Improving soundscapes in the Intensive Care Unit by a listener-centric approach

Master thesis by Babette van der Stelt

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I am proud to present my thesis, "Improving Soundscapes in the Intensive Care Unit through a Listener-Centric Approach."
Enjoy reading!

Babette van der Stelt

Executive Summary

Intensive Care Units (ICUs) are complex socio-technical environments where sound plays an essential role in clinical workflows, monitoring systems, and communication between healthcare professionals. However, several sound-induced problems have been identified in ICU environments, such as (mental) health complaints due to prolonged or excessive sound exposure, decreased concentration, extended response times, and alarm fatigue. At the same time, the ICU soundscape is shared by multiple user groups, while sound itself fulfils important functional roles. This makes improving soundscape quality a complex design challenge. This project seeks to advance the soundscape experience for various ICU stakeholders through the development of a consolidated, listener-centric design strategy.

This graduation project combines a listener-centric approach with a multi-perspective analysis to design a soundscape intervention strategy for the ICU at the Leiden University Medical Centre (LUMC). First, the acoustic environment was analysed through observations, sound measurements, and environmental mapping in order to structure the sonic environment and identify sound categories. Subsequently, the ICU was examined as an acoustic biotope, analysing relationships between sound functions, user roles, and user needs. These insights formed the basis for a problem analysis and sound-driven design exploration.

The research resulted in the development of "The Roadmap towards the Ideal Soundscape", a strategic design tool that visualises the current ICU soundscape and identifies opportunities for soundscape improvement. The roadmap integrates both short- and long-term design opportunities and supports stakeholders in developing awareness and making sound-conscious decisions. It therefore provides a tailored design strategy for the LUMC to improve the quality of the ICU soundscape.

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List of abbreviations

AI	Artificial Intelligence
AIOS	Arts I Opleiding tot Specialist
ANC	Active Noise Control
ANIOS	Arts Niet In Opleiding tot Specialist
CAL	Critical Alarms Lab
dB/dBA	Decibel
ECG	Electrocardiogram
ECMO	Extracorporeal Membrane Oxygenation
ED	Emergency Department
EMS	Emergency Medical Service
ER	Emergency Room
Hz	Hertz
ICU	Intensive Care Unit
ISO	International Organization for Standardization
LUMC	Leiden University Medical Centre
MDO	Multidisciplinair overleg
NICU	Neonatal Intensive Care Unit
OR	Operation Room
PICU	Paediatric Intensive Care Unit
PICS	Post-Intensive Care Syndrome
PICS-F	Post-Intensive Care Syndrome – Family
PTSD	Post-Traumatic Stress Disorder
RTA	Real-Time Analysis
SRQ	Sub-research question
TU Delft	Technical University Delft
TWAF	Designing The, With, Against sound For

Glossary

Action themes / Intervention opportunities
Specific areas or concepts for implementing improvements in the ICU soundscape.

Active Noise Control (ANC)
A technology or method that reduces unwanted sound by generating an opposing sound wave, effectively cancelling or diminishing the perceived noise.

Acoustic biotope
The sonic environment characterized by interactions between users and sounds, collaborating towards the collective/common mission/goal.

Acoustic environment
The sonic environment as a collection of perceivable sound, from sound sources to the receiver.

Alarm fatigue
Reduced responsiveness or desensitization caused by excessive or frequent alarms.

AIOS (Arts in Opleiding tot Specialist)
Resident physician training in the Netherlands, working in the ICU among other departments.

ANIOS (Arts Niet in Opleiding tot Specialist)
Non-resident physician in Dutch hospitals, performing ICU duties.

Biotope-polluting effects
When a sound negatively impacts the acoustic biotope or the collective mission.

Concentration issues
Difficulties focusing caused by excessive or distracting sounds in the ICU.

Design directions
Clusters of potential interventions derived from problem analysis to guide soundscape improvements.

EMD / Ambulance
Emergency Medical Dispatch and ambulance services providing pre-hospital care and patient transport.

ER (Emergency Room)
The hospital department where patients with acute medical conditions receive immediate care before admission or transfer to other units.

ICU (Intensive Care Unit)
Hospital unit providing critical care and continuous patient monitoring.

Listener-centric design
A design approach prioritizing the experiences and perceptions of users in relation to sound.

Listener experience
How ICU users perceive, interpret, and are affected by the acoustic environment.

Multi-perspective analysis
A research approach that combines different viewpoints to understand complex interactions between sound and users.

OR (Operating Room)
A controlled environment where surgical procedures are performed; also known as the operating theatre.

PICS (Post-Intensive Care Syndrome)
A set of physical, cognitive, and psychological impairments that can occur in patients after discharge from the ICU, often influenced by the ICU environment, including its soundscape.

PICS-F (Post-Intensive Care Syndrome – Family)
Psychological and emotional stress experienced by family members of ICU patients.

Roadmap towards the Ideal Soundscape
The final design output that integrates short- and long-term interventions into a strategic guide for ICU soundscape improvement.

Sound catalogue
A structured compilation of sound sources, their functions, and effects on users, derived from analysis.

Sound-conscious decision-making
Awareness-driven choices made by ICU staff regarding the improvement of the soundscape.

Sound-driven design
Designing with sound as an opportunity, using insights from multiple perspectives on sound to guide ideation.

Sound functions
The roles that sounds play in the ICU, such as alarms, communication, or ambient cues.

Sound-induced problems
Issues or negative effects caused by sounds in the ICU, e.g., alarm fatigue, mental health complaints, or concentration difficulties.

Sound masking
The use of additional sound, often low-level background noise, to reduce the perception or impact of unwanted or distracting sounds.

Sound modifiers
Design interventions that manipulate sounds before they reach the listener, often using active noise control or other technologies, to improve comfort and reduce negative effects.

Soundscape
The perceived/experienced acoustic/sonic environment in context.

Soundscape quality
The overall condition or experience of the acoustic environment, considering user comfort, health, and functional needs.

Targeted sound
Sound that is directed specifically to the intended listener, rather than being broadcasted to the entire environment, minimizing unintended exposure for others.

TWAF framework
Multi-perspective framework used to guide ideation and problem analysis (full name: To be filled in based on your thesis).

User needs
Requirements and preferences of different ICU user groups regarding the acoustic environment.

User roles
Functions and duties of ICU users that shape their interaction with sound and the collective/common mission.

1. Introduction

This chapter will introduce the project as a whole. It will explain the initially identified problems within the Intensive Care Environment and the project approach of addressing these problems.

1.1 Background and problem context

The Intensive Care Unit (ICU) of a hospital is known for being a sound-rich environment, characterized by a wide range of sound sources such as mechanical sounds from equipment, alarm signals or communication between staff members. Within the ICU, various soundscape users are present, including doctors, nurses, other healthcare professionals, as well as patients or their family members. Sounds can be essential for healthcare providers like alarm signals that indicate the patient's well-being, or sounds like verbal communication. Healthcare providers depend on sound to be able to perform their tasks. However, several studies have shown the potential negative effects of long-term or chronic exposure to noise on human health (Health Council of the Netherlands, 1999). These effects include sleep disturbance, high blood pressure and cortisol levels and weakened immune system.

In the ICU, multiple sound-induced problems have been identified. For instance, noise levels exceed 55dBA for 70-90% of the time, while the World Health Organisation recommends a maximum level of 30 dB for optimal sleep (Mackrill et al., 2013). Given that ICU patients require critical care, it becomes evident that these circumstances are not the most optimal for a healing environment.

Sound-induced problems have also been identified among ICU staff (Kebapcı & Güner, 2020). Among nurses and medical specialists, a phenomenon known as 'alarm fatigue' can occur, leading to delayed or absent responses to alarms and potentially reducing the quality of healthcare. Improving the ICU soundscape may therefore benefit staff and patients and therefore contribute to an improvement of healthcare itself.

Noise pollution in healthcare environments, particularly due to alarms, has previously been addressed mainly through noise mitigation strategies to reduce unnecessary alarms or unwanted sound events (e.g., speech) (Özcan et al., 2024). Additionally, introducing new sounds into a soundscape has been shown as a successful way to intervene in the soundscape experience and improve shared acoustic environments such as nursing homes (Devos et al., 2019).

Soundscape design for critical care settings, however, presents unique challenges. These environments involve multiple user groups with differing and sometimes conflicting needs regarding sound. Sounds such as alarms may be perceived as unpleasant, yet they are essential and cannot be easily reduced without compromising patient care. Soundscape design for critical care like the ICU, would therefore involve balancing and consolidating conflicting needs of all soundscape users.

Problem statement

Given the sound-related problems and the complexity of the ICU as a shared multi-user environment, there is a need to address these challenges through a consolidated soundscape intervention that integrates the functional role of sound with the diverse needs and perspectives of its users.

1.2 Project introduction

The following sections outline the project scope, its theoretical positioning within existing literature, and the research objectives guiding the design process.

1.2.1 Project scope

This graduation project is conducted within the MSc programme Integrated Product Design at Delft University of Technology (TU Delft). The project is carried out in collaboration with Leiden University Medical Center (LUMC) and is embedded within the Critical Alarms Lab (CAL), a Delft Design Lab in which researchers and designers develop future-oriented solutions for alarms and soundscapes in socio-technical environments. The primary stakeholders of this project are the supervisors of the CAL and the LUMC.

This project focuses exclusively on the adult Intensive Care Unit (ICU) of the LUMC. The target group includes all users of the adult ICU, regardless of their functional role within this context. The project aims to develop a consolidated soundscape intervention strategy that addresses sound-related challenges identified in this environment. The project does not impose predefined design limitations on the type of intervention; however, all analyses, design activities, evaluations, and potential system considerations must remain feasible within the six-month timeframe and comply with established medical safety standards, clinical procedures, and patient privacy regulations.

1.2.2 Theoretical framework

In response to the need for consolidated soundscape design in multi-user environments, a literature review was conducted on soundscape research and soundscape assessment approaches and methods (Appendix 2). The review indicates that current soundscape experience assessment frameworks do not sufficiently account for multi-user perspectives. While this limitation is relevant across various contexts, it becomes particularly critical in complex shared environments such as the ICU, where multiple users interact within the same acoustic setting. This issue is further elaborated in Chapter 2.

Traditional sound design approaches primarily focus on the optimisation or modification of individual sound sources. However, increasing technological development has transformed contemporary environments into complex acoustic landscapes in which multiple sound sources and listeners share the same space. At present, sound-centric perspectives are insufficient to address the complexity of socio-technical environments in which sound carries functional, contextual, and experiential meaning. These challenges require a broader and more holistic approach that incorporates context, culture, and listening experience.

Within this context, the concept of Acoustic Biotopes provides an alternative perspective by emphasising role-dependent listening and the functional relationships between users and sound in shared environments. In addition, the Sound-Driven Design method responds to traditional sound design approaches by broadening the design perspective beyond the modification of individual sound sources. It provides a methodological framework from a multi-perspective viewpoint, thereby enabling the development of inclusive and impactful outcomes in complex environments.

Based on the literature review and informed by the principles of Acoustic Biotopes and Sound-Driven Design, a listener-centric approach was developed as the methodological foundation of this project. This approach integrates multi-user perspectives and forms the basis for assessing and designing the ICU soundscape within this study.

The key studies that provide the theoretical framework for this project will be:

- Understanding Soundscape Experience, a new approach. (van der Stelt et al., 2024). This earlier conducted study provides a literature review on soundscape research and offers an alternative framework for the ISO standard's Soundscape Evaluation Framework (ISO 12913-1, 2014) with a listener-centric approach. (Appendix 2)

- Semantic models of sound-driven design: Designing with listening in mind (Delle Monache et al., 2022). This study forms the base on Delle Monache's (and colleague's) Sound-Driven Design Method, which is used in this project's approach.

- Acoustic Biotopes, Listeners and Sound-Induced Action: A Case Study of Operating Rooms (Özcan et al., 2022). This study uses acoustic biotopes to research and explain listening behaviour in socio-technological sound environments.

1.2.3 Aim and research questions

The aim of this project is to design a consolidated soundscape intervention strategy with a listener-centric perspective for the adult ICU in the LUMC. To achieve this aim, the project focusses on the following objectives:

- To conduct a comprehensive, multi-perspective analysis of the current ICU soundscape.
- To examine the interrelations between sound, user roles, and functional meaning within the ICU's acoustic biotope.
To develop a consolidated soundscape strategy that integrates the perspectives of all ICU user groups.

Based on the aim and objectives, the following research question is formulated which guides this design project:

How can the soundscape experience of multiple ICU user groups be improved through the development of a consolidated, listener-centric design strategy?

This research question is supported by several sub-research questions.

Sub-research question 1:
How can the acoustic environment of the ICU be described in terms of sound elements, systemic interactions and environmental context?

Sub-research question 2:
How do user roles within the ICU's acoustic biotope relate to sound functions, soundscape experience, and user needs?

Sub-research question 3:
What sound-induced problems and conflicts in user needs emerge within the ICU environment, and how can multiple perspectives frame the design space for soundscape interventions?

Sub-research question 4:
How can the insights from the analysis be translated into a consolidated soundscape intervention strategy for the adult ICU of the LUMC?

1.3 Methodological approach

The following section describes the project approach and outlines the methods used throughout the different phases of the project.

1.3.1 Project approach

The project will be approached using the Double Diamond design method, integrated with other design approaches to create a listener-centric, sound-driven approach. The Double Diamond consists of two diverging and two converging phases. While this method provides the overall structure of the project, the sub-research questions define its analytical progression. The alignment between the sub-research questions (SRQs) and the design phases is described below.

The Discover phase is guided by SRQ1 and SRQ2, which focus on understanding the current ICU acoustic environment and the relationships between user roles, sound functions, and soundscape experience. By addressing both environmental structure and user perspectives, a broad and multi-perspective analysis is enabled, forming the foundation for identifying problems and opportunities in the following phases.
Within the Define phase, SRQ3 guides the transition from environmental and role-based analysis toward the identification of sound-induced problems and conflicts in user needs within the ICU environment. Through this question, insights are generated regarding the complexity of the ICU soundscape, leading to a structured problem definition and the identification of design challenges.

The Develop phase focuses on translating multi-perspective insights into a clearly framed design space for soundscape interventions. The outcomes of this phase provide the conceptual foundation for the development of consolidated soundscape strategies.

The Deliver phase is guided by SRQ4, which focuses on translating the insights derived from the previous phases into a consolidated soundscape intervention strategy for the adult ICU of the LUMC. In this final stage, the consolidated soundscape intervention strategy is finalised and, where feasible, evaluated to assess its relevance, coherence, and applicability within the ICU context. The completion of this phase marks the conclusion of the graduation project.

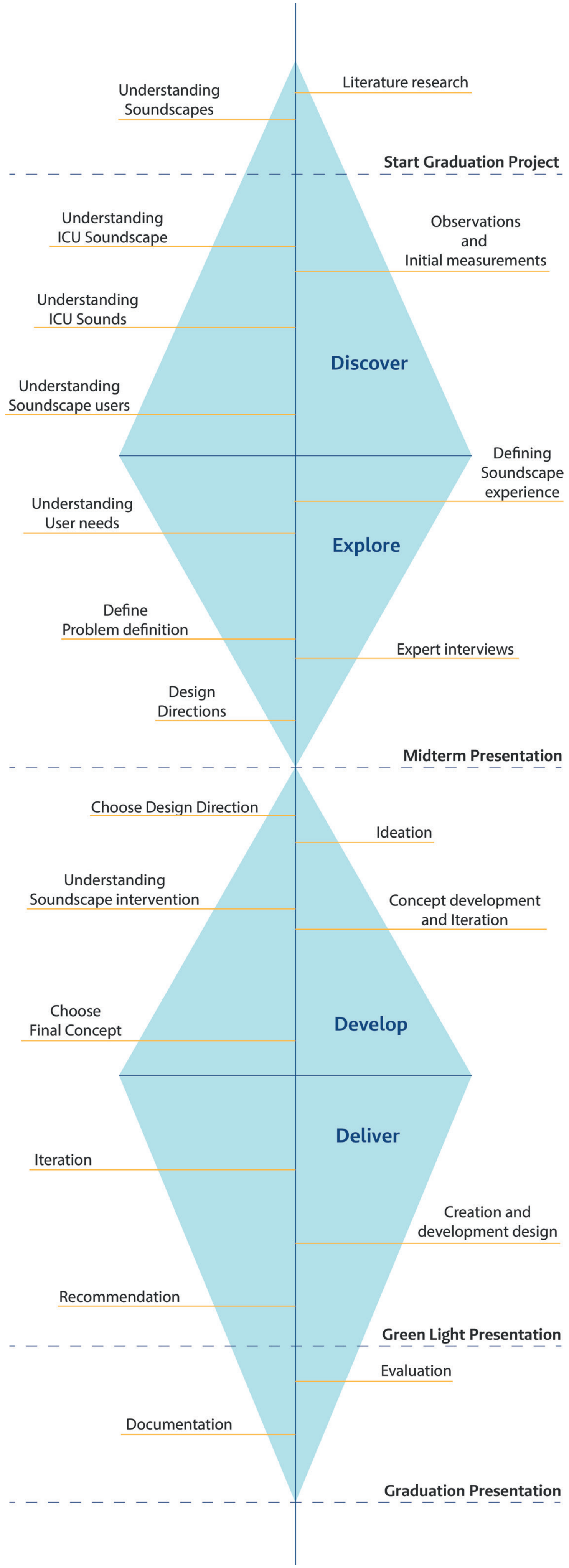

Figure 1 - The Double Diamond Approach

1.3.2 Methods

Several research, analysis, and evaluation methods were employed to address the formulated research questions. Due to the complexity and multi-faceted nature of the project, a mixed-method approach was adopted.

The table in Figure 2 provides an overview of the methods used in this graduation project, structured according to the analysis, synthesis, ideation, and evaluation phases of the design process. As the design process involved iterative cycles of development, the methods are not presented in chronological order. The table therefore serves as a comprehensive summary of the methodological activities conducted within each phase.

Phase	Method title	Collection method	Description
Analysis (observational)	Literature review	Literature analysis	Qualitative, secondary data collection
	Observative Shadow shifts	Observations	Qualitative, primary data collection
	Sound source categorization	Systematic observations	Quantitative, primary data collection
	Soundscape experience analysis	Unstructured interview and questionnaire	Mix-methods, primary data collection
	Culture analysis	Semi-structured interview	Qualitative, primary data collection
	User needs analysis	Literature analysis	Qualitative, secondary data collection
	Sound measurements	Systematic observations	Quantitative, primary data collection
	Sound experience analysis	Questionnaire	Quantitative, primary data collection
Synthesis	Problem analysis	Thematic synthesis	Mix-methods
	Design directions generation	Thematic synthesis	Mix-methods
	Soundmap generation	Computational data synthesis	Quantitative
	Sound catalogue	Integrative synthesis	Mix-methods
Ideation (Experimental)	Sound-driven design – expert interviews	Semi-structured interviews	Qualitative, primary data collection
	Sound-driven design – brainstorm session	Semi-structured brainstorm	Qualitative, primary data collection
Evaluation	Material peer review	Formative evaluation method	Qualitative
	Evaluation session	Co-evaluative participatory feedback session, semi-structed interview	Qualitative, primary data collected

Figure 2 - Overview of methods used in project

2. Introduction of Soundscapes

- This chapter introduces the key theoretical concepts underlying the project, including soundscape theory and acoustic biotopes.

2.1 Soundscapes

The soundscape is defined as "the acoustic environment as perceived or experienced and/ or understood by a person or people, in context" (ISO 12913-1, 2014).

The soundscape cannot be measured instrumentally. Descriptors of a soundscape reflect its meanings and the experiences it evokes. Soundscapes can be experienced as positive or negative and are often characterized by terms such as vibrant, eventful, monotonous, calm, chaotic, or uneventful, depending on the context in which they are perceived.

Measurements of the physical properties of sound, such as frequency, intensity, and duration, provide only a limited understanding of how sound is experienced in an environment. These quantitative data reveal little about the effects of sound on people, their behaviour, emotions, or well-being. Humans are sensitive beings, and our experiences are shaped by the interaction of all our senses with the environment. Sound therefore plays a crucial role when designing for the human experience. Yet it is often overlooked or reduced to technical specifications. There is a clear semantic gap between the subjective experience of sound and the way it is technically described. Over the past decades, research and design based on the concept of the soundscape have become increasingly popular. By approaching sound from this perspective, it becomes much clearer how it affects human experience and well-being. This approach enables the development of interventions that take into account the context, the users, and the meaning of sound.

The concept of the soundscape and the acoustic environment used to be widely interpreted. In 2014, the International Organization for Standardization (ISO) provided a standard definition. According to ISO 12913-1 (2014), the acoustic environment is "the sound at the receiver from all sound sources as modified by the environment".
Kang and Schulte-Fortkamp (2016) elaborated on this concept by synthesizing multiple studies, showing how the acoustic environment is shared among all individuals occupying the same indoor or outdoor space. The acoustic environment can be shaped and modified by all elements in a space as sound travels from the source to the receiver, undergoing reflections, absorptions, and other interactions. It can be measured instrumentally and described using acoustics and psychoacoustics, and its sounds and sources can be classified accordingly.

The soundscape in contrast, is most often described as a person's perceptual construct of the acoustic environment (Kang & Schulte-Fortkamp, 2016). It represents the sonic environment that an individual experiences around themselves. It encompasses the totality of sounds present in a specific space, while also referring to how these sounds are perceived and interpreted by the listener. Even when multiple people share the same acoustic environment, each may perceive a different soundscape.

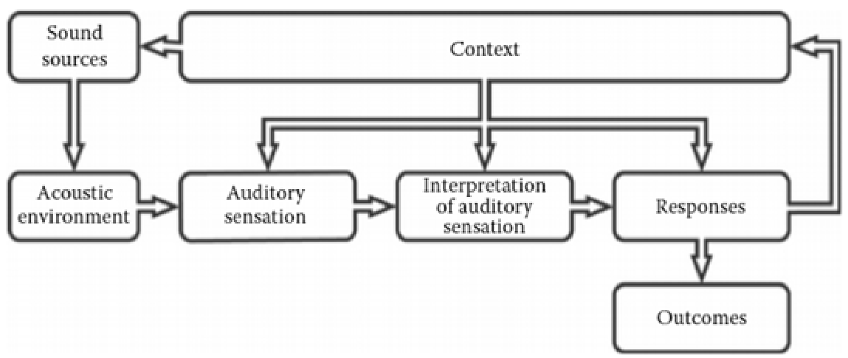

Figure 3 - Schematic representation of the soundscape, according to ISO 12913-1:2014

2.2 Soundscape quality

Sound can have a significant impact on people's well-being and health. Long-term or chronic exposure to noise has been shown in multiple studies to lead to several health issues, including elevated blood pressure, increased cortisol levels, sleep disturbances, concentration problems, and reduced performance (Health Council of the Netherlands, 1999; Van Kempen et al., 2005). In addition, noise can cause irritation, stress, or anxiety, which in turn may contribute to mental health issues such as burnout. It is therefore evident that a sound-conscious environment is essential for human health and well-being.

Initially, research on sound focused primarily on environmental noise and noise management. Traditional methods, such as measuring sound levels in decibels, focus on the physical properties of sound, but provide little insight into its effects on the listener. Studies adopting a noise management perspective often treat sound as a waste product. In contrast, the soundscape approach treats sound as a resource. This approach emphasizes understanding human perception and the enjoyment of the acoustic environment, which has become increasingly important for the management of the built environment and the design of spaces. Research has increasingly shifted toward examining how environmental sounds affect human well-being and how contextual factors contribute to both acoustic quality and the listener's experience (Aletta & Kang, 2020).

Whether we experience our environment as pleasant is partly shaped by subjective factors, including previous experiences and associations, our current activity, instinctive needs for safety or self-preservation, and even evolutionary drives, such as seeking a mate or securing a place within a community (Hekkert, 2006). Although we rarely consciously reflect on this process, it nevertheless affects us. Understanding these human experiences provides a solid foundation for designing for sound and experience in environments.

Describing the soundscape provides deeper insight into the perception and quality of the acoustic environment. The quality of the soundscape plays a significant role in the liveability of a space. Optimizing the sonic environment is not only beneficial for people's health and well-being but also contributes to an improved overall quality of life. In healthcare settings, a high-quality soundscape can contribute to a better recovery environment for patients while creating a more pleasant and productive work environment for staff. Pursuing an ideal soundscape in healthcare can therefore lead to improvements in the quality of care itself.

2.3 Acoustic biotopes

An acoustic biotope is defined as "an active and shared sound environment with entangled interactions and sound-induced actions taking place in a specific space that has a critical function" (Özcan et al., 2022). The concept originates from ecological biology, where it describes a habitat inhabited by different species and explains how sounds represent distinct meanings and possibilities for those species.

In a modern context, this concept is applied to socio-technological environments such as airplane cockpits, operating rooms, and intensive care units. In these complex functional environments, sound functions as a tool that enables users to contribute to a shared goal. Sounds convey actionable information that guides sound-induced behaviour among different actors, enabling coordination and task execution. Therefore, the acoustic biotope not only describes the physical space, but also represents a functional framework in which users collaborate as a team toward a shared objective. Sounds within this environment carry actionable information that is essential for achieving the collective goal. Within such an acoustic biotope, different users may fulfil distinct roles, each with a unique relationship to sound and its meaning.

