked a nuanced understanding of the three facets of connectedness previously identified.

To address this gap, a self-exploration phase was conducted to ideate potential solutions specifically for personal, social, and environmental connectedness within the ICU. Among these, environmental connectedness emerged as the most promising direction, as validated through the PMI (Plus, Minus, Interesting) method particularly for its personalization potential, emotional resonance, and practical feasibility.

This led to the development of a system-based approach, deemed most appropriate for implementing a personalised sound intervention. The proposed system accounts for patient preferences, involves relevant stakeholders, and delivers tailored soundscapes in response to psychological needs. An initial workflow was then outlined, detailing how the system could be introduced in the ICU from preference collection using a questionnaire format to dynamically adjusting the sound environment based on patient needs and feedback.

Initial Workflow of the system



06

CONCEPTUALISATION

This chapter builds on the insights from the initial ideation phase towards concept development and final design which is described in the nect chapter. It highlights all crucial decisions towards concept development through establishing design characteristics , interaction moments and usability tests to examine the design and present iteratively.

6.1 DESIGN CHARACTERISTICS

This section provides a detailed description of the concept development which was initiated with the design characteristics that were needed to create a sound system . Louwers et al. (2024b) conducted a study which defined five distinct characteristics for designing effective soundscapes system specifically tailored for the ICU environment.
The design characteristics are organised in five distinct chategories : User friendliness, Personalisation, Humanized, Familiar and Integration in the workflow.

These design characteristics are further elaborated using the WHY , WHAT and HOW framework as outlined in table 6 . Each characteristic has a distinct underlying purpose and the approach to achieve the desired outcome. However, the characteristics are interdependent and cannot function effectively alone or in partial combinations. They are interconnected and collectively address both informational and emotional needs.

USER FRIENDLY
The system should offer easy-to-use auditory, tactile, or visual cues, and be accessible for both patients and the people supporting them.

PERSONA-LISED
The system should offer a personalized experience based on each patient's unique needs, without adding extra workload for healthcare professionals.

HUMANIZED
System should be people-centered, keeping patients and users at the heart of the design to create a more human, less clinical environment.

FAMILIAR
Using familiar and recognizable sounds can help ground patients in reality and provide comfort, especially during vulnerable moments in their ICU stay.

INTEGRATED
The ICU's critical care context must guide the design, with soundscape features carefully integrated and adaptable, ideally linked to patient data systems.

Design characteristics	Why ? (Underlying purpose)	What? (desired outcome)	How? (The approach)
User-friendly	To make it easily accessible by all stakeholders in case the patient cannot control	lets user navigate easily without any extra burden	By providing easy to use platform to have control in all situations
Humanized	To let loved ones/ HCP feel like they are a part of a care routine	Adresses the efforts / control by staleholders by their involvement	By allowing loved ones give their recommentations for a better environment
Integrated	To not disturb the regular routine of the ICU but be a seamless addition	Prevents intrusions in any ways and any additional infrastructure	By implementing sound system in an accessible and easy to use set up with available resources
Personalised	To fulfill the varied needs and preferences of patients	Delivers relevant sound experience tailored to each individuals situation	By meeting rsound related requirements of patients
Familiar	To reduce the feelings of isolation from normal life and feel relaxed	Helps individuals feel connected and familaiar in a clinical environment	By introducing familiar environment at the need

Table 6 - Framework for design charateristics

6.2 DESIRED INTERACTION

Current interaction

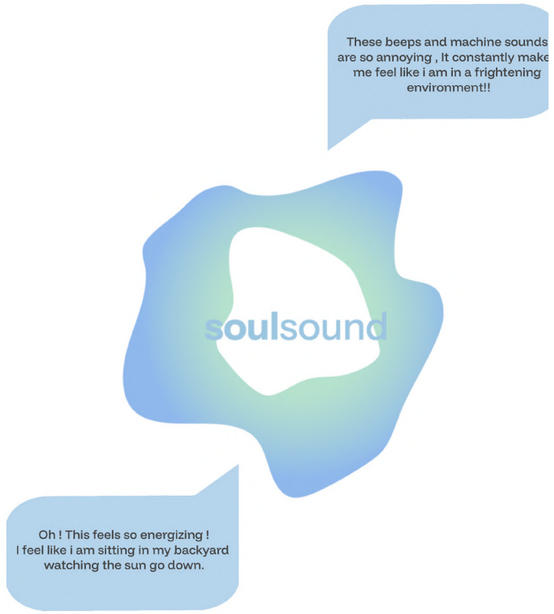
In the current ICU environment, patients are surrounded by clinical sounds from machines and alarms that can feel cold, impersonal, and even distressing. Their emotional needs are often unmet, and feelings of isolation or anxiety may increase. The sensory environment is focused solely on medical monitoring, with little consideration for emotional well-being or personal comfort.

Desired interaction

Through the soundscape system, the focus shifts from isolation to a sense of connection. Personalized and meaningful sounds are used to evoke positive memories and emotional warmth. This approach helps patients feel more grounded and supported, transforming the ICU environment into a space that nurtures both physical recovery and emotional well-being.

6.2.1 DESIGN OUTCOME

SoulSound - a sound optimisation tool for the ICU



Building on the design characteristics established , the soundscape system has been further developed as SoulSound. SoulSound is a sound based system designed for the Intensive Care Unit to support patients during vulnerable moments of the day. Its core objective is to re-establish a sense of connection between the patient and the external world through sound.SoulSound aims to achieve this by providing a psychological anchor with the help of custom built sonic environments during various times of the day to fulfill functional roles such as providing distraction during painful procedures, activation to promote alertness upon waking, reassurance during periods of loneliness in the absence of visitors, and calming support in preparation for sleep. These roles are identified as key experiential goals that the designed soundscapes must fulfill. SoulSound also considers important to engage HCP's in this system to control the sound environment in the ICU room and play a role in the emotional improvement of the patient.

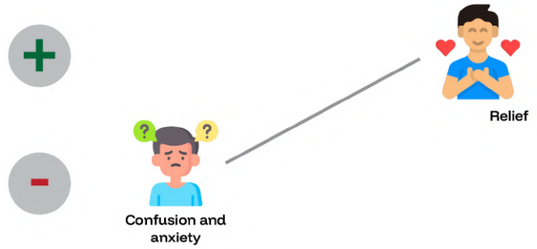
The following chapters outline the design development of SoulSound, which has been iteratively refined through multiple rounds of usability testing and expert evaluation.

6.2.2 IDENTIFYING MOMENTS FOR NEED OF CONNECTEDNESS

After defining the design characteristics and intended outcome, the next step was to conceptualize when the intervention would be most meaningful and identify the critical moments of interaction throughout the patient's day. This section builds on the earlier user journey mapping and highlights key phases morning, midday, evening, and night where ICU patients are most in need of emotional support and a sense of connectedness.

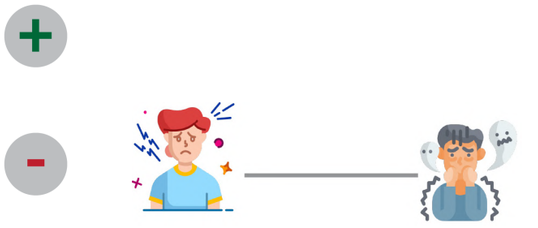
By examining the emotional fluctuations that occur during these timeframes, this analysis reveals moments of vulnerability as well as opportunities for positive engagement. These insights inform the design direction of the soundscape system, leading to the development of tailored sound functions - "To Activate," "To Distract," "To Reassure,"and "To Calm" each aligned with the specific fundamental need found unmet during those moments of the day.

MORNING - waking up



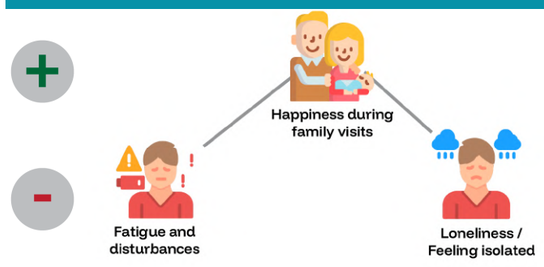
In the morning, particularly during waking up, research confirms that the patients often experiences confusion and a lack of positive stimuli in the environment. The emotional journey reflects the disorientation that may occur upon regaining consciousness in an unfamiliar and clinically sterile setting. To support this time of the day, the function of the soundscape system is desired "**To activate**" the patient to promote alterness and a sense of energy.

MID - DAY - examinations / procedures



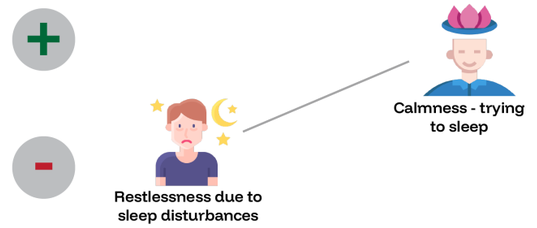
During midday, especially after coming from a surgery during procedures, spontaneous breathing trials , mobilizations or physiotherapy later in the admission patients often experience physical pain and discomfort to feeling fear and vulnerability. To support patients during this phase, the soundscape system should serve a distractive function desired "**To Distract**", offering a pleasant shift of attention to cope with the pain.

EVENING - post visitation hours



Family visits during evening hours bring moments of joy, comfort & emotional uplift, offering patients a sense of hope and normalcy amidst the clinical environment. However, once the visiting time end patients may experience an emotional decline, often marked by feelings loneliness for a long stretch of time. To support the patients during this time , the sound environment should serve the function "**To Reassure**" the patient as a means to provide a sense of belongingness .

EVENING - post visitation hours



At night, patients often struggle with restlessness and sleep disturbances, influenced by unfamiliar surroundings, clinical noise, or internal anxiety. As they attempt to transition into sleep, there is a need to cultivate a calm, secure, and emotionally grounding atmosphere. To support this shift toward rest and relaxation, the soundscape system should aim " **To Calm**" helping the patients to feel safe and relaxed.

6.2.3 SONIC AMBIENCE TYPES

The defined barriers to positive ICU experience in the previous section in relation with the fundamental needs i.e lack of relatedness , security , comfort and stimulation are related to a study performed by Louwers et al. (2022), which connects to sonic ambience types and sonic ambience qualities. This research also alligns well with the connectedness to environment direction which was earlier decided as a promising idea to conceptualise.

Table 7 illustartes the allignment between specific ICU events highlighted in the previous section, the unfulfilled fundamental need , related sound ambience type and the corresponding function the sound environment is desired to fulfil. This mapping provides a structured foundation for the timing and intent of the sound interventions, ensuring that they are emotionally supportive and contextually relevant.

EVENTS IN THE ICU	Waking up / staying awake	Examinations / post surgery procedure	Post visitation hours	Getting ready to sleep
RELATED FUNDAMENTAL NEED	Lack of Stimulation	Lack of stimulation	Lack of relatedness	Lack of comfort and security
SONIC AMBIENCE TYPE	Stimulating	Stimulating	Pleasurable	Comfortable
FUNCTION	To activate	To distract	To reassure	To calm

Table 7 : Mapping ICU Events to Psychological Needs and Corresponding Soundscape Functions

Stakeholders and touchpoints within the system

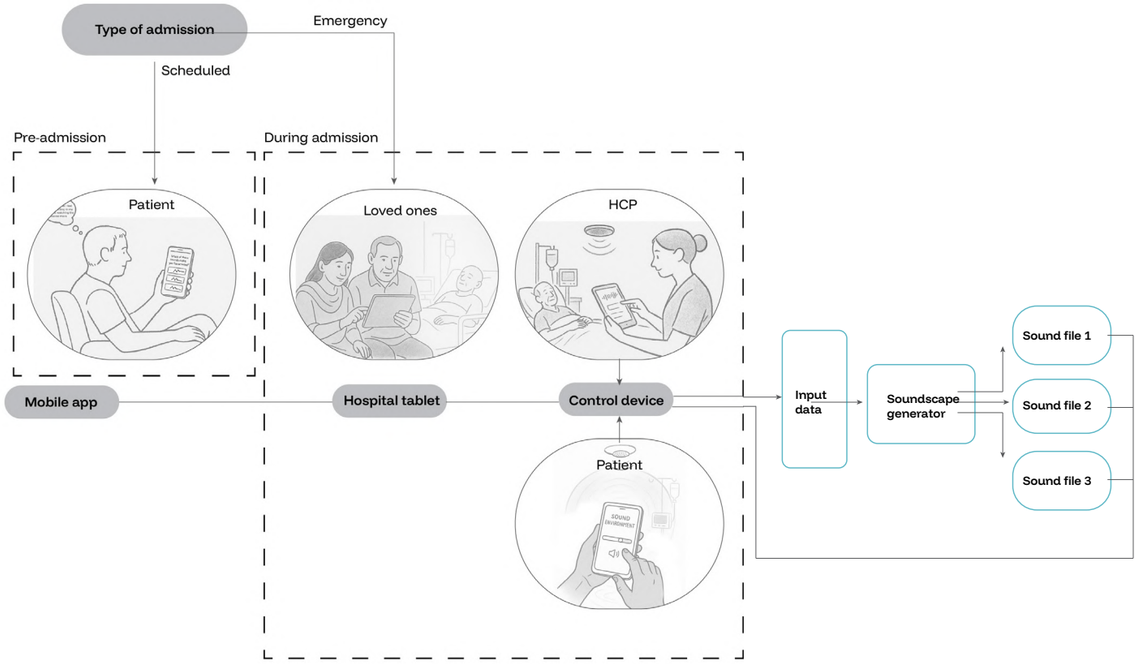


Fig 36 System flow used to define the most important interaction moments and touchpoints

6.2.4 PROTOTYPING

The interaction moments illustrated in the figure 36 serve as a foundational framework for initiating the user interface (UI) design process tailored to each stakeholder group. The functional requirements of the UI prototype are defined through specific use cases, in our case to communicate preferred sound choices that illustrate the interaction between users and the system. These use cases inform the development of the UI, beginning with basic interface elements for initial testing, which are subsequently refined into the final design.

To ensure early patient engagement and promote a sense of autonomy in shaping their environment within the ICU, it was deemed valuable to develop a pre-admission platform specifically for patients. To assess the feasibility of such an initiative, existing digital platforms at Leiden University Medical Centre (LUMC) were reviewed. This analysis revealed that there are currently no dedicated platforms providing patients with access to or control over their own data. Consequently, a new application system has been designed within the scope of this project, with the aim of serving as a prototype for future implementation. This proposed platform not only supports the current project's objectives but also has the potential to be expanded to include other health-related features in the future.

To support ease of use for patients, the hospital could facilitate the communication of information about the application at the time of admission confirmation either directly to the patient or indirectly through informational notices provided to their loved ones.

To explore the concept, several Figma prototypes Fig 37 were developed for both mobile and tablet interfaces to visualize the use case flow. The patient and loved one interfaces were designed with simple questions to reduce cognitive load during stressful times, while the HCP interface focusses on system control. The prototype functions as a connected system, where inputs from digital platforms are integrated and translated into auditory output through speakers where the soundscape will be exposed to the patient. The prototyping process was iterative; initial prototypes were tested and refined based on feedback from peers, supervisors and key stakeholders, allowing the researcher for continuous improvement of the concept.

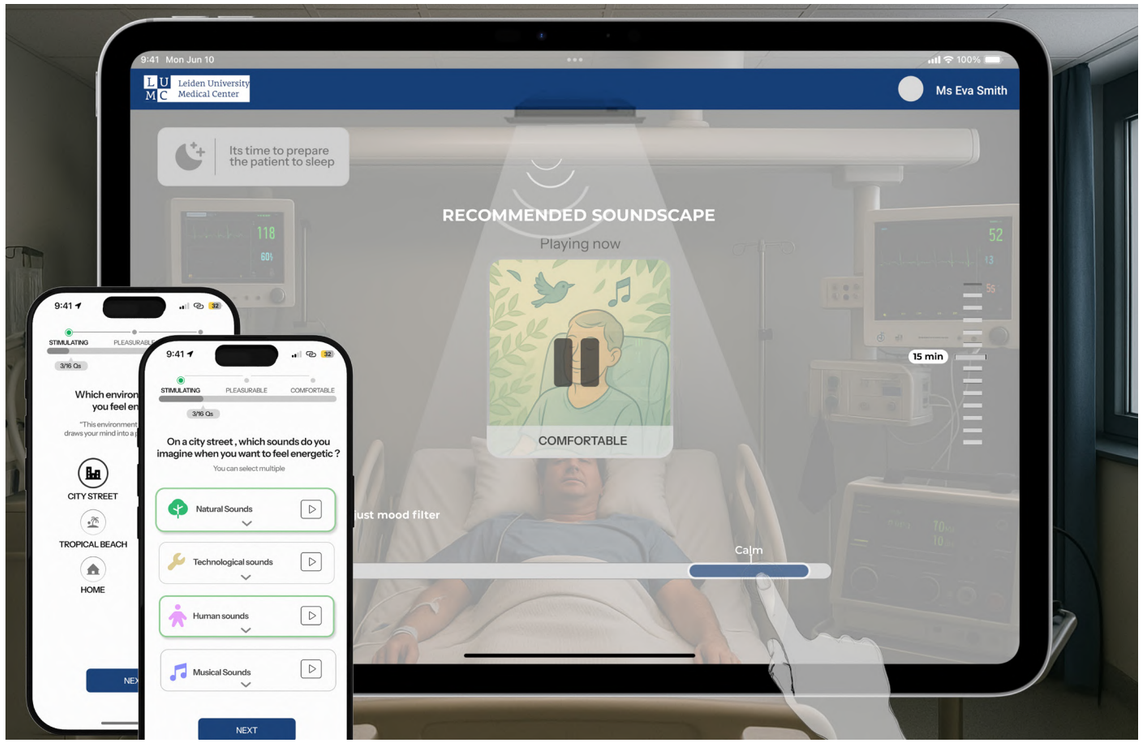


Fig 37 - Overview of the initial prototype used

6.3 USABILITY TESTS

ROUND 1

This section focusses of the usability tests conducted with the concept defined in the earlier section. This round of testing evaluated how easy and engaging is it for users to access the application. It is important to gain feedback, understand pain points and uncover areas of improvement.

Two key aspects were evaluated :
How easily can users understand and respond to the questions presented, and how effectively the icons and accompanying text work together to create an engaging and intuitive experience to select sounds. These work as principles aimed to provide design insights that guide the creation of the final concept based on the results.

The inputs received in the test will be used as a sample inventory for each individual participant useful to test in round two of the testing.

6.3.1 PART A (Mobile App)

This usability test is conducted to assess how easily users can understand the questions and to evaluate the level of user engagement when interacting with icons and accompanying text to select preferred sounds.

METHOD

Participants

8 students from TU DELFT recruited through the researcher's network participated in the study.

Procedure

The usability test started with an introduction to the study , explaining the goals and outcome. After the consent form was signed , they were asked to think out loud while they interacted with the prototype. They interacted with the prototype with a user scenario that the participant presented with. This involved preparing for a surgery before admission to set the sound preferences.

Scenario - You are scheduled for surgery in three days and are required to use the app to submit your sound preferences prior to admission. The prototype presents a single pathway, allowing you to explore pre-selected options for each sonic ambience function, represented as a scene. In the second part of the test , the participants gave prefereces for sounds as a result of the app questionnaire.

Tools

Figma based prototype was used for this testing which was used on a mobile phone. Fig 38 shows the prototype used

Questions

After interacting with the prototypes, participants answered the following:

1. How was your experience while completing the task?
2. What do you think of the questions and the way they are asked?
3. What do you think of the interface?
4. Did you understand what was going to happen with the answers you give?
5. What do you think of the length of the question session?
6. What would stop you from using this product if at all?
7. What would motivate you to keep exploring this product?
8. What will make you understand and select sounds better?

Metrics

Participants completed a system usability questionnaire (SUS) rating the prototype based on different parameters on the scale of 1 (strongly disagree) – to 5 (Strongly agree)

1. I thought the product was easy to use
2. I thought the questions and different elements in the product were easy to understand
3. I thought that I would be motivated to complete the entire flow
4. I thought that the product meets my expectations
5. I felt very confident using the product

ANALYSIS

Together with qualitative insights and questionnaire handouts , the user understanding and engagement will be assessed to find out pain points and areas of improvements.

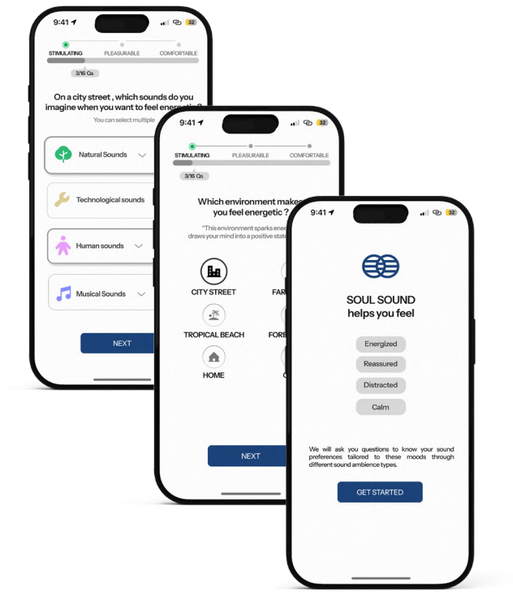


Fig 38- Mobile phone prototypes used for testing

RESULTS

Table 8 presents a summary of the findings from SUS usability questionnaire according to different criteria used. Detailed results can be seen in Appendix .

CRITERIA	min	max	average
n = 8 EASE OF USE	2.00	5.00	4.00
GRASPING QUESTIONS	3.00	5.00	3.88
MOTIVATION TO COMPLETE	1.00	5.00	3.88
EXPECTATION LEVEL	3.00	4.00	3.63
CONFIDENCE WHILE USING	3.00	5.00	3.88

Table 8 : Participant responses for SUS scales

Qualitative Insights : Along with the SUS usability questionaire, feedback from participants during interviews presented the qualitative results as well the strengths and weaknesses of the system as a whole highlighting the areas of improvement.

1. Participants were generally unaware of the auditory environment in the ICU, making it difficult to understand the app's purpose and functionality. It was learnt that this could be integrated in the app initially or through hospital pamphlets at the start of the admission.
2. Expert terminologies regarding the sonic ambience types were often misunderstood with the qualities listed in the following question.
3. Need for an onpoint and simplified structure was preferred by the users to minimize the strain and complex process to visualise sounds.
4. Some participants expressed the need to hear sounds as they click on it which would make the selection very direct and intuitive.
5. It was also preferred that the number of questions & the number of leading sub menus would be minimized.
6. The ability to edit probably through weekly changes to the sounds they selected previously was seen as a promising way to keep user engaged and motivated , also seen as a potential benefit in the ICU to reduce boredom .

Outcomes for preferences

Participant	Ambience type	Preferred sound categories
P2	Stimulating (activate)	Forest environment- Nature + Human + Musical
P3	Stimulating (Distract)	Cafe Environment - Technological + Human + Musical
P5	Pleasurable (reassure)	Beach Environment- Natural + Human
P6	Comfortable (Calm)	Home Environment- Human + Natural + Musical

Table 9 : Examples of sound preferences received as a result of the questionnaire

DISCUSSION :

The usability tests were conducted using a Figma-based prototype designed to evaluate the flow of interaction and the engagement between icons and text for selecting sounds. The prototype followed a questionnaire-style format, guiding users through a structured process. It began by asking users to choose an environment corresponding to a given sonic ambience type and its associated quality. After this , participants were presented with a curated list of sounds to choose from in four different categories of sounds. This sequence was repeated across three different ambience types, collectively addressing four functional roles intended for the soundscape system.

PROTOTYPE :

Experience of completing the task :

Strengths :

1. Participants appreciated the idea of building an own sound landscape for later use reinforcing a sense of control in a space you would least expect or demand for it.
2. Several participants expressed curiosity and interest with the guided structure and the ability to see the selections at the end.
3. Participants also noted that once the logic was clear, the interaction was smoother.

Weaknesses :

4. Some users were confused about the purpose of specific questions and lacked context for why they were being asked.
5. The process felt mentally demanding, especially for ICU context , due to long flows and dense content.
6. Some participants did not read all the information presented to them which caused confusion.

“ I WOULD NEVER IMAGINE HAVING MY OWN SOUNDS IN AN ICU! I LIKE THAT I HAVE THE CONTROL WITH ME ”
PARTICIPANT 2

Tone of the questions :

Strengths :

1. Participants found the questions engaging and easy to understand.

Weaknesses:

1. The questions were felt very repeatitive and long creating confusion.
2. Some participant expressed the need to have an emotion connected to the question rather than the ambience label.

Quality of the interface

Strengths :

1. The interface and the interactions were perceived as very simple for most of the participants.
2. Because it was a guided app ,the participant appreciated the less number of clicks on one page.
3. The neutral color pallete suggested a very un baised and undemading experience however some colors to brighten up would be preferred.

Weaknesses:

4. The amount of text was not well received on a mobile phone size for participants.

Outcome of the answers

Strengths :

1. The selection experience generated a curiosity in the participants and they expressed the need of an outcome.

Weaknesses:

2. The outcome of the structured process was not clear for most of the participants. There was a confusion if the samples were going to be displayed in the end , if they could edit them or whether it was going to played when the user requested.

“ I WOULD EXPECT THE SYSTEM TO INFORM ME BEFORE HAND WHAT WAS THE SITUATION ”
PARTICIPANT 5

Length of the question session

Strengths :

1. Particiants expressed the need of a progress bar highlighted clearly than what it looked like to inform better.

Weaknesses:

2. The length was felt long leading to impatience in most of the participants.
3. The ideal structure could be more intuitive with less steps and choices at each step.
4. Some inputs could also be left to the system which will reduce the obligation to compile a soundscape with all inputs from the user.

Motivation to use the product

Strengths :

1. The participant expressed that the system was something novel and the ability to hear your own memories through when you need it the most would be very nice.
2. Being bored and exploring new compositions would be a motivation to keep using.
3. A little bit of encouragement from the people would be a boost to use this system.
4. How the sounds will benefit me is a very curious thing in this system and the ability to provide feedback and change the selections is also nice.

Weaknesses:

1. Too many terminologies and questions would be stop most participants from using this system.
2. Some participants also expressed if they had to pay for this system , they would be hesitant to fill in.

Visualizing and selecting sounds

Strengths :

1. Icons and text together made a good combination to visualise sounds.
2. More than this , all participants expressed that the question about the environment made it easier to imagine sounds in that context than only with the emotion label.

Weaknesses:

3. Not hearing the sounds was a problem. It was expressed if there was a feature to listen to the sounds and imagine how well its combined together would benefit more.

“ I WOULD IIKE IF THE SOUNDS COULD BE PLAYED AS SAMPLES IN THAT CONTEXT, THAT WOULD INSTANTLY HELP ”
PARTICIPANT 6

CONCLUSION

As a result of the usability test , the strengths and weaknesses of the concept were highlighted leading to understand how it can be improved. From the usability scores , it was understood that the ease of use of the app was moderately high however the user flow and the questions could be re iterated to simplify the structure as well provide a very intuitive and minimal experience as the real context is very rushed and sensitive to give sub-menus as much priority and importance in this system. Participants expressed more explaination of the purpose of this application before hand and the need for sound examples, which is recommended as it can increase user engagement. These outcomes were in line with the literature. Thus, this prototype and the insights achieved will be used as a guideline to create the final design.