In earlier research (van der Stelt et al., 2024), the ISO framework for soundscape definition and soundscape experience assessment (ISO 12913-2, 2018) was evaluated. This framework typically considers listeners as a single, homogeneous user group when determining soundscape experience. As a result, all individuals exposed to the same soundscape are assumed to have the same soundscape experience. However, in practice, people can have very different relationships with sound depending on their role, task, or needs at a given moment. For example, in a hospital setting, a doctor may respond very differently to an alarm sound than a patient trying to sleep. To address this limitation, an alternative approach was proposed (Figure 4) in which the role of the listener, as described within the concept of the acoustic biotope, is explicitly taken into account. This approach allows soundscape experiences to be determined based on the differing tasks, intentions, and needs of distinct user groups.

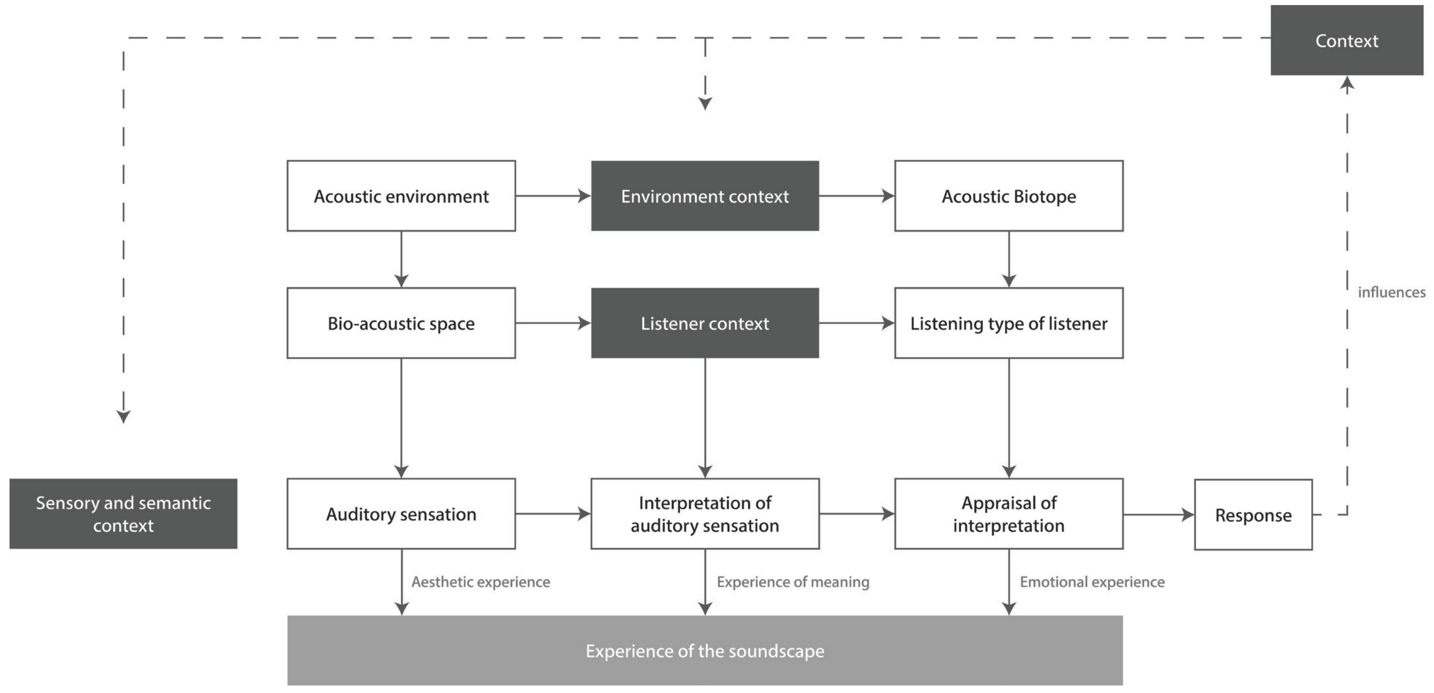

Figure 4 - Schematic representation of the perceived soundscape including the acoustic biotope

3. The ICU Soundscape

This chapter contributes to answering SRQ1 by describing and structuring the current ICU soundscape. The ICU environment, its sounds, and its users are mapped based on observational analyses.

3.1 The ICU environment

The Intensive Care Unit (ICU) is the department within a hospital that provides care for critically ill patients who require intensive and often life-saving treatment. Intensive Care Units are not built uniformly across hospitals; they differ substantially in architectural design, construction, spatial layout, and scale. In the Netherlands, there are 76 hospitals with a registered ICU department (IC-Register – NVIC, 2023), of which 44.5% have ten beds or fewer. The number of beds per room also varies. Some ICUs have all of their beds located in a single shared space, while others consist of multiple rooms with one or two beds each. An intensive care department for adults is commonly referred to as an ICU. There are also specialized intensive care departments for children, known as the Paediatric Intensive Care Unit (PICU), and for premature or newborn infants, referred to as the Neonatal Intensive Care Unit (NICU).

The adult ICU of the Leiden University Medical Centre (LUMC) has a total capacity of 26 beds and consists of a combination of single-patient rooms, double-patient rooms, and single-patient isolation rooms. The department is divided into five separate ICU units. ICU unit 5 is relatively new. Until less than five years ago, this location functioned as a Medium Care Unit and was later renovated into an additional Intensive Care Unit. Compared to the existing units, ICU unit 5 contains a higher number of specialized isolation rooms.

Staff members are distributed across the five units and are organizationally divided into three teams: ICU units 1 & 2, ICU units 3 & 4, and ICU unit 5. Patients are evenly allocated across these teams. Within the work environment, there are not many visible indications of the presence of five distinct units. For example, two of the five nursing stations are left unused in daily practice.

Patient admitted to the ICU

Most of the admissions in the ICU are planned in advance. (Informatiefolder Afdeling Intensive Care Volwassenen, 2025) Patients who undergo major surgery procedures are often admitted to the ICU postoperatively for close monitoring. Surgeries on vital organs, like the heart or brain, as well as full torso surgeries, typically require this form of aftercare (Verpleegafdeling Intensive Care Volwassenen, 2025). Next to planned admissions, the ICU also receives acute admissions. These include patients involved in accidents, patients who develop acute medical conditions such as severe pneumonia or sepsis, or patients who experience complications during a hospital stay. Patients admitted to the ICU are, by definition, seriously ill. Continuous monitoring or taking over some vital functions is often essential for these patients' survival. However, not every occupied ICU bed is necessarily occupied by a critically ill patient. In some cases, a patient's condition has improved sufficiently to allow transfer to another hospital department, but the transfer cannot take place due to a lack of available beds in this other department. As a result, the patient may remain in the ICU even though intensive care is no longer medically required.

Each ICU patient has at least one designated contact person, preferably two. These contact persons are usually close family members. ICU nurses typically provide daily updates to the contact persons regarding the patient's condition. Contact persons may also be consulted when additional information about the patient's medical or lifestyle history is required, or when treatment decisions need to be discussed. For planned admissions, contact persons are appointed in advance In cases of unplanned or acute admissions, this information may initially be missing. In such situations, nurses and physicians must determine who the patient is and who is related to them, which can be challenging, particularly when patients or their relatives do not speak Dutch or English.

As in other hospital departments, the ICU has regulations concerning visiting hours, the number of visitors, and what items may or may not be brought into the unit, such as flowers or food. Hygiene is a critical concern in the ICU. Patients often have compromised or dysregulated immune systems, making them

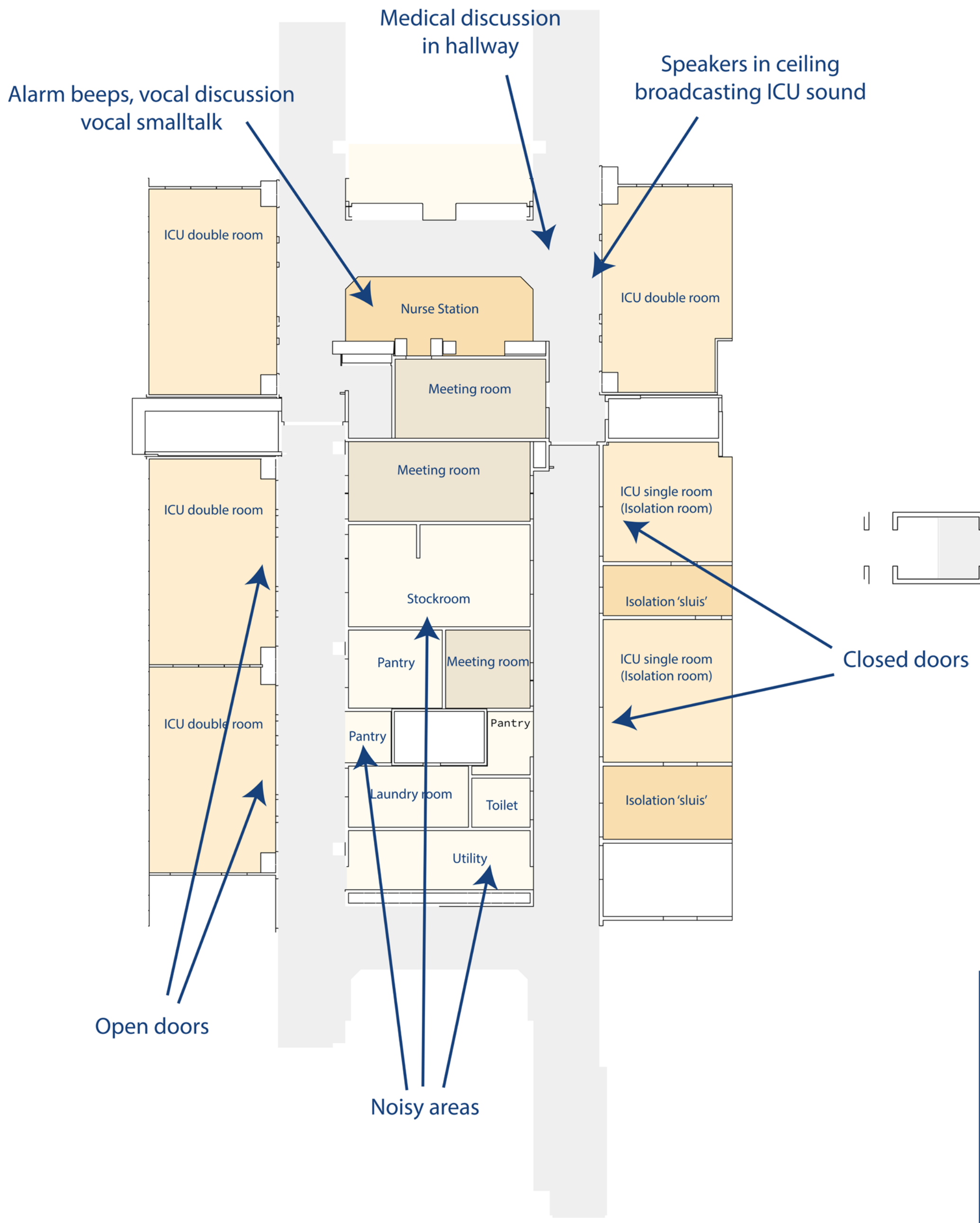

Figure 6 – Map of ICU Unit 5 showing example observations

Public space: Hallway, Elivators, Toilets

Utiliy space: Storage, Stockrooms, Garbage, Pantry

Office space: Offices, Meeting rooms, Family room

Caretaker space: ICU rooms

Caregiver space: ICU 'sluis', Nurse station

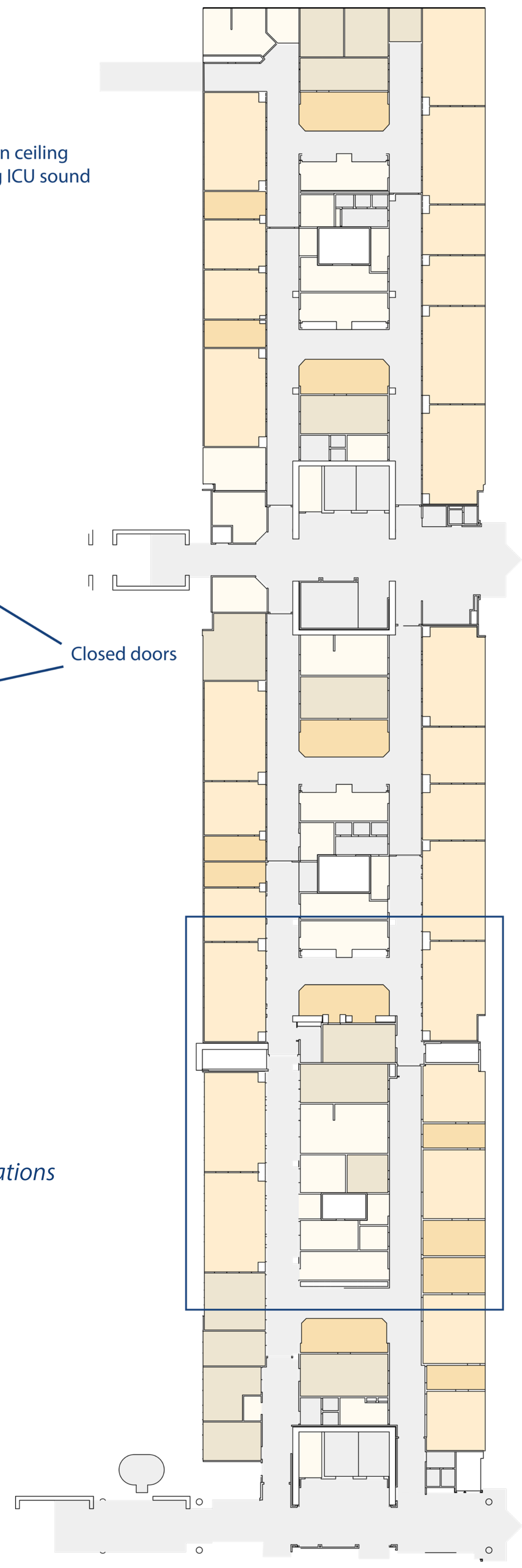

Figure 5 - Full map ICU LUMC

highly vulnerable to infections. Some patients are therefore placed in isolation as even minor infections, such as the common cold, can be life-threatening.

Many ICU patients are not fully conscious, communicative, or responsive. In these cases, family members or designated contact persons play an important role in the care process. Visits from relatives can have a calming effect on patients, but they may also be physically or emotionally exhausting. Every patient situation in the ICU is unique and therefore requires a personalized approach to care.

ICU Layout

In the ICU patient rooms, is the present equipment depended on the required care. Nevertheless, some devices are standard located in every room. At the head of the bed, a cardiac monitor is installed, displaying the patient's heart rate, blood pressure, and blood oxygen saturation. Below the monitor is the ventilator located, which regulates the patient's respiration. On the opposite side of the bed, an infusion pump is positioned to control the administration of medication the patient is receiving.

Furthermore, each room is equipped with a general computer on which a patient administration software is installed. This software is used throughout the hospital and presents patient data and treatment plans in a timeline format, alongside test results and imaging, ensuring that all relevant information for an individual patient is centrally accessible. A television is mounted on the ceiling at the foot of the bed and oriented toward the patient. Furthermore, a curtain rail is installed to allow privacy to be created around the patient when required. Various carts regularly enter and exit the patient room, carrying basic care supplies such as gloves and towels, or patient-specific medication. Other medical equipment and devices are not permanently present in the room and are only brought in when the care situation necessitates their use.

The central station, also referred to as the nurse station, is located in the corridor. Care professionals can work here behind a long counter that is shielded at the front, giving it the appearance of a reception desk. Behind this counter are several office facilities, including a telephone, the main unit of the intercom system, and multiple computers and monitors. Some of these screens display camera feeds from the patient rooms or combined cardiac monitor data from all patients, enabling nurses to maintain an overview of patients' clinical conditions from behind the nurse station. Other computers function as standard workstations for accessing patient records, reading emails, and preparing reports.

Figure 7 – Photo's ICU during observations

Alarm types in the ICU

Medical signals and alarms provide doctors and nurses with auditory information about a patient's clinical status. The medical devices that most frequently generate alarms in the ICU include the patient monitor, the ventilator, and the infusion pump. The patient monitoring system distinguishes between three types of auditory alarms based on priority. Red alarms indicate life-threatening changes in a patient's vital signs and represent the highest level of urgency, for example when a patient enters cardiac arrest. Yellow alarms warn healthcare professionals when vital signs exceed predefined thresholds, signalling a changing condition that requires attention, such as the need to adjust medication. Blue alarms are technical alarms related to the functioning of monitoring equipment and have a low priority; these may be triggered by issues such as a disconnected sensor or a measurement time-out, prompting healthcare professionals to check the equipment or sensor placement.

ICU alarms can further be categorized as actionable or non-actionable. Not all true alarms are clinically relevant and may therefore be considered non-actionable, for example when they provide information that is already known to the healthcare professional. Alarms may also be non-actionable because they are false alarms, providing misleading information without therapeutic consequences. Most non-actionable alarms are blue technical alarms (M. J. van Kekem et al., 2025). These alarms are sometimes difficult to prevent, for instance when a signal indicates missing sensor data while the patient is not being monitored for that parameter at all. The alarm management system has limitations and is unable to fully account for the wide variety of patient situations within their settings. In addition to being audible, alarms are displayed visually on patient monitors and at nurse stations. Yellow and red alarms are also audibly relayed to the nurse station to ensure timely awareness and response.

3.1.1 Key observations - ICU environment

Preliminary observations were conducted at the ICU of the LUMC. During the visits to the ICU, several observations were made that were considered characteristic or noteworthy and are therefore relevant to describe in more detail:

1. Alarm relay system

Red and yellow alarms are audibly relayed to the nurse station. However, this relay system does not account for the occurrence of multiple simultaneous alarm events. For example, when a yellow alarm is triggered for one patient, the corresponding alarm sound is broadcast at the nurse station. If a second yellow alarm is triggered while the first is still active, this additional alarm is not added to the auditory signalling at the nurse station. As a result, multiple alarm events may be represented by a single auditory cue. When healthcare professionals rely primarily on auditory signalling at the nurse station, this limitation increases the risk that alarms may go unnoticed.

2. Open door policy

With the exception of rooms housing fully isolated patients, ICU patient room doors are generally kept open during daytime hours. This practice is explained as a means of maintaining better connection and visibility between care professionals and patients. When closed, the doors function as effective sound barriers. When open, however, patients are exposed to noise originating from the corridor and surrounding areas.

3. Usage intercom system

The ICU is equipped with an intercom system that is called Akoesta. A microphone is embedded in the ceiling above the patient's bed. Sound captured by this microphone can be transmitted to a speaker at the nursing station as well as to a speaker in the ceiling just outside the patient room. This system allows patient room doors to remain closed without fully isolating nurses from auditive activities occurring inside the room. It was observed that sound transmission to the speakers outside the room is not always disabled when the door is opened. In such cases, the microphone may also pick up sounds from the corridor and retransmit them back into the corridor. In this case it is possible that a person who is talking directly outside the room may hear their own voice played back through the speaker above them.

4. Placement utility rooms

Some patient rooms are located directly opposite utility rooms, such as the pantry or laundry room. These areas contain sound-producing equipment and are sites of frequent activities that generate noise. When the doors of the opposing patient rooms are open, patients are exposed to these sounds.

3.2 ICU sounds

The ICU is a sound-rich environment. Day and night, there are constantly mechanical and electronic sounds from medical equipment present, such as ventilation or extraction systems, the steady hum of machines, or alarms or alert signals. In addition to these technical sounds, there are also sounds produced by human activity, including conversations, the opening and closing of drawers and doors, footsteps in the corridors, and the handling of equipment and supplies. The sounds in the ICU that are best recognized, can be broadly categorized into: machine and technical sounds, alarm sounds, human activity, restocking, gathering of supplies, medical discussions, and small talk.

The acoustic environment in the ICU is highly dynamic and varies considerably depending on factors such as the number of patients admitted, or the intensity of ongoing care, and the frequency of medical procedures. During busy periods, when ICU activity is high, the acoustic environment becomes particularly dynamic, with peak noise levels caused by alarms, staff activity, and equipment use. In contrast, during quieter moments when is unit is less active, these peaks largely disappear, and the urgency of sound-related challenges seems to diminish.

These observations highlight that the ICU acoustic environment is not static but fluctuates according to clinical activity and the changing needs of patients and staff. In the LUMC ICU, patient room doors are kept open as a standard practice. This means that patients are not only exposed to sounds from inside their room but also to sounds originating from outside, such as sound from activity in the corridor or in adjacent rooms that reaches the patient's room.

Figure 8 - Broad categorization of sounds in the ICU

3.2.1 Categorizing sound

Understanding these patterns is crucial for designing effective soundscape interventions. During the period from December 2024 to January 2025, observational studies were conducted to map the sounds present in the ICU. The aim of these observations was to gain insight into which sounds are audible in the ICU and how frequently these sound events occur.

Method

The observer was positioned inside an ICU patient room in which an unconscious patient was present. From this position, the observer was able to perceive sounds originating nearby the patient and the medical equipment, as well as sounds from the corridor or other areas of the ICU that reached the patient room.

During observation periods of 5 minutes, all occurring sounds were logged. Continuous sounds were counted as a single observation within each 5-minute period. This procedure was repeated for a maximum of 30 consecutive minutes.

Prior to the observations, a list of potential sound sources was compiled and physically available during data collection. Tally marks were used to record how often each specific sound was observed. Different coloured pens were used to distinguish between sounds originating inside the ICU room and those originating outside the room.
Observations were conducted at locations distributed across the entire ICU and took place between 08:00 in the morning and 20:00 in the evening.

Materials

A preliminary study was conducted to obtain an initial overview of potential sounds present in the ICU. This inventory was compared with a classification scheme for indoor sounds (Appendix 3) to ensure the completeness of the list of potential sound sources. This classification scheme is a translation of the sound classification framework for acoustic environments developed by Brown et al. (2011), which was originally designed for outdoor soundscapes. The translation, specifically adapted for indoor environments, is better suited for indoor soundscape research. After compiling the list, blank lines were added to allow for the inclusion of any sounds that may have been missed during the observations. The final list used can be found in Appendix 4.

Afterwards, the hard-copy tally sheets were digitized using Microsoft Excel, which was also used to generate charts and graphs for analysis purposes.

Results

A total of 345 minutes of observation time was collected, distributed nearly evenly across the period between 08:00 and 20:00. This made it possible not only to map the frequency of the present sounds, but also to analyse their distribution throughout the day. Figure 9 presents an overview of all observed sound events, distinguishing between sound sources originating inside and outside the patient room.

Mechanical sounds mainly originated from sources inside the ICU room. The ratio of sound sources inside versus outside the ICU room was 356:49, which can largely be attributed to the medical equipment connected to the patient. For the category of electrical alarms and signals, the inside–outside ratio was considerably more balanced (107:97). Remarkably, patients were exposed to nearly as many alarms and signals originating from other patients' equipment as from their own. For sounds resulting from human activity (199:416) and sounds produced by the human body (128:366), the majority of observed sounds originated from outside the ICU room. Given the evident intention to create as much rest and recovery as possible for the patient inside the room, this is not an unexpected observation. However, the high frequency of these occurrences may still be considered noteworthy. In total, patients were exposed more frequently to sounds originating from outside the ICU room than from within (790:928), primarily due to the high frequency of sounds related to human activity and the human body outside the room.

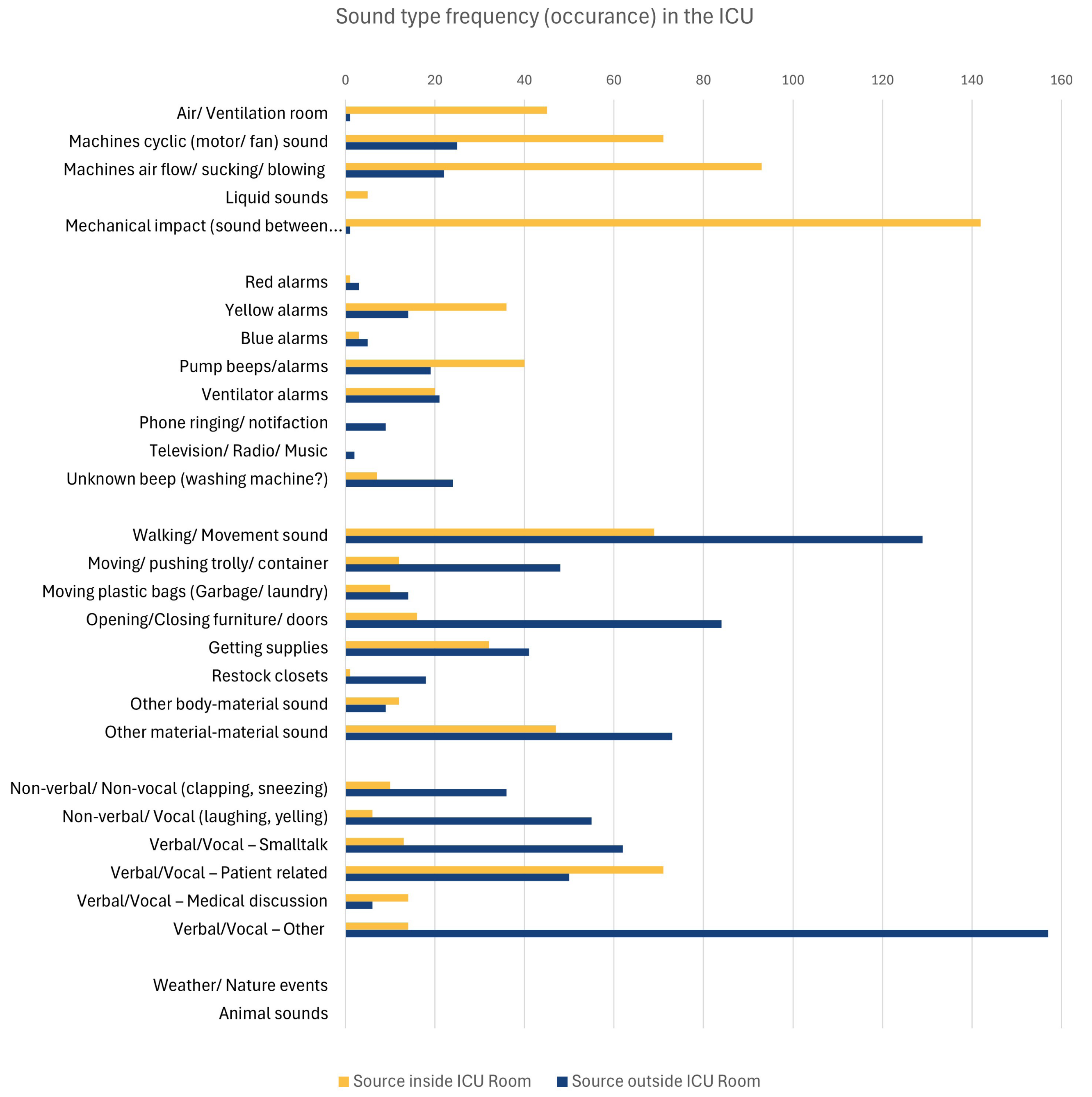

Figure 9 - Sound sources in the ICU - Total observation of sound occurence

In Figure 10, the observed sounds are displayed in a timeline, providing a representation of the progression of a typical day in the ICU. Throughout most of the day, sounds from outside the patient room were more frequently perceived than sounds from inside, with the exception of two points in time. These moments correspond with the handovers between different healthcare teams. The morning handover is generally more extensive than the afternoon handover and is often combined with physicians' rounds or specialist rounds, such as the ECMO round. This results in a peak in activity and sound production within the ICU room.

This does not imply that no sounds occur outside the room during these peak moments. The observations were conducted from the patient's perspective. During handovers, the increase in foreground sounds leads to the masking of background sounds, making them less perceptible.

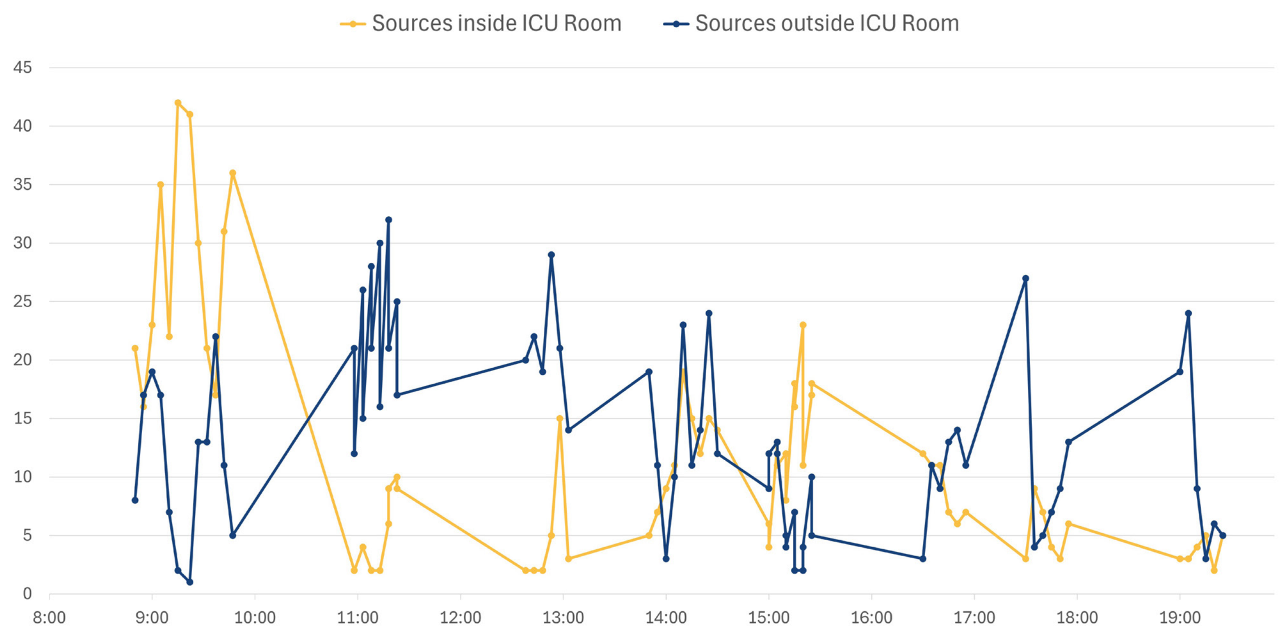

Figure 10 - Occurence of sounds - during the day (Inside/Outside)

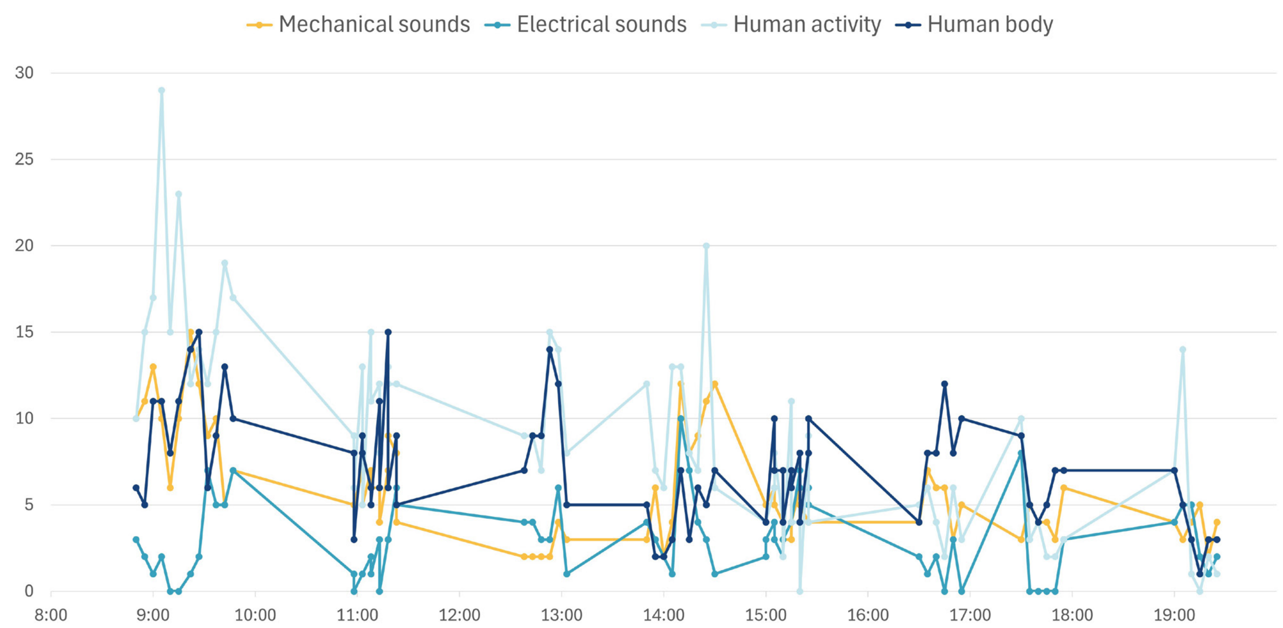

Figure 11 - Occurence of sounds - during the day (Sound catagory)

In Figure 11, the same timeline is presented, with the graphs representing the different sound categories. This figure clearly shows that the category of electrical signals and alarms has the lowest observation frequency throughout nearly the entire timeline, while human activity exhibits the highest frequency. However, this observational study represents an objective analysis of the acoustic environment. Characteristics such as sound level, pitch, impact, and meaning were not included in these representations. It means that sounds that occur less frequently may nevertheless have a greater impact on the listener than sounds that occur more often.

3.2.1 Key observations - ICU sounds

During the visits to the ICU, several observations were made that were considered characteristic or noteworthy and are therefore relevant to describe in more detail:

1. Contrast in sound levels

A quit ICU with low occupancy or limited activity is initially not perceived as an intense sound environment. At the LUMC ICU, sound levels were measured during different activity periods using a decibel meter. In the absence of sound-producing activities, the overall sound level is approximately 45 dBA. This contrasts sharply with busier periods, during which activities can generate peak sound levels of up to approximately 75 dBA. Subjectively, this difference is experienced as an increase in loudness by roughly a factor of ten.

2. Urge to sound reduction

During (morning) handovers, substantial activity occurs in the corridor, resulting in increased noise levels due to human movement, the transport of carts, the retrieval of materials, and the opening of doors and cabinets. In contrast, activity inside the patient rooms is deliberately quieter, out of consideration for patients who are often just waking up. The atmosphere inside the rooms is comparable to that of a library or church: upon entering, care professionals automatically lower their voices and move more calmly. The urge to this change of behaviour is not noticeable in the corridor. It was observed that corridor noise could dominate the acoustic environment of the patient room. For instance, doctors who were in discussion in the hallway were sometimes perceived louder inside the room than the doctor speaking to a patient who was actually inside the room.

3.3 ICU users

The ICU ecosystem consists of multiple roles, each with distinct tasks and responsibilities. Broadly, these roles can be categorized into healthcare receivers, healthcare professionals, and non-medical staff.

Healthcare receivers

Within this category, the user group of the patient can be identified. The patient is defined as the care-receiving individual. The care situation varies considerably between patients. As discussed in Chapter 3.1, there are multiple reasons for a patient to be admitted to the ICU. Accordingly, a patient's condition may range from fully comatose or unconscious to fully awake and alert. The length of stay in the ICU can also vary widely, from a few hours to several days or months. In addition to the physical conditions for which patients are treated, ICU admission is often associated with significant mental and psychological challenges, which are discussed in more detail in Chapter 4.1. Patients remain in the ICU continuously, resulting in a 100% daily exposure ratio.

In addition to the patient, family members are also considered care receivers. The family member is defined as the close relative of the care-receiving individual. While they do not receive medical care themselves, they are key stakeholders in the care process of their loved one. Unlike patients, family members are fully alert during their time in the ICU. They experience the situation and the environment without having the medical background knowledge to be able to understand and explain all events and procedures. Healthcare professionals therefore provide care to this group primarily through information provision, reassurance and guidance, supporting them throughout what is often a stressful and emotionally demanding process. On average, family members spend approximately four consecutive hours per day in the ICU, corresponding to about 16.7% daily exposure ratio, although this duration may vary depending on the specific situation.

Healthcare providers

The treatment team of ICU patients consists of healthcare professionals with diverse backgrounds and specializations. A core medical team that is permanently present in the ICU includes the intensivist (ICU physician), intensivists in training, non-training physicians (ANIOS), and residents or physicians in training (AIOS). This user group is defined as the ICU doctor, described as the care professional, responsible for the overall treatment plan and the execution of medical procedures. This core team is complemented by medical specialists such as cardiologists or neurologists, who visit the ICU for consultations or specific medical procedures. In addition, ICU doctors receive support from clinical specialists whose primary workplace is elsewhere in the hospital, such as microbiologists, physiotherapists, dietitians, and psychologists.

ICU doctors spend the majority of their shift within the ICU environment, although much of this time is spent in a designated office spaces, where they develop and discuss the treatment plans. After lunch, a multidisciplinary team meeting (MDO) takes place, CU doctors and various medical specialists review and discuss the admitted patients Microbiologists often participate in these meetings in an advisory role, particularly when complex clinical questions arise. The amount of time an ICU doctor spends continuously in the ICU varies depending on the shift type. A day shift lasts approximately 9.25 hours (corresponding to a 38.5% daily presence ratio), an evening shift approximately 6.75 hours (28.1%), and a night shift approximately 10 hours (41.7%).

Following the ICU doctor, the ICU nurse is introduced as the next key care professional on the unit. They are not physicians, yet they maintain the closest and most continuous contact with patients. Apart from the patients themselves, they are the staff members who spend the most continuous time on the ICU. The ICU nurse is defined as the care professional, responsible for the daily care and direct patient support.

ICU nurses are responsible for day-to-day patient care activities such as washing, feeding, and repositioning patients, but they also execute a substantial part of the medical treatment plan established by the ICU doctors. This includes administering medication, monitoring vital signs, and maintaining close proximity to patients to respond immediately in case of acute changes. ICU nurses rarely leave the ICU during their shift. When not actively engaged in bedside care, they remain at the nurse station, where they monitor patients while performing administrative tasks. The ICU nurses spend approximately 12.5 consecutive hours in the ICU per shift, both during day and night shifts, corresponding to a 52.1% daily presence ratio.

Non-medical staff

The last group that can be named is the non-medical staff. This user group is defined as personnel without direct patient contact or medical responsibilities. They primarily provide logistical and administrative support to the nurses and the ICU as a whole. They primarily provide logistical and administrative support to the nurses and the ICU as a whole. ICU care assistants, for example, are just like the nurses present on the unit for majority of the time. They prepare supplies, manage laundry and waste, and stock the various carts and equipment necessary for the nurses to perform their tasks. In addition, medical students may assist by preparing medications, while the ICU secretary works at the desk performing administrative duties. The unit is also supported by team leads and other office staff who are based in the ICU offices but spend little time on the unit itself, typically following regular office hours of around 8 hours per day, resulting in an exposure ratio of approximately 33.3%.

Other non-medical personnel, such as cleaners, restocking employees, and delivery staff, visit the ICU only briefly. Their presence ranges from a few minutes to a few hours, after which they return to tasks elsewhere. For instance, a cleaner spending one hour on the ICU would have an exposure ratio of 4.2%, while a delivery person with only ten minutes of exposure would have the lowest ratio of 0.69%.

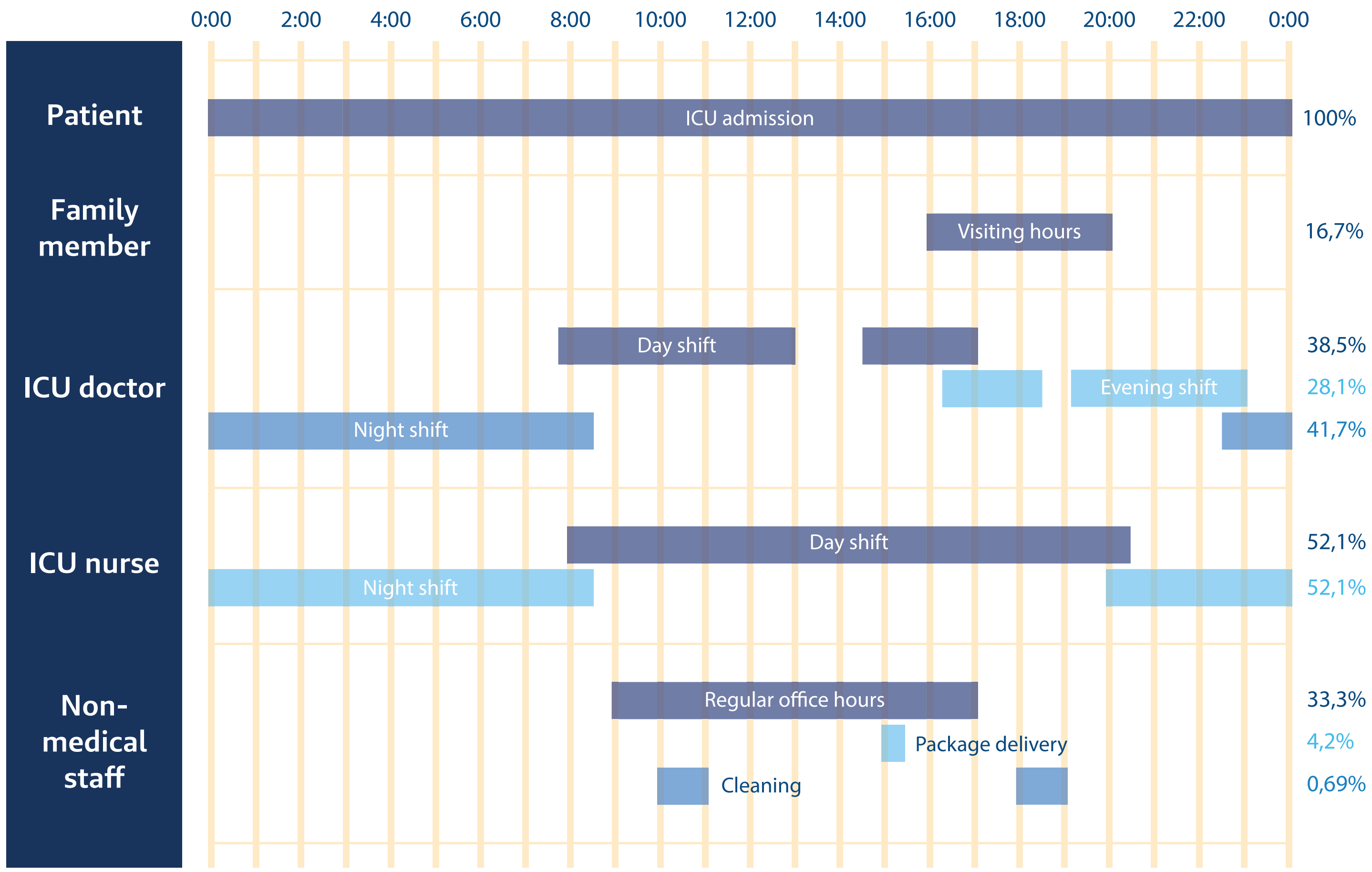

Figure 12 – Daily presence of ICU users and their exposure to the ICU soundscape

3.3.1 Key observations - ICU users

During the visits to the ICU, several observations were made that were considered characteristic or noteworthy and are therefore relevant to describe in more detail:

1. Deactivation non-actionable alarms

Alarm signals occur frequently in the ICU. The alarm provides the responsible nurse the necessary information to support their actions. It was notable that alarms were not always deactivated immediately once their cause and significance were understood. This observation suggests that the alarm sound become less urgent and indifferent once its meaning is clear. In many cases, first the complete intervention was performed before the alarm was deactivated. In some instances, alarms were ignored altogether when it was evident that they did not require action. Rapid deactivation of alarms or adjustment of alarm thresholds to reduce non-actionable alarms did not appear to be standard practice.

2. Time for deactivation alarm signals

During certain procedures or interventions, sensors may become (unintentionally) detached or temporarily register unrealistic values. This can trigger alarms without true clinical issues happening with the patient. As nurses are often fully occupied during such procedures, they may be unable to deactivate the alarm, causing it to continue sounding until the procedure is completed. These periods can range from 5–10 minutes to sometimes 30 minutes or longer. In such situations, habituation occurs and healthcare workers may no longer consciously register the alarm sound, as it no longer holds meaningful information. Moreover, these alarms are forwarded to the nursing station, where they could mask a second, potentially more relevant alarm originating from another patient room.

4. The Acoustic Biotope

This chapter contributes to answering SRQ2 by describing the acoustic biotope of the ICU, examining users' needs, and exploring the soundscape experience.

4.1 The acoustic biotope of the ICU

The concept of the acoustic biotope was introduced in Chapter 2.3. In the ICU's acoustic biotope, a shared mission or collective goal can be identified: "An ICU environment for the benefit of the patient". Users, their tasks, and the sounds in the environment should all serve to reach this common goal. Within the acoustic biotope, different users may fulfil distinct roles, each with a unique relationship to sound. The user groups representing different roles in the ICU setting are identified as follows:

- The patient
-> The care-receiving individual

- The family member
-> The close relative of the care-receiving individual

- The ICU doctor
-> The care professional, responsible for the treatment plan and medical procedures

- The ICU nurse
-> The care professional, responsible for the daily care and patient support

- The non-medical staff
-> Personnel without direct patient contact or medical responsibilities.

Each of these groups engages with the acoustic environment in a different way and can therefore be understood as representing distinct listener types, as described by Özcan et al. (2022). Figure 13 provides a schematic representation of the ICU acoustic biotope.

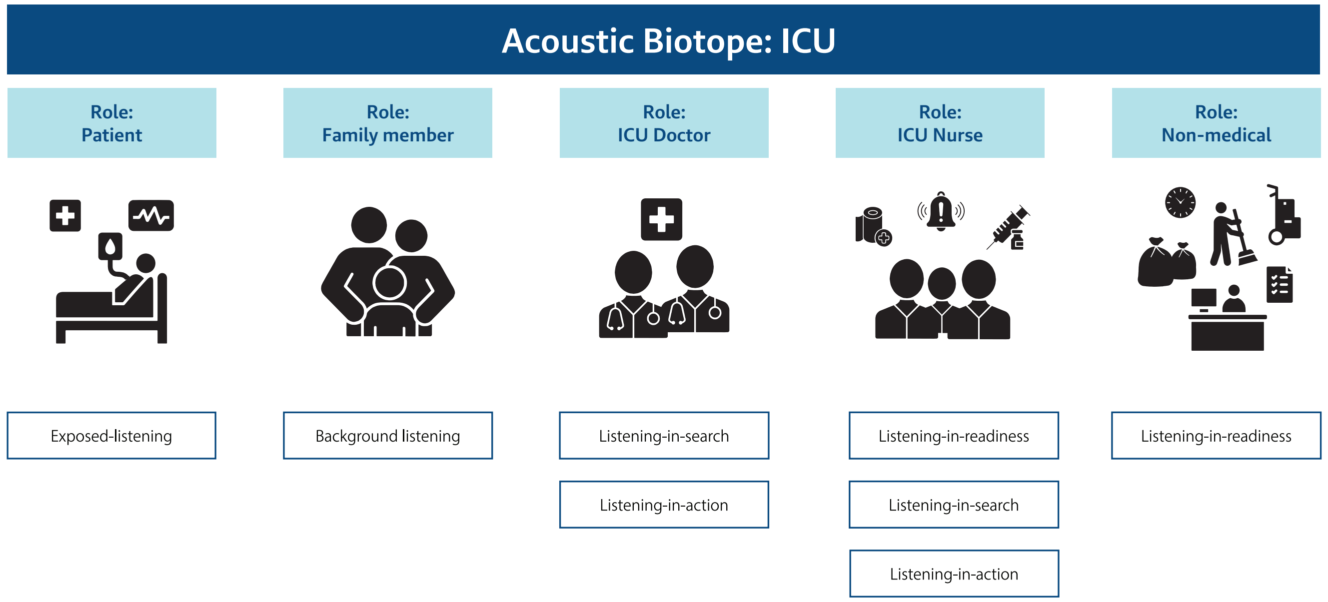

Figure 13 - Acoustic biotope ICU - Different roles and types of listening

Figure 14 - Types of listeners and listening in the acoustic biotope

The inactive listener – exposed-listening
Exposed listening represents the most passive type of listening. In this type, the listener has no control over the acoustic environment, although the auditory system continues to receive sound input. This type of listening is performed by ***inactive listeners***. Within the ICU-context, exposed listening most closely applies to the patient.

The passive listener – background listening
In background listening, the listener devotes minimal attention to sound. Sounds are recognized and ignored when they are familiar or redundant, unless they suddenly change. Background listening can be described as scanning the environment for potentially relevant information. The family member can be seen as one of these ***passive listeners***, for they do not actively engage with environmental sounds, but can recognize changes (such as alarm signals) and may react to this.

The active listener – listening-in-readiness
An intermediate level of attention is used for this type of listening, in which the listener remains in a continuous state of alertness to receive meaningful information. This listening mode relies on learned associations, enabling rapid identification of relevant sounds. Listening-in-readiness is characteristic for ***active listeners*** like ICU nurses engaged in secondary tasks and non-medical staff. Despite other activities, nurses will maintain auditory attentive for alarms and signals and can act immediately when medically relevant sounds are detected. For non-medical staff, sound as verbal communication is found to be essential. A call for assistance is immediately recognized and leads to an action.

Sound users – listening-in-search
Listening-in-search is an active type of listening in which the listener deliberately seeks specific acoustic cues that are immediately relevant to task performance. This requires a high level of attention for detail. It is performed by ***sound users***. The ICU doctor and the ICU nurse will be familiar with this listening type, for example during actively attending to a patient and interpreting auditory cues such as breathing patterns or heart rhythms.