Additionally, this usability test involved collecting participant preferences through a set of questions posed by the researcher, mirroring those in the application. This informed the usability testing in the second round.

LIMITATION

One limitation of the study was that the Figma prototype allowed participants to follow only a single guided path, which restricted their ability to freely explore or choose alternative options. Additionally, the participants involved were healthy individuals rather than members of the actual target group (critically ill ICU patients), which may have led to significantly different mindsets, needs, and reflections than those of the intended end users.

6.3.2 PART B (Tablet App)

METHOD

The second most important stakeholder in the soundscape system is the healthcare professional (HCP), who is responsible for adjusting the sound environment within the ICU room based on the observed emotional state of the patient. To support this functionality, a Figma-based prototype of a tablet interface was developed, specifically designed for HCP use.

While usability testing of this prototype is currently outside the scope of this project due to the requirement for hospital permissions and ethical approval the interface design has been reviewed in consultation with an Acoustic Expert from TU Delft who is directly involved in the project. This review focused on evaluating feasibility and identifying areas for improvement.

Key insights from (Kok, 2024) current design. HCPs demonstrated higher engagement with digital interfaces that align with observable patient behavior, allowing them to assess the situation and adjust the soundscape accordingly. Another critical takeaway was the importance of integrating the system seamlessly into the HCP's existing workflow however the design should be adapted to suit the control from remotely to inside of the room. The design presented in fig 39 incorporates these findings.

AREAS OF IMPROVEMENT AND INSIGHTS-

To enhance the frequency and practicality of use, it was recommended that the tablet-based control system be installed as an operator panel within the ICU room. This placement aligns better with the HCPs' workflow, allowing them to adjust the soundscape based on real-time patient observations rather than relying on remote or centralized control.

Regarding interface design, it was advised to carefully implement volume controls to avoid abrupt or inappropriate changes that may not suit the patient's condition. A default, comfortable sound level could serve as a baseline.

Additionally, incorporating time-based cues into the system could help guide HCPs in selecting appropriate sonic ambiences aligned with different times of day or patient needs.

CONCLUSION :

As usability tests with HCP's were out of the scope of this project, an evalution and feasibility discussion with an acoustic expert of the HCP control interfaces for the soundscape system produced good insights. They underscore the importance of a need based interface that seamlessly integrates with the daily HCP workflow within the ICU environment. These insights further guide the design refinements. While initial feasibility has been reviewed, further research and field testing with HCPs are essential to validate the effectiveness and usability of the design.

Fig 39- Tablet prototypes used for discussion

ROUND 2

6.3.3 USABILITY TEST (Soundscapes)

This section focuses on the second round of usability testing, which was informed by insights from the initial test phase. In this round, same participants from round 1 listened to curated sound compostions played in a controlled lab environment at various time points. At each time point, they evaluated their perception of the soundscape and the emotional state it evoked.

The aim of this test was to assess whether the personalized soundscape compositions, derived from participants' earlier preferences, effectively elicited the intended emotional states and supported the fundamental need for connectedness as established in prior research.

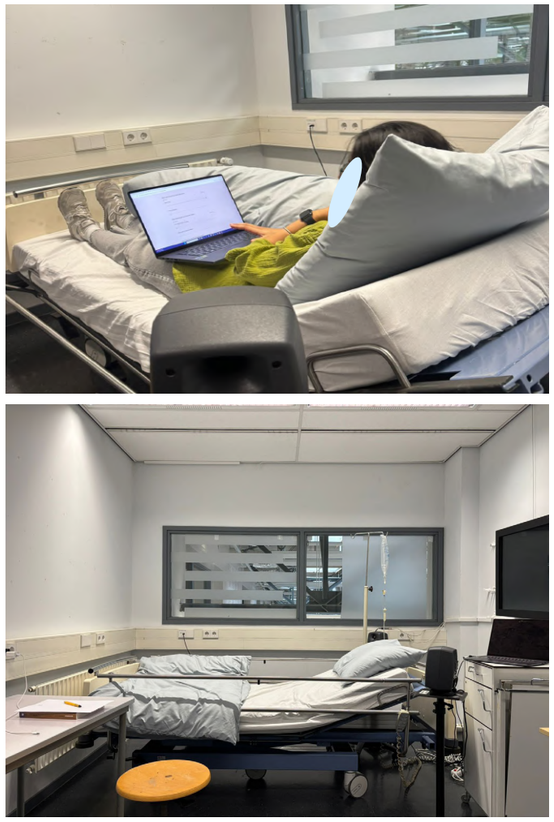


Fig 40 - Set up of the experiment

METHOD

Participants

Eight TU Delft students who participated in the previous study recruited through the researcher's network took part in this follow-up study. Prior to the main test sessions, a pilot round was conducted with the project supervisor to review the sound samples, determine a comfortable listening volume, and test the clarity and flow of the questionnaire.

Sound samples

The sound compositions were 90-second single-source acoustic scenes, created using free sound samples sourced from (Freesound, n.d.-a) and (BBC Sound Effects, n.d.-a) These samples were categorized into four groups: Natural Sounds, Mechanical Sounds, Human Sounds, and Musical Sounds. Each category was used to create soundscapes representing the three identified sonic ambience types, each linked to a specific functional role: Stimulating (to activate and distract), Pleasurable (to reassure), and Comfortable (to calm). These functional mappings of sound to ambience types were derived from insights gathered during the first round of testing using the mobile phone application.

In total , four sound samples were created for each participant for the testing round. (examples mentioned in table 9). These sound compositions were intended for playback through a set of mounted speakers as a patient intervention in ICU rooms. Playback through speakers was preferred over headphones due to hygienic and nurse workflow advantage as in the real scenario. The samples of the sound compositions are attached in the appendix.

For this project, the researcher independently prepared the sound samples, relying on a basic level of sound expertise. A narrative structure was applied, using the participants' preferred environments as contextual anchors, and relevant sound samples were sourced and layered accordingly. As a result, the reliability of the test outcomes is entirely tied to the researcher's creative interpretation and composition of the soundscapes.

Experiemental Setup

We used a box shaped lab-space with dimensions of 5.3 m (length), 3.2 m (width), 2.6 m (height) at Delft University of Technology (Fig. 41) with a patient bed (e) , bedside table (d) , and closed curtain to simulate a clinical setting that approximated the conditions of a single patient ICU room.

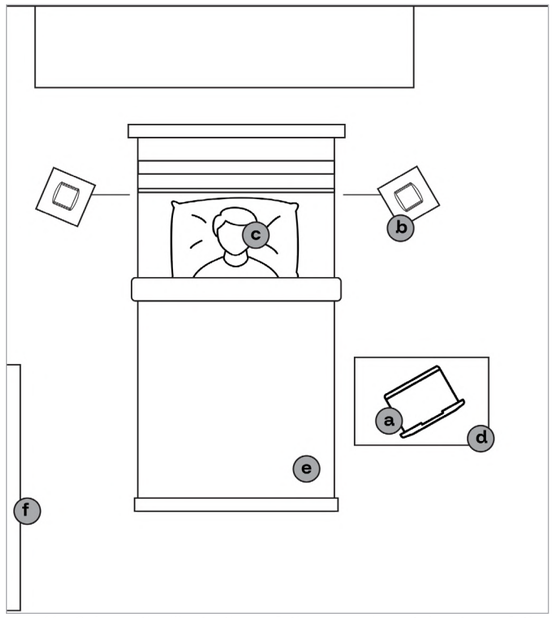


Fig 41- Schematic illustration of the experimental setup of the clinical setting in lab-space at Delft University of Technology, with participants in a hospital bed

Participants were in the middle of the bed.(c) Two Genelec 8020DPM studio monitors were placed on stands outside of view.(b) The researcher facilitated the experiment next to participant. The participants gave the ratings on the researcher's laptop (a) after every sound sample was played.In pilot testing, the sound levels were confirmed as being at a comfortable level. Participants did not have control over the sound level. Aside from the sound compositions, no other sounds (e.g., no medical alarms or other ICU sounds) were introduced in the space.

Experiemental procedure

The session began with an introduction to the aim and context of the study. As the participants in this study were the same as the participants in the previous study, consent forms were already filled out and the sound preferences were already taken into account. During this study the participants' heart rates were continuously monitored during the session using both an Apple smartwatch and a finger pulse oximeter.

Before the sound samples were played , the participants were asked to rate their perception and emotional state as a result of the labspace soundscape without sound compositions (i.e., the baseline). Following this, four curated sound compositions each 60 to 90 seconds long and derived from the participants' previously stated sound preferences were played. Between each composition, a 5-second pink noise was used to neutralize auditory carryover. After each sound sample, participants completed two tasks: rating the perceptual descriptors again and indicating the emotional state it evoked (e.g., activated, distracted, reassured, or calm).

Participants then evaluated how the soundscapes supported four fundamental psychological needs associated with connectedness: Comfort, Relatedness, Security, and Stimulation. For each need, both satisfaction and frustration phrased items were included (Huang et al., 2025). Each statement was rated on a 7-point Likert scale (1 = Not true at all, 7 = Extremely true). . The session concluded with a single reflective question on how strongly they felt connected to the outside world while listening to the sounds.

DATA ANALYSIS

Data from the eight soundscape desriptors was measured according to the proposed ISO soundscape standards to calculate the values and their relationship between the diagonal axes (i.e., monotonous- vibrant and chaotic- calm) and horizontal axes (i.e., annoying-pleasant and uneventful-eventful).

To evaluate the functional effectiveness of the soundscape system, participants were asked to rate a set of emotional descriptors on a 5-point Likert scale, allowing assessment of the main emotional impact of each soundscape. For the investigation of fundamental psychological needs, the (FUN) scales were employed to compute individual scores for both need satisfaction and frustration, thereby indicating whether each soundscape contributed to the fulfillment of specific needs. Heart rate measurements were analyzed as a physiological indicator to examine whether different soundscape ambiance types elicited measurable changes in the alertness and calmess level of the body. Additionally acoustical measurements for each sound ambience type are also analyzed.

RESULTS

This study aims to evaluate the impact of the soundscape system through a multi-dimensional approach that goes beyond assessing perceived attributes using the Circumplex Model of Affect. It includes an evaluation of physiological responses, psychological experiences, and acoustic characteristics. Physiological impact is assessed through variations in heart rate during soundscape exposure. The psychological dimension is examined using emotional descriptors and by measuring the fulfillment or frustration of fundamental psychological needs, as well as perceived connectedness. Acoustically, the study evaluates each sound composition by measuring the A-weighted equivalent continuous sound level (LAeq) over a defined period, providing an objective understanding of sound pressure levels.

1. PERCEIVED AFFECT ASSESSMENT

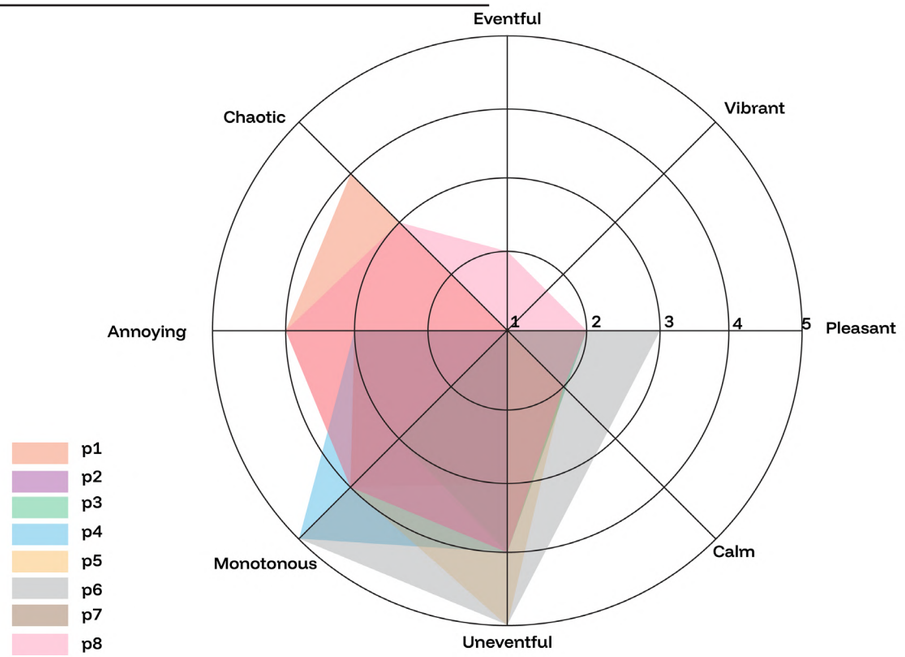


Fig 42 : Baseline soundscape assessment over all participants

The results are presented in four structured sections :

1. **Perceived Affect assessment**

2. **Psychological parameters**
   - Emotional responses
   - Need Satisfaction and Frustration
   - Perceived sense of connectedness

3. **Psysiological Parameters**
   - Heart Rate

4. **Acoustical Parameters**
   - A weighted equivalent sound level (LAeq)

Baseline

The radar chart (fig 42) depicts participants' perceptual evaluations of a baseline sound environment (consisting of sounds outside of the hallway and exisiting air ventilation system) along eight affective dimensions: Eventful, Vibrant, Pleasant, Calm, Uneventful, Monotonous, Annoying, and Chaotic, rated on a Likert scale from 1 (totally disagree) to 5 (totally agree). This follows the circumplex model of soundscape perception as advised by ISO 12913-2 and applied in the study by (Louwers, Pont, Gommers, et al., 2024a). The above Fig 42 supports emphasis on baseline hospital soundscapes being generally unpleasant and disorienting, especially when lacking personal relevance or familiar auditory cues. As interpreted by Louwers et al. (2024), the circumplex model plots pleasantness on the x-axis and eventfulness on the y-axis. From this chart: The baseline soundscape clusters toward the lower-left quadrant low eventfulness, low pleasantness aligning with the monotonous/uneventful and occasionally annoying areas.

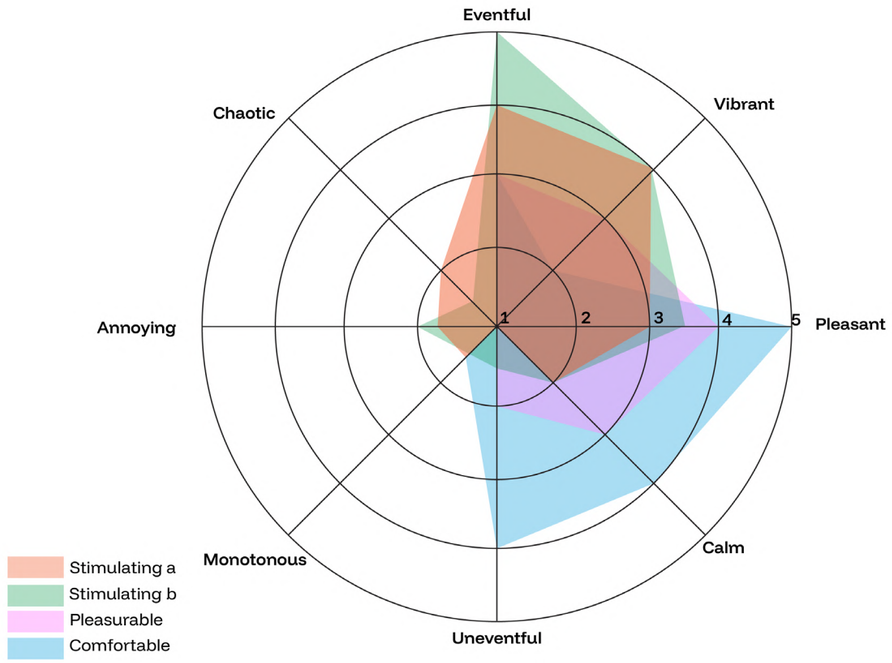


Fig 43 : Average perceived affect measurement across all ambience types

Sound Compositions

The radar chart in Fig 43 visualizes the average scores across all participants and confirms clear distinctions in the perceived functional roles of the four sound compositions Stimulating a, Stimulating b, Pleasurable, and Comfortable. As expected, Stimulating a and Stimulating b are both positioned high on Eventfulness and Vibrancy, validating their intended energizing function. Notably, Stimulating b appears to be the most eventful overall, with slightly elevated scores in Chaotic and Annoying dimensions, which aligns with the qualitative feedback from participants who reported auditory elements in these compositions as occasionally overwhelming rather than distracting.

The Pleasurable soundscape occupies a middle ground, rated moderately across Pleasantness, Vibrancy, and Calm suggesting that it was neither eventful nor uneventful. This positioning indicates a balance in the experience which alligns with the participant feedback where it was described engaging and momentous.

For the comfortable sound ambience types, the perceived affect is measured mainly in the pleasant , calm and uneventful quadrants showing a calming experience of listening.

Overall, the comparative analysis demonstrates that the sound compositions evoked differentiating and intended responses targeted towards their functional role. The results of this study also support the study by Louwers et al. (2024), and clearly establishes the ordering of the approach that is comfortable sonic ambience types were perceived as the least eventful followed by Pleasurable ones. Stimulating ambience type were the most eventful.

LIMITATION

One important limitation of this study lies in the composition quality of the soundscapes. The auditory stimuli were not professionally composed but instead assembled using freely available sound samples. While efforts were made to align these samples with the narrative structures identified as meaningful during earlier usability testing, the lack of expert sound design may have affected the emotional responses.

Additionally, the baseline condition used in the listening experiment did not incorporate ambient features typical of real ICU environments, such as medical alarms, door openings, or staff activity. The absence of these elements may have resulted in a baseline soundscape that was neutral, potentially exaggerating the perceived contrast between the baseline and the added sound compostions.

2. PSYCHOLOGICAL PARAMETERS

Emotional Responses

Emotional response	Min	Max	Mean	Standard Deviation
n = 8				
Activate	4.00	5.00	4.38	0.48
Distracted	4.00	5.00	4.50	0.50
Reassured	3.00	5.00	4.13	0.61
Calm	3.00	5.00	4.50	0.50

Table 10 : Statistical summary of the emotional descriptor ratings post sound composition

To assess the emotional impact of the soundscape system, participants (N = 8) were asked to rate four emotional descriptors—activated, distracted, reassured, and calm—after listening to a sound composition. The ratings were collected using a 5-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).
This emotional response analysis was conducted to examine how each soundscape ambience aligns with the researcher's intended goals, as previously illustrated in the patient journey map. The aim was to evaluate whether each soundscape effectively fulfills its functional role, following the assessment of pleasantness and eventfulness levels.

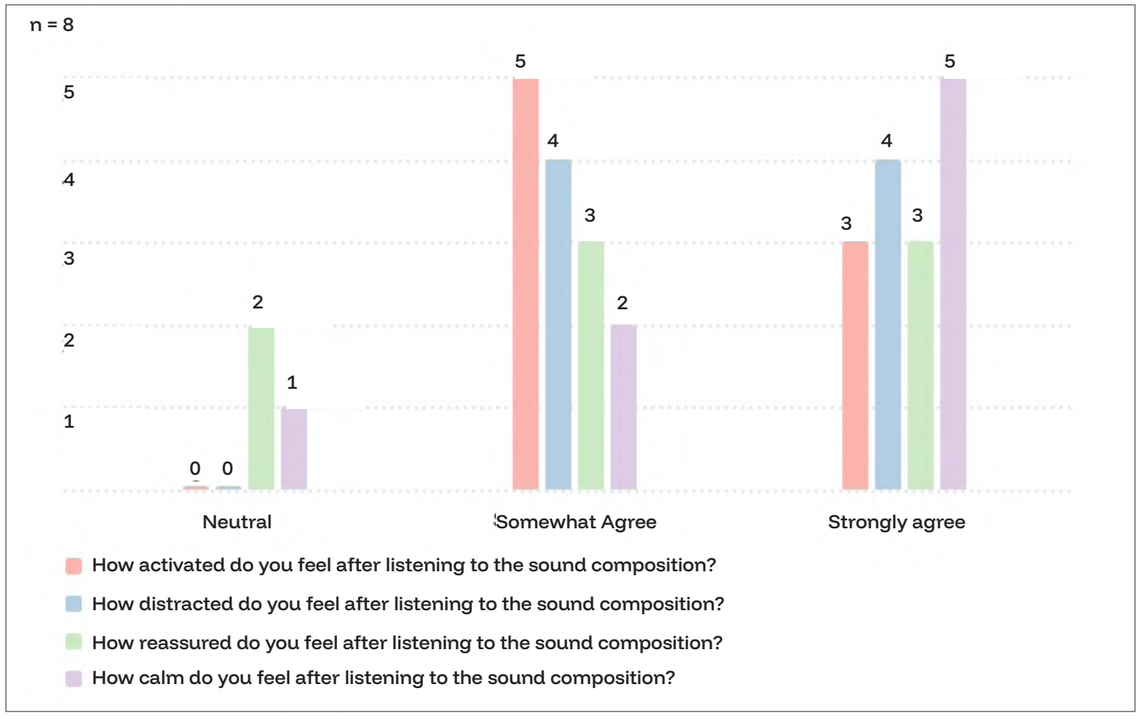


Fig 44 - Participant agreement levels on emotional impact of the sound composition

As shown in Figure 44, participants reported generally high levels of agreement with emotional effects induced by the soundscape. The highest mean ratings were observed for calm and distracted (M = 4.50), followed by activated (M = 4.38) and reassured (M = 4.13). All descriptors reached a maximum score of 5, indicating that at least some participants strongly agreed that the soundscape evoked the intended emotional state. The minimum rating observed was 3 for reassured and calm, suggesting some variability in individual experiences. As no responses appeared for somewhat diasgree and totally disagree, it as not been shown. The distribution of agreement levels is visualized in Figure 44 . Most responses clustered around Somewhat Agree and Strongly Agree, with calm receiving the highest number of Strongly Agree responses (n = 5). The emotional descriptors distracted and activated also received consistently high agreement levels, suggesting the sound composition successfully captured attention and maintained engagement. A few neutral responses were recorded, notably for reassured, indicating that this emotional state was less uniformly experienced.

Fundamental need fulfilment

Fundamental Need	Min	Max	Mean
n = 8			
Comfort satisfaction	2.00	5.00	4.13
Comfort frustration	1.00	3.00	1.50
Security satisfaction	3.00	5.00	4.25
Security frustration	1.00	2.00	1.38
Relatedness satisfaction	2.00	5.00	4.00
Relatedness frustration	1.00	2.00	1.25
Stimulation satisfaction	3.00	5.00	4.38
Stimulation frustration	1.00	2.00	1.13

Table 11 :Statistical summary of fundamental need satisfaction and frustration scores)

The analysis aims to assess how effectively the soundscape system supported the fulfillment of fundamental psychological needs. This was measured using both need satisfaction and need frustration scales, rated by participants on a 5-point Likert scale from Not true at all to Extremely true.

According to figure Table 11 , across all four needs, mean satisfaction scores were high (≥ 4.0), indicating that the soundscape system was generally successful in fulfilling participants' psychological needs. Stimulation had the highest satisfaction score (M = 4.38), suggesting that the soundscape effectively created sensory engagement and excitement for participants. Security also scored high (M = 4.25), implying that participants felt stable during the experience making them feel safe and familiar.

Comfort and Relatedness followed closely (M = 4.13 and M = 4.00), reflecting emotional ease and a sense of belongingness. In the satisfaction bar chart, (fig 45) most participants selected "Very True" or "Extremely True", with minimal responses in the lower agreement categories. This further supports the system's success in positive need fulfillment. Frustration scores were consistently low across all needs, with means close to the minimum rating of 1.0. This indicates that the soundscape system did not create psychological discomfort or deprivation. The corresponding bar (fig 46) chart shows that most participants chose "Not true at all", affirming that need frustration was minimal, and the system was effective in avoiding negative psychological states. Overall, the soundscape system demonstrated a strong positive effect on fundamental need fulfillment which is understood with the satisfaction scores.

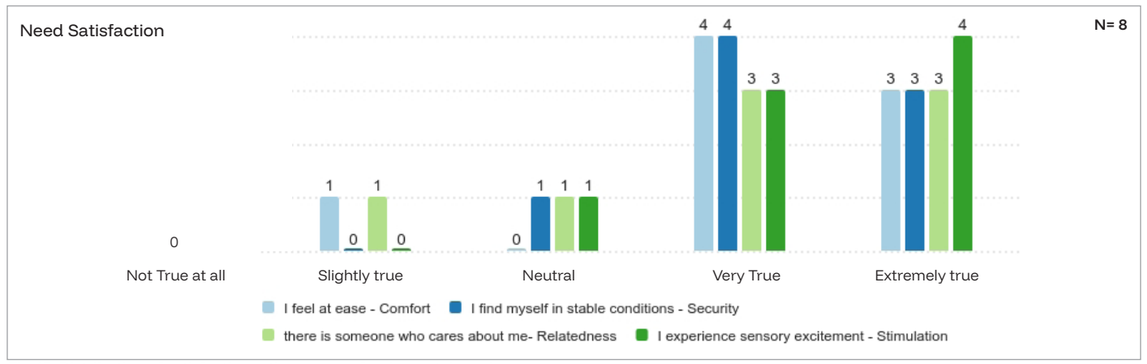


Fig 45: Distribution of satisfaction ratings across fundamental needs

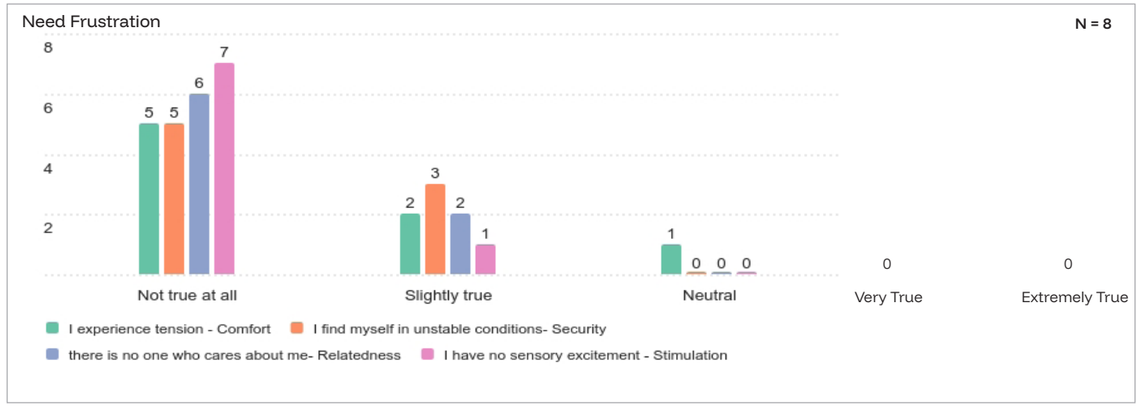


Fig 46 : Distribution of frustration ratings across fundamental needs

Perceived sense of connectedness

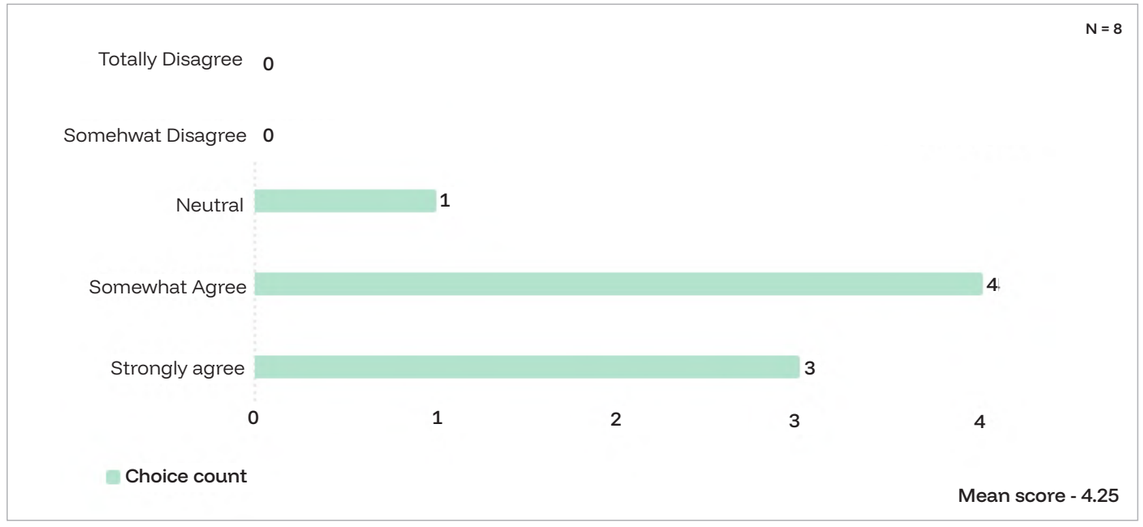


Fig 47 : Perceived sense of connectedness felt by participants during soundscape intervention

The sense of connectedness was previously conceptualized in this study through the fulfillment of four fundamental psychological needs: comfort, security, relatedness, and stimulation. As shown in earlier results, participants reported high levels of need satisfaction across these needs. To further validate this outcome, participants were directly asked whether the soundscape experience enhanced a sense of connectedness to the outside world.