Sound producers – listening-in-action
Listening-in-action is the most dynamic type of listening. The listener is not only attentive perceiving sound, but also actively produces sound as an integral part of the task execution. Sound functions as continuous feedback or as a 'too' for performing sensory-motoric actions. The listening type is performed by ***sound producers***, for whom sound-induced actions and reactions are essential to complete the task. Listening-in-action applies to the ICU doctor or ICU nurse during intensive patient care or procedures.

4.1.1 Informative value of sounds

Within acoustic biotopes, the informational value of sound is crucial for enabling sound-induced actions. In the functional environment of the ICU, sounds must convey actionable information that allows the listener to respond appropriately. A reduction in the informative relevancy of the present sounds, such as false information, (background) noise masking the auditory scene, or redundancy resulting from repeating the same message, can lead to a pollution of the acoustic biotope. Repetition of the same information like medical signals that do not provide new meaning, or false alarms that introduce irrelevant input to the acoustic environment, may result in habituation or reduced cognitive processing by the listener. When care professionals experience cognitive overload, it can lead to decreased response times or develop alarm fatigue.

Optimizing the acoustic biotope and making sound-conscious choices to prevent biotope pollution is an effective way to improve the soundscape , while maintaining awareness of the different user roles and the shared goal. Pollution of the acoustic biotope can be reduced by increasing the informative value of existing sounds and/or by limiting the overall number of sounds. Consequently, measures aimed at preventing acoustic biotope pollution may support the performance of healthcare professionals and thereby enhance the overall quality of care.

Categorizing sound

Based on the roles of the different soundscape users and their specific needs (as further elaborated in the next chapter), sound categories in the ICU can broadly be classified as either necessary or unnecessary from the perspectives of both healthcare receivers and healthcare providers. Figure 15 presents a schematic overview of this categorization.

Certain sound categories, such as mechanical or machinery-related sounds and activity sounds resulting from tasks like grabbing supplies, tend to be perceived similarly by both groups. However, other categories reveal a clear divergence in perception. The most pronounced contrast is found in alarm sounds and medical signals. While these sounds are highly informative and essential for healthcare professionals in monitoring patient safety, they are often experienced as disruptive, stressful, or unwanted by patients and family members.

This schematic representation therefore illustrates the conflicting needs and perceptions regarding sound among different ICU users, highlighting the complexity of designing an acoustic environment that serves all stakeholders.

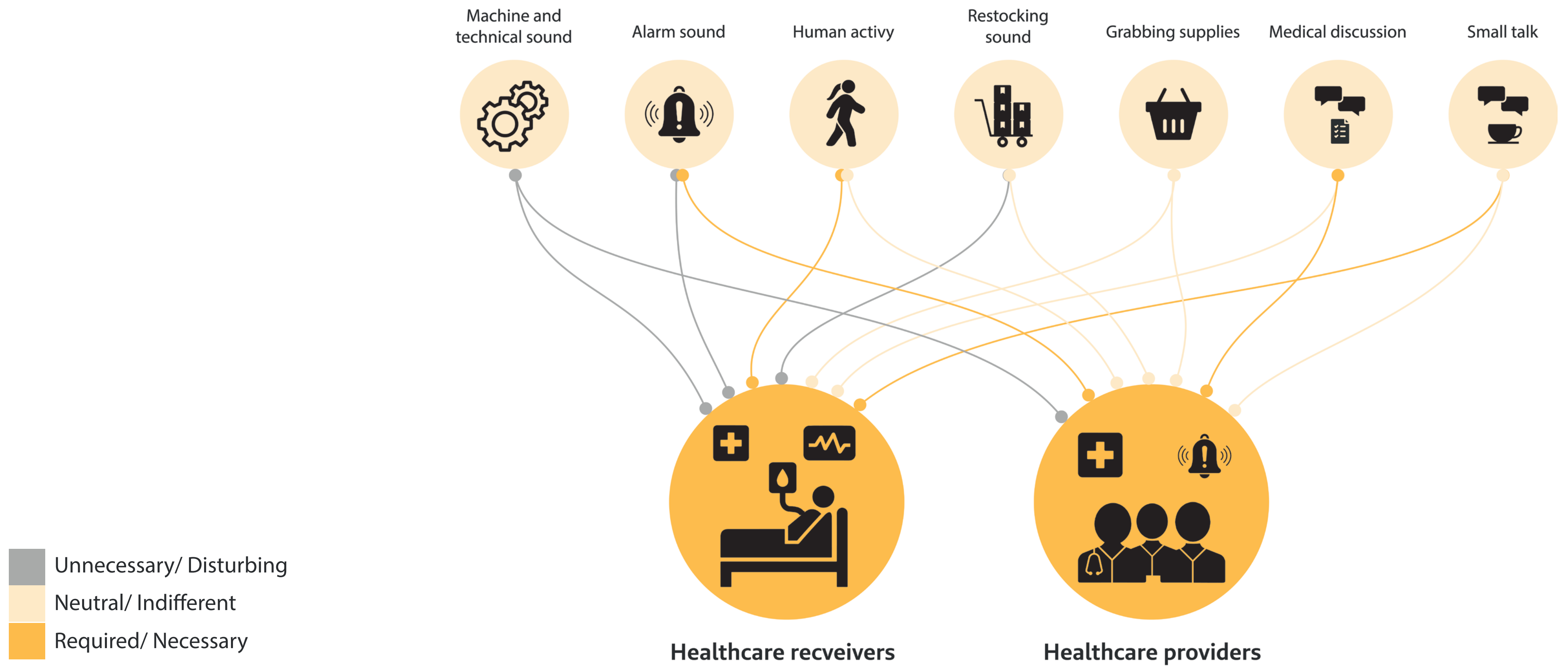

Figure 15 - Relations between user groups and sound categorization

4.2 User needs

ICU soundscape users each have a distinct relationship with the environment and therefore different needs. A soundscape experience analysis was conducted with ICU users (see Chapter 4.3). Through unstructured interviews, insights into users' needs were obtained. These insights were later confirmed and further elaborated during expert interviews with expert users (see Chapter 5.2).

In general, healthcare receivers primarily aim to recover and eventually return home. Healthcare providers have the desire to deliver the highest quality of care. and to perform their professional duties as accurately and thoroughly as possible. They aim to maintain close connections with their patients and strive to perform their tasks as accurately and thoroughly as possible. Non-medical staff typically do not have direct interaction with healthcare receivers. They are primarily focused on completing their tasks and leave the ICU once their work is finished.

4.2.1 ICU culture

Within the hospital environment, several departments are dedicated to critical care. The Emergency Department (ED), Emergency Medical Services (Ambulance), the Operating Room (OR), and the Intensive Care Unit (ICU) are examples of clinical settings in which patients may be unconscious, clinically unstable, or at risk of acute destabilization (Schell et al., 2018). Comparing the ICU with these other critical care environments helps to illustrate the distinctive culture of the ICU. During exploratory visits to other clinical settings within the hospital, qualitative observations and informal conversations with healthcare professionals provided insight into the characteristics of these environments.

The human body can be compared to an extremely complex chemical factory. It is often stated by healthcare professionals that all medical interventions are ultimately inferior to the body's own capacity to regulate, repair, and heal itself. In emergency settings at the ED or the Ambulance, the primary goal is to stabilize the patient as quickly as possible so that the body can regain balance and resume its own regulatory processes (Four Major Differences Between ICU and ER Nurses, n.d.). Medical treatment in these contexts is therefore focused on rapid intervention aimed at restoring physiological equilibrium.

Patients admitted to the OR are, in most cases, relatively stable individuals who are intentionally anesthetized and medically controlled. During surgery, medical interventions temporarily take over bodily functions, but once these interventions are withdrawn, the body can again be trusted to restore balance, allowing the patient to regain consciousness. In this context, medical treatment is designed to support and control the body while trusting its inherent capacity to recover once external intervention ceases.

In contrast, patients admitted to the ICU are critically ill. Their bodies are no longer able to function independently, and the internal "chemical factory" cannot be relied upon to maintain balance. While stabilization remains essential, ICU care is fundamentally aimed at supporting, strengthening, and gradually restoring bodily functions over time. Medical treatment in the ICU is therefore characterized by continuous monitoring and prolonged intervention, with the goal of slowly guiding the patient back toward physiological stability (ICverpleegkundige.com, n.d.).

When a patient deteriorates or crashes in the ICU, the situation is often more critical than in the other settings described. Unlike patients in the ED, ambulance care, or the OR, the ICU patient's body cannot be expected to recover on its own. Without medical intervention, the patient will not survive.

Healthcare professionals describe ICU culture as involving a much more direct and frequent confrontation with death. ICU personnel are often characterized as highly proactive and quick to intervene, whereas operating room (OR) staff tend to adopt a more wait-and-see approach. From the perspective of OR personnel, ICU staff may sometimes appear to have less trust in the body's natural capacity to recover. However, this attitude is widely understood as a logical response to working in an environment where critical illness and death are part of everyday practice.

It is also noted that workflows in the operating room (OR) and in ambulance care are generally faster and more efficient than those in the ICU. In these settings, medical supplies and medications are typically located in close proximity, making it easier to maintain a fast, efficient, and structured way of working. In contrast, ICU personnel often need to move across large parts of the unit to obtain necessary supplies, which inherently slows the workflow. Although medical protocols must be followed in all hospital departments, adherence to protocols is described as being particularly strict in the ICU. Each step of treatment is carefully discussed, verified, and checked against established guidelines before action is taken. As a result, even though ICU healthcare professionals may feel a strong urgency to intervene quickly, the intervention process itself often takes more time due to the complexity of care and the need for thorough verification.

It is often stated that, in both the OR and the ICU, hierarchical distinctions between

Figure 16 – Impressions of the ICU, ER, OR, and Ambulance. (Image sources: Werken bij UMC Utrecht, LinkedIn LUMC Leiden, UMC Utrecht, and LUMC)

doctors, nurses, and assistants are less clearly apparent than in other hospital departments. Although physicians ultimately carry formal responsibility for patient outcomes, nurses and assistants are the professionals who maintain continuous bedside presence. They administer medication, closely monitor the patient's condition, and directly observe processes of deterioration or recovery. As a result, nurses and assistants may at times possess more immediate or practical insight into a patient's condition than their supervising physicians. In many cases, physicians recognize this expertise and consult with nurses or involve them in the decision-making process. However, there are also situations in which nurses feel that their professional judgment is insufficiently acknowledged. In such instances, they may feel compelled to strongly advocate for their patients' well-being. This dynamic can contribute to a professional attitude characterized by assertiveness and perseverance, traits that are sometimes interpreted by others as rigidity or even arrogance, particularly in experienced or older ICU nurses who have been toughened by years of handling challenging situations. Across all critical care settings, efficiency and clarity are essential. There is little room for indirect communication or excessive politeness when rapid action is required. In environments where healthcare professionals frequently feel neglected, pressured or overlooked, it is understandable how certain communication styles and professional attitudes may develop.

The blind spot

Comparing the OR with the ICU revealed other results as well. An anaesthesiologist assistant who worked in the ICU during the COVID pandemic shared her observations on alarms and other sounds. In the OR, healthcare personnel remain close to the patient and the monitor for the full period during which they are responsible for that patient. This constant proximity makes it easier to be aware of the patient's status and allows more freedom to adjust alarm thresholds or silence notifications. Since the patient's condition can be visually confirmed at all times, there is less need to rely on this auditorily as well.

In contrast to the OR, where the period of responsibility typically extends only for the duration of the surgery, the period of responsibility for patients and monitoring in the ICU spans the entire shift of the staff. When healthcare professionals need supplies or medication, they must leave the patient's bedside. Stepping away from the patient or leaving the monitor at the nurse station means losing continuous visual confirmation of the patient's status. This is why auditory signals are far more important in the ICU, compared to the OR. ICU Nurses rely on auditory confirmation to maintain connection with patients who are in their blind spot (Hu et al., 2026).

Additionally, in the OR, staff usually care for one patient at a time. In the ICU, personnel often manage multiple patients simultaneously and also keep an eye on other patients under the care of their colleagues. For example, if a nurse hears an alarm from a patient whose primary nurse is attending another patient, it is common practice to quickly enter the room and glance at the monitor to quickly check the patient's status.

At the LUMC, ICU patient room doors are kept open, despite the fact that they are highly acoustically isolating and could reduce patient exposure to noise. Keeping the doors open exemplifies the ICU's culture and the necessity to minimize blind spots. Closing the doors would enlarge these blind spots and could compromise patient care. Given that patients in an acute life-threatening situation could die without immediate intervention, nurses are simply not taking risks.

4.2.2 Isolation and Connectedness

As introduced in the previous chapter, patients in the ICU are critically ill and can range from being fully unconscious to fully awake. It is often unclear what patients are capable of perceiving in their surroundings. When a patient is conscious enough to perceive, but too weak to open their eyes, they experience the environment primarily through sound. In this state, the acoustic environment becomes a key source of information, helping patients answer questions such as "Where am I?", "Am I okay?", "What's going to happen to me?", or even "Am I still alive?". Former ICU patients often describe the moment of waking up in an unfamiliar environment, being unable to recognize elements that would provide answers to these questions, as the most terrifying experience during their ICU stay (E. van Houwelingen Msc et al., 2021).

This study aimed to identify the fundamental needs of ICU patients. It is well known that many patients are unable to recall large parts of their ICU stay afterwards. Nevertheless, the comfort or discomfort patients experience in the moment has been shown to influence the recovery process. Restless patients are therefore often calmed with medication. Patients who cannot open their eyes rely heavily on auditory stimuli for orientation. When they are unsure of their surroundings, they seek reassurance in recognizable sounds to connect with the environment. An acoustic environment filled with unfamiliar noises heightens patients' sense of disorientation and uncertainty, whereas familiar sounds with clear human meaning, are essential for grounding patients in the present.

The study concluded that patients in the ICU are at high risk of experiencing isolation or alienation, particularly when the experienced soundscape is unvaried, unfamiliar, or disruptive. To help prevent these negative experiences, patients are in need of connectedness, recognition, comfort, and security, alongside appropriate stimulation and autonomy (E. van Houwelingen Msc et al., 2021) (Louwers, Pont, Van Der Heide, et al., 2024).. When designing soundscape interventions to benefit patients, it is important to address these themes. The acoustic environment should include elements that reduce patient isolation and foster a sense of connectedness. Ideally, soundscape interventions could help calm patients, potentially reducing the need for sedative medication.

As explained in earlier chapters, long-term or chronic exposure to sound (noise) can itself lead to health issues. Patients would therefore benefit from reduced overall noise exposure and a soundscape with as few disruptive elements as possible. In addition, an ICU stay can directly contribute to health complications, a phenomenon known as Post-Intensive Care Syndrome (PICS).

PICS is a collective term for a range of physical and mental health problems that can develop in patients as a result of an ICU stay. These may include physical issues, such as muscle loss or weakness; cognitive impairments, such as reduced concentration or memory; and psychological problems, including depression, anxiety, or post-traumatic stress disorder (PTSD). (Post Intensive Care Syndroom (PICS) | St. Antonius Ziekenhuis, n.d.)

Although the exact causes of PICS are not yet fully scientifically understood, it is recognized that a comfortable and calming environment can help mitigate these symptoms. Providing clear information, effective communication, and reassurance can reduce the fear and uncertainty experienced during an ICU stay. Likewise, a soundscape that minimizes unfamiliar or potentially stressful elements may play a meaningful role in limiting PICS-related symptoms.

Patients are not the only healthcare receivers at risk of developing PICS. It is recognized that family members can also experience symptoms resulting from an ICU stay, a condition labelled PICS-F, where the "F" stands for family. PICS-F can include psychological problems such as depression, anxiety, sleep disturbances, post-traumatic stress disorder (PTSD), and possibly complicated grief. Scott et al. (2019) identified anxiety and uncertainty as key factors affecting the well-being of family members of ICU patients. Family members are in need of clear information and reassurance. It was expresses that the 'not knowing' is the worst part of their ICU experience, often leading to feelings of uncertainty, anxiety and distress. In addition, they require comfort and emotional support. ICU staff aim to provide this guidance while being careful not to give unrealistic hope.

4.3 Soundscape experience

As introduced in Chapter 2, the soundscape refers to the acoustic environment as perceived or experienced by the user. In this context, it describes how the ICU's acoustic environment is experienced by different ICU user groups. The soundscape experience perspective adds not only a subjective dimension to the analysis of the ICU's acoustic environment, but also provides insight into the quality of living conditions within the ICU in terms of pleasantness and comfort, themes that also emerged during the discussion of user needs in the previous chapter.

In January 2025, qualitative interviews were conducted with ICU staff. During these interviews, participants were asked to complete a questionnaire and evaluate the acoustic environment at that moment based on their subjective experience. The aim was to gain a broader understanding of the ICU soundscape.

Method

The interviews were conducted on the ICU itself, at the central station or nearby it. ICU staff was given a tablet containing a questionnaire. Participants completed the questionnaire while simultaneously providing verbal elaboration on their experiences or giving additional examples. A total of 17 individuals participated in the interviews. They were categorized into different user groups: 5 doctors or doctors-in-training, 6 nurses, 2 ICU care assistants, and 4 non-medical staff (team leaders, logistics personnel, cleaning staff). Participants' ages ranged from 21 to 60 years, and the male/female ratio was 5/12.

Participants were asked to describe the present soundscape, as well as the sounds or sound categories they could identify. Analyzing a soundscape by describing it using descriptors is recognized as a standard measurement approach in ISO TS 12913 (1–3). Within the questionnaire, participants were therefore asked to evaluate the current soundscape using the following descriptors:

- Pleasant (Aangenaam/Prettig)
- Calm (Kalm/ Rustgevend)
- Uneventful (Rustig/ Statisch)
- Monotonous (Saai/ Eentonig)
- Annoying (Onaangenaam/ Onprettig)
- Chaotic (Chaotisch/ Hectisch)
- Eventful (Druk/ Dynamisch)
- Vibrant (Levendig/ Vrolijk)

Participants indicated the extent to which they agreed that the soundscape could be described using these descriptors on a scale from [1. Strongly disagree] to [5. Strongly agree].

Material

The online questionnaire was created using Google Forms and displayed on a Galaxy Tab S6 tablet. The software Microsoft Excel was used to analyse the responses.

Results

During the measurement, the soundscape was experienced by participants as neutral or normal. A high level of human activity was identified, such as talking and movement in the corridors. A small percentage (5.9%) reported experiencing the environment as truly calm, while no majority described the environment as rather busy (41.2%). More than half of the participants indicated that the situation was experienced as the normal course of events (52.9%).

When asked whether the acoustic environment was appropriate for the ICU, 15 /17 participants responded with "zeker/very" or "absoluut/ extremely". When asked whether the acoustic environment was appropriate for the activities taking place at that moment, 14/17 participants responded with "zeker/very" or "absoluut/ extremely". A complete overview of the responses can be found in Appendix 5.

The questionnaire responses were further analysed by user group. The data are presented in a two-dimensional representation of the soundscape description using the Circumplex Model of Soundscape Attributes (Figure 17).

The differences between the user groups are relatively limited. Doctors and nurses evaluated the soundscape generally more negatively than care assistants and non-medical staff. Non-medical staff was even relatively positive about the soundscape. A possible explanation for this is that participants from this group typically do not spend extended periods in the ICU. They are exposed to the soundscape for a shorter duration than doctors and nurses.

Participants were asked to describe which sounds they found disturbing. 5/17 participants identified conversations or chatter from others as disturbing sounds. Secondly, alarm sounds were also mentioned as disturbing by 4/17 participants. At the same time, when asked which sounds are important for performing their work effectively, participants most frequently mentioned communication (6/17) and alarms or emergency signals (9/17). In their explanations, several participants indicated that they become accustomed to the sounds over time, after which they are less noticeable. Additionally, multiple participants expressed a degree of acceptance of the sound environment, stating that it is "just necessary" or "unavoidable after all."

A provisional conclusion from this analysis is that healthcare professionals have developed an acceptance-oriented attitude toward the acoustic environment. Prolonged exposure to the sound environment appears to have led to habituation, resulting in a relatively neutral description of the soundscape in response to direct questions. However, the secondary questions reveal contradictions, indicating that the current acoustic environment does indeed involve tensions and conflicts.

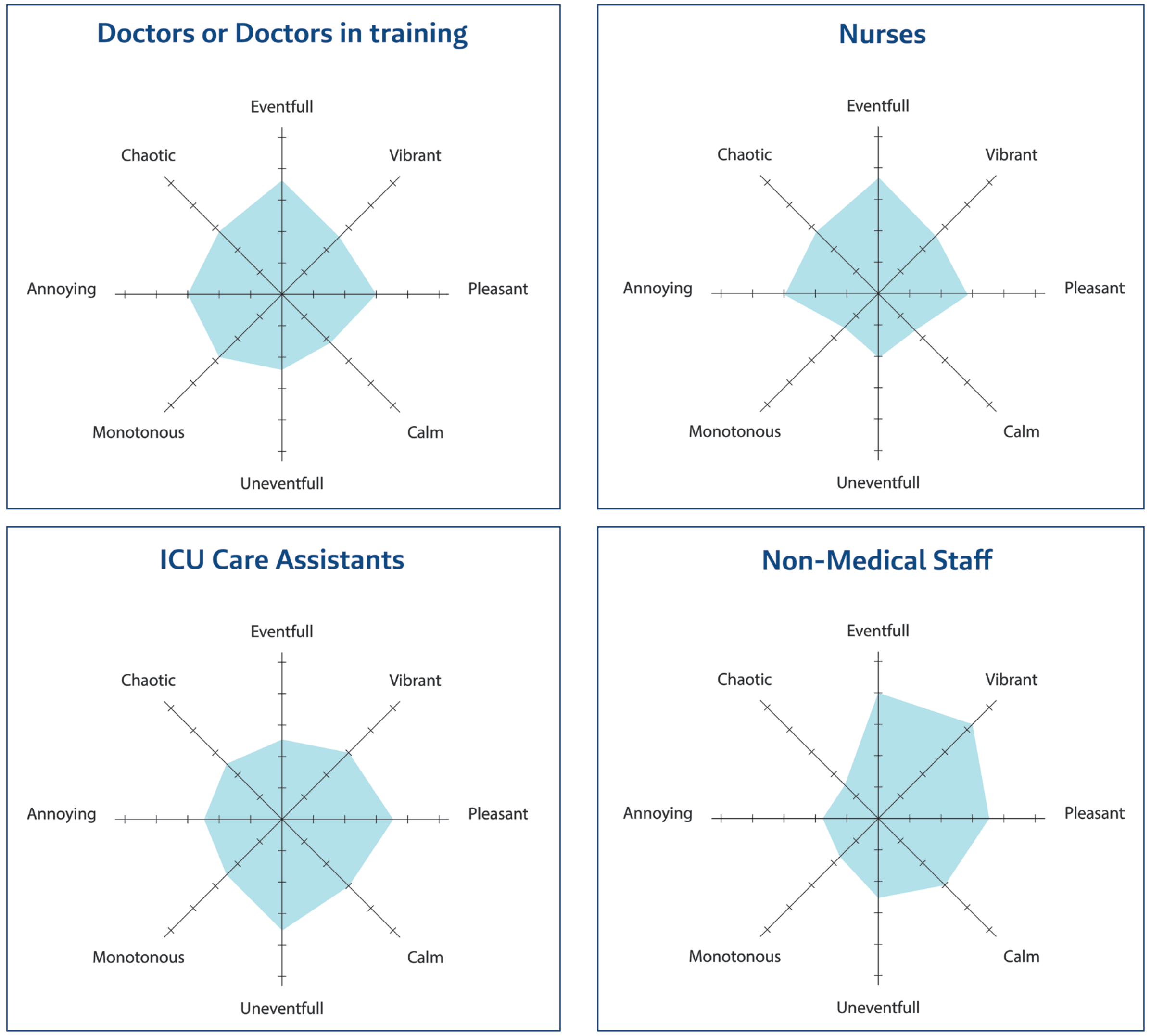

Figure 17 - ICU Soundscape experience - Circumplex model 4 user groups

5. Design Opportunities

This chapter addresses SRQ3 by conducting a problem analysis of the ICU soundscape. The main problems are identified and translated into design opportunities using the sound-driven design method

5.1 Sound-induced problems at the ICU

In the ICU, the relationships between users and sound are complex. The ICU soundscape comprises both unwanted noise and necessary or desirable elements, like informative signals, communication, and reassuring factors. While some sounds are unavoidable, others are essential and indispensable for patient care and safety. These differing roles of sound result in conflicting user needs, which calls for a consolidated approach that balances informative value, soundscape experience and user comfort and well-being. Within the ICU environment, five main sound-related issues have been identified, which are discussed in the following sections. Some of these issues involve multiple user groups, resulting in a complex user-problem structure (Figure 18).