As illustrated in Figure 47 , 7 out of 8 participants responded positively, with 4 selecting "Somewhat Agree" and 3 selecting "Strongly Agree." Only one participant rated their experience as "Neutral," and none disagreed. These findings confirm that the soundscape system succeeWded in evoking a connection to the outside, which is especially valuable in environments like the ICU where patients often face isolation from familiar people and settings.

3. PHYSIOLOGICAL PARAMETERS -

Heart rate Measurements

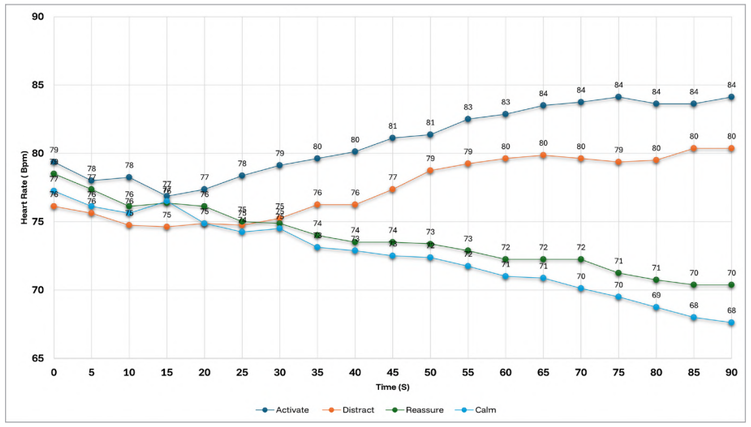


Fig 48: Average of heart rate trends over time across all the ambience types

The graph in the fig 48 presents the average heart rate (in bpm) recorded across a 90-second period for four different sonic ambience types measured on a pulse oxymeter. Activate sounds consistently show a rising trend among all participants. While Distract sounds exhibit a moderate elevation in heart rate over time which indicates a mild effect potentially attributed to the redirection of attention. Reassure sounds show a downward trajectory suggesting a calming and stabilizing influence.Calm sounds show the most pronounced reduction in heart rate averagely. These results show the potential that soundscapes can modulate physiological states. Averagely, Stimulating ambiences (Activate, Distract) are associated with moderately elevated heart rates, while comforting environments (Reassure, Calm) are linked to a moderate reduction in heart rate over time. This also suggests that soundscapes can be utilized to support circadian alignment starting with energizing tones in the morning & soothing ones at bedtime.

4. ACOUSTICAL PARAMETERS

Baseline LAeq,10mins : 42.8

Sound Compostion	Ambience type	LAeq,90s
Activate	Stimulating A	47.2 - 63.5
Distracted	Stimulating B	47.7 - 60.5
Reassured	Pleasurable	47.3 - 52.7
Calm	Comfortable	44.8 - 50.6

TABLE 12. (Psycho)acoustic indicators per sound composition: measured sound level, LAeq,90s

To evaluate the acoustic characteristics of the sound compositions & understand the extent to which they alter the auditory environment, it was essential to measure the sound pressure levels (SPL) across all compositions. These measurements provide a comparative understanding of how each soundscape influences the environment in relation to a baseline condition. Using a calibrated sound pressure meter (Bedrock SM30), the baseline SPL & the corresponding levels for each sound composition were recorded.

Since each ambience type consisted of eight different sound compositions, the measurements were expressed as a range based on the A-weighted equivalent continuous sound level over a 90-second duration (LAeq 90s). This metric captures the average sound energy over a defined period . The resulting table 12 presents the measured LAeq ranges for all compositions in comparison to the baseline, offering insight into their relative acoustic impact.

QUALITATIVE INSIGHTS

Participants shared several notable reflections after the soundscape experience. Many reported that they immersed themselves fully in the compositions often closing their eyes which helped them imagine being in a low-stimulation environment, similar to lying in an ICU bed before the sounds began. Several participants expressed that the comfortable soundscapes evoked a deep sense of calm, with some even mentioning they felt as though they could fall asleep. In contrast, stimulating ambiences, such as café scenes or a bustling city morning, were described as refreshing and energizing, creating a sense of liveliness. However, a few participants noted that the lack of control over the sound playback during the experiment occasionally made certain elements particularly volume changes feel rushed or chaotic, even if those aspects were not central to the soundscape's intended design. Interestingly, while the sounds evoked connection with environments rather than with specific individuals, this was seen as aligning well with the project's goal: to foster a sense of connection through environmental familiarity. Overall, participants described the experience as novel and enjoyable, appreciating the emotional shifts brought by the varied sound combinations and mood.

"I FELT LIKE I WAS SITTING NEXT TO MY CAT , HEAR HER SNIFFING IN A CALMING ATMOSPHERE. MADE ME FEEL HOMELY. "
PARTICIPANT 8

"I WOULD LOVE TO HAVE CONTROL OVER THE SOUNDSCAPES MYSELF, ESPECIALLY TO CURE BOREDOM & NEGATIVE THOUGHTS."
PARTICIPANT 3

"THE SOUND MOVING BETWEEN TWO SPEAKERS MADE THE EXPERIENCE MORE ENGAGING & IMMERSIVE, CONNECTED WITH A MEMORY. "
PARTICIPANT 1

DISCUSSION

In this study , the effectiveness of need based sound compositions was studied and analysed with 8 participants in a simulated ICU set up at the Delft University of Technology. Four personalised sound compositions per participants were used to test whether they evoke the intended emotional response and evaluate their effect of the soundscape perception. All sounds were played at the same volume level and this might have served as a limitation for the user testing.

The elements used in the sound compostitions as well the narrative has definitely created an impact on the perceived attribute ratings. For e.g car sound, coffee machine sounds, rooster in the morning sounds was perceived to be more eventful that waves and forest wind sounds. It was also commented by one of the participants that the structure of the sound composition in terms of the storyline also created in impact in perceiving it. This led them to rate stimulating sound composition into chaotic and annoying quadrants in some situations.

Additionally, for all the participants , we found that the soundscape's position was moved from the monotonous & annoying quadrants to vibrant and calm quadrants in the circumplex grid. Through this study , it confirmed that the sound compositions evoked the desired affective responses & it can also be confirmed the functional role of every sonic ambience type designed for a particulat event in the ICU has also been achieved which paves a path for the design intervention to be succesfully implied in ICU settings.

CONCLUSION

Research has proven that the negative perception of the current soundscape of the ICU may lead d to long-lasting psychological impairments in patients post discharge. In this study we tried to examine that if positive sounds as a source of need fulfilment and physiological changes can lead to positive experiences to individuals.

Findings from the various methods employed in this usability evaluation indicate that soundscapes designed to evoke specific emotional responses and fulfill user needs can offer a promising alternative for enhancing auditory experiences in critical care settings. These results provide initial evidence supporting the feasibility of implementing such a design intervention in real ICU environments.
Data from the perceptual attribute assessment and need satisfaction survey revealed notable shifts in emotional parameters and a high degree of need fulfillment attributed to the added sound layers.

Along with this , the results from the heart rate measurements also confirmed changes in the intended direction of the functional role of the soundscape. To conclude , designed sound compositions according to the suggested sounds can create positive outcomes in terms of personal touch and match the needs in different situations. This research could in turn result in improved outcomes in ICU patients by reducing stress and long term PICS related symptoms.

07

FINAL DESIGN

This chapter presents the final design of SoulSound and its brand identity. Informed by various iterations based on the insights from usability tests and the research , the concept is presented through its key functionalities, application scenarios, storyboards, and user interface designs. This chapter concludes with an evalution test with experts.

7.1 INTEGRATION OF SOULSOUND IN ICU

To be able to implement the designed intervention in the ICU , it is necessary to understand the requirements of the set-up and therfore opportunities and limitations along with establishing the supportive functionalities of the system. This section highlights the requirements and presents the system through functionalities followed up with the previously defined categorization for the conceptualisation.

7.1.1 GENERAL REQUIREMENTS :

When designing a sound system for the ICU, it is crucial to consider both the practical and clinical requirements of the environment. The device should be easy to maintain and reposition , without obstructing the work of the caregiving staff. It should be intuitive and ergonomic for caregivers to use, fitting seamlessly into the existing setup without introducing unnecessary complexity. Additionally, to reduce maintenance demands, it should operate without batteries and be easy to store when not in use.

The placement of the speaker is particularly important. It should be positioned close enough to provide an immersive audio experience without becoming an intrusive presence or causing discomfort to the patient. This proximity ensures the sounds remain ambient rather than sharply focused, reducing the risk of auditory strain or stress. At the same time, it is critical to avoid placing the device too close, as this can raise concerns about hygiene and infection control, both of which are critical in an ICU setting. A well-integrated design that blends naturally into the existing context will be more acceptable to both patients and caregivers.

7.1.2 KEY FUNCTIONALITIES OF THE SYSTEM :

Enhancing connectedness through personalised soundscapes

The most important function of the system is to provide a personalised sound environment as some sounds can be perceived differently by individuals. To fulfil the need of connectedness to the outside world it is necessary to get inputs based on familiar environments from the patient in order to create personalised soundscapes and expose them in the ICU. Through the final system, it takes into account individual sound preferences related to sound categories to fulfil functional role of the sonic environment throughout the day. The soundscape generator processes all this data and creates soundscapes in real time.

Giving power over environment through dynamic controlability (Patient & HCP)

Before and during the adminssion in the ICU , the patient is given the final responsibility to log in their preferences as well as change them during the experience depending on the change in events. This gives them a feeling of autonomy and power over the environment. The final design also allows HCP's to have a control over the system and adjust the soundscape based on the requirements and the desired behavior of the patient at particular times of the day. Moreover it is critical that the system is easily integrated into the workflow of the HCP.

Promoting psychological support through adaptive sound management

Based on the research, a patient's emotional well-being is closely influenced by the surrounding contextual conditions, which must be carefully considered when designing a sound-based system for the ICU. Given the complex acoustic environment of the ICU, it is essential for the system to dynamically adapt its output, ensuring that the sound levels align with the patient's immediate context. This involves reducing volume during critical moments such as medical rounds, family visits, or when healthcare professionals are present, while also being responsive to sudden changes in the patient's condition or environment. Such adaptability is crucial for providing the right auditory support at the right moment, fostering a sense of comfort and connectedness without adding to the sensory burden.

7.1.3 HARDWARE COMPONENTS

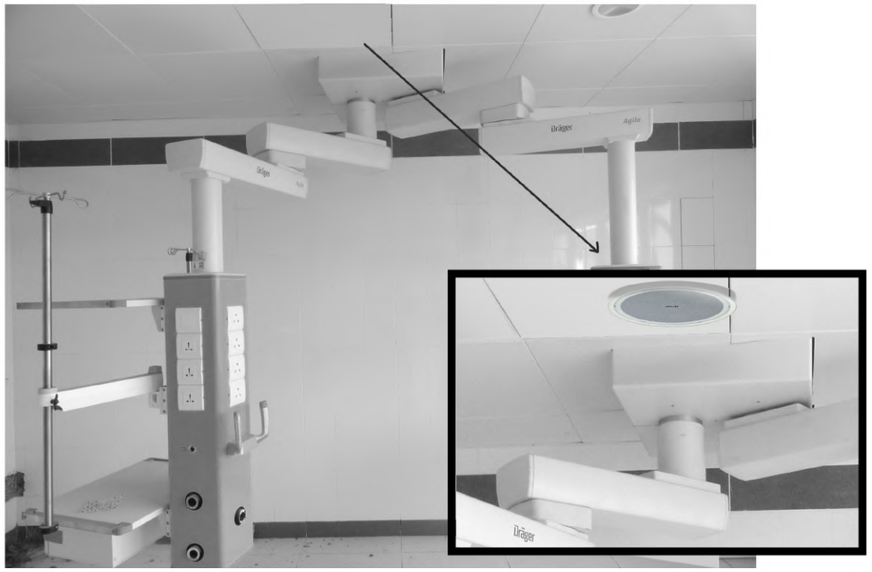
This section outlines the technical feasibility of integrating the proposed sound system within the current ICU infrastructure at LUMC. It specifically focuses on the hardware components required namely, the speaker units and evaluates their potential integration. Two distinct options for the type of speaker and their placement along with the pros and cons are presented, each designed to enable optimal sound dispersion while maintaining compatibility with the clinical environment. Both options offer distinct advantages and can be implemented effectively depending on the specific context, room type, and architectural layout. According to the researcher, the SoulSound system is flexible in its implementation and can be effectively adapted to work in both configurations

Option 1 (fig 49) involves a ceiling-mounted directional speaker positioned above the patient's head, providing focused audio delivery with minimal interference to medical workflows. Option 2 (fig 50) uses two compact Bluetooth parametric speakers mounted on the DIN rails at either side of the head, allowing immersive left-right spatial audio. This setup integrates well with existing infrastructure, offers easier installation and maintenance, and aligns with available power sources. As learned from Van Houwelingen (2022), speakers used in the ICU should not rely on batteries and must be powered via sockets for safety and reliability. Hence the selected speakers can connect over wifi and are powered by sockets.Table 13 presents the pros and cons of both the options.

OPTION	1	2
Pros	• Aligned with the patient's head for optimal directional sound. • Non-intrusive: No obstruction to staff or equipment. • Mimics natural and ambient sound delivery , perceived as passive. • Tamper proof - out of patient reach	• Support wireless communication. • Allows for spatial audio design (left-right separation) which is more effective. • Installs on pendant rails; simple to adjust or maintain. • Angle or individual speaker can be tailored.
Cons	• Challenging Installation: Requires ceiling modifications. • Higher distance may reduce sound focus. • Low flexibility: Difficult to reconfigure once mounted.	• May obstruct staff or equipment access. • Extra hardware close to the patient may be distracting or unsettling. • Hygiene risk: Needs strict cleaning due to touch exposure.

Table 13: Overview of the pros and cons of the placement options

1 Audfly ceiling mounted directional speaker



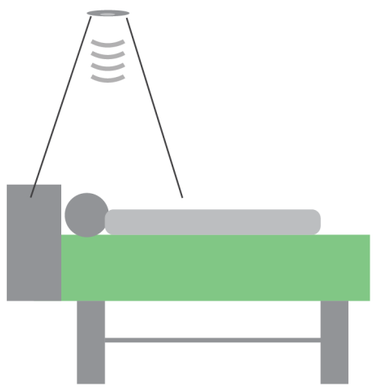


Fig 49 - Placement option 1

Audfly Bluetooth parametric speakers (2 units)

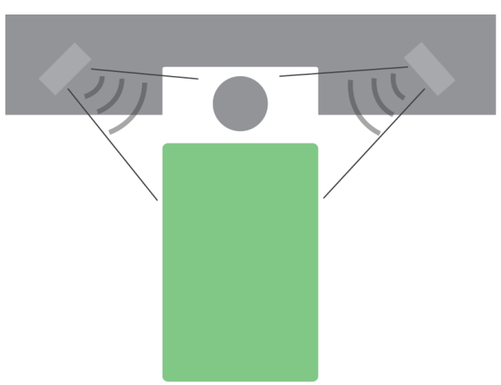


Fig 50: Placement option 2

7.1.4 SYSTEM IMPLEMENTATION

An adaptive and responsive sound management system relies heavily on a well-designed software architecture. In the proposed sound system concept, no integration with existing patient data systems is required. Instead, the system operates independently, drawing input from a dedicated patient-facing app, which can be filled out by the patient or their loved ones. The focus is on capturing real-time emotional states, preferences, and contextual events rather than biographical or medical data. This ensures privacy and simplifies implementation while enabling the system to dynamically generate appropriate soundscapes based on live inputs. The software is linked to a curated library of sound samples, allowing it to assemble personalized auditory experiences that reflect the current needs or moods of the patient without reliance on clinical records.

Flow of the system :

The SoulSound system operates through an event-driven architecture composed of three interconnected layers: event producers, event channel, and event consumer.

At the input stage, **event producers** include the patient's sound preferences gathered through the mobile app, preference data submitted by loved ones via the tablet app at the start of admission, live observations and controls from healthcare professionals (HCPs), and real-time environmental data such as noise levels or room activity detected by sensors.
These various inputs generate events that are transmitted through the **event channel**, the core communication layer responsible for relaying event data efficiently between the producers and the system's core processing units.
This stream of information is received by the **event consumer,** which in this system is the soundscape generator. Based on the incoming events, it actively selects and adjusts appropriate sound files to match the patient's current context. The final output is delivered through speakers in the ICU room.

Implementation :

Fig 51 shows a flowchart visualisation of the soundscape system applied to be implemented in the context. The main event in this system is the data acquisition which mainly consists of data from the patient app i.e the preferences based on specific function and the data from the exisiting sound environment as sound pressure levels. This data is used to create the soundscape used to mask the current sound environment. The soundscape generator receives the preferences in categories(Human, Natural, Musical and Technological) which is further used to create the relevant composition based on th eventfulness and the function it intends to fulfil. The system correctly filters the right sound files necessary to create a balance between all categories keeping the volume and amplitude in mind. This is then converted into a sound file which is delivered via the speaker in the room. The control device in the room and the mobile app that the patient can use to give feedback to the system are connected to the speakers to provide real time updates to the soundscape. The new feedback then generates a new soundscape for a new event and the cycle goes on.

The new Soundscape :

The main purpose of the system is to generate a new soundscape in the real world environment based on positive sounds. This new soundscape is produced as a result of the individual preferences for each patient tied to a specific function (attribute) and conveyed as a result of the input from the HCP or patient in real time. The sound scape generator produces soundscape for each specific ambience which is connected to the the options the HCP's have to choose from. For eg. If the HCP chooses activate function, the stimulating ambience type soundscape will be played as it fulfills the necessary event demand. The distrubution of preferences from the quesionnaire for the natural, human , technological and musical sounds make these different sound ambiences in a perfect balanced combination for each patient.

The HCP options are - "To activate" and "To distract" for stimulating type , " To Reassure" for pleasurable type and "To calm" for comfortable ambience type. These decrease in eventfulness throughout the day and allow the HCP to change according to the patient state.

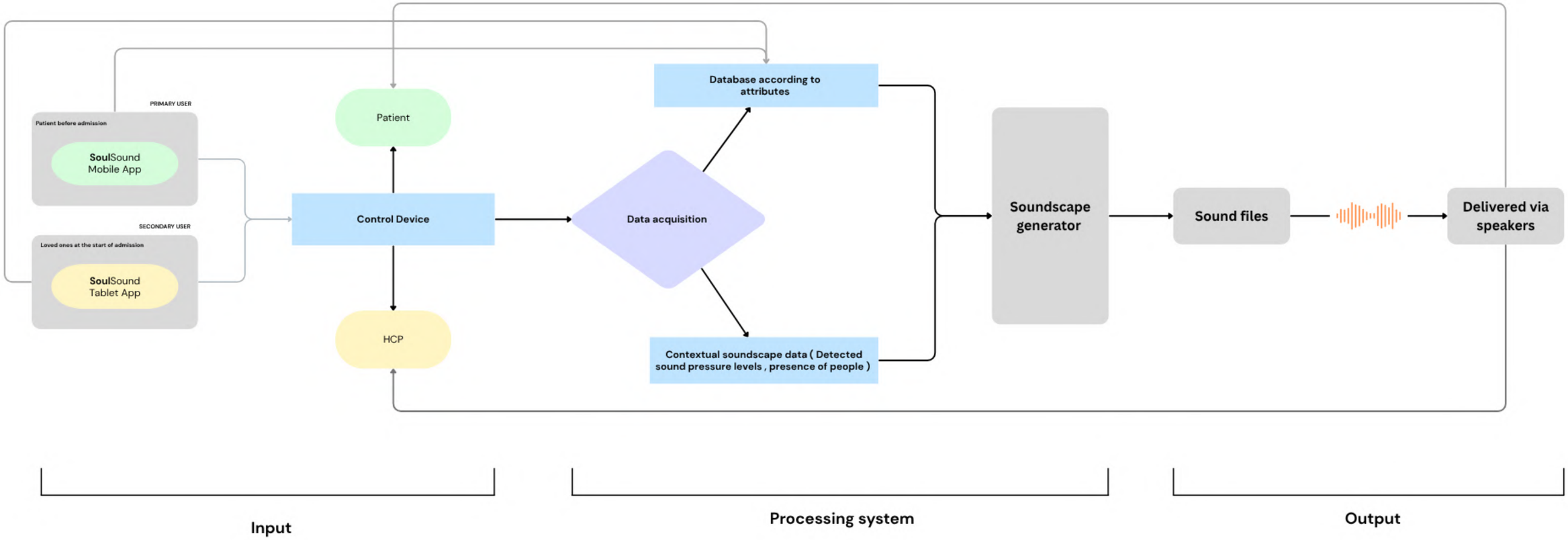
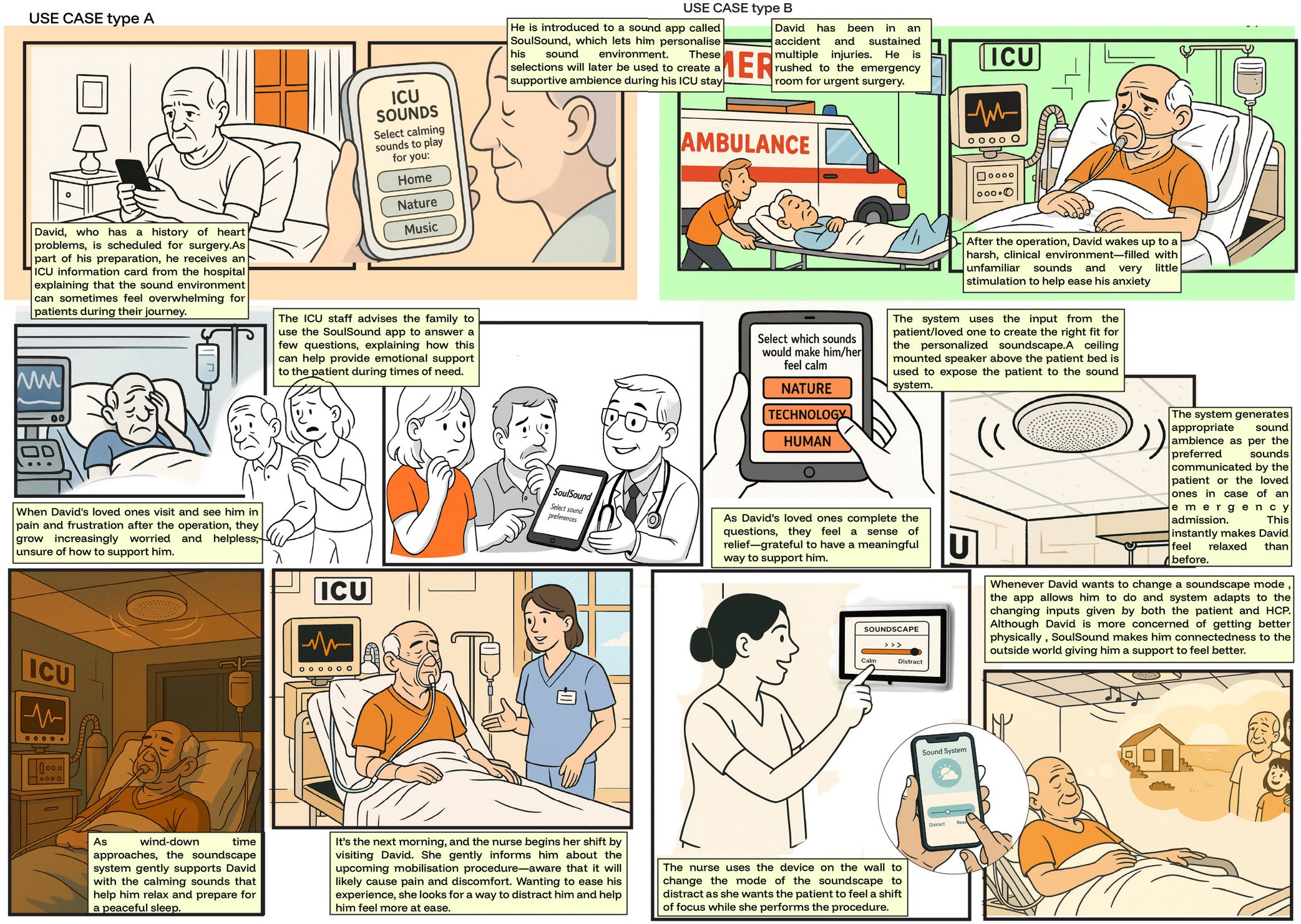


Fig 51 : System architecture diagram of the Soundscape system with input & output

7.2 STORYBOARD

This section through Fig 52 illustrates the system storyboard which helps understand different parts of the system effectively highlighting the product use, timing and stakeholder's roles. The storyboard is read from left to right following each row.

Figure 52: Storyboard of the system



USE CASE type A : Scheduled admission

USE CASE type B : Emergency admission

7.3 VISUAL IDENTITY

This section presents the brand image of the SoulSound System.