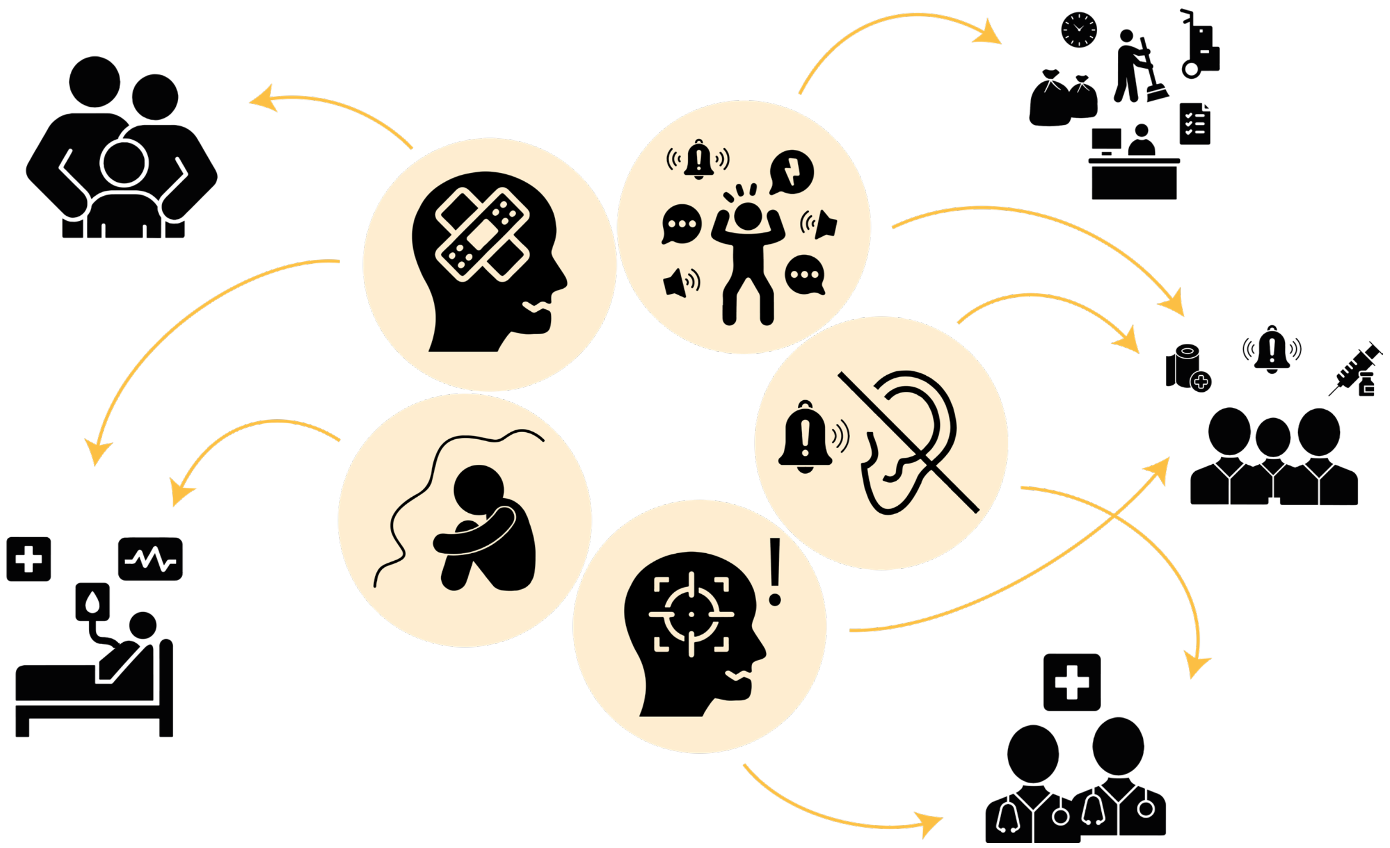

Figure 18 - Visualisation of the user–problem complex

1. Experiencing (mental) health issues

This issue is recognized by both patients and their family members. As explained in Chapter 2.2, long-term or chronic exposure to noise increases the risk of various health problems. These include physical effects such as elevated blood pressure, increased cortisol levels, cardiovascular problems, and sleep disturbances. Noise exposure is also associated with mental health effects, including annoyance, anxiety, stress, burnout-related symptoms, and PTSD. The ICU is known for its sound-rich environment, where patients frequently experience restlessness and disrupted sleep. PTSD symptoms reported by former ICU patients, partly attributed to prolonged exposure to alarms and medical signals, have become known as a serious issue.

Chapter 4.2 further describes how both patients and family members may develop symptoms of PICS or PICS-F. These conditions encompass a range of physical and psychological problems resulting from an ICU stay, including muscle loss or weakness, cognitive impairments such as reduced concentration or memory, and mental health issues such as depression, anxiety, or PTSD. Although overexposure to sound has not been proven to be a direct cause of PICS, there are notable similarities between noise-related effects and post-ICU symptoms. Consequently, soundscape interventions aimed at reducing excessive sound exposure could play a meaningful role in limiting PICS-related complaints as well.

2. Issues with orientation, isolation, and alienation

As introduced in Chapter 4.2, patients admitted to the ICU are at high risk of experiencing isolation or alienation. Each patient is unique and differs in their need for contact, activity, or rest. Consequently, it is not possible to establish a universal guideline for the ideal level of interaction or connection. However, an unvaried or unfamiliar environment can intensify feelings of isolation and may ultimately lead to alienation.

When patients struggle with orientation, sounds originating from medical machines or alarm signals, particularly within an unfamiliar soundscape, can be experienced as estranging or even frightening. This represents a sound-induced issue that is not a matter of sound quantity or frequency, but is shaped by the meaning and interpretation of sound elements. Patients have a fundamental need for familiarity, connection, and reassurance. In some cases, the soundscape plays a crucial role in fulfilling these needs. Consequently, simply removing sounds with low medical informational value does not necessarily benefit the patient, which illustrates the design challenge of accommodating multiple user needs.

3. Concentration issues

Concentration problems are commonly recognized among doctors and nurses. As discussed in Chapter 4.1, pollution of the acoustic biotope, such as continuously present ambient background noise or the unnecessary repetition of informative sounds, can lead to habituation or cognitive overstimulation. Although such sounds may become less consciously noticeable over time, the auditory system continues to register these stimuli and the brain continues to process them. This persistent processing increases mental and cognitive load, which can result in difficulties with concentration or impaired task performance.

The ICU is a stimulus-rich environment. Prolonged exposure to this level of sensory input can lead to cognitive fatigue. Healthcare professionals often recognize this effect as mental exhaustion after long shifts or as difficulty maintaining focus throughout the day, caused by the continuous processing of auditory and visual stimuli within the ICU environment.

4. Alarm fatigue

Alarm fatigue is an acknowledged phenomenon in socio-technical healthcare environments such as the OR, the ED, and the ICU. It refers to a form of cognitive fatigue that arises specifically from repeated exposure to the same type of stimulus, in this case, medical alarm signals. When an environment is saturated with alarms over extended periods or at high frequency, the brain becomes habituated to their presence, and responsiveness to these signals decreases.

In addition to concentration difficulties and general fatigue, alarm fatigue can also result from cognitive overload. Although the auditory stimuli from alarms continue to reach the brain, their processing becomes increasingly ineffective. Consequently, healthcare professionals may have prolonged response times to alarms, or may miss them entirely, with potentially serious implications for patient safety.

5. Sound masking

In a sound-rich environment with multiple overlapping auditory sources, sounds can interfere with or even overpower one another. Whether a particular sound is perceivable or masked depends on the characteristics of the individual sounds present, like sound intensity (volume) and the frequency spectrum (pitch). Louder sounds typically dominate and are therefore more easily perceived than softer ones. Sounds with distinct frequency ranges are easier to differentiate, whereas sounds sharing a similar frequency range are more likely to overlap, reducing the clarity or audibility of certain signals.

Sound masking becomes particularly problematic when important auditory cues are partially or fully drowned out by other sounds. For instance, speech can become difficult to understand despite being spoken at an adequate volume, or a patient call bell in the hallway may go unnoticed because it is masked by dominant sounds within the ICU room.

During qualitative interviews, ICU staff frequently report situations in which they either did not hear someone calling for help or felt that they themselves were not heard. In this environment, healthcare professionals rely heavily on auditory signals. Medical communication and alarm signals must remain perceptible, as masking of essential sounds can have immediate consequences for both teamwork and patient safety.

5.2 Sound-driven design

The identified sound-induced problems reflect the complexity of the ICU as a socio-technical environment, in which different users maintain distinct relationships with sound and therefore have different soundscape-related needs. Addressing these issues requires a holistic approach that considers sound as more than a mere byproduct or waste element for which reduction is the primary goal. Instead, it calls for a design perspective that recognizes sound as a multifaceted phenomenon, one that fulfils various functional, cognitive, and experiential roles and can be understood from multiple points of view.

Della Monache and colleagues (2024) introduced the TWAF framework (Designing The, With, Against sound For) as a method for designing from a multi-point-of-view perspective. By explicitly taking multiple perspectives on sound and sound-induced design problems into account, the framework enlarges the design process, allowing sound to be considered beyond a single functional or technical role. In doing so, the framework acknowledges the complexity of sound and creates room for a listener-centric approach.

The TWAF framework was used as a foundation for a multi-perspective design method, enlarging the design space and enabling the exploration and investigation of alternative design perspectives for soundscape interventions within the ICU. Expert interviews were organized, to which sound designers, design researchers, acoustic engineers and expert users were invited, each offering a different perspective on sound.

- Design THE sound.

Sound designers were asked to contribute their sonic and creative view, focusing on the aesthetic qualities of sound and the perceptual implications of listening.

- Design WITH sound.

Design researchers were asked to provide an experiential and integrative view, focusing on how sound can be combined with other design elements.

- Design AGAINST sound.

Acoustic engineers were asked to contribute their technical and mitigative view, focusing on reducing or controlling sources and systems that produce unwanted or potentially harmful sounds.

- Design sound FOR.

Expert users were asked to provide a cultural and purpose-driven view, focusing on the listening experiences of different soundscape user groups and the meanings attributed to sound within those groups.

In February 2025 multiple expert interviews and brainstorm sessions were organized. Through participatory design insights could be generated for ideation. Insights gained from the expert brainstorm sessions were used to develop different design directions addressing the conflicting needs and challenges experienced by ICU soundscape users.

Method

In total, 9 participants were interviewed, including 2 sound designers, 3 design researchers, 2 acoustic engineers and 2 expert users. Six participants were between 25-35 years old, and 3 participants were between 50-60 years old. Six participants were female and three were male.

The expert interview consisted of two parts
- Part 1. Informative presentation
- Part 2. Interview and Brainstorm session

The interviews were conducted in a one-to-one setting, with only the interviewer and the specific expert present. Data was collected manually. The interviewer noted down quotes and conclusions made by the participants, while the participants drew and wrote on the map and on blank paper themselves. All hard-copy material was checked for errors together with the participant at the end of the interview. The insights were compared and clustered by the researcher afterwards.

Material

The following equipment was used during the expert interviews:

- A laptop running a PowerPoint presentation
- A3-printed maps of the full ICU of the LUMC
- A3-printed maps of partial ICU units of the LUMC
- Empty A3 and A4 white paper
- Multicolour markers and fine-liners, 30 pieces in total.

Procedure

Prior to the interview, participants were extensively informed about the ICU environment, the ICU users, and the problem analysis. This was done through a presentation with slides, combined with interactive storytelling and drawing on an A3-printed map of the ICU unit at the LUMC. Participants were free to ask questions during the presentation and received additional information on topics of interest to them. This part had a duration between 30 min - 1 hour.

The interview itself consisted of two main questions. The interviewer asked follow-up questions based on the participants' responses:

Question 1: Based on all the information we just discussed, from your own the point of view, what are your first impressions or what is striking to you?

Question 2: Do you know ways or techniques to enhance or block sound, or maybe create a distinction between sound types being enhanced/blocked and others not?

The first question resulted in reactions regarding the ICU soundscape and environment, immediate improvement opportunities, and/or detailed reflections on the complexity of specific problem clusters.

The second question resulted in a brainstorm on design opportunities for soundscape interventions aimed at solving (part of the) pre-defined problems. This part had a duration between 30 min - 1 hour.

Results

The hard-copy results of the brainstorming sessions, along with the clustered insights, can be found in Appendix 6. These formed the foundation for the developed design directions, which are discussed in Chapter 5.3.

5.3 Design Directions

Analysing the ICU environment and its soundscape, as well as the users, their needs, and the problems they experience, has led to a deeper understanding of the relationships between users and sounds within the ICU context. The Sound-Driven Design method was subsequently used to explore and enlarge the design field from multiple points of view. By clustering the insights according to these views, five distinct design directions emerged, each addressing specific tensions and opportunities within the ICU soundscape.

As can be seen in Figure 19, each design direction was conceptually rooted in a specific TWAF view, reflecting the dominant lens through which the soundscape was approached.

Design Direction 1 is driven by *Design sound FOR.*
Design Direction 2 is driven by *Design sound FOR and Design AGAINST sound.*
Design Direction 3 is driven by *Design AGAINST sound.*
Design Direction 4 is driven by *Design WITH sound.*
Design Direction 5 is driven by *Design THE sound.*

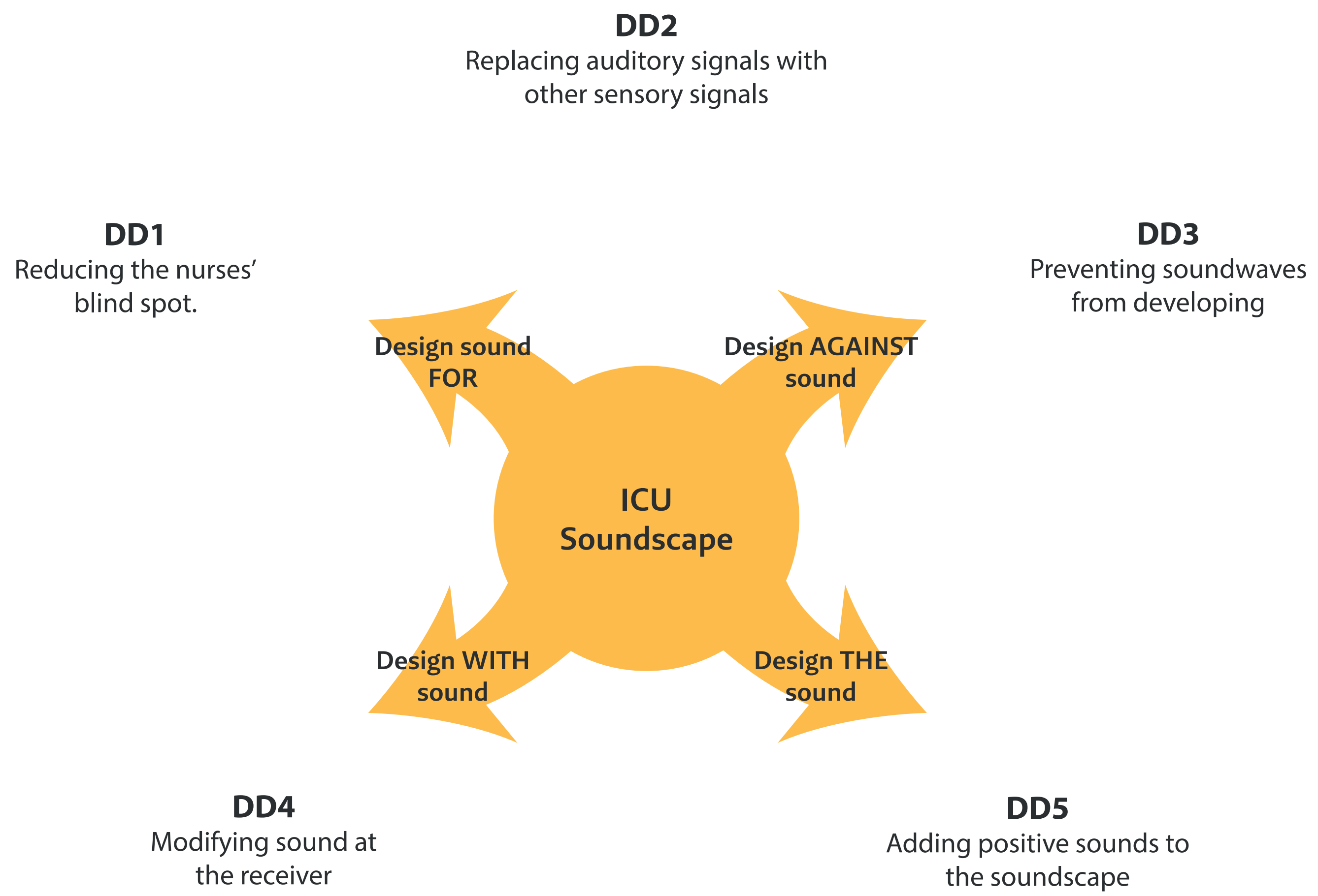

Figure 19 - Design Directions originating from the TWAF-framework

DD1: Reducing the nurses' blind spot

Healthcare providers are responsible for their patients from the moment they receive them until handover to another department. In other critical care settings, such as the OR, healthcare providers remain physically next to the patient and have continuous visual confirmation of the patient's status. In the ICU, however, healthcare providers like nurses are not always at the bedside. They may be collecting medication or supplies, or attending to another patient. As a result, ICU nurses experience a blind spot in visual confirmation while remaining responsible for the patient. It explains why ICU nurses prefer specific workflows or hold particular positions toward certain events. This blind spot may partly explain why auditory medical signals are so important, and why certain work practices, such as leaving ICU room doors open, are preferred.

Reducing this blind spot creates opportunities for chances in the workflow and create room for sound interventions that may contribute to decreasing alarm fatigue, sound masking, and concentration-related issues.

DD2: Replacing auditory signals with other sensory signals

Healthcare providers and receivers do not share the same preferences regarding sound types within the soundscape. The most conflicting sound types identified are alarm sounds and electrically amplified signals. Caregivers rely on medical signals to perform their work effectively. However, alarm sounds can act as stressors for patients and family members, or fill the soundscape with unfamiliar sounds that may contribute to feelings of anxiety or isolation.

While care professionals require alarm signals, these signals do not necessarily need to be auditory. Care receivers, in contrast, do not depend on medical signals, particularly not acoustic ones. Replacing auditory signals with signals perceived through other senses could contribute to reducing overall noise levels and help mitigate alarm fatigue and sound masking problems.

DD3: Preventing sound waves from developing

When there is little activity inside an ICU room, it was observed that external activity becomes greatly perceptible. Alarms or other sounds originating from distant parts of the unit could still be heard clearly inside individual rooms, indicating that sound can travel far within the ICU environment.

As a result, patients are exposed to medical signals from other patients, as well as to noise generated by utility equipment. Preventing sound waves from developing and reflecting throughout the ICU unit could reduce patients' exposure to unwanted sound. Potential solutions may involve integrating acoustic damping materials into the design, while ensuring that healthcare functionality and sterility requirements are not compromised.

DD4: Modifying sound at the receiver

Active Noise Control (ANC) is commonly known from its application in noise-cancelling headphones. It functions by generating anti-sound—an opposing waveform added to a specific sound, which results in phase cancellation. The closer this process occurs to the receiver (the human ear), the more effective it becomes.

This technique is less suitable for large spaces, as cancellation occurs only locally where the waveforms meet. Increased reflections from walls and other surfaces further reduce its effectiveness. Although ANC cannot be applied to an entire room, similar technologies are implemented in the automotive industry under the name Active Sound Management (Bose Automotive - Active Sound Management, 2026), where small speakers placed near the driver's head reduce engine noise and enhance the driving experience.
Within this design direction, the opportunities of active noise control for ICU patients are explored. Disturbing sounds like alarms could potentially be cancelled, while preferred sounds remain audible. Because alarm sounds typically have a distinct frequency spectrum, they may be relatively easy to recognize and target. Technologies such as machine learning could be integrated into a system capable of modifying sound locally for the patient without interfering with healthcare operations.

DD5: Adding positive sounds to the soundscape

Soundscape literature suggests that removing negative sounds does not automatically result in a positive soundscape. To create a more supportive auditory environment, positive sounds must also be introduced (Cain et al., 2013). The Critical Alarms Lab has conducted studies on this topic. Recent research has shown that a (paediatric) ICU soundscape combined with nature sounds, like birdsong or rainfall is generally perceived more positively than without (Özcan et al., 2023) (Louwers et al., 2022). In another project by AMII are AI-based technologies that monitor patients' physiological indicators (such as heart rate, blood pressure, and ECG) explored in order to assess whether a generated soundscape has a calming effect (Ayotte & Zaïane, 2021). By combining a database of environmental sounds with adaptive algorithms, it may be possible to determine whether a patient responds positively to certain auditory stimuli.

If patients can be made calmer through user-specific soundscape interventions, this may contribute to reduced use of sedatives and an overall improvement in patient comfort. Therefore, exploring natural sounds as a potential enhancement for the ICU soundscape seems promising.

6. Concept Development

This chapter addresses SRQ4 by presenting the concept selection and development process, translating insights from the analysis into the final design.

6.1 Idea selection

Each of the design directions addresses a subset of the identified sound-induced problems. The complexity of the ICU as an environment is such that it cannot be resolved through a single, isolated intervention. Figure 20 provides an overview of how the design directions relate to the problem analysis. While the individual design directions are not intended to function as holistic solutions on their own, the identified issues are also not fully separable. The problems are interconnected, and addressing one issue may generate secondary effects that contribute to mitigating others as well.

Moreover, the design directions are not mutually exclusive. The proposed idea directions can be combined in future design explorations, and multiple soundscape interventions may coexist to address ICU-wide sound-related challenges in a more holistic manner.

	(Psychological) Health issues	Isolation and desorientation	Concentration issues	Alarm fatigue	Sound masking
DD1 Reducing the nurses' blind spot.	✓	X	✓	✓	✓
DD2 Replacing auditory signals with other sensory signals	✓	X	X	✓	✓✓
DD3 Preventing soundwaves from developing	✓	X	✓✓	✓	✓✓
DD4 Modifying sound at the receiver	✓✓	✓	X	X	X
DD5 Adding positive sounds to the soundscape	✓✓	✓✓	X	X	X

Figure 20 – Mapping of design directions to the identified problems

After a thorough analysis of the various design directions, it became clear that, although each proposed intervention is promising and could contribute to potential solutions for sound management within the ICU, testing a single intervention in practice within the clinical environment is highly challenging. Limitations in time, resources, and the need to ensure patient safety make it unlikely to be realistic to fully implement and evaluate a single concept within the scope of a graduation project.

The original assignment, "*Design a consolidated soundscape intervention for the adult ICU of the LUMC to improve the soundscape experience for all users, including patients, families, and healthcare professionals*", emphasizes creating a solution that encompasses multiple user groups. An ICU-wide approach, in which multiple design directions are integrated cohesively, aligns better with this goal.

To date, no sound interventions have been implemented in the LUMC ICU, unlike other Dutch hospitals such as Erasmus MC in Rotterdam, where previous soundscape interventions have already been implemented and have resulted to improvements in the soundscape. Enabling users to understand, recognize, and communicate about the sound environment, creates an important first step toward an improved soundscape, making short-term opportunities valuable as well. An ICU-wide approach that establishes a solid foundation for future improvements is therefore more suitable for the LUMC.

Selected concept

This insight led to the proposal to develop a roadmap specifically tailored to the LUMC ICU, mapping the current sound situation and potential design interventions: a roadmap toward an improved ICU soundscape.

To enable sound-conscious decision-making, stakeholders must first develop awareness of the current acoustic environment and its effects on all user groups. Without the vocabulary to articulate what is being experienced, meaningful communication about improvements cannot take place. The roadmap should therefore incorporate a tool that facilitates the development of shared language and makes the intangible nature of sound more tangible and graspable.

6.2 Additional analysis

As introduced in Chapter 6.1, making the sound environment tangible constitutes an essential step in enabling stakeholders to make sound-conscious decisions. To render this abstract and often implicit dimension of the ICU perceptible, the data collected through the extensive analyses has been translated into a visually and systematically structured sound catalogue. This catalogue integrates both objective and subjective data, making the sound environment concrete and discussable for diverse stakeholders.

In addition to the analyses already conducted, physical measurements of acoustic parameters and an extensive experiential study were added, thereby providing a holistic dataset of the current soundscape. The analysis now integrates objective observations and quantitative measurements alongside the subjective perceptions and experiences of the various user groups. Furthermore, the influence of sound on the broader acoustic environment and the pollution of the acoustic biotope has been systematically characterized. Through these additions, the analysis provides an integrated and comprehensive representation of the current soundscape, which will be further elaborated in Chapter 6.3.

6.2.1 Sound measurements

In June 2025, sound measurements were conducted in the ICU with the aim of mapping the physical characteristics of commonly occurring sounds. These measurements enabled comparisons between the physical properties of sound and the observations and experiences described within the soundscape analysis.

Method

Sound data were collected from individual sound events with the use of specialized measurement equipment. The measurements were carried out on a Friday afternoon between 13:00 and 15:00. Sound events were identified by the researcher and isolated as much as possible. At all times, it was ensured that the privacy of patients and healthcare professionals, as well as the quality of care, was not compromised.