BRAND IMAGE

Building on the insights so far , the design has been improved on several levels. In order to make the system recognisable and trustable , it is necessary to develop a brand image which not only highlights the functions and the benefits but also reflects a character which is engaging. A brand identity is not just about aesthetics, it's about communication. Brand identity conveys the brand's core values, tone, and personality without using words. It tells users what the brand stands for. With a goal to make the system very user friendly and accessible , this new identity will be showcased through the logo, the product design and the tone of communication.

SoulSound

SoulSound is a healing-centered brand that brings emotional support into clinical spaces through the power of personalized sound. It exist to reconnect patients with comfort, calm, and a sense of self. SoulSound aims to enhance emotional well-being and connectedness in the ICU through personalized, need-based soundscapes. Its a platform that reflects the power of sound not just as music but as sound composed into layers.

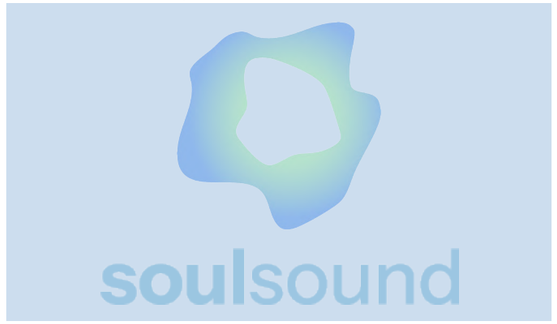


Figure 53: Brand logo

Brand personality

The overall visual language of SoulSound shown in fig 53 is crafted to reduce the anxiety and encourage a sense of familiarity and trust within all the stakeholders. It moves away from the clinical and administrative aesthetics typically seen in hospital interfaces,instead aims to create a safe space to express and create a control over environment through senses.

SoulSound embodies a soothing, empathetic, and emotionally intelligent brand personality. Through its typography and color selection it focusses on emotionally resonant and subtle design.

Logo

The SoulSound logo is a soft, organic shape that subtly conveys the idea of a sound aura or sound cloud symbolizing the invisible but deeply felt presence of sound in healing. It adapts fluidly to the interface's changing color themes. Paired with the lowercase, rounded type in Instrument Sans, the logo embodies approachability and familiarity. The logo is subtly integrated throughout the user interfaceto reinforce the calming presence of the brand with the user.

Typography

SoulSound uses Instrumental Sans , a rounded and warm typeface intended to capture a subtle and calming feeling. This choice promotes: Clarity and legibility (important for patients of all ages), A friendly, non-intimidating tone , a neutral modern feel, maintaining professionalism as a hospital centred brand.

Colors

SoulSound uses subtle but engaging gradients of colors in the user interface shifting with the changing ambience or mood type to retain the engagement and build curiosity. Throughout the design it used blue, purple , peach and mint green to reflect the intended feeling. These gradients create a gentle, non-clinical aesthetic, helping the interface feel more inviting and less like a medical device.

With this brand identity , the next section presents the final design through the user interfaces of SoulSound informed by the testing results and iterations.

7.4 FINAL USER INTERFACES

Fig 54 presents an overview of the user interfaces for “SoulSound” which is a soundscape system designed to create personalised sound environments for patients in the Intensive Care unit. The system aims to enhance patients’ comfort and connection to the outside world by offering tailored sounds suited to different emotional states or needs.

The interfaces are designed for three different stakeholders in this system namely , the patient , the helathcare providers and the loved ones.

The use of this system starts with the patient pre-admission (in case of a scheduled admission) using a mobile phone app that allows the patients to communicate his/ her sound preferences for each dedicated sound ambience type related to a function /mood. These final interfaces have been designed drawing upon the insights from usability tests in round 1 conducted to test the engagement and usability. The mobile app features a very quick questionnaire type process as the patients will already be in a stressed state. The aim of this app is to empower the patients to actively participate in shaping their own sound environment in the ICU and giving them an idea of the sterile sound environment which can be overwhelming.

HCP’s use a control device with a digital platform installed in every ICU room to select and manage the appropriate sound mode - Activate, Distract, Reassure, or Calm according to the patient’s current clinical or emotional requirements. This provides the HCP’s to extend their care beyond just physical measures but emotional too. This control device manages sound which is delivered via speakers placed in the room for a personalised and comforting experience for each individual patient. The interface does not demand a lot of extra load from the HCP’s but instead provides a direct and intuitive overview of the soundscape and options to change or adjust it.

In case of an emergency admission when the patient cannot communicate with the mobile phone application , the system provides an easy to use tablet application from the hospital which allows the loved one answer guided questions about the patient’s preferences. This enables family members or close friends to contribute meaningfully to personalizing the patient’s auditory environment, reinforcing connection, familiarity, and emotional support even when physically apart. The next sections will explain each screen in detail and will clarify what exactly is visualised with each component.

Scan the Qr code
for SoulSound video

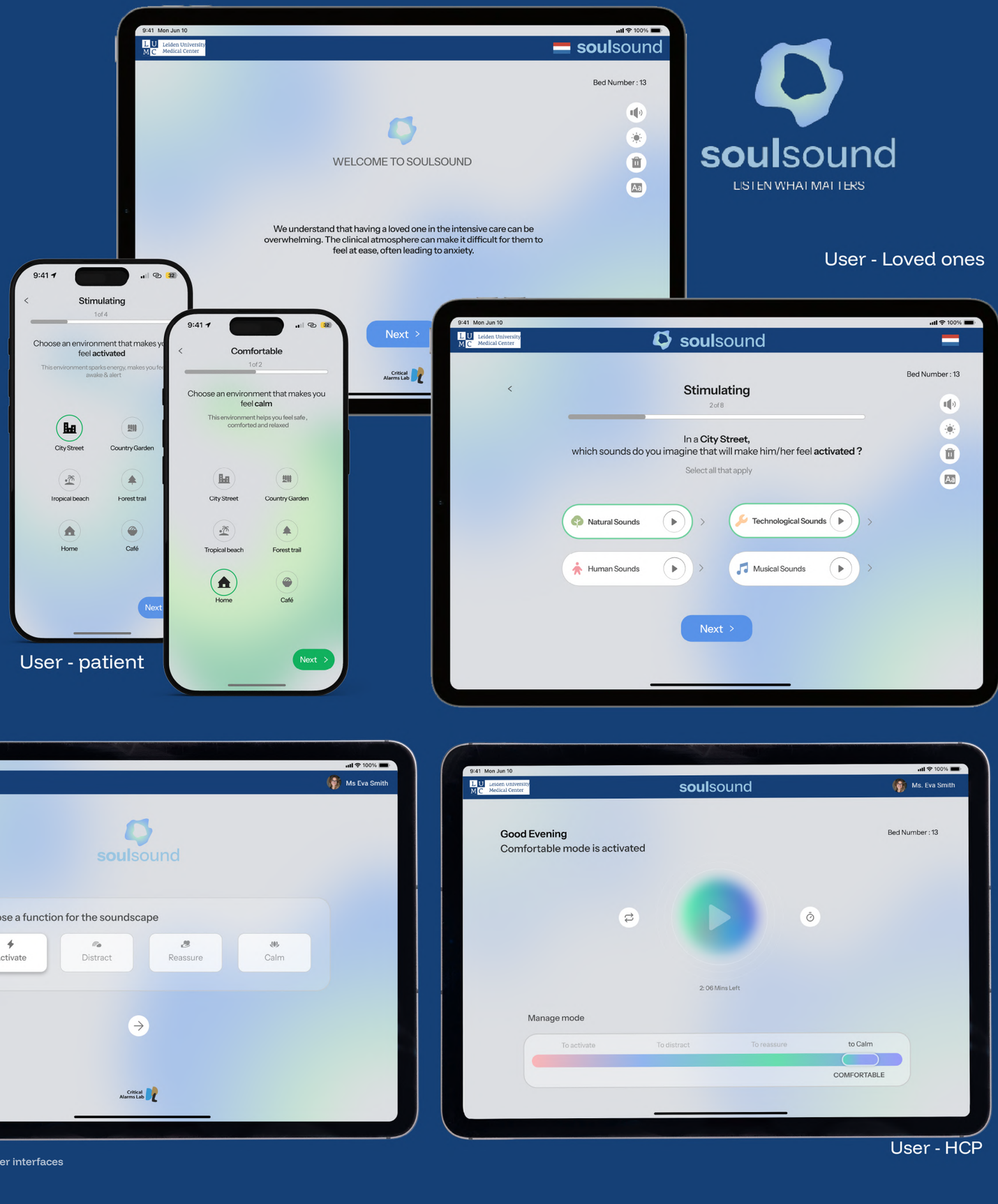


Fig 54 : Overview of the user interfaces

Introduction to SoulSound pre-admission
User - patient

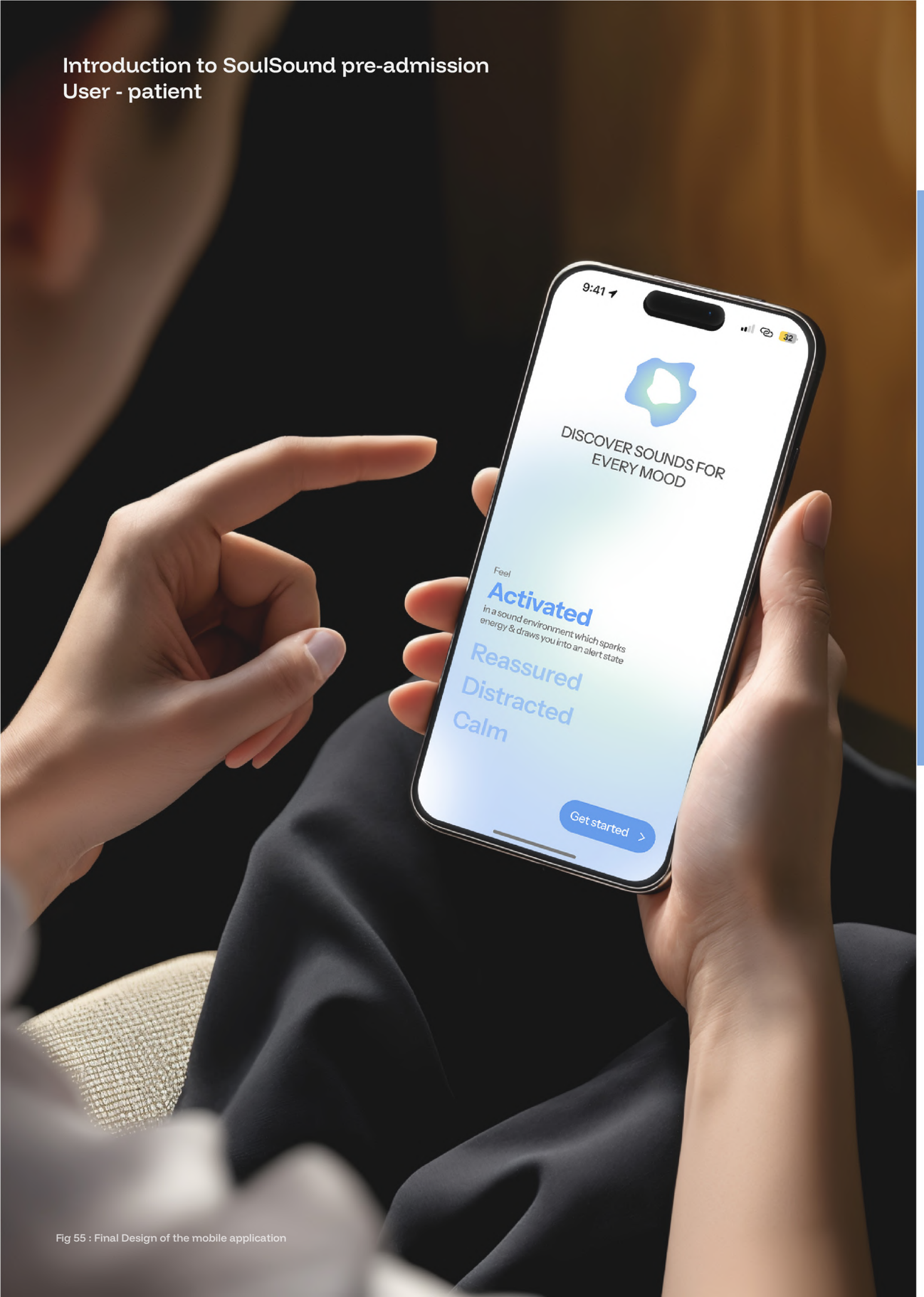


Fig 55 : Final Design of the mobile application

1 **Introduction** — Information about SoulSound is sent to the patient once admission to the ICU in confirmed.

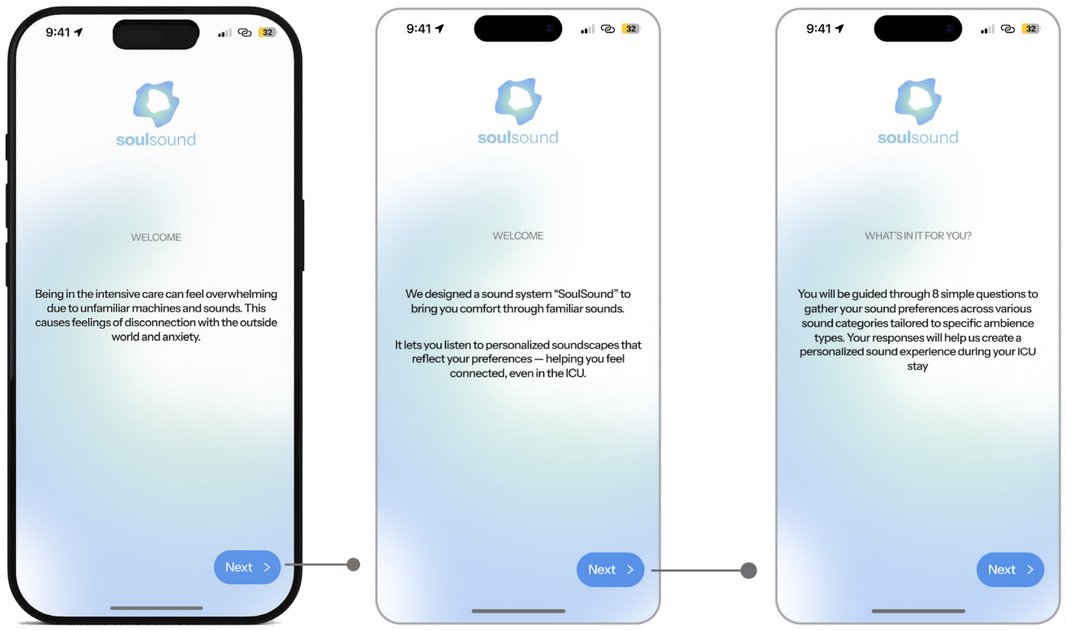
2 **Downloading** — Using an unique identification number , the patient downloads the app on his mobile device.

3 **Getting familiar** — With a series of information screens , the patient gets familiar with the purpose of the app.

4 **Setting preferences** — Once familiarized, the patient can set his preferences for sound according to each category.

Introduction screens

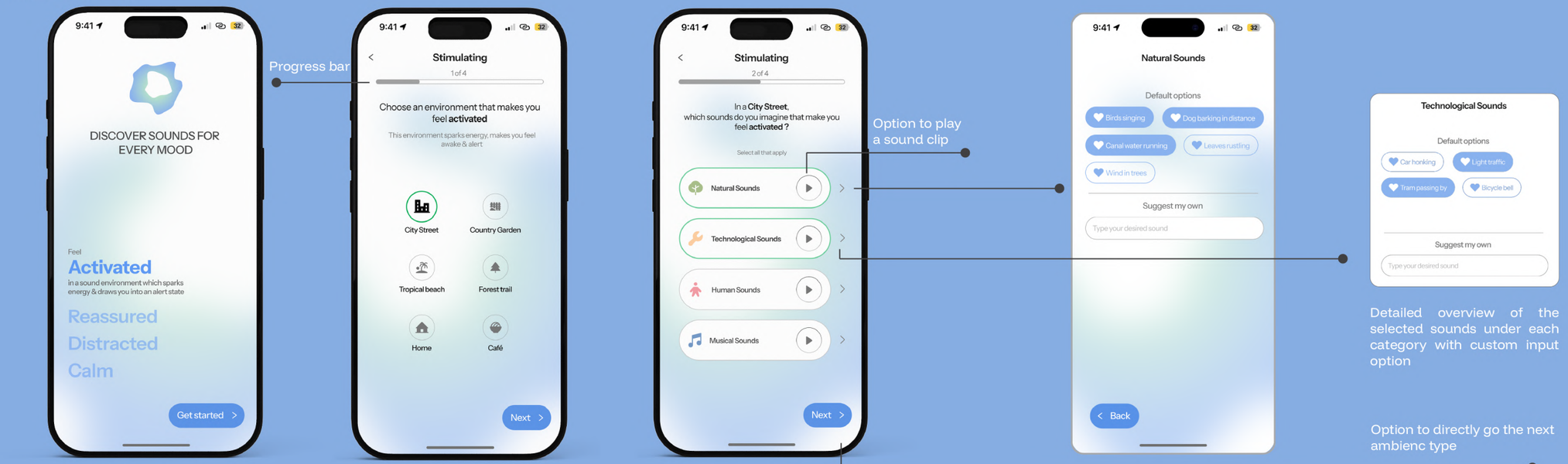
This image illustrates the splash screens of the mobile application intended for patient use prior to hospital admission. The application flow begins with a concise and clear introduction to the context and purpose of the app. The onboarding experience concludes by presenting an overview of the emotional states or moods that users will explore within the app.



Questionnaire screens

The screens below display the questionnaire flow beginning with the first ambience type, "Stimulating" which corresponds to the mood "Activate." From this point onward, each screen dynamically guides the user based on their selected preferences for 3 different ambience types.

Mode - Activate

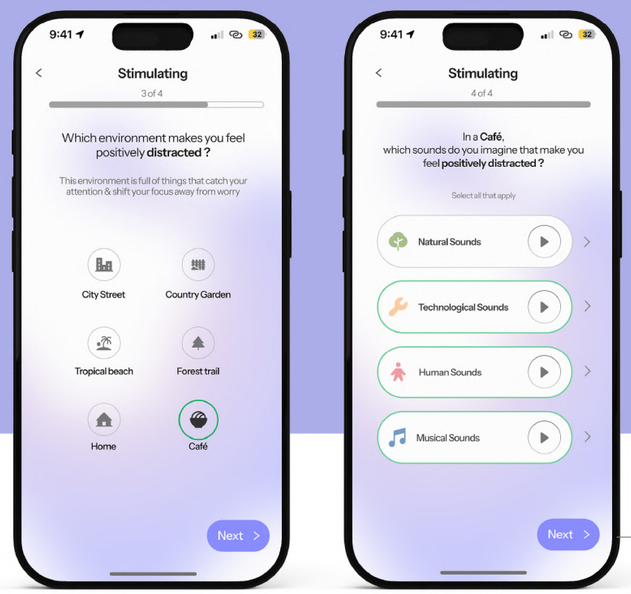


Overview of moods to set prefereces for

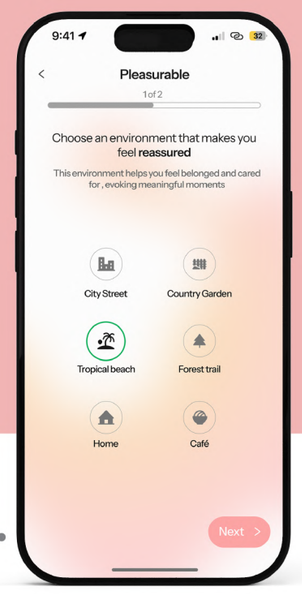
Option to select an environment for the mood

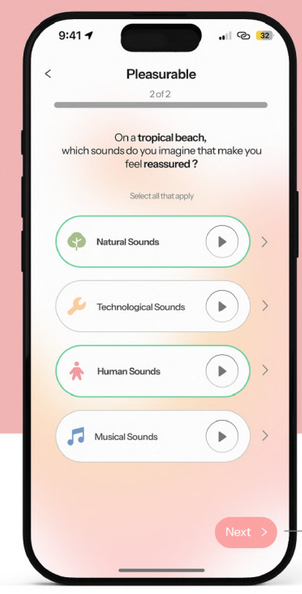
Sound preference selection according to four categories for the selected environment

Mode - Distract

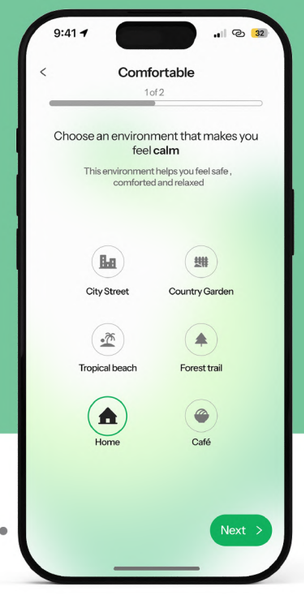


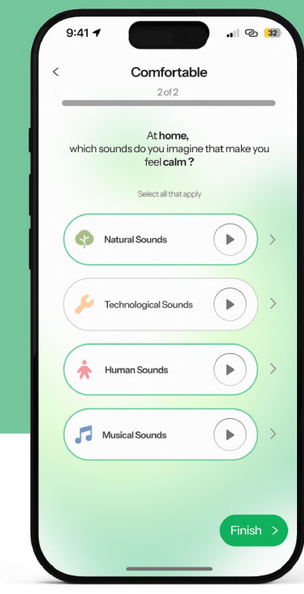
Mode - Reassure





Mode - Calm





Rest of the screens follow the same pattern for a total of 8 questions. As demonstrated above, each sound category screen will provide the option to go in details of the default sounds , edit them or input their own if desired.

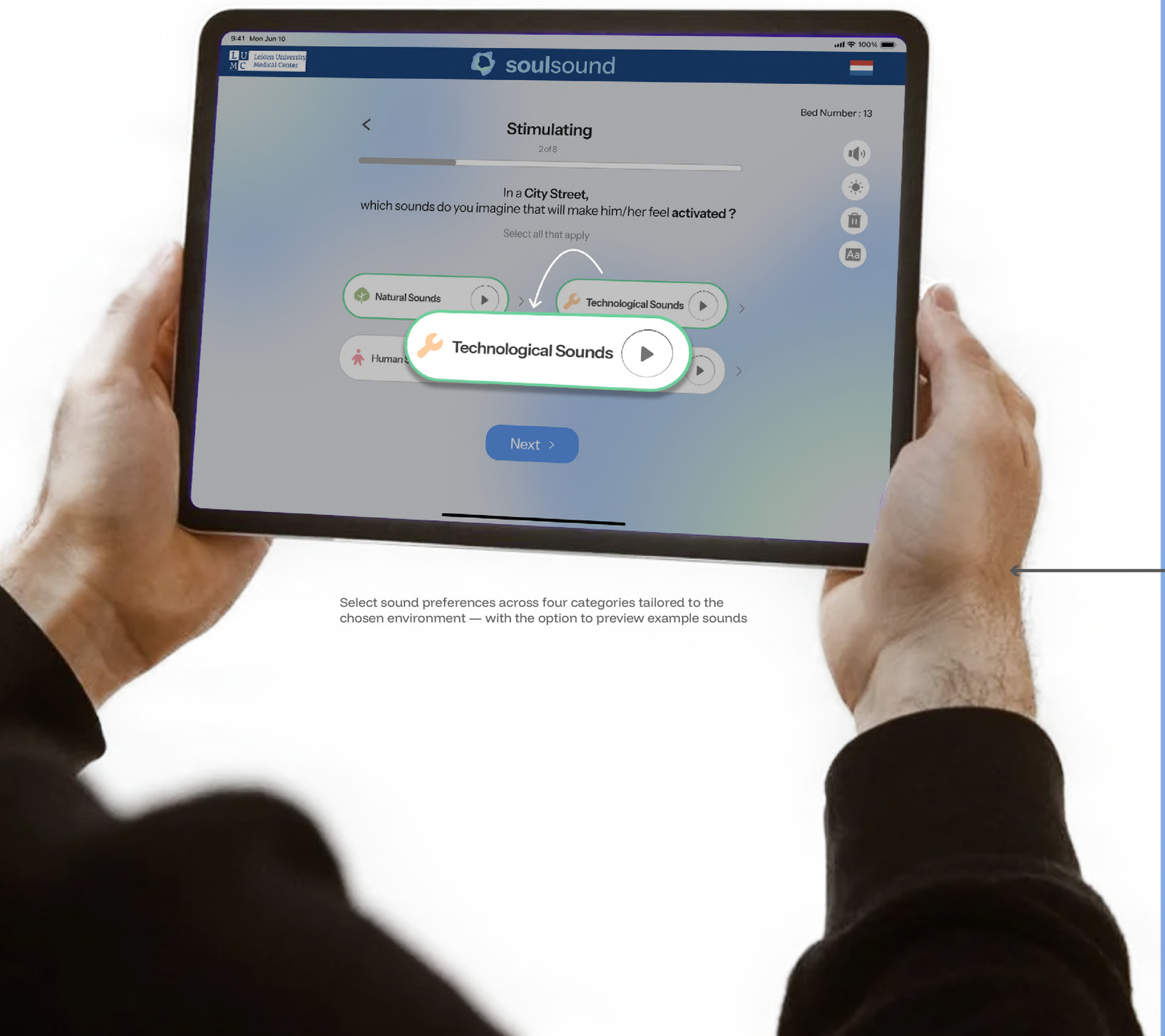
The logic -
Once an environment is selected, the system suggests default contextual sounds organised into categories. For e.g if the user selects beach , sounds specific to beach will be shown in categories to select from. The user can select multiple sound options with atleat one required. These inputs are then stored in the system and processed to generate soundscapes for each user separately for four different moods.

Fig 56 : Detailed design of the mobile application

Introduction to SoulSound at the start of the admission

User - Loved ones

The interface for the loved ones is designed to incorporate into the hospital tablet which is used in their clinical routines. It maintains the same visual language and tone as the mobile phone interface.



Select sound preferences across four categories tailored to the chosen environment — with the option to preview example sounds

The user flow starts with the onboarding screen explaining the goal and questions

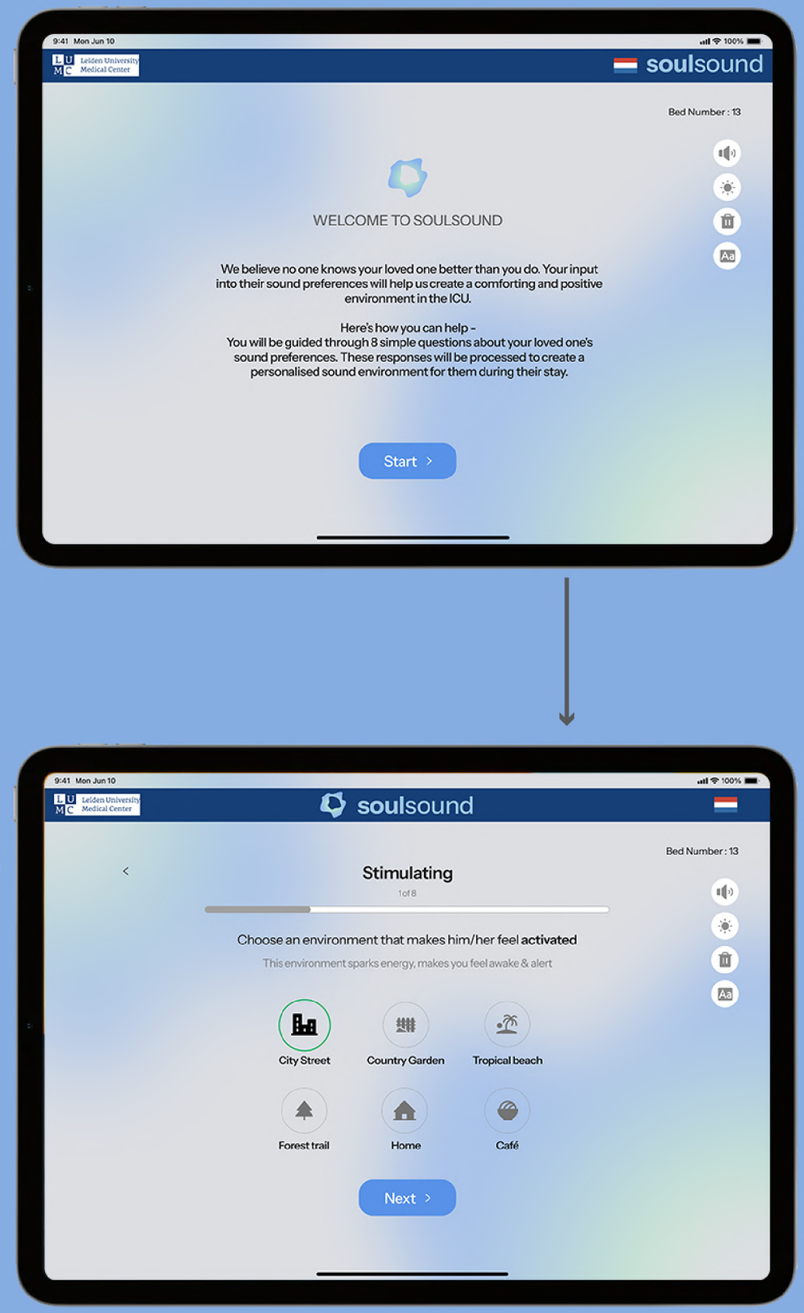


Fig 57 : Final Design of the Tablet application for loved ones

Introduction to SoulSound during admission

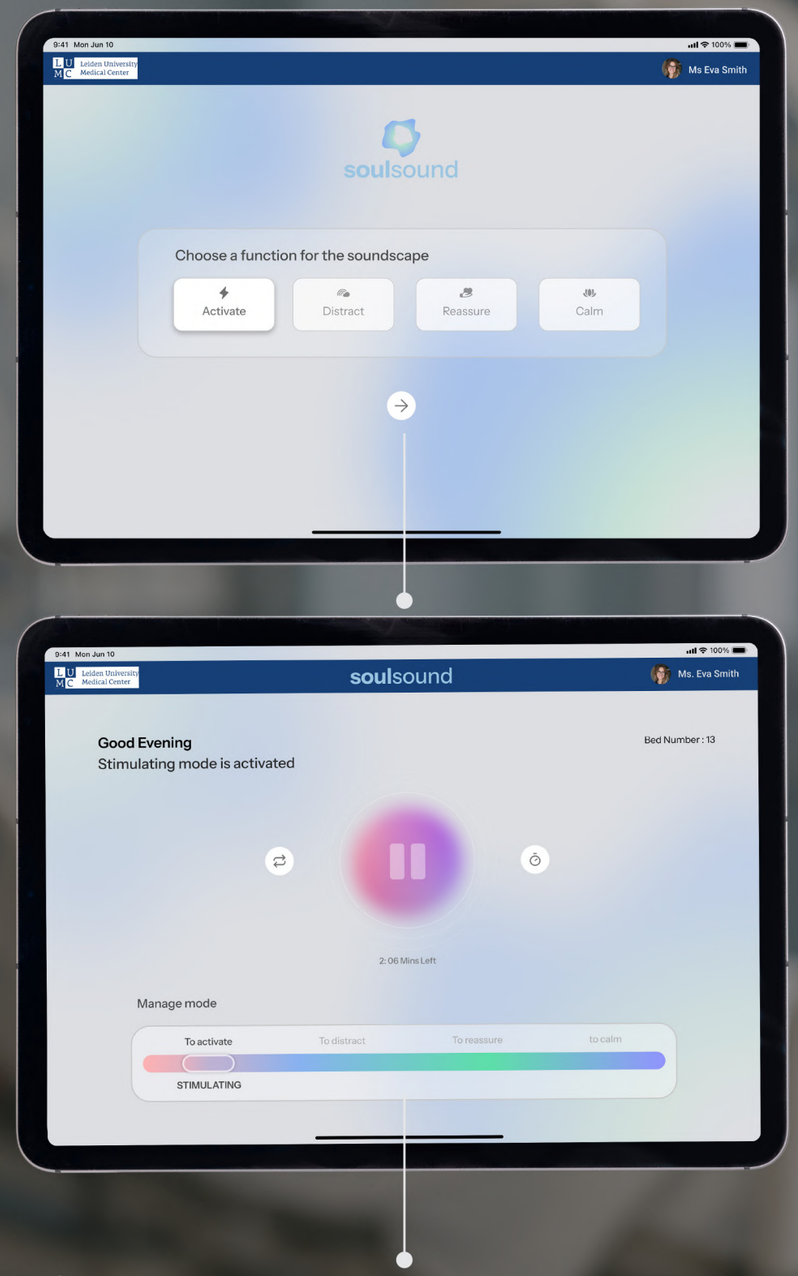
User - HCP

Control device interface showing an active status of the Comfortable soundscape mode

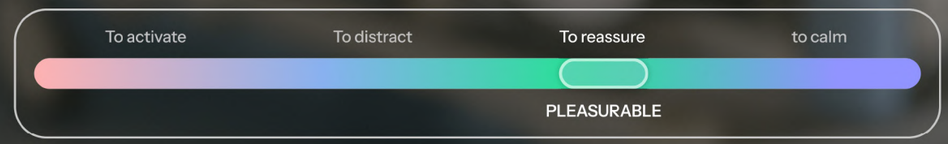
Soundscape Session timer for Mode Duration control

Fig 58 : Final Design of the control device interface for HCP

When another nurse takes over , these modes will give an overview for the selection of the soundscape

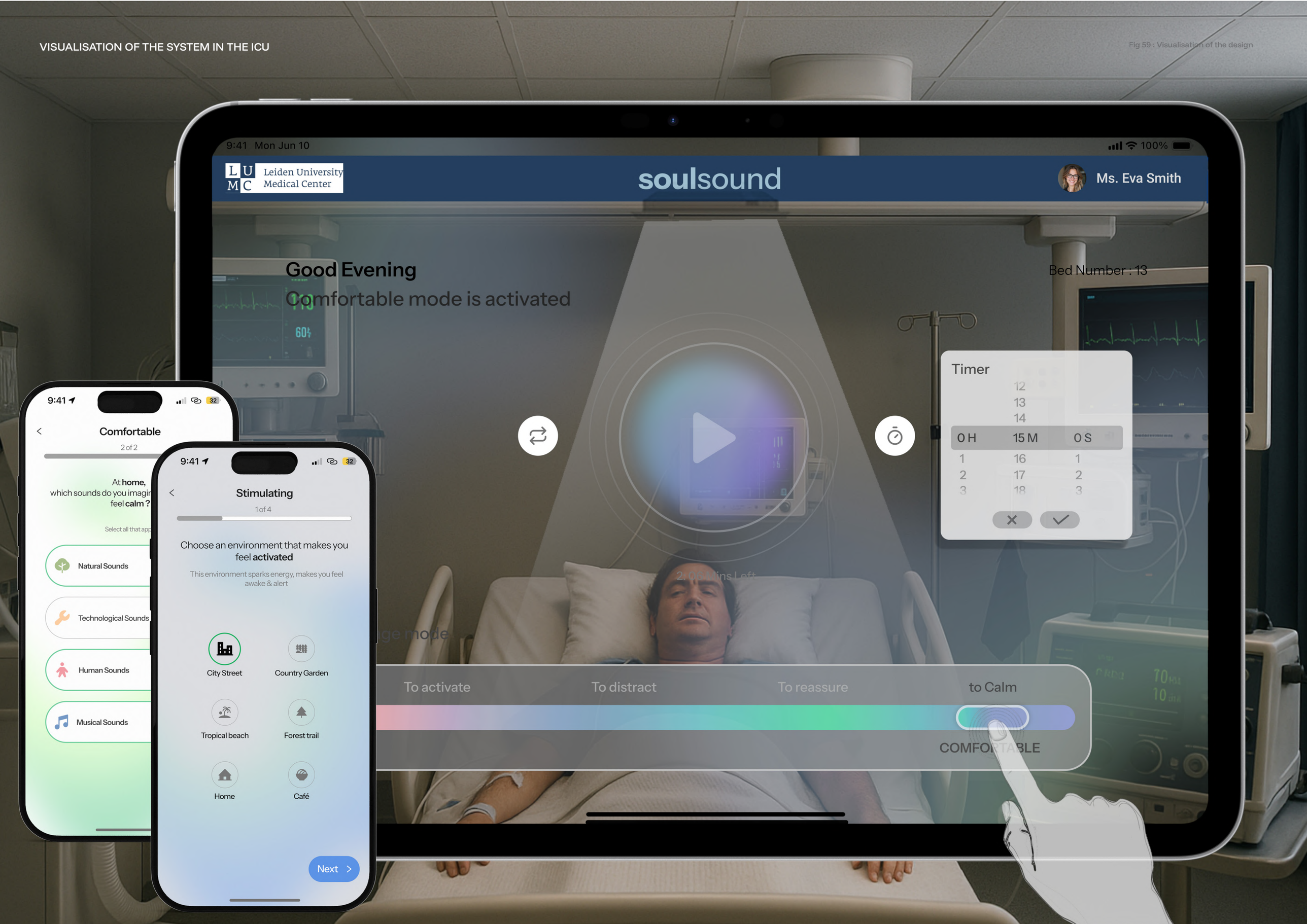


Manage mode



Easy and intuitive mode management bar for shifting between functions

Fig 59 : Visualisation of the design



7.5 EXPERT EVALUATION

7.5.1 AIM

The aim of this Concept Evaluation session is to gather expert feedback on the SoulSound system as an overarching concept. The evaluation seeks to understand how different stakeholders in the healthcare domain perceive the concept's relevance, usability, potential integration within the clinical environment. To ensure a comprehensive perspective, insights will be collected from four fields of expertise: Healthcare staff, Researcher in Healthcare, Ex-ICU patient & hospital technician. The feedback will be outline the strengths & weaknesses of the current concept & explore opportunities for future work.

Fields of expertise :
The experts were either part of Delft University of Technology or the Leiden University Medical Centre. The fields of expertise are highlighted below.

Healthcare professionals – ICU nurses and physician :
Bring firsthand experience in daily patient care, workflow integration, and challenges in the acceptance of such a system in the ICU environment.

Technical Advisor :
Contributes technical knowledge related to infrastructure, equipment compatibility, and the feasibility of integrating audio system within existing ICU setup.

Healthcare design and usability expert (TUD) :
Offers a human centred perspective towards the system especially in high-stress environments like the ICU. Brings valauble insights into evaluation of multi stakeholder needs ensuring it is accessible and intuitive considering the behavioral impact.

EX-ICU patient : Contributing through lived experiences how SoulSound can become a part of the ICU journey.

7.5.2METHOD

All experts were contacted via email and invited for in-person interviews. The sessions were conducted either at Leiden University Medical Centre (LUMC) or on the TU Delft campus, depending on the expert's availability. Each interview followed a consistent structure: it began with a brief explanation of the project's context, the identified problem, and the proposed design solution. The SoulSound prototype was then presented to demonstrate its core functionalities and to serve as a stimulus for discussion. Given the limited time availability of participants, semi-structured interviews were used to ensure that key aspects of each expert's domain were addressed. The interview guide consisted of prepared questions, used as prompts to initiate discussion and evaluate critical elements of the design. The full list of questions can be found in Appendix.

7.5.3 DATA COLLECTION

Semi structured interviews were used to collect qualitative data. To create an overview of the test results , this qualitative data from interviews was clustered into interesting insights. The data was plotted in a diagram using the Plus-Minus-Interesting table format.

7.5.4 RESULTS :

Table 14 shows a table with the most important results of the qualitative research. Additionally, all expert insights were organized into thematic clusters, allowing for a more structured analysis based on the evaluation categories that emerged. The data that was generated during the interviews was analysed and the following clusters emerged: Acceptance by healthcare professionals, Patient centred relevance, Technical intergration and feasibility, Sound types and strategy and Possible role of technology. Each cluster includes a summary of the main insights, supported by direct quotes from the experts to illustrate and contextualize the findings.

Overall impression of the concept:

The overall impression of the soundscape system, as gathered from experts across nursing, healthcare usability, and technical domains, was largely positive, highlighting both its emotional impact and implementation feasibility. Healthcare professionals appreciated the system's simplicity and intuitive interface, noting that it could integrate well into ICU workflows without becoming a burden. They valued its potential to support patients emotionally especially during night shifts or rehabilitation exercises by providing a calming and familiar auditory environment. However, they also expressed caution around its use with vulnerable groups like delirious or unconscious patients, where personalization might be misinterpreted or not appropriate at all. From a usability and healthcare design perspective, the system was seen as more than a playlist , it was praised for its meaningful and structured approach to sound, offering patients a sense of control and connectedness in a disorienting environment. Technically, the use of directional , ceiling-mounted speakers was considered feasible, provided the system maintains strict standards for electrical safety, hygiene, and integration with existing hospital infrastructure. Concerns were raised about Bluetooth connectivity, potential interference, and the added complexity if AI were introduced, especially if it created autonomous feedback loops based on physiological data.
From a patient perspective, a clear need for tailored sound environment was highlighted with a strong willingness to be a part of a preference based sound system, however the timing of introduction of the system to the patient was found critical. Overall, the concept was seen as promising and implementable in the near future especially for enhancing psychological well-being. It was also looked at as a structured and innovative modification into the current sound practices of the ICU.

	PLUS	MINUS	INTERESTING
EXPERT 1 ICU Nurse	It is good that the concept supports buildings sounds from preferences. It takes it beyond what television or radio can offer.	The app guided system may face limited engagement during pre-admission or early admission phases, as patients and their loved ones are primarily focused on physical health concerns; its implementation might be more suitable once the patient's condition stabilizes.	Music can act as a pain sedative and serve as an effective distractor.
EXPERT 2 ICU Nurse	Once implemented, such interventions can serve as subtle cues - when sounds play at specific times, they can signal moments like patient rest, prompting staff and visitors to become more mindful and respectful of the environment.	It is technically unclear how the selected sound categories will combine into a pleasant soundscape; certain environments may create confusion or discomfort despite being initially marked as preferred.	The inclusion of café sounds, which often contain machine-made elements, raises an intriguing question about their appropriateness in the ICU context.
EXPERT 3 Healthcare and usability expert	Not just a simple playlist, but a thoughtful, high-level integration of sound designed with purpose and psychological intent is a key strength of the system.	It depends on the context and criticality of the situation; in more acute moments, it may feel like a "nice-to-have" rather than a necessary support tool.	The potential integration of AI introduces both opportunities and risks. It could enable adaptive soundscapes linked to physiological parameters, but may also shift the system toward a medically regulated device by creating feedback loops.
EXPERT 4 Technical advisor	The use of directional speakers is a promising approach, as it allows targeted sound delivery without disturbing the overall ICU environment.	Despite the potential of the sound intervention, existing ICU sounds like alarms and beeps will still persist; unless these are managed or reduced, the new system risks adding to the acoustic clutter rather than enhancing the environment.	The primary risks associated with the system are likely related to electrical safety and hygienic compliance, both of which are critical in the ICU context and must be carefully addressed before implementation.
EXPERT 5 EX-ICU Patient	The potential of personalised ambient sounds which changed with moods was found very promising and very helpful as a distraction from the distressing environment.	The participant revealed that sounds typically associated with home such as children's voices or cooking would intensified feelings of absence and emotional vulnerability, rather than providing relief.	It was found interesting that the SoulSound system could extend its calming and ambient qualities not only to the patient but also to visiting family members by enabling a more soothing environment during visiting hours.

Table 14 : Overview of the results from PMI method from all experts using meaningful insights

1. ACCEPTANCE BY HEALTHCARE PROFESSIONALS

"IT LOOKS EASY. SO IT LOOKS SIMPLY TO ACTIVATE."
(NURSE 1)

"SYSTEM SOUNDS VERY MUCH IMPLEMENTABLE FOR THE NEAR FUTURE."
(NURSE 2)

Strengths:

The interface was described by the nurses as simple, intuitive & easy to understand , indicating strong potential for seamless adoption without the need for extensive training or onboarding. Features such as swipe-based controls & compatibility with existing devices, like nurse tablets, reinforce the system's ability to integrate into daily workflows without adding complexity. The wall-mounted control device was also seen as a practical addition, especially considering the frequency with which the system might be used. Nurses particularly valued the opportunity to actively influence the environment in support of patient well-being, viewing the system as a non-clinical tool that enhances their caregiving practices. Notably, it offers a structured way to implement soundscapes than radio.

Challenges

The system currently relies on HCPs to interpret the patient's emotional state to determine appropriate soundscapes. It was questioned whether they should have the authority to make such decisions which was realised as a future research opportunity.
In critical or busy periods, non-essential systems no matter how beneficial are often deprioritized. If the sound system is not seen as clinically critical, staff may skip using it during peak times, limiting its overall impact.

2. PATIENT CENTRED RELEVANCE

"CERTAIN SOUNDS CAN HELP IN THE CIRCADIAN RHYTHM REGULATION LIKE ACTIVATING IN THE MORNING TO CALM IN THE NIGHT , IN THAT ORDER ."
(NURSE 2)

"I THINK I KNOW. IT WILL BE SOMETHING I WAS GOING TO USE IF IT WAS AVAILABLE WHEN I WAS IN ICU."
(EX-ICU PATIENT)

Strengths:

The system's potential to address individual patient needs through personalized sound preferences was seen as highly promising by the HCP and patient.The involvement of family members via the tablet application was regarded as especially meaningful, offering them a structured and emotionally supportive way to contribute, beyond generic music suggestions. This was confirmed by the ex-ICU patient, who emphasized how a simple choice in auditory environment such as nature sounds helped her cope during intubation while conscious. Experts identified key moments where the system could offer therapeutic value, including sleep support, emotional comfort during loneliness, distraction during physiotherapy. The patient further suggested that familiar environmental sounds, like bicycles or footsteps outside her ICU window, could enhance connection to life beyond the room. The system was also acknowledged for its potential to support circadian rhythm alignment through time-sensitive ambient soundscapes, reinforcing its relevance to patient- centric care.

Challenges

The system may not be applicable to all patients especially patients who are delirius or unconscious. In such cases, sound may be misinterpreted, potentially increasing anxiety or confusion rather than alleviating it. Tailoring the system fo r different patient conditions and ensuring it is adaptable remains a key requirement.

3. TECHNICAL INTEGRATION AND FEASIBILITY

"THE IDEA OF USING DIRECTIONAL SPEAKERS WILL WORK WELL .IT'S A SMART WAY TO DELIVER SOUND TO THE PATIENT WITHOUT DISTURBING THE REST OF THE ICU ENVIRONMENT."
(TECHNICAL ADVISOR)

"ITS NOT THE SAME WITH THE AIRPODS ON, BUT WHEN THE SOUND IS COMING FROM A SPEAKER ABOVE YOU… IT FEELS MORE LIKE YOU'RE PART OF THE ENVIRONMENT, SO I CAN IMAGINE THAT."
(EX-ICU PATIENT)

Strengths:

Experts considered the use of ceiling-mounted directional speakers to be highly appropriate for the ICU environment. This was also strongly pointed out by the patient that ambient sounds through speakers created better impact than airpods. Directional sound delivery was seen as a smart way to personalize the auditory experience without disturbing others in the unit. Wired connectivity was strongly preferred over Bluetooth due to its stability and compliance with hospital protocols, which prohibit wireless interference near sensitive medical equipment. Additionally, the system's design was viewed as compatible with existing infrastructure and potentially easy to install, especially when paired with nurse tablets or wall-mounted control units. The ease of use of a questionnaire based sound selection app was also mentioned postively as a feasible option by the patient.

Challenges

Experts highlighted the effectiveness of this system after admission which can also potentially take in patient's preferences on the spot and giving them an ability to change the soundscapes themselves. Intergration of this system without working out the source of the ICU sounds like beeps and alarms was seen as a challenge as it will add to the chaos in ICU. The amount and time of sound exposure will also play a role according the patient as it might add to the stimulation.

4. SOUND TYPES AND STRATEGY

"CAFE SOUNDS MIGHT FEEL WARM AND SOCIAL TO SOME, BUT FOR OTHERS, MACHINE NOISES IN THAT MIX COULD ADD TO CONFUSION."
(NURSE 1)

" LISTENING TO SOUNDS FROM HOME WOULD NOT HAVE WORKED FOR ME… I HAVE TWO LITTLE BOYS AND I MISSED THEM SO MUCH… I DIDN'T WANT TO HEAR THEM."
(EX-ICU PATIENT)

Strengths:

Experts appreciated the system's approach of using sound for specific psychological functions such as distraction, reassurance, or activation rather than treating it as a passive music player. The idea of categorizing sound by its functional role was seen as a thoughtful way to align audio content with patient needs. It was also found promising that these sounds came from real environments while the experts knew the use of white noise and some types of natural sounds.

Challenges

An insightful point raised was the emotional discomfort associated with overly familiar or personal home related sounds as emphasized mainly by the patient. Such sounds could intensify feelings of longing and absence. This raised the questions about how content would be curated and controlled: Who selects the sounds? How often are they updated? Moreover, not all environments are acoustically neutral sounds like a café ambiance may include machine noises that could be jarring in the ICU. It was also technically unclear among the experts how the selected sound categories will combine into a pleasant soundscape.

5. POSSIBLE ROLE OF ADVANCED TECHNOLOGY

"AI ADDS RISKS IF LINKED DIRECTLY TO PHYSIOLOGICAL PARAMETERS. IF IT STARTS FEEDING SOMETHING BACK TO THE PATIENT, IT ADDS TO THE MEDICAL COMPLIANCES.."
(HEALTHCARE & USABILITY EXPERT)

Additonally, the potential use of AI for dynamic sound adaptation was viewed as both an opportunity and a risk. While AI could personalize experiences based on physiological data, experts expressed challenges in creating automated feedback loops without human oversight. This could unintentionally shift the system toward medical device classification, raising regulatory challenges and ethical questions.

7.5.5 DISCUSSION

All five experts participated in the evaluation session and two of the healthcare staff also successfully interacted with the HCP prototype presented during the session in person.

The primary goal of the evaluation session was to gather feedback of the concept from experts belonging to various disciplines this project is placed in. Overall the study achieved its goal as valuable insights were gathered not just from the healthcare perspective but also from a technical, usability perspective & most importantly from a patient perspective. This gave the study a holistic approach.

The qualitative insights highlighted a strong interest among experts in using non-pharmacological interventions like soundscapes to support emotional well-being in the ICU mainly highlighted from a strong affirmation from the patient regarding its potential. However, integrating such interventions into clinical routines requires careful positioning of the system not as a "nice-to-have," but as a valuable tool that complements medical care. The findings suggest a need to reinforce the clinical relevance of soundscapes, especially in relation to stress reduction, circadian rhythm regulation, & patient-centered care delivery. While healthcare professionals acknowledged the benefits of customizing the environment, the responsibility for interpreting patient needs & selecting the appropriate sounds for soundscapes was questioned.

Regarding the user interface & usability of the interfaces, both the nurses commented that it was very easy to understand and use as the interface did not feel like an extra task. The patient interview noted that if the selection process is simple such as clicking on options rather than writing it would be feasible even early in recovery.

Experts viewed directional speakers and wall-mounted controls as practical options for ICU integration both in terms of the mounting as well the passive experience highlighted by the patient. Yet, significant concerns were raised around the coexistence of soundscapes with medical alarms. The idea of silencing or softening alarms during sound playback introduces both opportunities & risks. Overall SoulSound was perceived as a feasible & easily implementable solution for the ICU. The limitation of the study was the limited sample size of experts which restricts the generalizability of the findings. Given the positioning of the system starting with a pre-admission focus, the future interation of SoulSound could focus more on how can the preferences be gathered during admission after the patient feels a little stabilized as suggested by almost all experts.

7.5.6 CONCLUSION

To conclude, the expert evaluation of the SoulSound system has provided valuable insights that will inform future iterations of the concept. The system shows strong potential to address the psychological needs of ICU patients by offering moments of comfort, distraction, stimulation, emotional reassurance particularly during vulnerable phases of their stay by means of the soundscapes. By enabling personalized sound experiences involving both healthcare professionals & family members in shaping the auditory environment, the system empowers patients with a sense of agency in an otherwise high-tech, impersonal setting. These findings validate the direction of SoulSound & support its further development as a meaningful intervention in the ICU.

08

FUTURE RECOMMENDATIONS

In this chapter the relevance of the project is discussed. This chapter describes the overall conclusion of the project by presenting final recommendations and a reflection on the project.

8.1 VALIDATION OF SOULSOUND

This section evaluates the final design based on three criterias - feasibility , desirability and viability of the design.

FEASIBILITY

For SoulSound to be feasible , it needs to be seamlessly adapting to the ICU set up requiring minimal disruption in the ICU workflow. The integration of SoulSound appears to be highly feasible with the wall mounted control device connected to the speaker set up of the room. It allows for quick and intuitive interaction, requiring only minimal input from healthcare professionals. This reduces the cognitive and operational load on staff, enabling them to engage with the system without disrupting their existing workflow. Experts noted that the simplicity of navigation, combined with the placement of the control unit within the patient's room, supports seamless usage during routine care activities.

From a technical standpoint, both the hardware and software components of SoulSound demonstrate strong compatibility with hospital infrastructure. The system does not interfere with existing medical equipment and adheres to safety and hygiene standards. The use of directional audio technology was particularly well received, as it allows targeted sound delivery to the patient without disturbing the broader acoustic environment of the ICU.

Personalization of soundscapes through the preference collection system is considered both practical and meaningful. However, discussions remain regarding the optimal timing for collecting these preferences whether prior to admission or after the patient has stabilized. While pre-admission collection offers the potential for early customization, post-admission engagement may ensure more accurate and relevant input, especially as patients become active participants in their care. Further exploration is required to determine how sound categories can allign well with the preferences apart from the questionnaire format. From the usability tests it was clear that the categories were well understood but there was a mismatch between interpreting some questions and it was technically difficult to see how the sounds combined. Despite these considerations , SoulSound evaluates as a feasible design solution and can be further developed towards implementation.