After isolating a sound event, two parallel real-time analysis (RTA) measurements were performed, starting simultaneously and with a maximum duration of 4 seconds. Both RTA measurements analysed the sound event in terms of sound level (dB) across the sound pitch (frequency), after which the data was processed through Fourier transformation and plotted as an amplitude spectrum/ frequency spectrum (2d-graph, sound level-frequency representation) and as a spectrogram showing the data over the four-second duration (3d-graph, time-frequency representation). No recognizable or traceable audio data were recorded or stored. It is important to note that the stored data cannot be reverse-engineered into identifiable sound, such as a waveform, thereby ensuring privacy.

In total, data was collected from 20 distinct sound events, which are included in the sound catalogue.

Materials

The following equipment was used for the sound measurements:

- An omnidirectional microphone: Dayton Audio EMM-6 precision electret condenser microphone
- An audio interface: Focusrite Scarlett Solo, including USB cable
- The software Open Sound Meter
- XLR cables

The microphone was connected to the audio interface via XLR cabling, and the audio interface was connected to the laptop. The software Open Sound Meter recognized the measurement microphone as the input device, enabling the analysis to be performed within the software environment. All measurement data were stored locally on the laptop.

The measurement setup was designed to be portable by carrying the audio interface in a backpack, from which two cables extended to the microphone and the laptop. These were carried by hand while moving through the ICU. This deliberately minimal setup was chosen to have an impression as unobtrusive as possible.

Limitations

Due to the absence of calibration equipment, the decibel values cannot be used to indicate absolute sound levels. For RTA measurements, however, this information is not required, as the relative differences in sound level across frequencies remain valid.

In all measurements, the microphone was positioned at a distance between 40–60 cm from the sound source. Differences in distance can be neglected when comparing data across different sound events. This makes it possible to compare all twenty measurements to one another on a relative real-world scale.

When recording individual sound events, it was not possible to fully isolate them from other sounds, as the measurements were conducted in a real-world setting. Background noise from air conditioning, ventilation, or acoustic reflections could therefore not be completely eliminated. Since this applied to all recordings, the measurements remain highly suitable for comparative analysis.

Figure 21 - Sound measurement set-up

Results

An overview of the complete measurement results can be found in Appendix 3. The graphs provide a clear representation of the acoustic characteristics of the identified sound events.

Sound signals, such as beeps and alarms, are characterized by peaks at specific frequencies, often accompanied by repeating peaks at the octave intervals of these frequencies (Figures 22 and 23).

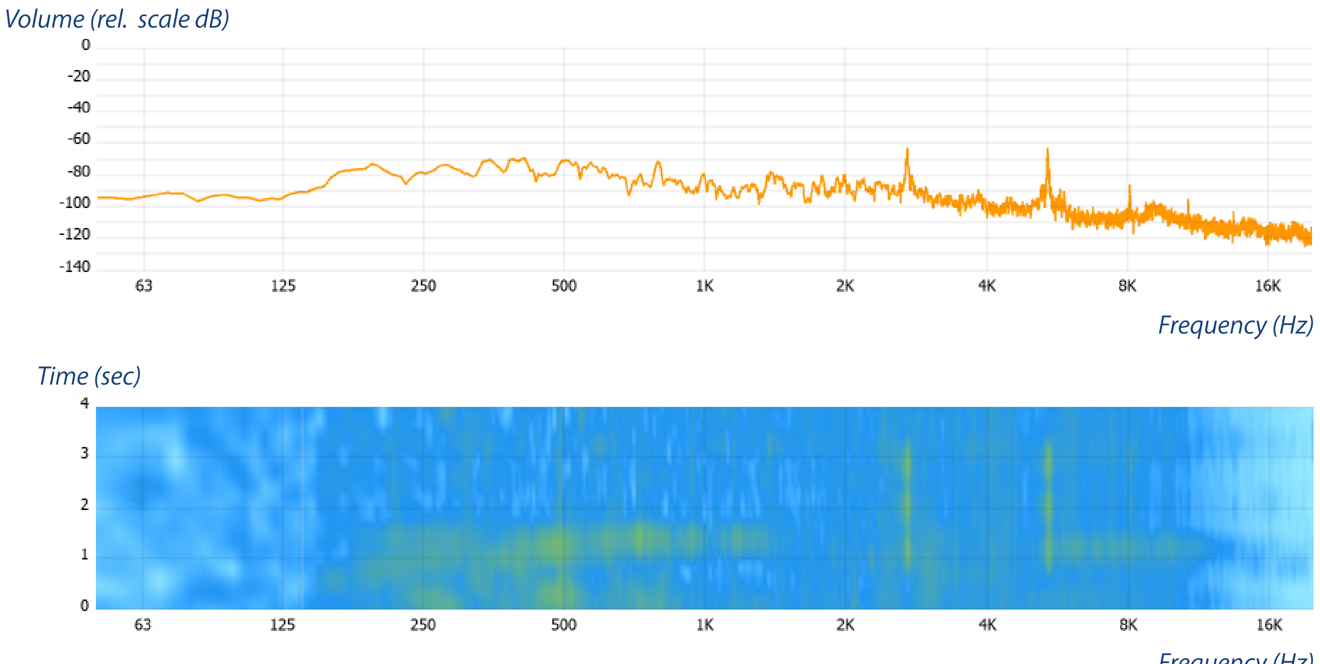

Figure 22 - RTA - Reanimation chart signal (3.11)

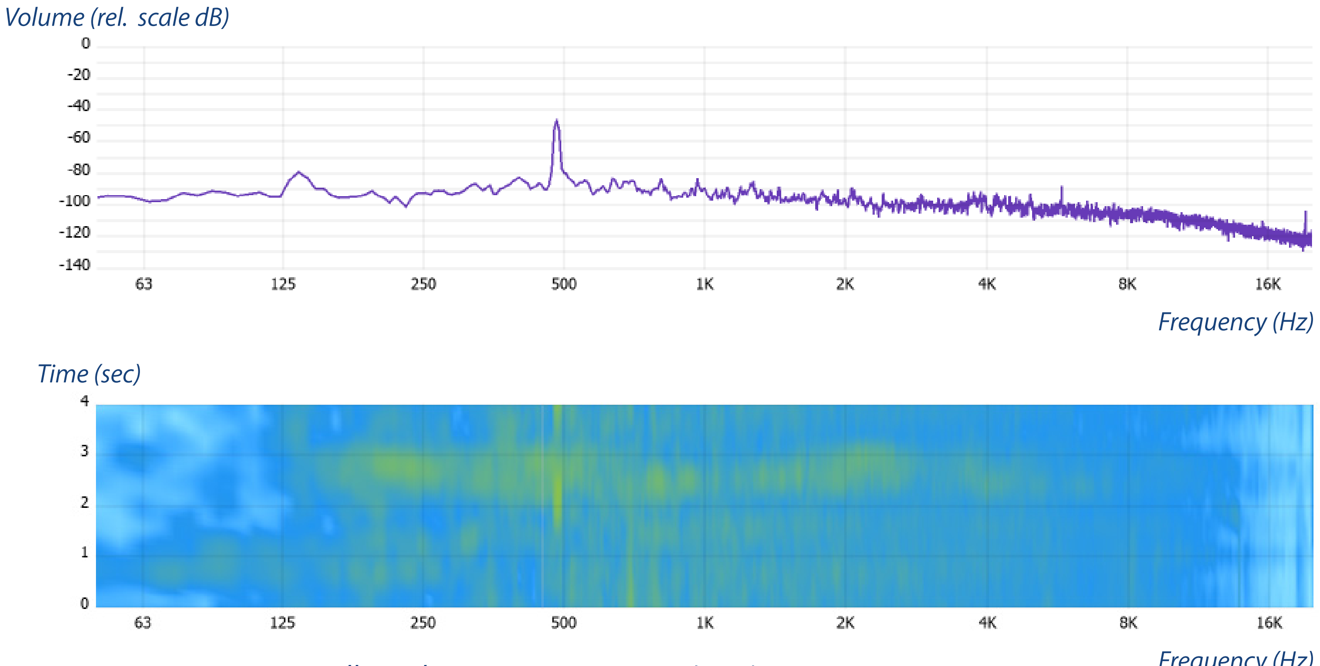

Figure 23 - RTA - Yellow alarm at nurse station (3.13)

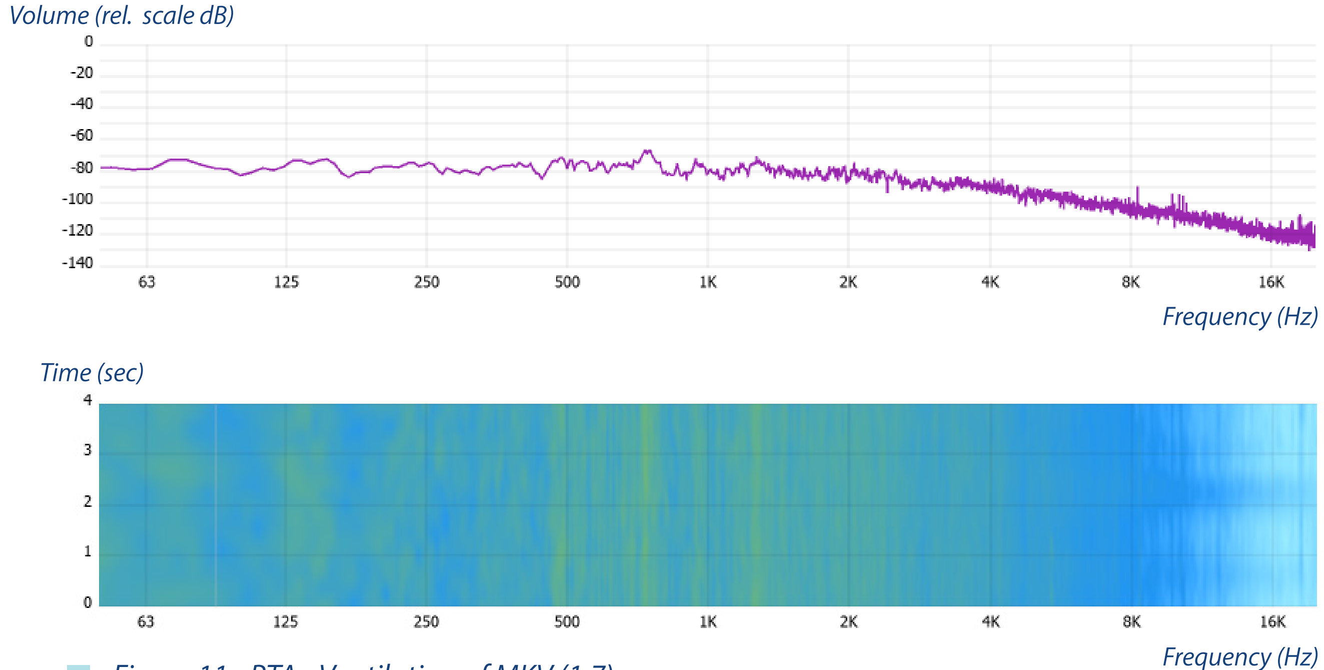

Figure 11 - RTA - Ventilation of MKV (1.7)

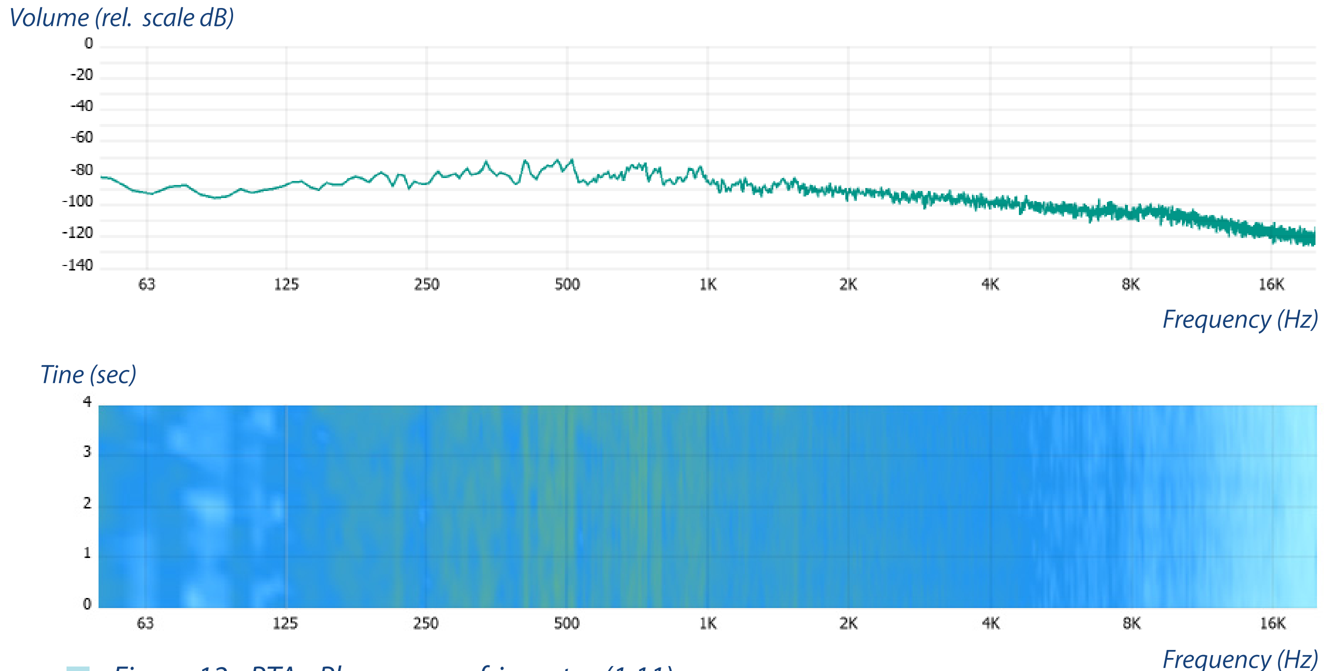

Figure 12 - RTA - Pharmacy refrigerator (1.11)

Continuous sounds, such as ventilation or the hum/whir of machines, tend to have the characteristics of noise, a broad-spectrum layer across multiple frequencies. his can be observed in sounds such as the MVK ventilation system or the steady machine hum of devices, such as the refrigerator in the pantry (Figures 24 and 25).

Sounds from incidental events or impact-generated noises appear to be the most acoustically prominent. The spectrograms clearly show the difference between the absence and presence of these sounds. The most impactful sounds are identified as: the slamming of a cupboard door in the pantry, the rustling or tearing of packaging in the pharmacy while retrieving supplies, the coffee machine producing a beverage, and the rolling of the coffee cart through the corridor (Figures 26 and 27).

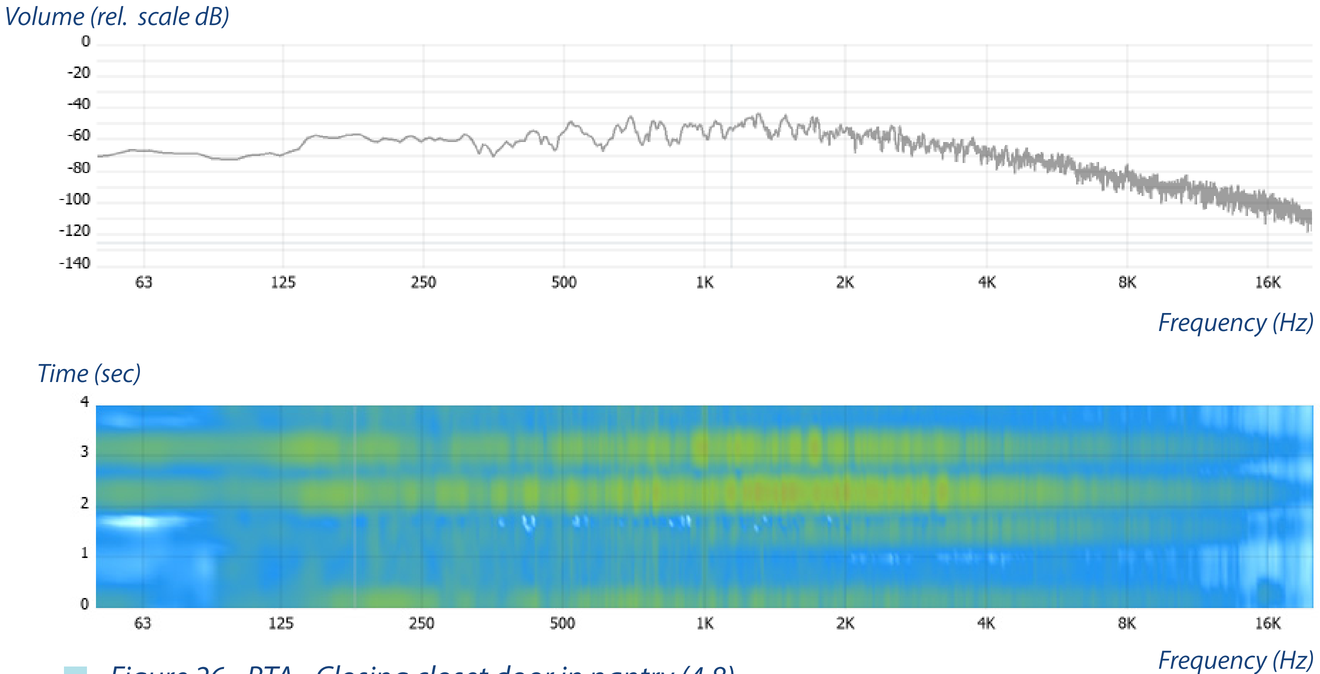

Figure 26 - RTA - Closing closet door in pantry (4.8)

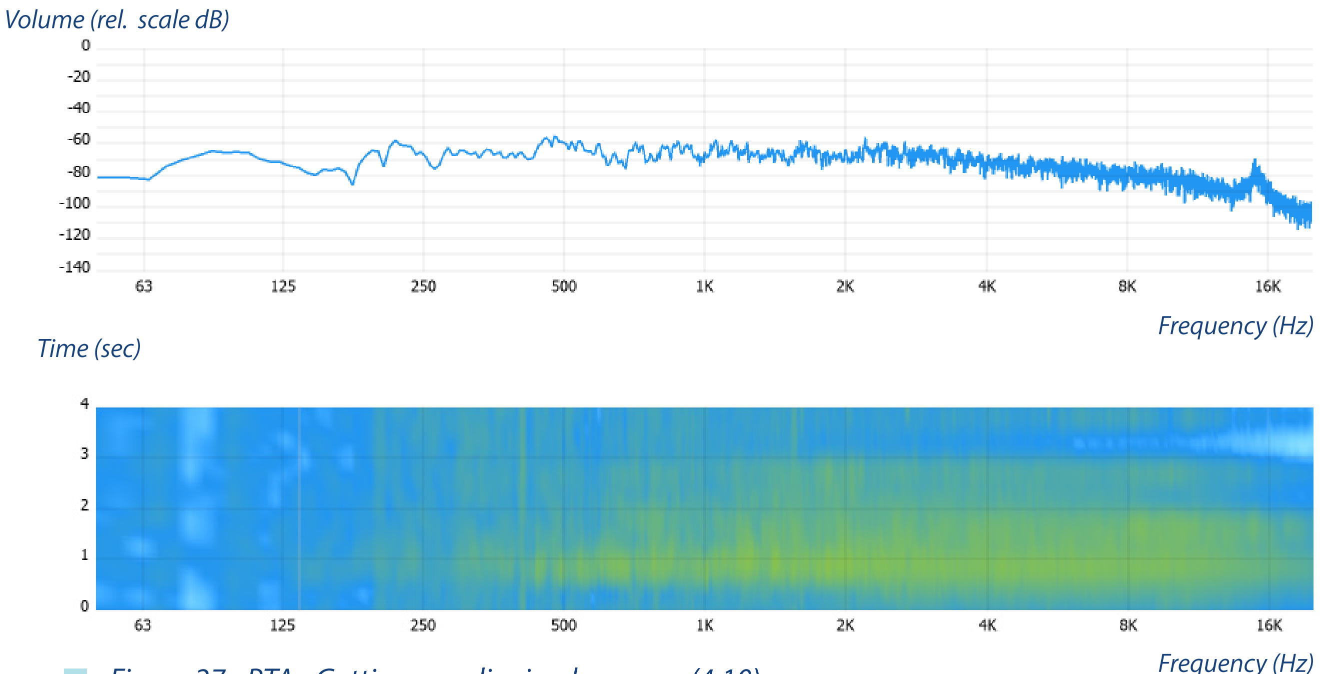

Figure 27 - RTA - Getting supplies in pharmacy (4.10)

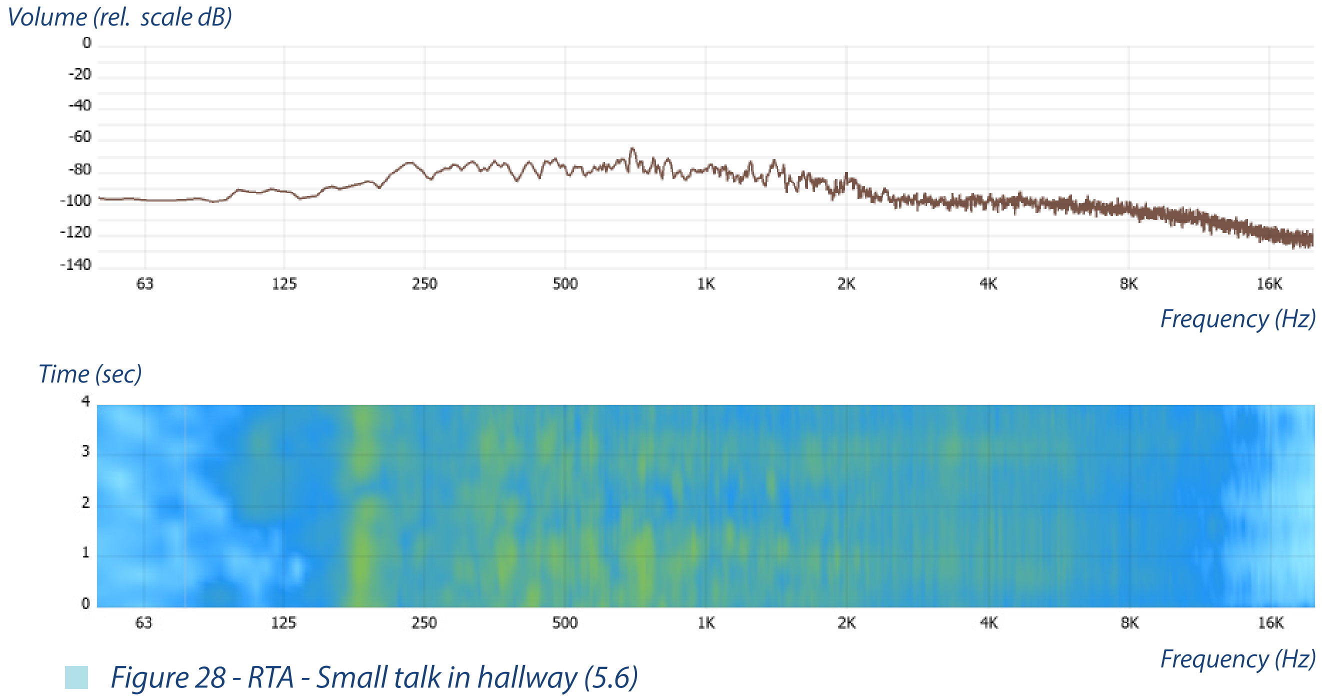

Figure 28 - RTA - Small talk in hallway (5.6)

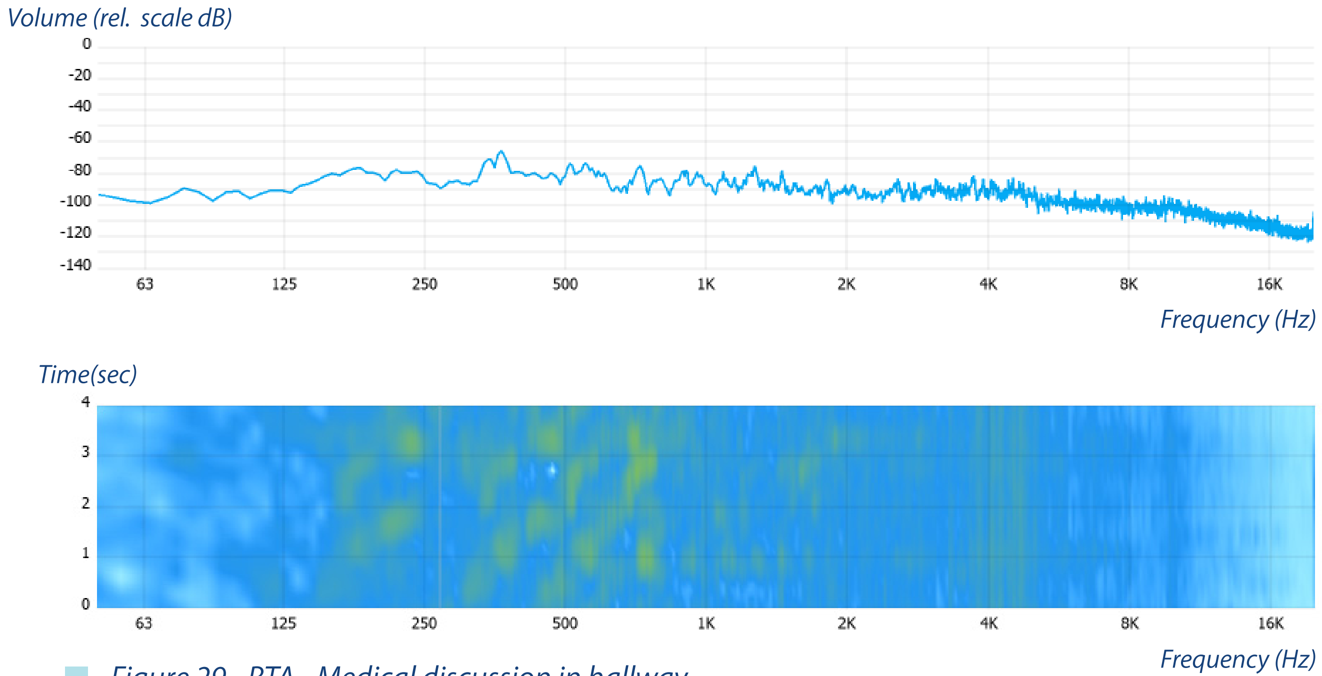

Figure 29 - RTA - Medical discussion in hallway

Sounds such as speaking, laughing, or phone conversations display a dynamically speckled spectrogram. The characters of these sounds are similar. However, the captured sound events show that medical discussions occurred at a lower volume than casual small talk between colleagues (Figures 28 and 29).

6.2.2 Soundmap

Data of 18 sound events was used to create a sound map of the ICU. A sound map is a visual representation of sound levels on a floor plan.

The sound map was produced using the software RAP-ONE II, the internal software of the company SoftdB, a global expert in acoustic comfort and the enhancement of indoor sound environments. For this analysis, a one-year license was obtained, allowing full access to the software.

The sound events were positioned on the map at the locations where the original sound events were recorded (Figure 30). The sound map represents a hypothetical scenario on a Friday afternoon around 2:00 PM. The scenario is realistic, as all these sound events actually occurred in reality. However, it is open to discussion how realistic it is for all these sounds to occur simultaneously.

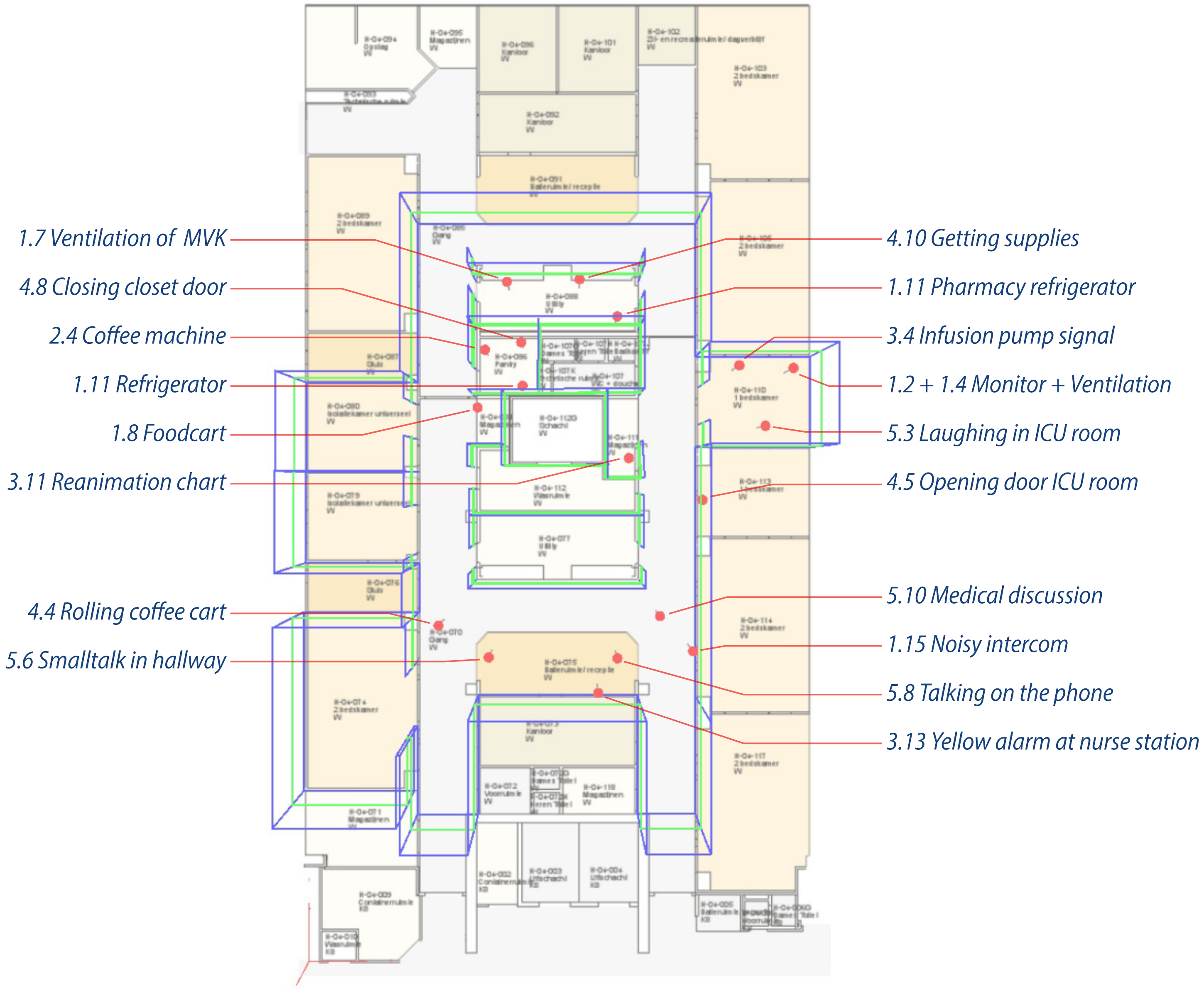

Figure 30 - Measurements for Soundmap - Sound sources and their locations

Soundmap generation results

In the sound map (Figure 31), a section of the ICU is displayed, showing how it is exposed to sound. In this scenario, several ICU patient room doors are open. The sound sources in the utility spaces, such as the pantry and the pharmacy, generate the most impactful sounds. It can be observed how these sounds develop along the hallway and even reach the ICU patient rooms. The sounds produced inside the ICU rooms themselves and at the central station are less impactful but contribute to a continuous layer of background sound throughout the ICU.

All results obtained from the sound measurements are consistent with the observations previously made in the ICU.

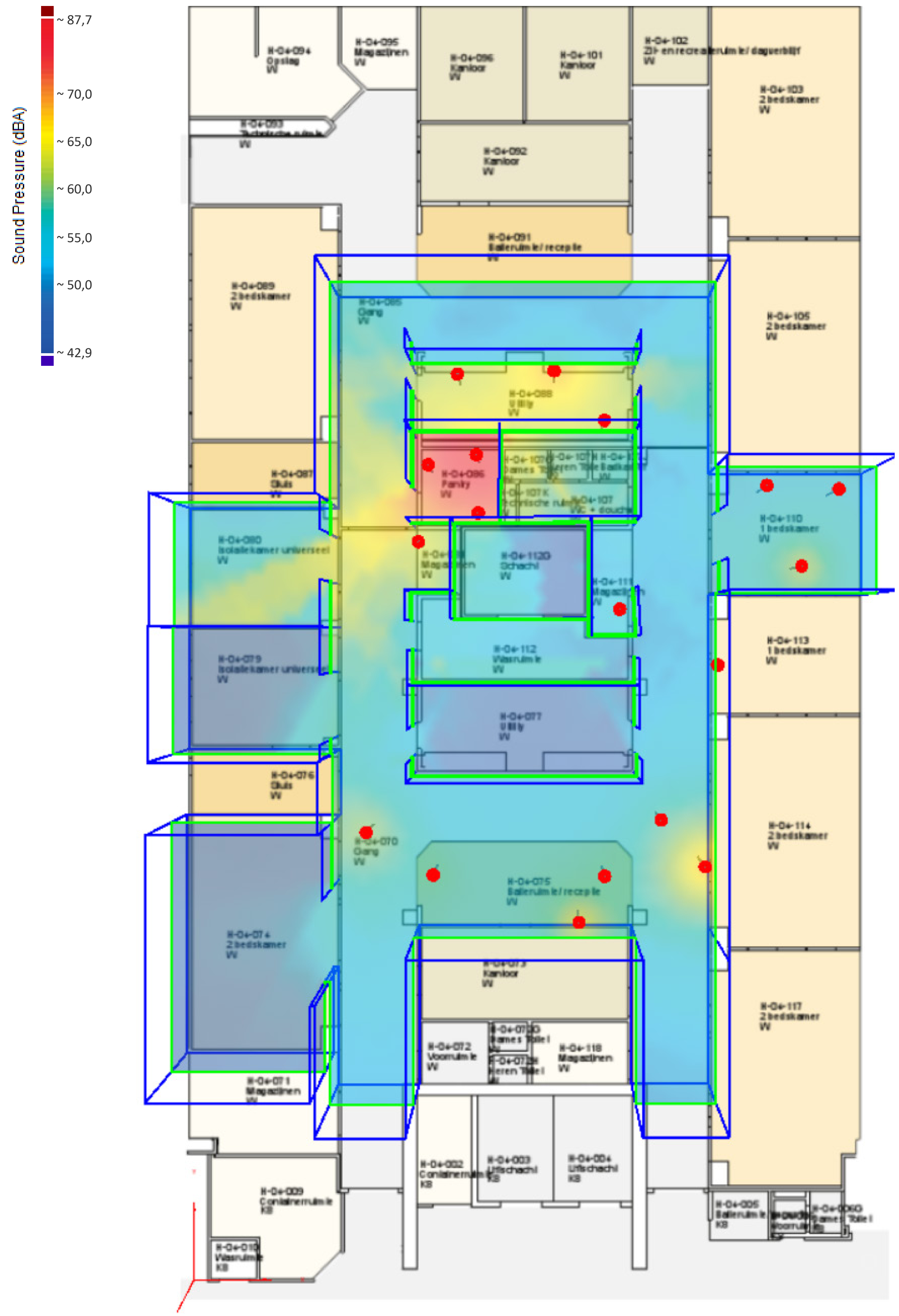

Figure 31 - Soundmap ICU - Friday afternoon 13:00-15:00, 18 sound sources

6.2.3 Experience of sounds

The sounds identified in the ICU form the basis of the sound catalogue. In a final analysis, healthcare professionals were asked to evaluate the individual sounds in order to gain deeper insight into the characteristics of an ideal ICU soundscape.

Method

The compiled list of sounds was used as the basis for a questionnaire, which was administered in printed form (see Appendix 8). For each individual sound, three multiple-choice questions were asked. Participants indicated their responses by ticking the appropriate box.

The three questions were as follows:

1. What do you think of the sound?
(Assessment of the aesthetic quality of the sound: how does the sound itself come across?)
Response options:
a. Unpleasant / Annoying
b. Neutral / Indifferent
c. Pleasant / Fine

2. How does this sound affect your work?
(Assessment of the necessity of the sound for delivering safe and effective patient care.)
Response options:
a. Disturbing / Unnecessary
b. Neutral / Indifferent
c. Necessary / Needed

3. How would a patient experience this sound?
(Estimation of how a patient might perceive this sound.)
Response options:
a. Disturbing / Unnecessary
b. Neutral / Indifferent
c. Pleasant / Wanted

The questionnaire was completed by doctors and nurses (n = 11). Participants were allowed to leave questions unanswered if they were unsure, which occurred primarily with the third question.

Materials

The sounds included in the sound catalogue were collected with the other analyses conducted in this study. A pilot study of the questionnaire indicated that improvements could be made by translating the questionnaire into Dutch. In addition, participants experienced difficulty in separating the physical and aesthetic characteristics of sounds from their functional necessity or perceived need. By addressing these aspects in separate questions, the questionnaire became easier to understand.

The questionnaires were administered in paper format and completed using a pen or fine liner. The completed forms were subsequently digitized using Excel software, which was also used to conduct the analyses.

Results

The results of the questionnaire are included in the sound catalogue, which is presented in full in Chapter 6.3.

The results show that ***Continuous mechanical sounds*** are predominantly experienced as neutral or indifferent. Sound users have little interaction with these sounds, they are not considered disturbing, but neither are they perceived as desirable.

Also in the category of ***Incidental mechanical sounds***, perceptions are most often neutral or indifferent, although not as strong as for the previous category. Within this category, there is a higher expectation that patients would perceive these sounds as disturbing.

In the category of ***Electronically amplified or generated sounds***, a clear contrast is shown. Most of these sounds are experienced as disturbing and unpleasant, while at the same time being regarded as largely necessary or needed. Medical signals occurring within ICU patient rooms are generally considered necessary, whereas non-medical signals are predominantly perceived as disturbing. Notably, opinions regarding medical signals originating from the central station or from other ICU rooms appear more divided. Compared to other medical signals, sounds from these locations are more often perceived as disturbing or unnecessary.

Human activity sounds are generally perceived as neutral by healthcare staff, although it is expected that patients would experience these sounds as more disturbing. ***Human body sounds*** are evaluated more variably within this category. Sounds that are considered less necessary are also perceived as less pleasant. ***Outdoor sounds*** the ICU are not considered necessary, but are nevertheless perceived as predominantly pleasant.

6.3 Sound Catalogue

The results of the analyses described above have been assembled into the sound catalogue, which can be accessed as an Excel file via the link or QR code provided in this chapter.

The ICU acoustic environment was examined from multiple perspectives. Sounds identifiable within the ICU are included in the sound catalogue and, where information was available, supplemented with their physical characteristics and perceptual evaluations per user group. Sounds and sound sources were identified and objectively analysed on their occurrence. Measurements of the physical acoustic environment provided insight into the nature and character of sounds within the ICU soundscape. Finally, the perception of the soundscape was analysed to assess how different user groups experience the acoustic environment. Together, these results have been integrated into a comprehensive ICU sound catalogue.

General

The first columns of the sound catalog contain general information about the identified sounds. The sounds are categorized into the following main groups:

1. Continuous mechanical sounds
2. Incidental mechanical sounds
3. Electric amplified/ generated sound
4. Human activity sounds
5. Human body sounds
6. Outdoor sounds

These columns also specify the location of the sound source and provide a general description of each sound.

Measurements

The second set of columns refers to the sound measurements and the analysis of the physical characteristics of the sounds. In these columns, sounds are described using technical spectral terminology, such as bandwidth, tonality, and frequency dominance.

When a symphony of sounds is present simultaneously, some sounds may be masked while others become acoustically prominent. Within the layered structure created by overlapping sounds, the relationships between sounds are described. Sounds with a broad frequency spectrum at low sound levels are more likely to blend into background noise, whereas sounds with distinct tonal peaks may remain audible across multiple layers.

Acoustic information

Chapter 2.3 and Chapter 4.1 introduced the concept of the acoustic biotope and the acoustic biotope of the ICU. Pollution of the acoustic biotope can be mitigated by increasing the informative value of the present sounds, and/or by reducing the overall number of sounds. The third set of columns provides an indication of the informational value that the sounds in the catalogue may carry. It also specifies whether these sounds are likely to contribute to an overload of repeated information or to the introduction of false or irrelevant information.

Sound event occurence

Based on the previously described analysis of the frequency of sound events within the ICU, a categorical scale was developed. In the next column, sounds are classified according to the following categories:

1. (Almost) never present
2. Limited presence
3. Occasional present
4. Frequently present
5. Always present

Sound experience

The following columns present the results of the perceptual study discussed in Chapter 3.2. The values in these columns represent the percentage of responses given for each specific answer relative to the total number of responses.

The sound catalogue is included in Appendix 9 and can be explored in detail via link or the QR code provided on this page.

Or click HERE

6.3.1. Conclusion

The sound catalogue consolidates all collected knowledge, making the relationships between the physical properties of sounds and their role within the soundscape clear. Many of the revealed associations are unlikely to be surprising. The information in the sound catalogue largely aligns with the experiences initially perceived by listeners in the ICU. Nevertheless, there is often a lack of knowledge and vocabulary to adequately describe what is being experienced and what causes these perceptions. This chapter therefore not only provides the foundation for a roadmap towards an improved soundscape, but also represents the first step in understanding and articulating the experiences of the sound environment.

The relationships highlighted in the sound catalogue are summarized into a number of main themes. In the detailed version of the sound catalogue (in the Excel sheet), the various tabs reference these conclusions.

Continuous background sounds

A clear pattern is visible for continuous sounds with a broadband or tonal-over-broadband character, which contribute to a continuous layer of background noise. These sounds have minimal informative value and are always present. In terms of both aesthetic value and necessity, these sounds are perceived as neutral. Users do not care much about them, and minimizing them would not disadvantage anyone. However, through their contribution to background noise, they may add to the pollution of the acoustic biotope, meaning that reducing them could benefit the sound environment

[See sounds 1.1 t/m 1.14]

High informative value

A distinct pattern is also seen in electronic signals with medium or high informative value, particularly alarms and other medical sound signals. These sounds often consist of a single pitch in a higher frequency range, which is not overshadowed by other sounds. This gives them a penetrating and easily identifiable character. These sounds are perceived as both highly necessary and highly disturbing. If unnecessary repetition or false activation occurs, they contribute to acoustic biotope pollution. Due to their high informative value, such pollution has an immediate impact on the acoustic biotope, which likely contributes to the negative perception of these sounds.

[See sounds 3.1 t/m 3.6 en 3.10 t/m 3.18]

Impactful sounds

In the categories Incidental mechanical sounds and Human activity sounds, several sounds are described as impactful and loud, with a broadband or tonal-over-broadband character. These sounds are perceived as neutral in terms of aesthetic value and necessity, but patients are estimated to experience them predominantly negatively. The soundmap (Chapter 2) shows how some of these impactful sounds strongly affect the acoustic environment and reach patients at high volume. Their informative value is minimal, and due to their volume and reach, they can mask other (more informative) sounds, creating acoustic pollution. Limiting these sounds (in volume) would not only improve the experience of the environment, but also reduce acoustic biotope pollution.

[See sounds 2.1 t/m 2.4, 4.3, 4.4 en 4.7 t/m 4.10]

Communication

In the category Human body sounds, a distinction is visible between minimally informative and highly informative verbal/vocal sounds. Highly informative sounds, such as medically related communication between healthcare providers or with a patient, are perceived as relatively more necessary and pleasant than non-medical communication. While all forms of communication can be distracting to healthcare providers' concentration, medical communication is considered less disruptive than colleagues' casual chatter. Patient experiences are expected to be most positively for patient-related communication and predominantly negatively for non-medical communication.

Qualitative interviews confirm this pattern but also emphasize that maintaining a good working atmosphere and friendly interactions among colleagues is highly valued. According to healthcare providers, it is important to maintain a relaxed and easy-going team atmosphere, as a more depressive atmosphere can quickly take hold in the ICU. Non-medical communication such as small talk or casual chatter cannot easily be minimized without creating conflicts between these interests.

[See sounds 5.5 t/m 5.11]

Nature sounds

Natural sounds in the Outdoor sounds category, such as animal sounds or weather-related sounds, are perceived very positively by both healthcare providers and patients. However, these sounds are rarely observed on the ICU. It is plausible that an increase in such sounds could improve the acoustic experience.

Nature sounds, like birdsong or rainfall, are often used in soundscape-related studies to enhance the perception of a soundscape. Recent research has shown that a (pediatric) ICU soundscape combined with natural sounds is generally perceived more positively than without (Özcan et al., 2023). Therefore, exploring natural sounds as a potential enhancement for the ICU soundscape seems promising.

[See sounds 6.1 en 6.3]

7. Final design

This chapter presents the final design, The Roadmap to the Ideal Soundscape, and its evaluation

7.1 Roadmap

The final design of the graduation project is titled "The Roadmap Towards the Ideal Soundscape", a plan specifically tailored for the LUMC to address sound-related challenges in the ICU and to empower stakeholders to make sound-conscious decisions.

The final deliverable consists of three components. First, an analysis report that maps the current sonic environment of the ICU, analyses key relationships, and highlights areas for improvement to move towards the ideal soundscape. Second, a poster that visualizes the roadmap, including a timeline linking design opportunities to users and organizational structures. Finally, an interactive presentation for ICU physicians, aimed at co-creating the vocabulary necessary for sound-conscious decision-making and raising awareness of the sound environment.

The Roadmap poster is included in Appendix 10. The Analysis report and Roadmap poster can be explored in detail via link or the QR code provided on this page.

7.1.1 The Ideal Soundscape

Describing the ideal soundscape is more complex than simply striving for the most positive sonic experience. In the ICU's acoustic biotope, there is a shared mission or goal: "An ICU environment for the benefit of the patient". Users, their tasks, and the sounds in the environment should all serve to reach this common goal. Optimizing the acoustic biotope and making sound-conscious choices to prevent biotope pollution is an effective way to idealize the soundscape without losing sight of the roles of the sound users and the shared goal (Özcan & Edworthy, 2025).

The ideal soundscape cannot be created all at once. It will requires a combination of short- and long-term actions and plans. Sound-conscious decisions at each step will lead to improvements in the sonic environment. Collaboration with multiple stakeholders, new research, or other design initiatives will be necessary to realize these solutions. By mapping all action points, a roadmap emerges in which each partial solution can contribute to the overall solution.

The conclusion themes from the sound catalogue indicate areas where optimization of the acoustic biotope is possible. These themes form the basis for reducing pollution of the acoustic biotope and make stimulation of a pleasant soundscape experience concrete and actionable.

The action themes have been identified as follows:

1. Minimize background noise
2. Minimize biotope pollution of highly informative sounds
3. Minimize impact sounds
4. Communication guidelines
5. Introduce nature sounds

The final prodcuts can be explored in detail via link or the QR code provided above.

Or click HERE

Minimize background noise

The background noise layer is primarily caused by a number of devices and machines producing a continuous mechanical hum. In addition, reflections and reverberations of sound waves off walls, floors, and ceilings create additional residual noise, which becomes part of the background layer. This layer has low informational value but can lead to cognitive fatigue for listeners, potentially causing concentration issues or alarm fatigue. This is the type of sound that goes unnoticed until it suddenly stops. By minimizing background noise, healthcare staff are expected to feel less fatigued and maintain better concentration, likely without being able to explicitly identify the reason.
Background noise can be reduced by limiting unnecessary sounds or restricting the range of existing sounds. For example, turning off unused devices and machines, or ensuring that sounds reach only the intended receiver. Other strategies include enclosing sound zones or creating quiet zones. Thoughtful use of the Akoesta intercom system can prevent duplicate or unnecessary broadcasts.

Minimize biotope pollution of highly informative sounds

Within the ICU biotope, users will be most alert to sounds with the highest informational value, such as medical alarms and signals. Pollution with these sounds will therefore have a major impact on the efficiency and effectiveness of sound-induced actions within the acoustic biotope. These sounds also carry across the ICU and negatively affect the patient's soundscape experience. Unnecessary repetition or false activation does not contribute to achieving the shared goal. Minimizing biotope pollution from medical signals and alarms will improve both the sound environment and the working conditions, but these measures always require care and precision to maintain patient safety.

Studies are already being carried out on system improvements and alarm reduction strategies. Future applications are expected to have a positive impact on biotope pollution. Additionally, other things can be considered as well, like more targeted signalling to limit the spread of these sounds across the ICU, defining quit and sound zones, or portable/wearable devices that deliver alarm signals only to the relevant users.

Minimize impactful sounds

Impactful sounds have a polluting effect due to their volume (sound level) and reach, which can drown out other (informational) sounds. The high contrast with the rest of the sonic environment, makes them particularly impactful in the acoustic environment. In spaces designed for rest and recovery, these sounds are highly disruptive. Reducing these sounds will positively affect the patient's soundscape experience.

Acoustic damping measures can soften the impact of certain sounds. Sound-absorbing materials can be applied to doors and carts to reduce material-on-material impact noise. Loud sounds with high reach can be shielded to prevent their propagation into quieter zones.

Communication guidelines

Conversations and verbal communication are a a wide-ranging source of sound production. The informative value in the acoustic biotope depends on the topic and the participants in the conversation. Whether a conversation is necessary or desirable depends on the context and the listener's role. It is important to clearly determine when and where space and opportunity for various conversations exist without disturbing others. Establishing quiet zones could be helpful in formalizing these communication guidelines. It is crucial to accommodate all forms of communication to meet the needs of all users of the sound environment. For example, it is more effective to designate a location for low-information conversations than to simply try to reduce them.