DESIRABILITY

Desirability evaluates how well does SoulSound meets the needs of its users patients, healthcare professionals, and family members. For patients, the system offers a sense of emotional support, comfort, and control in an otherwise sterile and high-stress ICU environment. By allowing them to engage with personalized soundscapes that reflect their preferences ,the system helps reduce anxiety, promote relaxation, and restore a sense of self thereby addressing critical psychological needs during their hospital stay. However since the design could be evaluated with real target group, this remains as a discussion point whether this is achieved in its real sense. The current evaluation is based on what the experts commented while the future research can make more informed evaluation.

From the perspective of the healthcare professionals, the SoulSound system is desirable as it empowers them to create a more humanised care environment while keeping their routines in place. This is achieved with the simple and intuitive sound management tool for the HCPs to be able to control the environment depending on the emotional state of the patient.

For family members, the system offers an opportunity to participate meaningfully in the patient's recovery process, even when physical presence is limited. This shared sense of contribution enhances emotional reassurance for both patients and their loved ones, reinforcing the system's desirability as a tool that fosters connection and healing across all stakeholders involved.

VIABILITY

The viability of the SoulSound system lies in the sustainabiliy and long term use in the ICU environment. It outlines whether the system can be maintained and scaled over time delivering value to the hospital as well the primary user of the system , the patient. Operationally , SoulSound works as a retrofit system adapting well with the existing equipments in the ICU without requiring any custom made devices which might cost a lot. Secondly, SoulSound is aimed to improve recovery tiime and shorten admission time thus becoming a cost effective scalable option.

Overall SoulSound's objective towards non-pharmacological, patient-centered care also aligns with growing healthcare priorities around emotional well-being and holistic recovery making it not only feasible but a viable option within contemporary systems.

8.2 CONCLUSION & LIMITATIONS

This study explores how a personalised soundscape system could improve the psychological well-being of critically ill patients in the Intensive Care Unit (ICU) by addressing the fundamental human need for connectedness. Through an extensive context study at the Leiden University Medical Centre (LUMC), it was found that ICU patients often experience psychological distress due to a constant exposure to medical noise, lack of environmental control, and social isolation. These insights, combined with literature and stakeholder interviews, revealed a gap in existing sound interventions , most of which focus on noise reduction, rather than on enhancing the patient's emotional experience through sound.

Building on this understanding, the project followed a human-centered, multi-method research approach. Using patient journey mapping, stakeholder interviews, and contextual observations, the project identified critical psychological needs autonomy, relatedness, comfort, and security as particularly unfulfilled in the ICU. These needs formed the foundation for designing the SoulSound system: a personalized, multi-stakeholder soundscape intervention intended to offer emotional support to ICU patients. The system was developed through iterative design phases, including co-creation workshops, ideation, and usability testing. The final concept was shaped to include four core soundscpe functions - calming, distracting, activating, and reassuring - delivered through a mounted directional speaker and controlled via intuitive interfaces for patients, loved ones, and healthcare professionals.

The system was evaluated through usability session in a simulated ICU set up at IDE and expert interviews both at TU Delft and LUMC offering rich diversty in disciplines. Results highlighted the concept's strength in offering personalization, emotional comfort through sounds, and user-friendly interaction. Healthcare professionals appreciated its seamless integration into ICU workflows and potential to humanize care without disrupting clinical routines. Directional speakers were especially well-received for their non-intrusive delivery of sound. However, challenges were noted regarding timing of preference collection, role boundaries for healthcare staff, and ensuring safe technical integration within a highly regulated hospital environment. Based on this feedback, recommendations were made for further development, including real-world pilot testing, deeper personalization through biographical input or AI, and expanded application in related healthcare domains such as mental health and dementia care.

In conclusion, this thesis demonstrates that a personalised soundscape system like SoulSound can serve as a subtle yet impactful intervention to enhance connectedness and emotional support for ICU patients. While future refinements are necessary, particularly around implementation logistics, data-driven personalization and sound types, the study confirms the system's potential as a viable, desirable, and feasible innovation for humanizing critical care through sound.

LIMITATIONS OF THE STUDY

- One of the primary limitations of this study was the inability to conduct interviews with ICU patients in the early phases of research. As a result, the psychological impact of sound had to be assessed indirectly through the perspectives of healthcare professionals.

- The sound pressure level measurements within the ICU were conducted over a short duration. This limited timeframe provided only a partial understanding of the acoustic environment, making it difficult to determine the most appropriate times of day for implementing the system when ambient noise levels are lowest.

- The final intervention could not be tested in a real ICU setting with patients or their families. Instead, the evaluation was conducted solely with healthcare and technical experts, which restricted the ability to assess patient-facing usability and emotional impact .

- All usability tests were conducted with a limited sample size, which restricts the generalizability and statistical strength of the findings.

- The sound compositions used in the testing phase were created by the researcher without the involvement of a professional sound designer. This may have led to suboptimal audio quality and reduced the authenticity of the simulated soundscape experience. Future development should involve an experienced sound designer for content curation.

- The SoulSound system may not be suitable for all ICU patients particularly those who are unconscious, heavily sedated, or experiencing delirium thereby limiting the universal applicability of the intervention.

- Finally, the solution comes with a rish. Unless the existing ICU sound sources (e.g., alarms, equipment noise) are addressed or reduced, the added intervention could unintentionally contribute to the acoustic load rather than creating a healing environment.

8.3 RECOMMENDATIONS

This section presents the final recommendations, concluding the thesis by outlining key directions for further development. These recommendations are drawn from the evaluation insights discussed in the previous section and aims to guide future improvements of the system.

RECOMMENDATIONS FOR SOULSOUND APP/ TABLET INTERFACE

- Since the app currently functions as a guided questionnaire, future iterations could explore integrating a Gen-AI–powered system. This would allow the app to generate personalized sound options based on the user's specific inputs, making the experience more contextual and adaptive. Additionally, Gen-AI could enable real-time creation of soundscapes, allowing users to preview and listen to customized compositions directly within the app.

- Different sound categories can be displayed as an overview giving the user a better idea of what to expect.

- In the future iterations , a memory based sound environment can also be used as a prompt to generate specific landscapes for specific emotionals needs.

- Future iterations can enable co-creation with family by allowing patients and loved ones to build a shared playlist or select from meaningful presets.

- Regarding the SoulSound nurse device , it could be Integrated into existing hospital software or nurse monitor (like a plugin) to avoid introducing a separate device, reducing cognitive and physical burden.

TESTING OF CONCEPT WITH PATIENTS IN CONTEXT

To ensure the effectiveness of the SoulSound system among both patients and healthcare professionals, it is essential to demonstrate its impact within a real ICU environment. This requires conducting in-context testing that explores how the system performs under realistic clinical conditions. Various soundscapes need to be developed and tested systematically to evaluate their emotional and psychological effects on patients. In particular, attention must be given to the transitions between different soundscapes along with the duration of the playback , as abrupt or poorly timed shifts could lead to confusion especially among sensitive patient groups. While the current evaluation has offered valuable initial insights into the system's design and interaction qualities, a broader and more diverse patient sample ideally exceeding 50 participants is necessary to draw more robust conclusions. Larger-scale testing will allow for more accurate assessment of usability, patient response, and integration into ICU routines, ultimately strengthening the case for real-world implementation. As suggested by experts during the evaluation, the ceiling-mounted directional speaker emerged as the more suitable option among the two options presented. Future research should focus on testing the system with this setup to assess its effectiveness in a real ICU environment.

INTRODUCING SOULSOUND DURING THE ADMISSION

It is recommended to introduce SoulSound shortly after patient admission, once the condition has stabilized, to ensure meaningful engagement. At this stage, patients can act as primary users providing sound preferences and adjusting soundscapes themselves thereby fostering a sense of self-agency and control during their ICU stay.

COLLECTION OF PREFERENCES

Future research can focus on exploring ways to extract preferences other than a questionnaire and the study based on sonic ambiences only. Although SoulSould is established viable, other mediums of data collection can be looked into which does not require filling out anything before or during admission.

EXPANSION IN OTHER HEALTHCARE DOMAINS

The SoulSound system holds potential for expansion beyond the ICU into other healthcare domains such as operating theatres , mental health facilities (for emotional regulation and grounding), and dementia care settings (to evoke memory and familiarity). Each context offers unique opportunities to tailor soundscapes for therapeutic and behavioral support.

USE OF TECHNOLOGY

Future developments could explore the use of technology to create autonomous, self-learning soundscapes that adapt in real time based on physiological parameters such as brainwaves and heart rate. By continuously monitoring these signals, the system could intelligently adjust the auditory environment to support the patient's emotional and cognitive state without requiring manual intervention.

9.3 PERSONAL REFLECTION

This project has boosted my confidence in working for healthcare due to many reasons that unfolded throughout the journey of this project. It not only provided me with invaluable insights of working in a sensitive set up like that of an Intensive Care Unit but also to learn the ins and outs of how a design intervention can be shaped and made to be implemented. Being an international student, navigating in the foreign healthcare system was challenging but I had the privilege of connecting with exceptionally kind and supportive individuals, some of whom went above and beyond to assist me with my project. My external supervisor and the ICU intensivist provided me with great insights to shape the project.

After knowing the initial assignment during the literature review phase , I knew very little of the effects of sound on individuals while ICU patients was a very novel path to explore in this subject. I knew right from the beginning that a personalised approach was going to be my guiding principle throughout this project and how i wanted to design specialised experiences for each individual patient through a product service approach in the ICU. Through the following literature research , analysis , interviews and finally coming to the research statement , valuable insights kept adding and refining to lead to a design. This journey involved a lot of ups and down as a design thinker. With the wealth of valuable findings I gathered at every phase and integrating them into a design solution that aligned with the project's specific goals and converging the relevant findings for this report was very challenging. However, this experience was immensely educational and eye opening and I am deeply grateful to my supervisors for their guidance throughout the process.

Reflecting on the healthcare domain I worked in , I recall speaking about this with a few friends at the start of the project. We talked about the challenged the medical field gets to be able to succesfully deliver a design intervention while maintaning all the considerations from the hospital's side. But today, I can proudly say that SoulSound takes into account all these challenges and creates a starting point towards an advanced and supportive ICU rather than just a high tech ICU. Throughout this journey, I came to understand how deeply intertwined emotional well-being is with physical recovery, especially in critical settings like the ICU. Exploring sound as a part of this well being was a very innovative touch to this project which i am grateful to add to in my list of accomplishments. In this project I not just understood sound in a different perspective but also got to layer different sounds together , work with sounds and see what affects it creates on individuals and the results were very well alligned with the goals i had set. Designing for this context brought forward complexities I had not anticipated from ethical considerations and data sensitivity to the practicalities of embedding a new system into clinical workflows.

However, these challenges also became the driving force behind the project's relevance. Rather than focusing solely on building a new technological solution, the goal evolved into creating something that truly fits the ICU context.

Finally reflecting on the discipline of work i got to work on because of this project lies exactly at the interaction i am deeply passionate about - healthcare , connected devices and emotional design. Developing SoulSound was not just about crafting an experience, but about making space for patients' voices, their feelings, and their environments to be better acknowledged in design processes. Through iterative prototyping and conversations with stakeholders, I could validate not just usability, but desirability something often overlooked in technical medical tools. Someday I would like to see this sound system implemented as a must have requirement in the ICU just like the physical care routines. This thesis addressed the gaps i found in the research and applies the soundscape research into an actionable design with a planned framework. My hope is that these learnings will serve as a basis for future explorations in sound-based design and inspire designers to take on challenges in healthcare.

Thank you for reading :)

If anything sparked interest , feel free to reach out to me.

- Avanti Deshpande

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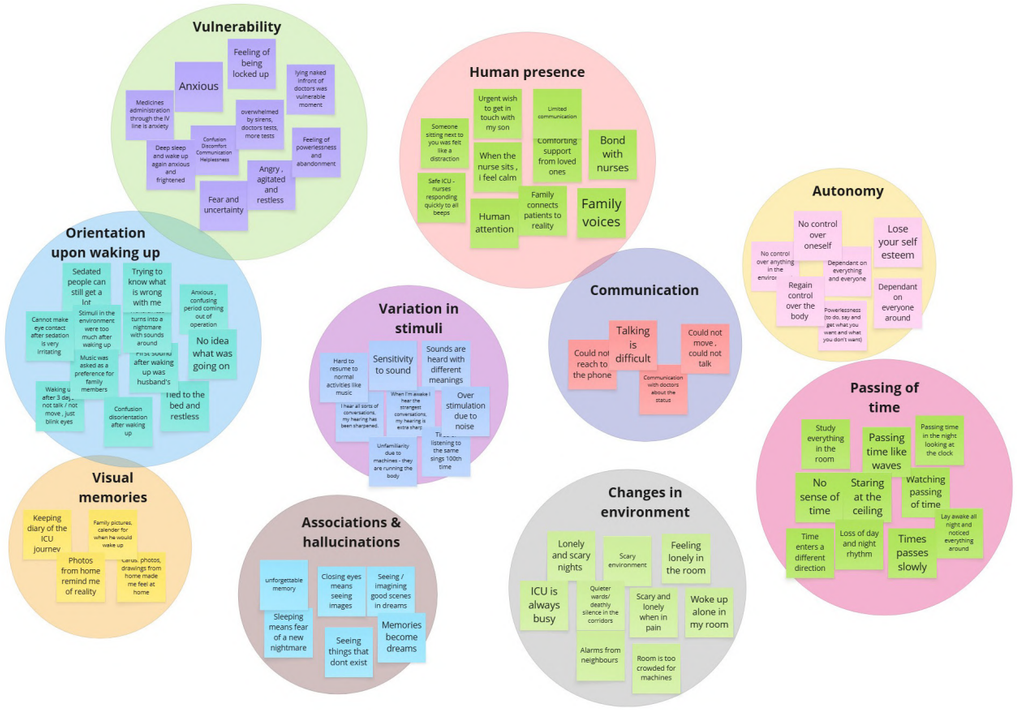
APPENDIX

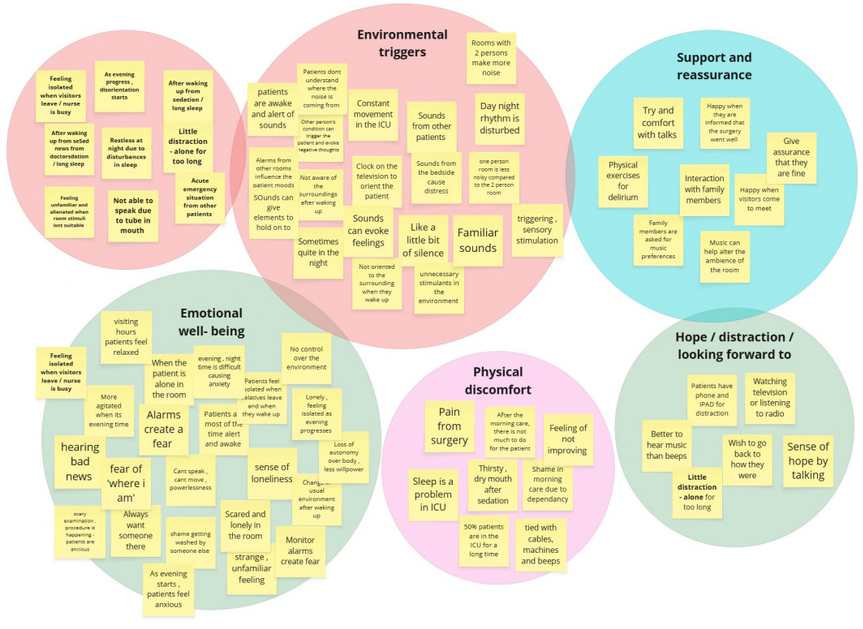
APPENDIX A - PATIENT EXPERIENCES

This section includes the qoutes and analysis from both patient and HCP perspectives sourced from literature, survey and interviews.

A-1 CLUSTERS OF PATIENT PERSPECTIVES



A-2 CLUSTERS OF NURSE PERPECTIVES - QUESTIONNAIRE RESPONSES



A - 3 SURVEY QUESTIONS

1. Which of the following sounds cause most distress to patients?

2. How do the current sounds in the ICU affect the patients' experiences?

3. Specific times during a nurse shift when patients seemed sensitive or vulnerable?(Select all that apply)

4.Should the patients be given the option to chose from a library of different types of sounds ?

5. Have you ever experienced or heard about the use of natural sounds in healthcare settings?

6. Have you had any preferences or suggestions related to music/ sound from patients / family members?

A - 4 INFORMED CONSENT

Participant ID: .....

Understanding the impacts of Sound and Light in the Intensive Care Unit (ICU)

This research is conducted as part of the Graduation project within the MSc study program at Industrial Design Engineering Delft.

Participant Informed consent:

You are being invited to participate in this research study titled "*Understanding the impacts of sound and light in the Intensive Care Unit (ICU) environment.*"

This study seeks to examine the environmental impacts within Intensive Care Units (ICUs), specifically investigating how sound and light exposure influence the physical and emotional well-being of patients during their ICU stay.

I acknowledge that I received sufficient information and explanation about the research and that all my questions have been answered satisfactorily. I was given sufficient time to consent my participation. I can ask questions for further clarification at any moment during the research.

I am aware that this research consists of the following activities:

1. Research Activity 1: Online questionnaire with open and close ended questions
2. Research Activity 2: Face to face interviews to understand ICU routine(upon availability.)

I am aware that data will be collected during the research, such as notes, photos, video and/or audio recordings. I give permission for collecting this data and for making photos, audio and/or video recordings during the research. Data will be processed and analysed anonymously (without your name or other identifiable information). The data will only be accessible to the research team and their TU Delft supervisors.

The photos, video and/or audio recordings will be used to support analysis of the collected data. The video recordings and photos can also be used to illustrate research findings in publications and presentations about the project.

I give permission for using photos and/or video recordings of my participation:
(select what applies for you)

- ☐ in which I am recognisable in publications and presentations about the project.
- ☐ in which I am not recognisable in publications and presentations about the project.
- ☐ for data analysis only and not for publications and presentations about the project.

I give permission to store the data for a maximum of 5 years after completion of this research and using it for educational and research purposes.

I acknowledge that no financial compensation will be provided for my participation in this research.

With my signature I acknowledge that I have read the provided information about the research and understand the nature of my participation. I understand that I am free to withdraw and stop participation in the research at any given time. I understand that I am not obliged to answer questions which I prefer not to answer, and I can indicate this to the research team.

The researchers take the applicable COVID-19 measures into account. I confirm to respect the COVID-19 measures taken and will follow instruction about these provided by the researchers.

I will receive a copy of this consent form.

Last name	First name
___ / ___ / 2025 Date (dd/mm/yyyy)	Signature

A - 5 QUALITATIVE ANALYSIS FROM NURSE INTERVIEWS

Word Cloud as a result of the Qualitative analysis

APPENDIX B- CONNECTEDNESS SURVEY

B-1 SURVEY DESIGN

This section includes the questions from connectedness survey. Important is to note that the questions from section C.1.4 are repeated across all other 8 fundamental needs.

Questions -

B.1.1 Consent - (Yes / No)

- I have read and understood the information given about the study.
- I understand that taking part in the study involves giving sound descriptions and answering survey questions related to it.
- I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and that I can withdraw from the study at any time, without having to give a reason.
- I understand that information I provide in the form of anonymised descriptions and ratings from this survey will be used for publications, reports and presentations.
- I agree that my answers can be quoted anonymously in research outputs.
- I give permission for the survey data that I provide to be archived on TU Delft servers for 25 years, so it can be used for future research and learning.

Understanding the need of connectedness
B.1.2

- What does sense of connectedness mean to you? Can you describe with a few keywords?
- I feel the most physically connected to environment or nature when_____
- I feel the most mentally connected with myself or my thoughts when _____.
- I feel the most socially connected with my family and friends when _____
- When you describe feeling connected to a person, place, or thing, what factors do you believe strengthen this sense of connection? Please elaborate

B.1.3 Need Fulfilment through sound

- 1. Which of the following needs do you associate with the most in feeling a sense of connectedness? (select all that apply)

Fundamental need	Definition
Beauty	Feeling that your environment is a place of elegance, coherence and harmony, rather than feeling that it is disharmonious, unappealing or ugly.
Stimulation	Being mentally and physically stimulated by novel, varied and relevant impulses and stimuli, rather than feeling bored, indifferent or apathetic.
Comfort	Having an easy, simple relaxing life, rather than experiencing strain, difficulty or overstimulation.
Security	Feeling that your conditions and environment keep you safe from harm and threats, rather than feeling that the world is dangerous, risky or a place of uncertainty.
Competence	Having control over your environment and being able to exercise your skills to master challenges, rather than feeling that you are incompetent or ineffective.
Relatedness	Having warm, mutual, trusting relationships with people who you care about, rather than feeling isolated or unable to make personal connections.
Fitness	Having and using a body that is strong, healthy and full of energy, rather than having a body that feels ill, weak, or listless.
Autonomy	Being the cause of your actions and feelings that you can do things your own way, rather than feeling as though external conditions and other people determine your actions.
Recognition	Getting appreciation for what you do and respect for who you are, instead of being disrespected, under-appreciated or ignored

B.1.4 Sound preferences for needs

- If you selected security, answer the following questions (If not , scroll down to go to your selected need)
- Security - A feeling that your conditions and environment keep you safe from harm and threats, rather than feeling that the world is dangerous, risky or a place of uncertainty.
- Try to imagine an environment that makes you feel secure
- What things or events are happening in this environment?
- What sounds would these events make?
- How do these sounds make you feel connected?

B -2 RESULTS

B.2.1 Summary of Qualitative analysis from connection perception qoutes (n = 28)

B.2.2 Results from analysis from each of the connectednes facets

B - 3 RESULTS FROM IMAGINED ENVIRONMENT AND SOUNDS FROM SELECTED FUNDAMDENTAL NEED

APPENDIX C - DESIGN EXPLORATIONS

C-1 CONSENT AND PLANNING

CONSENT - CO CREATION SESSION

Consent to participate in a co creation – brainstorming session and to use the outcomes.

I agree to participate in the co-creation session conducted by and recorded by Avanti Deshpande as part of her graduation project about designing sound-based systems for the intensive care environments.

I understand and consent to the use and release of the recording by Avanti Deshpande. I understand that the information obtained in this session is used for research purposes only and that it will not be used for any other purposes and will only be viewed by those working on the graduation project of Avanti Deshpande. I hereby consent to the recording and acknowledge that Avanti Deshpande may copy and use it freely without requiring further permission.

I understand that participation in this session is voluntary, and I agree to immediately raise any concerns or areas of discomfort during the session.

Please sign below to indicate that you have read, and you understand the information on this form and that any questions you might have about the session have been answered.

Name participant:

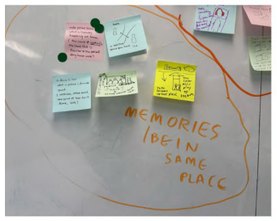
Signature:

Date: 26/03/2025

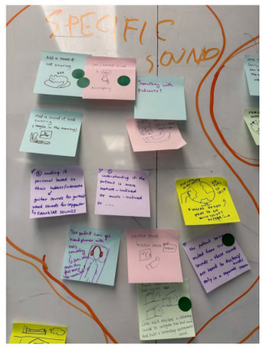
Time	Method	Details
5 mins	Introduction and consent	
10 min	Context and Intensive Care	The current Sound experience is not optimal for patient well-being, but how? Studies have shown that patients, relatives and healthcare professionals (HCPs) rank hearing alarms, medical device sounds, or other patients among the highest in severity of perceived stressors in ICUs (Krampe et al.,2021). Listening to sounds caused by other patients, staff conversations, alarms, or machinery (Xie et al., 2009) causes sleep disruptions (Elbaz et al., 2017) and loss of orientation (Ballard, 1981) It was also found that patients in single-patient ICU rooms experienced the soundscape as alienating, unvaried, unfamiliar, and disruptive (Louwers et al., 2024).
5 min	Aim and Design Question	PROBLEM STATEMENT - The sensory overload in the ICU, characterized by a lack of connection to the outside world, nature & family members along with an impersonal setting significantly compounds feelings of isolation and affects the psychological needs and well-being of patients. Design brief : How might we design a system which uses personalised soundscapes that enhance connectedness to the environment , nature and loved ones within critically ill patients in the adult ICU during moments of isolation.
5 min	Introduction to initial concept	
20 mins	Brainwriting with post-its	The research group writes ideas to the brief on post its.
20 mins	Spontaneous clustering	The research group sorts ideas into themes on the spot
10 mins	Hits or Dots	The research groups selects the most appealing ideas with stickers
20 mins	C - box matrix	The research group places the ideas on a matrix - feasibility vs originalitywith coloured stickers

C - 2 ANALYSIS AND REFECTION OF CREATIVE FACILITATION SESSIONS

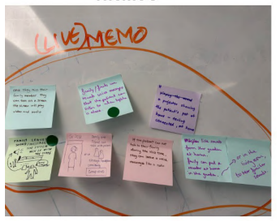
Theme 1



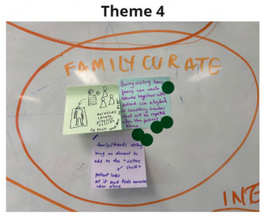
Theme 2



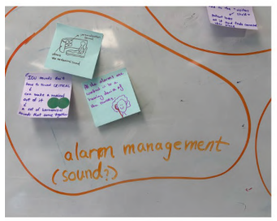
Theme 3



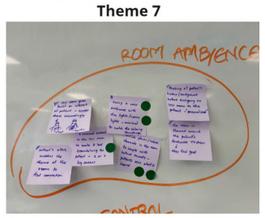
Theme 4



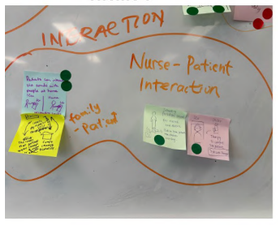
Theme 5



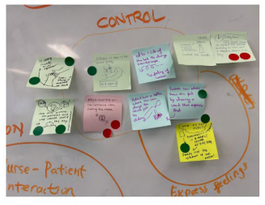
Theme 7

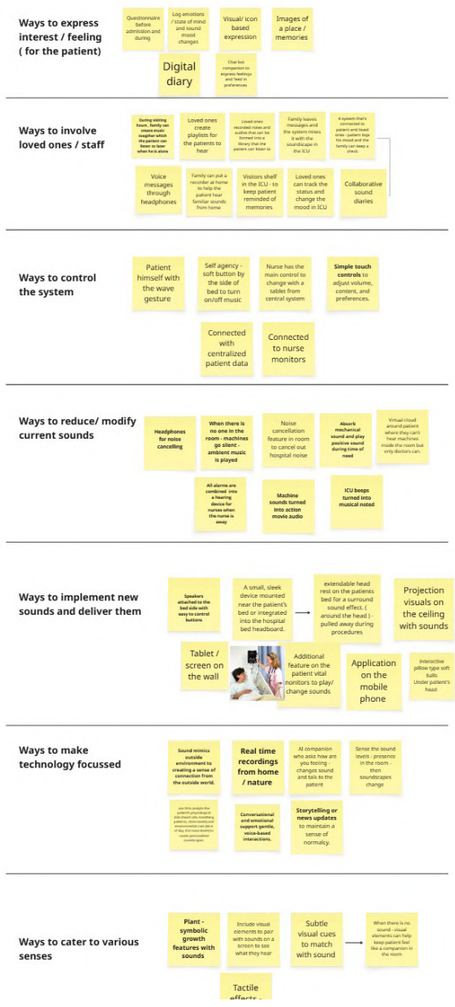


Theme 6

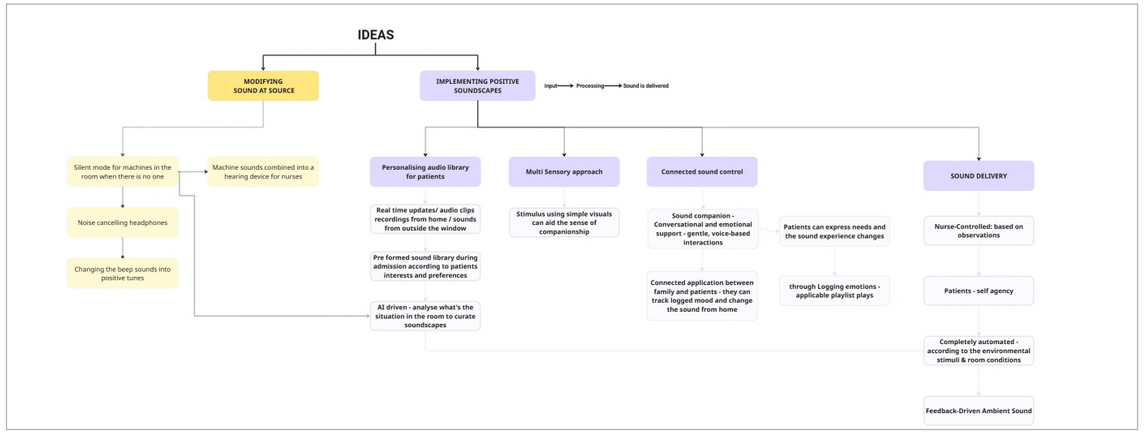


Theme 8

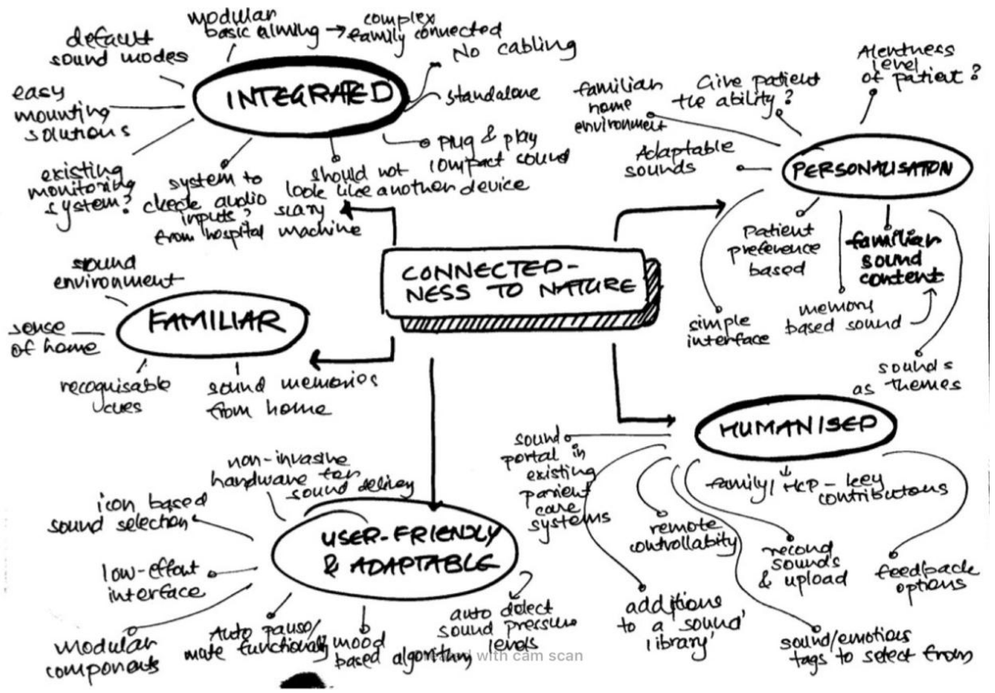


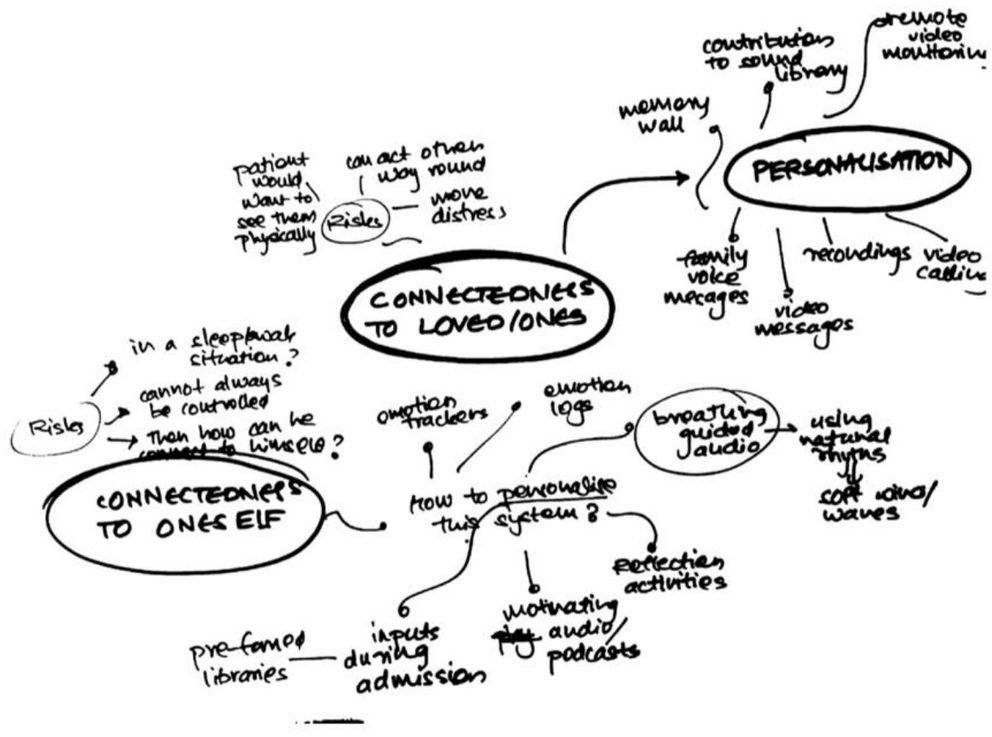


C - 3 INTERPRETATION FROM ANALYSIS INTO A MIND MAP OF IDEAS PRODUCED



C - 4 - RESULTS FROM SELF EXPLORATION HOW TO SESSION

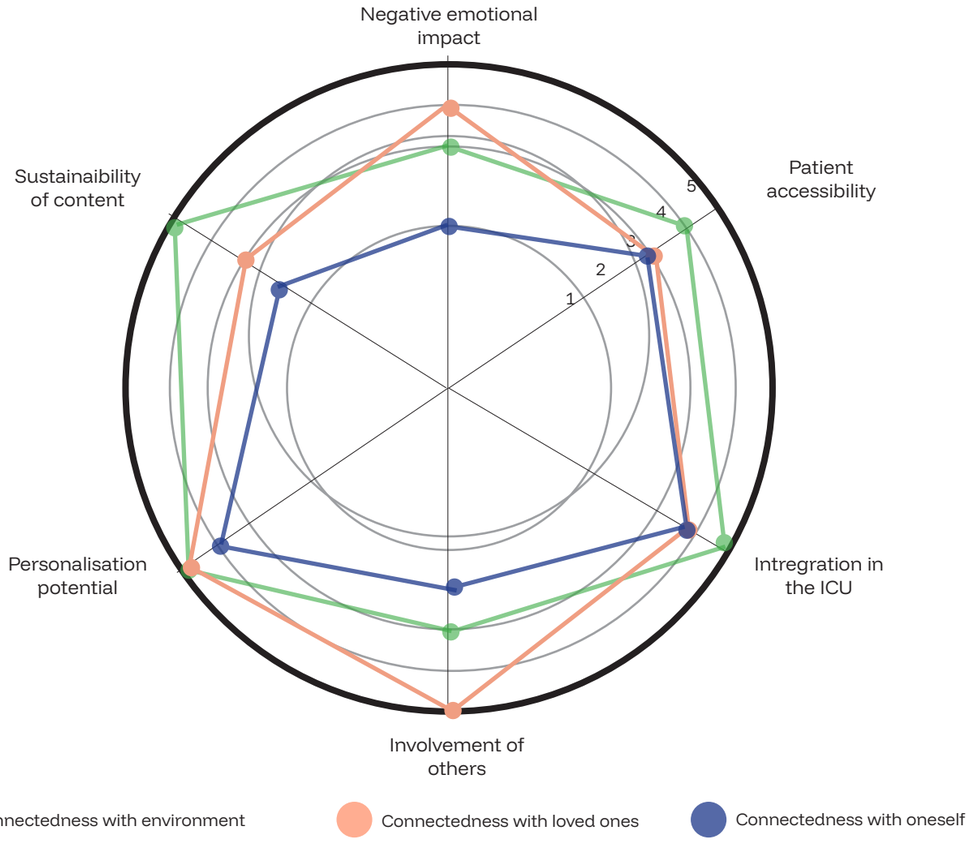




C 5 - SELECTION CRITERIA FOR CONNECTEDNESS DIRECTIONS

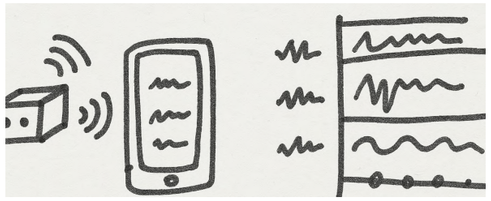
Six distinct criterias were identified to weigh the direction in form of a radar chart (What Is a Radar Chart? | Jaspersoft, n.d.) to understand the strengths of each concept and further take it ahead.

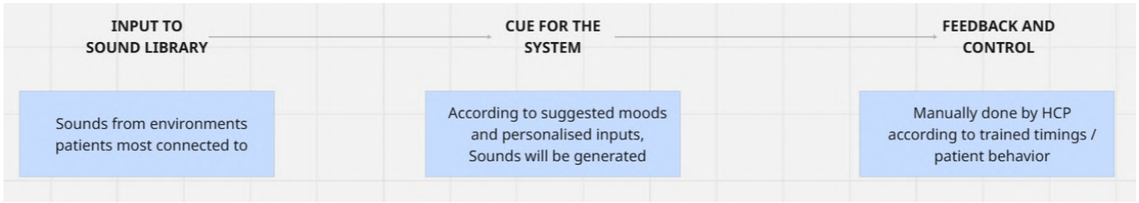
- Patient Accessibility – Can a non-verbal, immobile, possibly sedated patient experience it?
- Negative Emotional Impact – How deeply might it affect their sense of comfort or well-being?
- Personalization Potential – Can it be tailored to the individual patient?
- Sustainability Over Time – Can it provide ongoing value, or does it become repetitive/limited?
- Involvement of Others – Does it require active participation from family/staff?
- Integration into ICU Workflow – Can it coexist with medical priorities and equipment without disruption?



APPENDIX D - CONCEPTUALIZATION

This section includes the system approach used to create the wireframes and UI design guided by the key intercations moments and stakeholders. This is followed by wireframes for mobile and the tablet version of the design





D.1 - STAKEHOLDERS

The soundscape system involves three main stakeholders: patients, healthcare professionals (HCPs), and loved ones, each playing a unique role in shaping

Use Cases & Interaction Moments :

1. Patients
Use Case:

Express sound preferences based on mood or emotional state.

Interaction Moment:

Before admission : Patients select preferred sound types (natural, musical, etc.) for differents moods across three types of ambiences.

Daily use:

Patients receive tailored soundscapes

2. Loved ones
Use Case:

Provide system input in behalf of the patient at times of emergency admission

Interaction Moment:

During admission : They select different sound choices for the patient to be able to played when the patient is stabilized.

Periodic updates:

They may contribute new audio as the patient progresses.

3. Healthcare providers (HCP) :
Use Case:

Trigger, monitor, and adjust soundscapes according to clinical routines and observed patient states.

Interaction Moment:

During daily rounds or procedures: HCPs select a sound mode (e.g., “to calm” or “to distract”) based on patient behavior.

Manual overrides or feedback:

When patient behavior suggests a change in stimulation is needed.

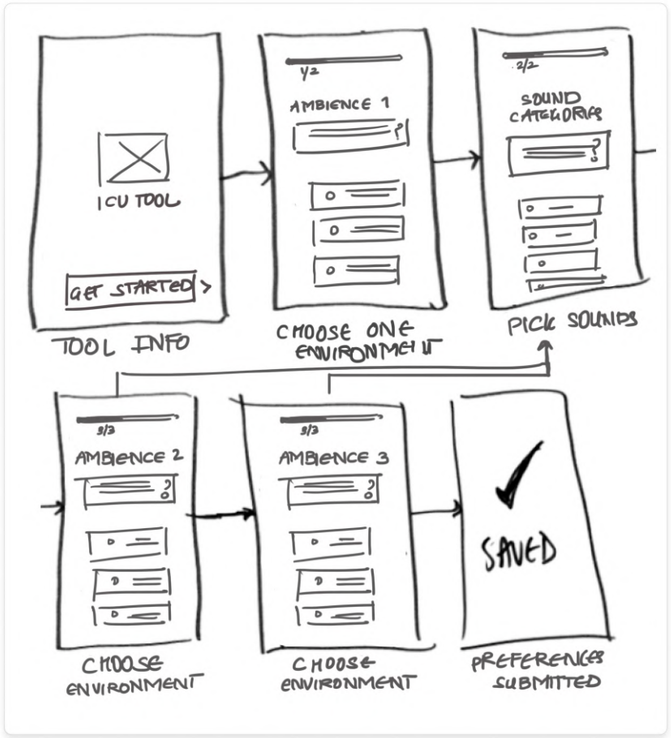
D.2 UX PRINCIPLES

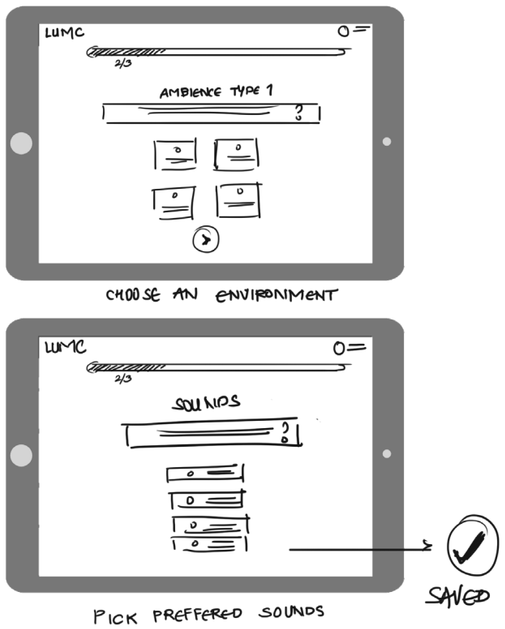
1. Simplicity :
Simplicity in UX design ensures that the interaction is to the point and unclutered focussing only on the essential elements. For SoulSoun , this principle is especially important to minimize the interaction time.

2. Consistency :
Consistency in UX design ensures using uniform visual and functional elements across the interface so users build familiarity and trust. For our system , it is essential to maintain the visual langauge and interaction consistent across the mobile and tablet version.

3. Accessilbity :
Accessibility in UX design ensures that users of all abilities can perceive, interact with, and benefit from a product (Kaur, 2021). This allows us to look at each part of the system in detail to suit the purpose.

D.3 WIREFRAMING

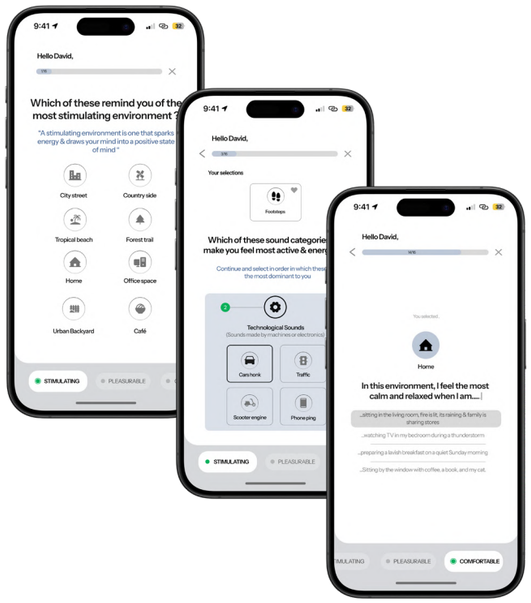




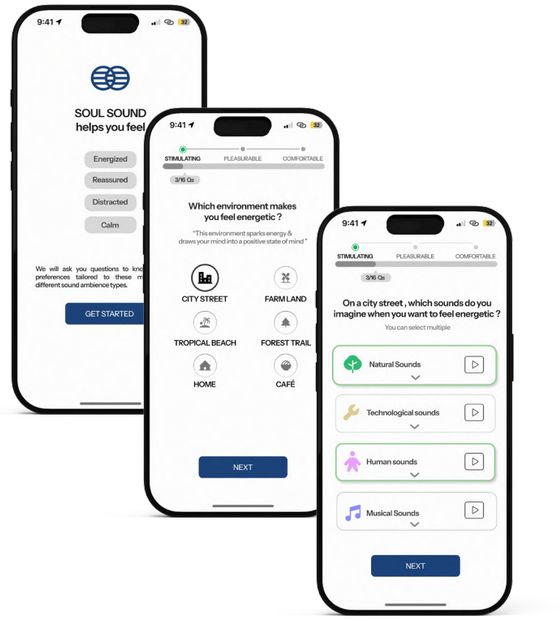
D.4 LOW FIDELITY WIREFRAMES FOR USER TESTING

User - patient
Objective - to collect sound preference in form of simple questions based on an environment. It was ensured that the design lanaguge stayed consistent across the tablet app as learnt from the design principles in the previous section.

Part A

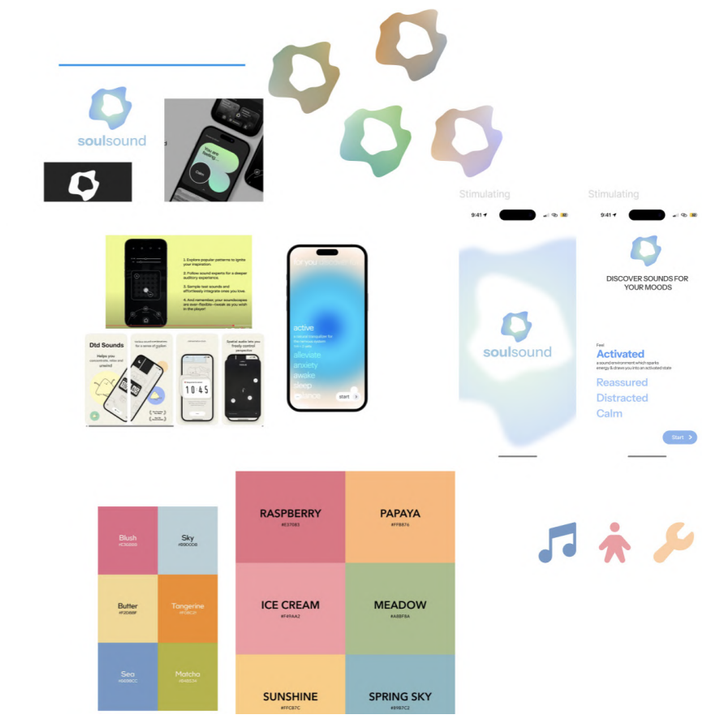


Part B

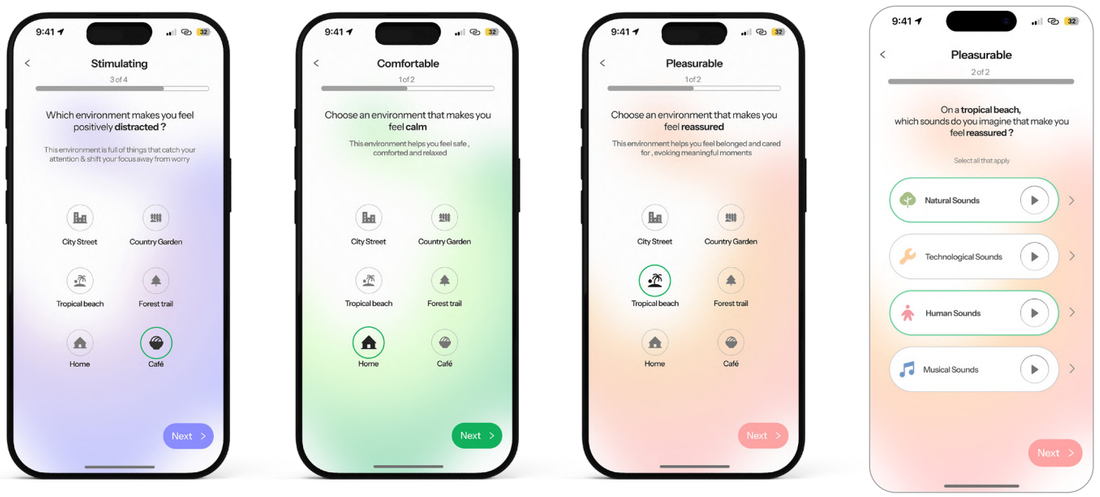


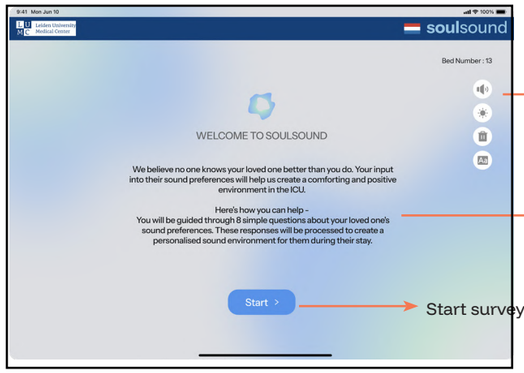
User -HCP
Objective - to be able to select appropriate fucntion for the soundscape in the room

D. 5 LOGO AND COLOR PALLETTE



D. 6 DETAILED UI DESIGNS

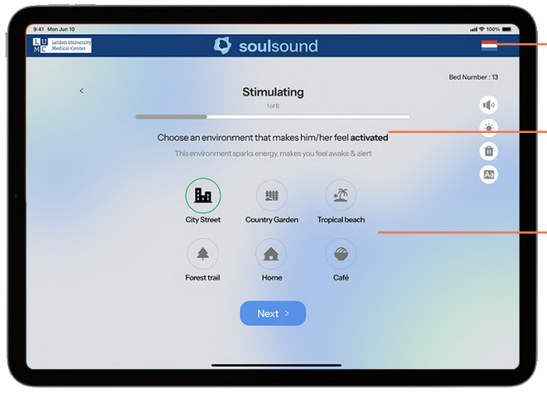




Increase/ decrease sound levels , brightness , delete data , change font size

Explaination

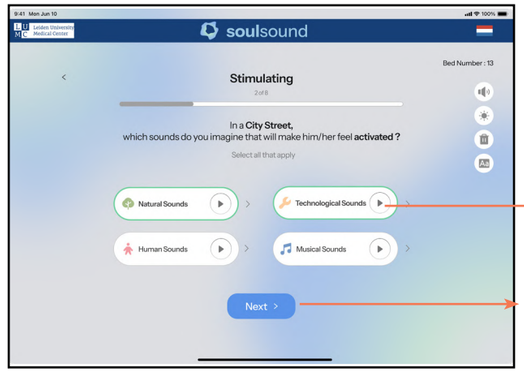
Start survey



Change langauge

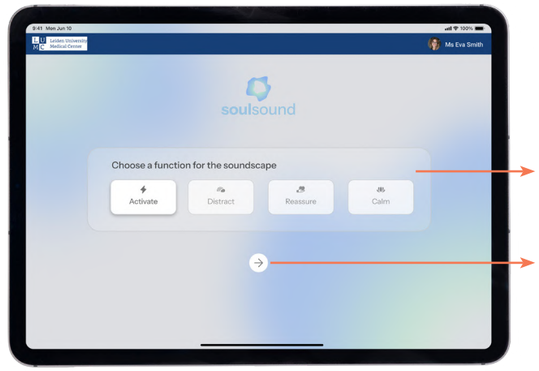
Question and explaination

Options to choose



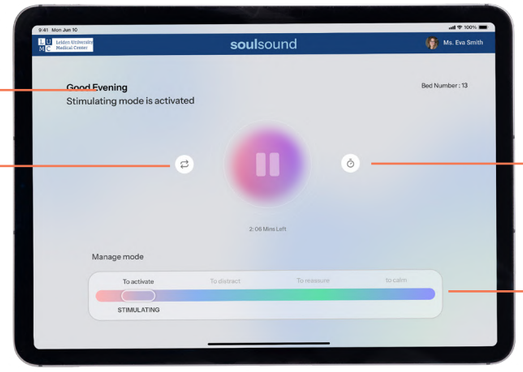
Listen to audio clip

Next ambience



Select mode

Next

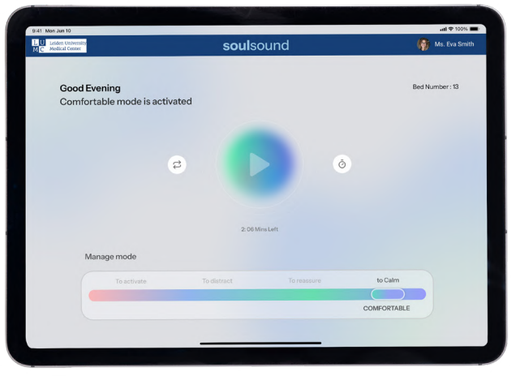


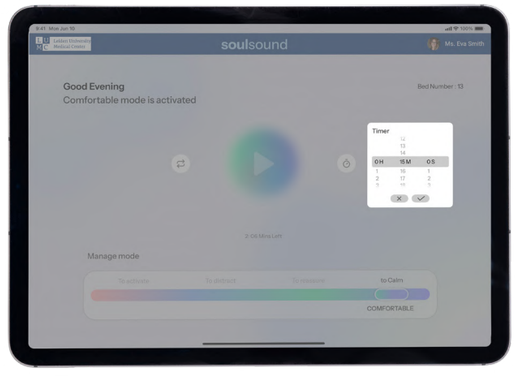
Shows current Soundscape

Loop option

timer option

Manage mode bar





APPENDIX E - USABILITY TESTS

This section includes the procedures and results from both usabillity tests. The first usability round was conducted for the mobile phone application and the second for soundscapes.

E.1 CONSENT FORMS

Understanding the impacts of Sound in the Intensive Care Unit (ICU)

This research is conducted as part of the Graduation project within the MSc study program at Industrial Design Engineering Delft.

You are being invited to participate in this research study titled "*Understanding the impacts of sound in the Intensive Care Unit (ICU) environment.* "This study is part of the research conducted to understand the environmental impacts within Intensive Care Units (ICUs), specifically investigating how sound influences the physical and emotional well-being of patients during their ICU stay. This research will be conducted to ideate solutions for the underlying effects and come up with ideas by co-creating with fellow IDE researchers.

Participant Informed consent:

I acknowledge that I received sufficient information and explanation about the research and that all my questions have been answered satisfactorily . I was given sufficient time to consent my participation. I can ask questions for further clarification at any moment during the research.

I am aware that this research consists of the following activities:

1. **Testing the Soundscape System** – Engaging with the designed sound system intended for ICU settings in a simulated set-up in IDE
2. **Evaluating the User Experience (UX)** – interacting with the interface and providing feedback.
3. **Perceived Affect of Sounds** – Sharing emotional responses and the perceived sense of connectedness with the outside world through the played sounds.

I agree to participate in the **user testing session** conducted and recorded by Avanti Deshpande as part of her graduation project about designing sound-based systems for the intensive care environments.

I understand and consent to the use and release of the recording by Avanti Deshpande. I understand that the information obtained in this session is used for research purposes only. The photos, video and/or audio recordings will be used to support analysis of the collected data. The video recordings and photos can also be used to illustrate research findings in publications and presentations about the project.
I understand that participation in this session is voluntary, and I agree to immediately raise any concerns or areas of discomfort during the session. I give permission for using photos and/or video recordings of my participation:

(select what applies for you)

- ☐ in which I am recognisable in publications and presentations about the project.
- ☐ in which I am not recognisable in publications and presentations about the project.
- ☐ for data analysis only and not for publications and presentations about the project.

I give permission to store the data for a maximum of 5 years after completion of this research and using it for educational and research purposes.

I acknowledge that no financial compensation will be provided for my participation in this research.

With my signature I acknowledge that I have read the provided information about the research and understand the nature of my participation. I understand that I am free to withdraw and stop participation in the research at any given time. I understand that I am not obliged to answer questions which I prefer not to answer, and I can indicate this to the research team.

I give permission to store the data for a maximum of 5 years after completion of this research and using it for educational and research purposes.

I acknowledge that no financial compensation will be provided for my participation in this research.

With my signature I acknowledge that I have read the provided information about the research and understand the nature of my participation. I understand that I am free to withdraw and stop participation in the research at any given time. I understand that I am not obliged to answer questions which I prefer not to answer, and I can indicate this to the research team.

The researchers take the applicable COVID-19 measures into account. I confirm to respect the COVID-19 measures taken and will follow instruction about these provided by the researchers.

I will receive a copy of this consent form.

_____	_____
Last name	First name
___ / ___ / 2025	_____
Date (dd/mm/yyyy)	Signature

E.2 ROUND 1 -INTERVIEW QUESTIONS

Questiona asked after the figma prototype interaction

1. How was your experience while completing the task?
2. What do you think of the questions and the way they are asked?
3. What do you think of the interface?
4. Did you understand what was going to happen with the answers you give?
5. What do you think of the length of the question session?
6. What would stop you from using this product if at all?
7. What would motivate you to keep exploring this product?
8. What will make you understand and select sounds better? (colors, actual sounds played)

E.3 ROUND 2- PROCEDURE

Introduction :

1. The session begins with a short video titled "ICU of the Future" to set the context and immerse participants in the ICU environment.

2. This experiment explores how positive and personalized soundscapes can help reduce patient anxiety and foster a sense of connectedness, aiming to alleviate feelings of isolation and loneliness.

3. Participants will listen to a sequence of sound compositions curated based on their previously recorded preferences.

4. After each sound, participants will complete a short evaluation of their perceptual and emotional responses.

5. To capture physiological responses, participants' heart rate will be monitored using an Apple smartwatch and oximeter throughout the session.

Part 1: Sound Experience Evaluation-

Baseline Measurement-

1. A baseline sound is played.

2. Task 1: Participants rate the sound using the following descriptors on a 5-point Likert scale (1 = Not at all, 5 = Extremely):

3. Vibrant, Calm, Pleasant, Annoying, Monotonous, Chaotic, Eventful, Uneventful.

Sound Composition Trials-

Four personalized sound compositions will be played in randomized order, with a brief pink noise interval (5 seconds) between each to reset emotional and cognitive state .

Each sound (60–90 seconds) is followed by:

Task 1: Rate the same sound descriptors (as above) on a 1–5 Likert scale.

Task 2: Rate emotional response specific to the goal of each sound:

Sound 1: "How activated do you feel after listening?"
Sound 2: "How distracted do you feel after listening?"
Sound 3: "How reassured do you feel after listening?"
Sound 4: "How calm do you feel after listening?"

Part 2: Evaluating Psychological Needs and Connectedness

Participants are asked to reflect on how the soundscape experience fulfilled the following needs. Each item is rated on a 7-point Likert scale (1 = Not true at all, 7 = Extremely true).

1. Comfort
I feel at ease.

I experience tension.

2. Relatedness
There is someone who cares about me.

There is no one who cares about me.

3. Security
I find myself in stable conditions.

I find myself in unstable conditions.

4. Stimulation
I experience sensory excitement.

I have no sensory excitement.

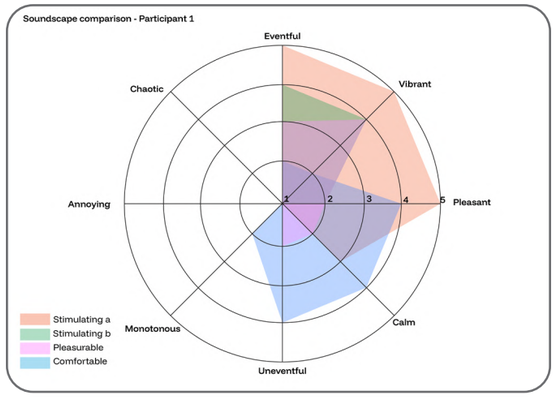
Closing Question:

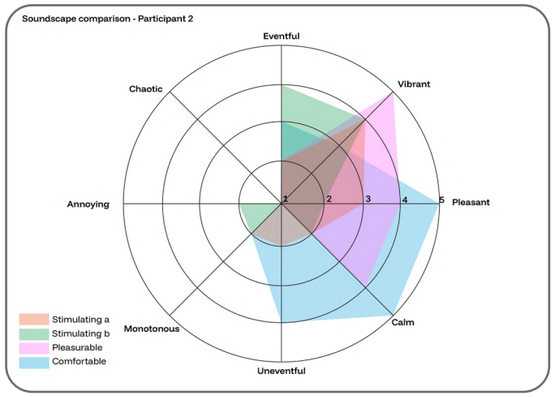
"On a scale of 1 to 5, how strongly did you feel a sense of connection to the outside world while listening to these sounds?"

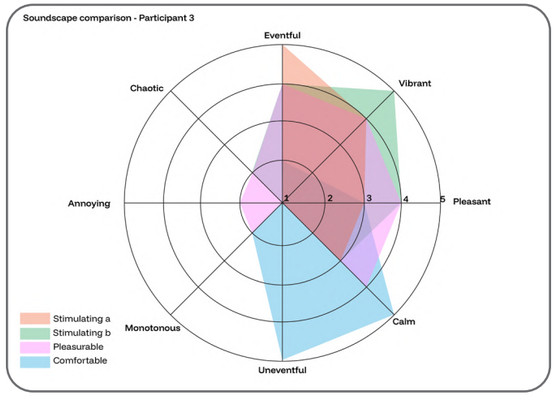
Qr code containing all sound compositions used for testing

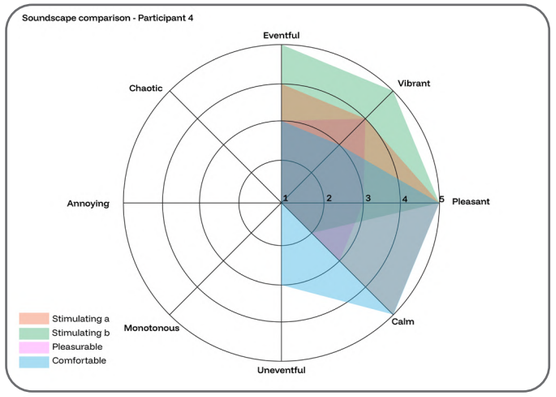
E.4 RESULTS

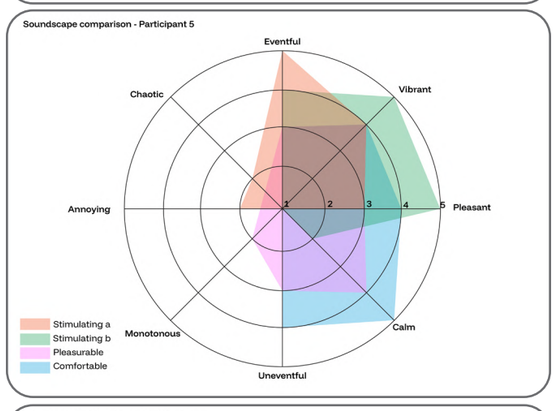
1. Individual responses for soundscapes for perceived attributes

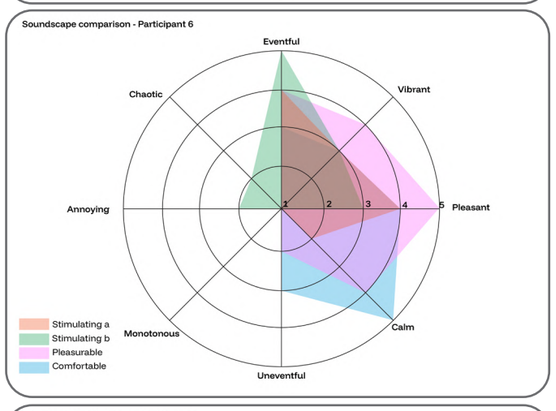


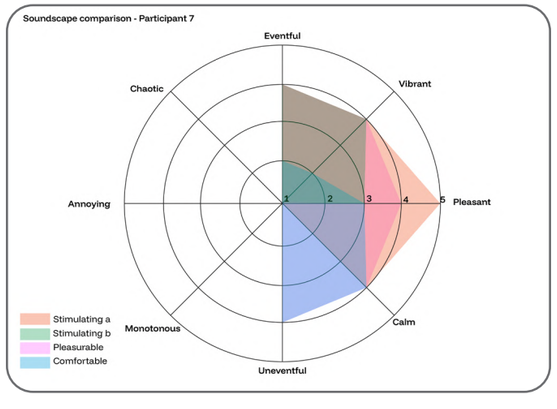


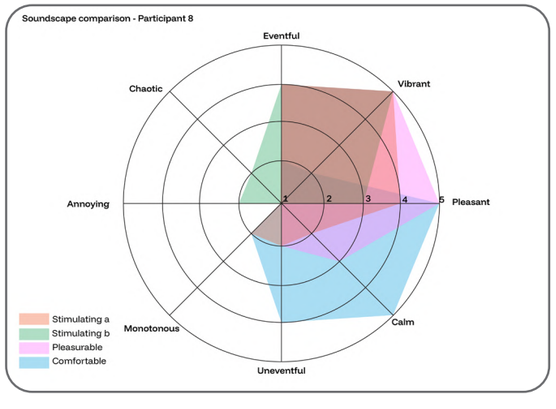




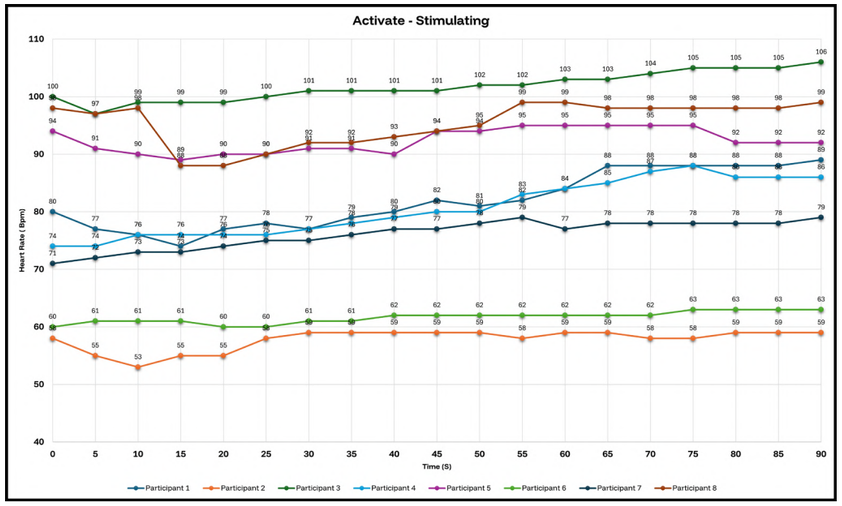




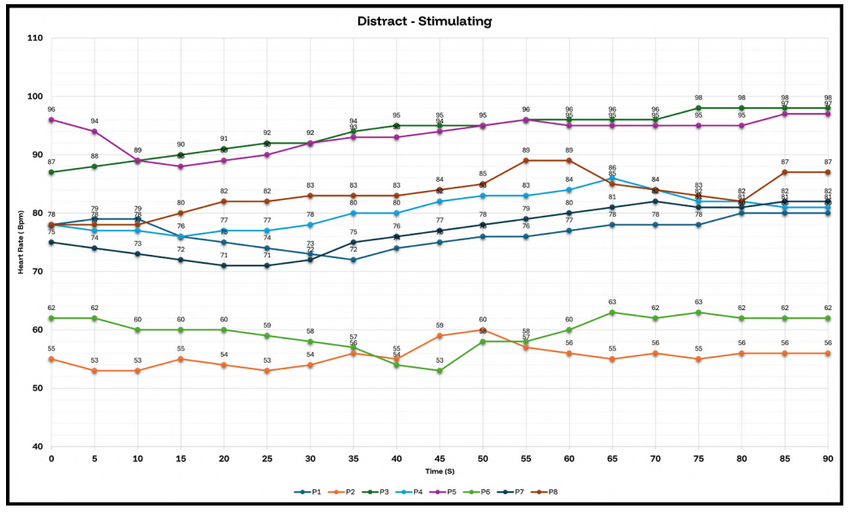




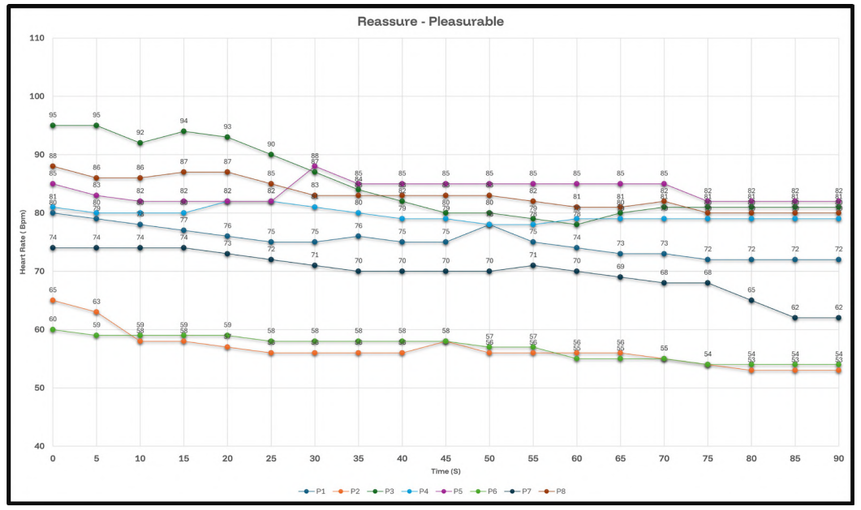
2. Heart rate variability of individual soundcapes



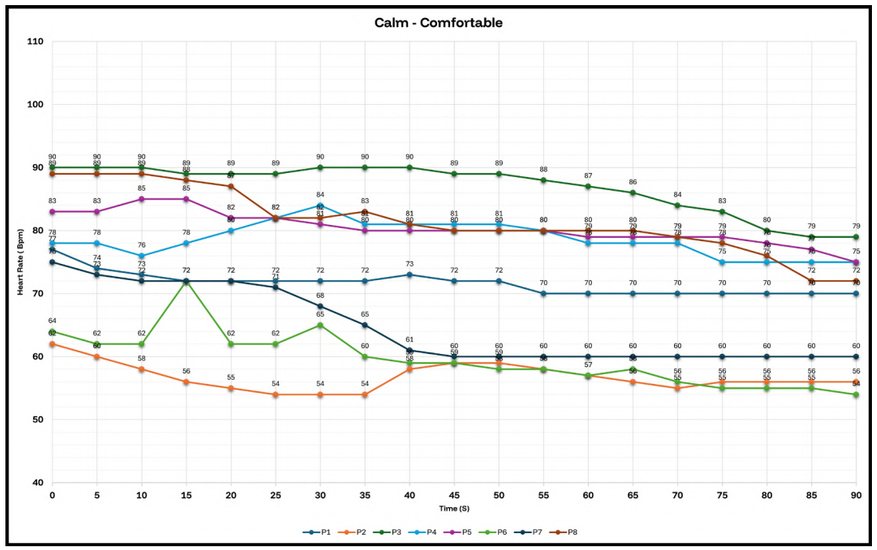
Heart rate trends over time during the stimulating ambience type (For function activate)



Heart rate trends over time during the stimulating ambience type (For function distract)



Heart rate trends over time during the pleasurable ambience type



Heart rate trends over time during the comfortable ambience type

APPENDIX F - EXPERT EVALUATION

Interview guide -
A. ICU NURSES -

1. Do you currently take any steps to support patients through sound? For example, reducing noise or playing music?
2. What is your initial impression of the SoulSound system as a supportive tool for patient well-being? Any functionality that struck you?
3. Do you see value in using personalized soundscapes blending natural, musical, technological, and human sounds from familiar environments in the ICU? Why or why not?
4. Which moments during a patient's stay do you think this system would be most helpful?
5. Do you foresee any challenges in collecting sound preferences from patients or their relatives for personalization through the designed mobile phone application?
6. Are there any patient groups or conditions where you think SoulSound would or would not be appropriate?
7. Would this digital device support in your everyday workflow? Or would it feel a added burden?
8. Could this system potentially support you in your caregiving practice in emotional aspects?
9. The system uses a control device fixed in every ICU room on the wall with a digital interface. Do you think this placement be practical?
10. Does the interface—such as sliding to change between modes feel intuitive to you?
11. Do the different sound modes (e.g., calm, reassure, activate, distract) seem appropriate for addressing emotional changes in patients?
12. Do you have any concerns, suggestions, or feedback about implementing this system in your ICU?

B - TECHNICAL ADIVSOR -

1. What is your initial impression of the SoulSound system?
2. How feasible do you think the SoulSound system is to implement in a real ICU setting, based on your technical expertise?
3. What are the main technical parameters such a system will take into account in terms of both software and hardware?
4. What are the major infrastructural constraints (power, cabling, mounting, etc.) we should be aware of when installing an audio system like SoulSound?
5. For the sound management, SoulSound works on a digital system using a control device placed in each room. What could be the best practices to install such a system?
6. What type of speaker systems (e.g., directional speakers, ceiling-mounted, bedside-integrated) do you think would work best for the ICU environment considering hygiene, noise control, and spatial constraints?
1. Are there restrictions or specific standards that need to be followed when placing new electronic devices in an ICU?
2. How does a new system typically get tested or validated technically before implementation in LUMC's ICU?
3. Do you see any risk of the SoulSound system interfering with other critical care equipment in the room?
4. Are there any types of alerts, thresholds, or safety interlocks you believe should be built into such a system to meet hospital standards?
5. Do you have remarks , concerns or future vision to this system?

C - HEALTHCARE AND USABILITY EXPERT -

1. Based on your expertise in human-centered design and usability, what is your initial impression of the SoulSound system?
2. How do you see the relevance of such a system in addressing psychological needs of the patients in a high-tech but at the same time sensitive environment like the ICU?
3. In your opinion, how well does the SoulSound system integrate with the existing ICU workflows?
4. If this project had to continue in the future to be implemented in the hospital, what would be the key aspects to test such a system with patients and what are the concerns?
5. Do you think a system like this, which relies on sound preference personalization, risks adding cognitive load for patients or their families? (when sometimes this might not be the priority or need)
6. What do you believe are the biggest barriers to adopting non-pharmacological interventions like soundscapes in clinical settings?
7. Do you think the system, as currently designed, can effectively engage all intended stakeholders?
8. What are your thoughts on integrating AI into future versions of the Soul Sound system to autonomously adapt soundscapes based on real-time physiological data?
9. Do you have any remarks, suggestions for the system in terms of the implementation or the usability?

D - EX-ICU PATIENT
1. What was your perception of the overall sound environment of the ICU?
2. Were there any sounds that made you feel uncomfortable / familiar ?
3. Did you do anything do change the sound environment of the ICU ?
4. Would you like to have some control over what you hear while in the ICU — like being able to choose calming or uplifting sounds?
5. What do you think about SoulSound?
6. Do you think a system like SoulSound could help other patients feel less anxious or more connected?

APPENDIX G - PROJECT BRIEF

DESIGN FOR our future

TUDelft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	Deshpande 7602	IDE master(s)	IPD ☐ DfI ✓ SPD ☐
Initials	A.P	2nd non-IDE master	
Given name	Avanti Pravin	Individual programme (date of approval)	
Student number	6022790	Medisign	✓
		HPM	☐

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Dr. Elif Ozcan Vieira	dept./section	HCD/ DA
mentor	Dr. Ela Fasllija	dept./section	HCD/DA
2nd mentor	Floor Heimstra		
client:	Leiden University Medical Centre -LUMC		
city:	Leiden	country:	The Netherlands
optional comments	The chair is well connected with Erasmus MC anf brings hospital connections and sound design expertise to the table. The mentor is a post doctoral acoustic researcher in the same dept with a lot more expertise in sound and light in healthcare settings which fits well for the project.		

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in by the Chair of the supervisory team

Sign for approval (Chair)

Name Elif Ozcan Vieira Date 10 March 2025 Signature

DESIGN FOR our future

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student Avanti Pravin Deshpande Student number 6022790

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Enhancing emotional & physical connectedness in ICU patients through a soundscape system.

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The Intensive Care Unit (ICU) environment is critical for patient survival, yet it presents a significant challenge to emotional and psychological well-being of the patient. Patients often experience distress due to excessive , unwanted noise and persistent artificial lighting, which disrupts sleep, circadian rhythms, and cognitive stability. This sensory overload caused majorly by the unhealthy ICU soundscape contributes to anxiety, fear, and disorientation, leaving fundamental human needs unfulfilled (Louwers et al., 2022; Darbyshire et al., 2019). The absence of natural light cycles, disconnection with nature (outside world) and lack of meaningful interactions throughout the day isolates patients, weakening their sense of connectedness.(Tronstad et al., 2020) This project aims to solve this issue by designing a patient-centered environment that enhances connectedness and comfort, ultimately improving psychological health and recovery contributing to an advanced and personalised ICU.

This project is a collaboration between IDE's Critical Alarms lab at TU Delft and the Leiden University Medical Centre at Leiden which aligns with LUMC's commitment to patient-centered care and innovation in medical practices. The primary stakeholders include critically ill ICU patients, healthcare providers (nurses and intensivists) and family members.(Patients are the main focus for the design, HCPs interact and control the system according to the need , and family inputs/ wishes enhances value).Their interests align with the central goal—to enhance comfort and improve overall well-being by reshaping the ICU experience.

By leveraging need-based design principles (Desmet & Fokkinga, 2020), this project will explore how thoughtfully designed sensory interventions can create a restorative ICU environment. The opportunity lies in developing a testable design intervention that improves emotional and physical connectedness through adaptive soundscapes. However, the sensitive ICU context presents challenges as direct patient testing is limited due to ethical constraints, and integration into existing hospital systems requires thorough feasibility assessments and considerations.

→ *space available for images / figures on next page*

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The sensory overload in the ICU, characterized by a lack of connection to the outside world, nature & family members along with an impersonal setting significantly compounds feelings of isolation. This environment significantly affects the psychological well-being of patients (Tronstad et al., 2020). The current interventions & practices in sound lack personalisation and a system based approach but rather focusses on standalone independant approaches that do not cater to specific patient perspectives.
Needs are essential for human well being and shaping positive experiences. Activities or environments that feel enjoyable or meaningful often fulfil one or more fundamental needs (Desmet & Fokkinga, 2020). Research in psychology refers to the phenomenen of connectedness as a need, a deep sensation of sharing an emotional and physical connection that can make one feel alive and awakened. A sense of connection to nature and other people even in their absence, play a vital role in mental health and resilience (Hill, 2006; Sparks et al., 2014). Despite it signficance in critical care, the research around this sense of connectedness in the ICU context and the role of sound is unexplored creating a significant opportunity in a design intervention. The aim of this proejct is to explore the potential of a soundscape system to address this need during moments of disconnection caused by the isolation & unfamiliar atmosphere. Through this approach, the project provides the hospital with an opportunity to improve patient outcomes & reduced stress for the healthcare staff & family members.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a personalized sound based system that enhances a sense of mental and physical connectedness in critically ill patients during their ICU stay.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

This project will follow a user-centered design approach, emphasizing context-driven insights at each phase.
Field Research & Context Mapping:Through first-hand qualitative observations, the ICU environment will be analyzed from a patient's perspective. Shadowing nurses & doctors will help map interactions, while analyzing previous results from ICU patients interview will explore the impact of sound on emotions and needs.To understand the need of connectedness, Student questionnaires will explore perceptions of connectedness through sound while a soundscape experience workshop will study sensory needs across identified needs in different ICU scenarios.
Co-Creation & Ideation:Building on field research and literature, co-creation sessions with nurses and students will define the design vision. Generative methods like 4Ws and 1H will help establish design goals and an interaction vision.
Concept Development & Evaluation:Concepts will be refined through iterative prototyping (SWOT analysis & Harris profile selection) from low to high-fidelity—validated via surveys and sound expert sessions & nurses. The final design will be developed, focusing on usability and interaction, with the product interface / system tested in a simulated ICU setting.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	18th Feb 2025
Mid-term evaluation	15th April
Green light meeting	20th June
Graduation ceremony	21 July 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

As a healthcare enthusiast and a Medesign aspirant, I have been very keen to work in the medical field, where design and innovation can directly impact patient well-being. When I stumbled upon the project opportunity in sound of ICU with the Leiden Medical Centre I instantly got drawn towards it. The idea of applying user-centered design in a hospital setting, working towards improving the comfort & experience of critically ill patients, felt deeply meaningful. Before the observation study carried out for this project , I had never stepped foot in an ICU and I realised thats it an entirely different world. Seeing the overwhelming noise, artificial lighting, & medical equipment made me realize just how complex it really is.
For this project I want to explore and experiment with technology as much possible to practically make it work in ICU set-up and nothing more can be more exciting than working with sound and light both of which brings immense opportunities for a design outcome as well. Apart from this I want to learn how to mindfully work in a sensitive atmosphere like that in an ICU and work with nurses , doctors and patients.

The competencies i would like to develop in the course of this project :
- Collaborating in an interdisciplinary team of medical professionals and designers.
-Experiment with sound and light technologies to create a working prototype with a measurable impact in an ICU setting.
-Managing goals and deadlines effectively while ensuring high-quality deliverables.
- Carry out an end to end design research project by myself with an external organisation