Introduce nature sounds

"Simply removing negative sounds however, is not enough — if negative sounds are not replaced by more positive ones the soundscape can become less negative but not necessarily more positive." Cain, Jennings & Poxon (2013)

This quote is highly applicable to the ICU soundscape. The first four action themes describe how sounds can negatively affect the soundscape. However, to make the soundscape experience positive, it is important to introduce positive sounds. Adding nature sounds to the ICU soundscape has high potential to contribute to a calming acoustic environment aimed at patient rest and recovery.

7.1.2 Roadmap timeline

The poster serves as a supportive visual tool, illustrating which sound-conscious decisions can be made to establish a sound-aware ICU environment. The identified action points are categorized into short-term, mid-term, and long-term interventions.

Short-term actions are expected to be implemented without the need for involvement from stakeholders outside the ICU healthcare team. Mid-term actions require a degree of policymaking and organizational alignment. These may involve reviewing protocols, obtaining managerial approval, or making decisions that require the engagement of team leadership or hospital management, and therefore cannot be executed independently by the ICU team. As a result, these processes are expected to take more time than short-term interventions. Long-term actions, in addition to internal policymaking within the hospital environment, require engagement from stakeholders beyond the hospital setting. Developments such as product design innovations or broader management decisions at the level of the wider healthcare community are anticipated to take several years. Nevertheless, they provide a forward-looking perspective on the future development of the ICU environment.

Awareness

For the individual ICU healthcare professional, the primary focus lies in developing awareness of the sonic environment and the existing sound situation. Once individuals develop awareness of how the sound environment is structured and gain insight into how behaviour, often enacted unconsciously, may create unintended and undesirable effects within the ICU soundscape, they are better able to distinguish between desirable and undesirable soundscape elements. As individuals become familiar with the vocabulary used to describe sound situations, they are better equipped to communicate about these issues with colleagues and other stakeholders.

Mission

Once this awareness is developed, ICU team members are enabled to engage collectively in dialogue about the sound environment and to make informed, sound-conscious decisions. Shared agreements can be established regarding verbal communication, acoustically impactful actions, and other forms of biotope-polluting behaviour.

This collective awareness allows the team to recognize the acoustic biotope as an integral part of the care environment and to align sound-related practices with their shared clinical mission, fostering a deeper understanding of what all ICU users need in order to fulfil that mission effectively.

Environment

Several of the recommended interventions exceed the scope of collective team arrangements within the ICU. These involve structural adjustments, such as revising protocols to optimize task allocation in accordance with the roles within the acoustic biotope, or reconfiguring the functional layout of ICU spaces to establish clear task zones and quiet zones. Interventions at the hospital level consequently focus on enhancing the ICU environment as a system, addressing spatial and organizational conditions that shape the soundscape.

Design

The most long-term future vision for the ICU includes improvements to equipment and alarm management in medical devices. Design opportunities that require further research and development can be introduced to the ICU, tested, and evaluated. Examples include targeted sound, where alarms and signals reach only the designated receiver instead of being generally broadcasted, potentially through the use of wearable devices. Other design opportunities involve rethinking alarms as auditory signals and implementing them through alternative sensory channels, such as visual or tactile feedback. Further development of technologies as active noise control can ultimately enable targeted noise cancellation within the ICU setting, marking a significant step towards optimizing sonic hospital environments.

7.1.3 Presentation

In March 2026, the presentation at the ICU took place. During this session, the sound-related challenges were presented, along with an explanation of how the results had been obtained. The roadmap poster was introduced to the ICU physicians as a visual representation of the final design.
The presentation also created space for dialogue and reflection, inviting participants to critically engage with the findings and explore how the proposed action points could be integrated into their daily practice. In this way, the session marked the first step toward collectively translating the roadmap into concrete, sound-conscious actions within the ICU. An evaluation of the final design took place. This is discussed further in Chapter 7.2.

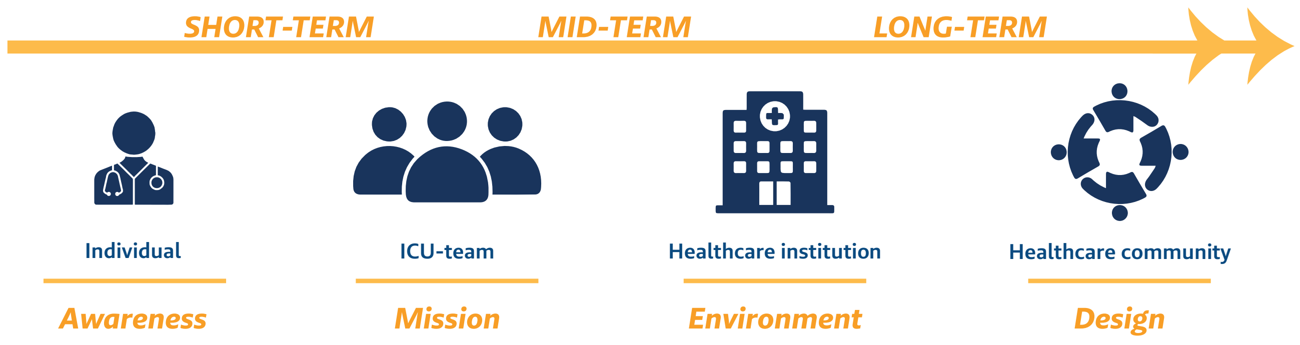

Figure 32 - Organizational structure of the Roadmap poster

7.2 Evaluation

The final design was presented to ICU physicians in March 2026. Feedback was collected from these expert users, who were able to provide a representative and critical perspective on the design. The aim of the evaluation was to assess the perceived realism and practical usefulness of the roadmap, and to identify directions for further refinement and development.

Method

The evaluation session took place at the LUMC, previous to the multidisciplinary team meeting (MDO). The combined presentation and evaluation session lasted approximately 30 minutes.

In total, 14 participants were present, with a male-to-female ratio of 6:8, all between 24-37 years of age. The group consisted of 4 researchers/students, 2 general physicians (basisarts), 2 non-resident physicians (ANIOS), 2 resident physicians (AIOS), 1 fellow ICU and 3 co-assistants. The participants' professional experience in the ICU ranged from one week to five years.

The session was structured as follows:

- General introduction (5 minutes)
- Project presentation (10–15 minutes)
- Participatory co-evaluation session (10–15 minutes)

During the project presentation, the identified ICU sound-related problems and the need for a soundscape intervention were introduced. The development of the sound catalogue was explained, including how it informed the formulation of action themes for soundscape improvement. Subsequently, the roadmap was presented per organisational level, demonstrating how the proposed design opportunities could contribute to improving the ICU sound environment.

For the co-evaluation session, participants received a printed version of the roadmap poster and three differently coloured Post-it notes. They were invited to provide written feedback directly on the Post-its and, if deemed necessary, on the poster itself.

Each colour corresponded to a specific evaluation question:

- Yellow – What is realistic?

Does the roadmap reflect or represent your experience in the ICU?
Do you consider the proposed roadmap realistic?

- Green – What are the strengths?

What aspects of the roadmap do you find valuable, helpful, or generally positive?

- Pink – What are the improvement points?

What is missing from the roadmap?
What elements could be improved?

This colour-coded structure supported the systematic categorisation of feedback.

Materials

The following materials were used during the evaluation session:

- A PowerPoint presentation
- Printed hard-copy versions of the roadmap poster
- Three differently coloured Post-it notes
- Pens and fine-liners
- Informed consent forms

Data collection

Prior to the start of the session, participants were asked to complete an informed consent form. The form included the collection of basic demographic information, including profession, gender, age, and years of professional experience.

The collected feedback data is digitalised via the software Microsoft excel and saved locally.

Results

The full results can be found in Appendix 11, where the feedback comments were categorised and labelled into general reflections, strengths, and areas for improvement. Overall, the comprehensive analysis and extensive research that informed the development of the roadmap were greatly appreciated by the participants.

Reflection and recognition
The participants' responses demonstrated a strong degree of recognition and alignment with their own experiences in the ICU. Several phenomena described in the roadmap were confirmed through personal examples, and sound-induced issues were explicitly recognised. Participants highlighted the importance of addressing these challenges and expressed that the identified problems were relevant to their daily practice. No comments were made indicating that the roadmap failed to reflect their experiences.

In addition, participants responded to specific design opportunities presented in the roadmap and provided complementary suggestions. Several discussed the possibility of implementing legislation or formal sound requirements for equipment manufacturers, encouraging the development of quieter devices or improved sound management systems. Others proposed spatial interventions, such as assigning dedicated break rooms or alternative room allocation strategies for patients to better manage sound exposure. These responses indicate openness among physicians to engage in discussions about sound-aware solutions within the ICU context.

Detailing and concrete actionabilty
Participants noted a perceived gap between the conceptual principles of the roadmap and concrete actions that healthcare professionals could implement in practice. There appears to be a need for an intermediate translation step between the designer, who formulates thematic and conceptual directions, and the expert users, who operate within detailed clinical workflows. To enable this translation, domain-specific knowledge at an operational level is required, ensuring that proposed actions are feasible, context-sensitive, and aligned with daily practice.

Such a translation process is also essential to ensure that recommendations become actionable without appearing prescriptive or patronising. This risk may be heightened when initiatives are introduced by external parties rather than by professionals within the clinical field.

Ownership and continuity
Participants emphasised the importance of assigning clear ownership to the awareness process within the ICU team. A designated individual or working group could support the initiation, maintenance, and long-term continuity of sound-related awareness efforts. This was considered particularly relevant given the frequent staff turnover within the ICU, including temporary personnel such as trainees and interns, which may pose a continuity risk. Clear responsibility is therefore needed to ensure sustained awareness over time.

To enable realistic implementation of the roadmap, clear ownership of the process is likely required to actively initiate and maintain short- and mid-term actions, while developing tailored implementation solutions suited to the ICU context.

8. Future Vision

This chapter concludes the thesis by revisiting the research questions, summarising the main findings, and presenting recommendations for future research and practice

8.1 Conclusion

In this thesis, listener-centric design methods were explored to develop a consolidated, user-centred strategy for improving the ICU soundscape. By analysing the ICU soundscape from both an environmental and user-centred perspective, the research aimed to identify sound-induced problems and translate these insights into soundscape design opportunities. To address the main research question, several sub-research questions were investigated throughout the project.

Sub-research question 1:
How can the acoustic environment of the ICU be described in terms of sound elements, systemic interactions and environmental context?

An extensive analysis was conducted to structure and describe the acoustic environment of the ICU. Through observations, sound measurements, and analyses of the spatial environment and user presence, the ICU sonic environment was mapped and categorised. The analyses revealed that the ICU acoustic environment consists of a complex combination of technological sounds, medical signals, and sounds originating from human activity or communication. These sound elements interact continuously within the clinical workflow, creating a dynamic acoustic environment that changes throughout the day depending on user activities. The analyses provided gained insight into how the dynamics of the sonic environment and the physical characteristics of the present sounds affect the acoustic environment. This formed the foundation for further analysis of sound functions and soundscape experience.

Sub-research question 2:
How do user roles within the ICU's acoustic biotope relate to sound functions, soundscape experience, and user needs?

The ICU was further examined as an acoustic biotope in which different user groups interact with sound in distinct ways. By analysing user roles, user needs and the informative value of sounds, the relationships between users and sound could be identified and described. In addition to the structural insights obtained in SRQ1, this analysis provided further insight into how the ICU soundscape is experienced by different user groups and how these experiences relate to their roles and responsibilities within the environment. his allowed the acoustic biotope of the ICU to be described and provided insight into how individual sound events can have a polluting effect within the acoustic biotope. Considering both the perspective of individual user needs and the role of sound within the collective mission of the acoustic biotope reveals a clear picture of the conflicting needs, which forms a foundation for further problem analysis.

Sub-research question 3:
What sound-induced problems and conflicts in user needs emerge within the ICU environment, and how can multiple perspectives frame the design space for soundscape interventions?

Building upon the environmental and user-centred analyses, a problem analysis was conducted to identify sound-induced issues within the ICU soundscape. This analysis revealed an interconnected user–problem complex, highlighting the complexity of the ICU as a socio-technical environment. Through expert interviews and ideation sessions guided by the multi-perspective TWAF framework, opportunities for soundscape improvement were identified and clustered into design directions. This results show that these design directions address overlapping subsets of problems and can be combined in future design explorations, reflecting the systemic complexity of the ICU soundscape.

Sub-research question 4:
How can the insights from the analysis be translated into a consolidated soundscape intervention strategy for the adult ICU of the LUMC?

The design directions identified in SRQ3 form a connected and coherent set of opportunities, particularly valuable for long-term soundscape improvement. At the same time, the LUMC ICU has not yet implemented any formal soundscape interventions, making short-term, targeted design opportunities especially valuable as well. To develop a consolidated soundscape strategy specifically tailored to the LUMC, it was necessary to integrate both short- and long-term perspectives and to provide a guide for stakeholders, enabling sound-conscious decision-making.

The final product 'The Roadmap towards the Ideal Soundscape' translates the insights from all analyses into a comprehensive sound catalogue, a visual representation of the current ICU soundscape. It presents action themes and corresponding intervention opportunities, while a timeline poster structures these interventions across organizational levels and offers guidance for future design exploration and implementation.

Addressing the research question.
How can the soundscape experience of multiple ICU user groups be improved through the development of a consolidated, listener-centric design strategy?

This research has shown that a listener-centric approach, combined with a multi-perspective analysis, proves valuable for exploring and creating knowledge of a complex sonic environment, such that of an ICU. It demonstrates that analysing and comprehending the different roles that sounds play, and the varied effects they have on all user groups, is crucial for achieving comprehensiveness in problem analysis.

The final design, The Roadmap towards the Ideal Soundscape, provides a consolidated strategy to improve the ICU soundscape. It translates the environmental and user-centred analyses into a structured overview of action themes and design opportunities, supporting all ICU user groups while considering both individual and collective needs.

Overall, the study demonstrates that a listener-centric, multi-perspective approach not only enables a thorough understanding of the ICU soundscape but also provides a tangible framework for implementing interventions that enhance the soundscape experience of all user groups.

8.2 Recommendations and Discussion

The proposed design should be regarded as a first step in a longer trajectory towards improving the soundscape quality of the ICU. The roadmap opens the way for further design initiatives and research projects that can build upon the insights generated in this study. While the roadmap illustrates a potential future journey towards an improved ICU soundscape, several recommendations can be made to support the continuation and practical implementation of this work.

1. Bridging the gap between design insights and practical implementation

A gap remains between design recommendations formulated by researchers or designers and the ability of healthcare professionals to translate these insights into concrete daily actions. ICU staff are accustomed to working in a highly structured, protocol-driven and action-oriented environment. As a result, there is a need for a translation step that converts conceptual design recommendations into clearly defined and actionable steps.

Because designers are not healthcare providers themselves, they may lack the detailed operational knowledge of daily ICU workflows that is required to develop such task-level instructions in a meaningful and non-condescending manner. The evaluation confirmed that while the roadmap and its concepts were understandable, participants expressed a need for more concrete guidance regarding what specific actions should follow. Future work could therefore focus on developing practical implementation guides or co-created action plans together with ICU staff.

2. Assigning ownership within the ICU team

As also emerged during the evaluation, continued progress will likely require an owner within the ICU team, preferably at a management or coordination level. This person or working group could be responsible for maintaining awareness among ICU staff and guiding the transition towards more sound-conscious decision-making.

The final design alone is not sufficient to initiate change autonomously. Active engagement and ownership from ICU stakeholders are required to initiate improvements and ensure continuity over time. This is particularly relevant given the relatively high turnover of staff in the ICU, including temporary personnel such as trainees and interns.

3. Periodic evaluation and monitoring of progress

The roadmap proposes intermediate goals and potential interventions; however, these are currently conceptual and have not yet been empirically tested. To assess whether improvements in soundscape quality are actually achieved, periodic evaluations or repeated soundscape analyses are recommended. Such monitoring and adjustment would make progress measurable and provide insight into which interventions are effective and which may require adjustment.

4. Inclusion of first-hand patient perspectives

Due to the importance of maintaining patient safety and privacy, this research relied primarily on expected patient experiences rather than direct patient participation. Future research could benefit from including first-hand patient perspectives on the ICU soundscape. Direct input from patients could enrich the understanding of how sound affects recovery, comfort and well-being, and may reveal additional design opportunities.

5. Knowledge exchange between hospitals

Finally, hospitals such as the LUMC could benefit from exchanging knowledge and experiences with other hospitals that are exploring soundscape quality improvements. Collaboration on a broader scale could facilitate the sharing of implementation strategies, lessons learned and design ideas. In addition, collaborative research initiatives may make it easier to organise experiments and pilot interventions that must comply with strict safety and ethical regulations, which can otherwise limit the feasibility of testing sound-related interventions in clinical environments.

References

Aletta, F., Guattari, C., Evangelisti, L., Asdrubali, F., Oberman, T., & Kang, J. (2019). Exploring the compatibility of “Method A” and “Method B” data collection protocols reported in the ISO/TS 12913-2:2018 for urban soundscape via a soundwalk. Applied Acoustics, 155, 190–203. https://doi.org/10.1016/j.apacoust.2019.05.024

Aletta, F., & Kang, J. (2020). Promoting Healthy and Supportive Acoustic Environments: Going beyond the Quietness. In MDPI eBooks. https://doi.org/10.3390/books978-3-03928-273-9

Aletta, F., Mitchell, A., Oberman, T., Kang, J., Khelil, S., Bouzir, T. a. K., Berkouk, D., Xie, H., Zhang, Y., Zhang, R., Yang, X., Li, M., Jambrošić, K., Zaninović, T., Van Den Bosch, K., Lühr, T., Orlik, N., Fitzpatrick, D., Sarampalis, A., . . . Nguyen, T. L. (2024). Soundscape descriptors in eighteen languages: Translation and validation through listening experiments. Applied Acoustics, 224, 110109. https://doi.org/10.1016/j.apacoust.2024.110109

Aletta, F., & Torresin, S. (2023). Adoption of ISO/TS 12913-2:2018 Protocols for Data Collection From Individuals in Soundscape Studies: an Overview of the Literature. Current Pollution Reports, 9(4), 710–723. https://doi.org/10.1007/s40726-023-00283-6

Axelsson, Ö., Nilsson, M. E., & Berglund, B. (2010). A principal components model of soundscape perception. The Journal of the Acoustical Society of America, 128(5), 2836–2846. https://doi.org/10.1121/1.3493436

Ayotte, B., & Zaïane, O. (2021, December 14). “AI Sound System for ICU Patients | Amii.” Alberta Machine Intelligence Institute. https://www.amii.ca/updates-insights/ai-smart-sound-anxiety-icu

Benocci, R., Afify, A., Potenza, A., Roman, H. E., & Zambon, G. (2023). Toward the definition of a Soundscape Ranking Index (SRI) in an urban park using machine learning techniques. Sensors, 23(10), 4797. https://doi.org/10.3390/s23104797

Berghman, M., & Hekkert, P. (2017). Towards a unified model of aesthetic pleasure in design. New Ideas in Psychology, 47, 136–144. https://doi.org/10.1016/j.newideapsych.2017.03.004

Bose Automotive - Active Sound Management. (2026). Bose Automotive. https://automotive.bose.com/technology-systems/active-sound-management

Bostan, I., Van Egmond, R., Gommers, D., & Özcan, E. (2024). ICU alarm management reimagined: Sound-driven design and the role of acoustic biotope. Proceedings of DRS. https://doi.org/10.21606/drs.2024.553

Cain, R., Jennings, P., & Poxon, J. (2013). The development and application of the emotional dimensions of a soundscape. Applied Acoustics, 74(2), 232–239. https://doi.org/10.1016/j.apacoust.2011.11.006

Claudio, D., Deb, S., & Diegel, E. (2021). A framework to assess alarm fatigue indicators in critical care staff. Critical Care Explorations, 3(6), e0464. https://doi.org/10.1097/cce.0000000000000464

Darbyshire, J. L., Müller-Trapet, M., Cheer, J., Fazi, F. M., & Young, J. D. (2019). Mapping sources of noise in an intensive care unit. Anaesthesia, 74(8), 1018–1025. https://doi.org/10.1111/anae.14690

Davies, W. J., Adams, M. D., Bruce, N. S., Cain, R., Carlyle, A., Cusack, P., Hall, D. A., Hume, K. I., Irwin, A., Jennings, P., Marselle, M., Plack, C. J., & Poxon, J. (2012). Perception of soundscapes: An interdisciplinary approach. Applied Acoustics, 74(2), 224–231. https://doi.org/10.1016/j.apacoust.2012.05.010

De Ulhôa Carvalho, M. L., Engel, M. S., Fazenda, B. M., & Davies, W. J. (2024). Evaluating the perceived affective qualities of urban soundscapes through audiovisual experiments. PLoS ONE, 19(9), e0306261. https://doi.org/10.1371/journal.pone.0306261

Delle Monache, S. D., Misdariis, N., Özcan, E., Hug, D., Lenzi, S., Pauletto, S., Rocchesso, D., & Spagnol, S. (2024). How do you sound design? Articulating experiences and cultures via listening. Proceedings of DRS. https://doi.org/10.21606/drs.2024.168

Delle Monache, S. D., Özcan, E., & Misdariis, N. (2024). Designing [The, with, against] sound [For]: towards a semantic-oriented coding scheme for protocol studies in sound-driven design. Proceedings of DRS. https://doi.org/10.21606/drs.2024.761

Delle Monache, S., Misdariis, N., & Özcan, E. (2022). Semantic models of sound-driven design: Designing with listening in mind. Design Studies, 83, 101134. https://doi.org/10.1016/j.destud.2022.101134

Devos, P., Aletta, F., Thomas, P., Petrovic, M., Mynsbrugge, T. V., Van De Velde, D., De Vriendt, P., & Botteldooren, D. (2019). Designing Supportive Soundscapes for Nursing Home Residents with Dementia. International Journal of Environmental Research and Public Health, 16(24), 4904. https://doi.org/10.3390/ijerph16244904

E. van Houwelingen Msc, Dr. E. Özcan Vieira, G.L.M. Louwers MSc, & Dr. J. van Bommel. (2021). Improving the daily ICU experience from a critically ill patient's perspective [Master Thesis]. Faculty of Industrial Design Engineering, Delft University of Technology. http://repository.tudelft.nl/

Engel, M. S., Fiebig, A., Pfaffenbach, C., & Fels, J. (2021). A review of the use of psychoacoustic indicators on Soundscape studies. Current Pollution Reports, 7(3), 359–378. https://doi.org/10.1007/s40726-021-00197-1

Fahy, Y. P., Tronstad, O., Waldmann, J., & Fraser, J. F. (2024). Incorporating Patient and Family Perspectives into ICU Environmental Design: A Systematic Review and Narrative Synthesis of Existing Literature. HERD Health Environments Research & Design Journal, 18(1), 194–204. https://doi.org/10.1177/19375867241302414

Four Major Differences Between ICU and ER Nurses. (n.d.). https://web.archive.org/web/20220813093834/https://www.florence.cz/casopis/archiv-florence/2021/6/four-major-differences-between-icu-and-er-nurses/

Framework of product experience. (n.d.). International Journal of Dsign. https://www.ijdesign.org/index.php/IJDesign/article/view/66

Han, Z., Kang, J., & Meng, Q. (2022). The effect of foreground and background of soundscape sequence on emotion in urban open spaces. Applied Acoustics, 199, 109039. https://doi.org/10.1016/j.apacoust.2022.109039

Health Council of the Netherlands. (1999). Public Impact of large airports. (1999/14E).

Hekkert, P. (2006). Design aesthetics: Principles of pleasure in design. In Psychology Science (Vols. 2–2, pp. 157–172). https://pure.tudelft.nl/ws/portalfiles/portal/54686438/Hekkert_P._Design_aesthetics_principles_of_pleasure_in_design.pdf

Herranz-Pascual, K., Aspuru, I., & García, I. (2010). Proposed conceptual model of environmental experience as framework to study the soundscape. https://hdl.handle.net/11556/2257

Hong, J. Y., & Jeon, J. Y. (2020). Comparing associations among sound sources, human behaviors, and soundscapes on central business and commercial streets in Seoul, Korea. Building and Environment, 186, 107327. https://doi.org/10.1016/j.buildenv.2020.107327

How to make space for vocals. (n.d.). Sage Audio. https://www.sageaudio.com/articles/how-to-make-space-for-vocals

Hu, H., Feng, T., Ge, H., Li, J., Wu, X., & Wu, X. (2026). Differential cognitive control in response to task severity during technologically-induced concurrent multitasking: The role of risk awareness in ICU nurses. Safety Science, 196, 107112. https://doi.org/10.1016/j.ssci.2026.107112

IC-Register – NVIC. (2023, November). https://www.nvic.nl/ic-register/

ICverpleegkundige.com. (n.d.). Voordelen combibaan IC en SEH verpleegkundige. Retrieved March 1, 2026, from https://www.icverpleegkundige.com/voordelen-combibaan-ic-seh-verpleegkundige/

Informatiefolder afdeling Intensive Care Volwassenen. (2025). LUMC. https://www.lumc.nl/afdelingen/intensive-care/overige-folders/intensive-care---volwassenen/

ISO 12913-1. (2014). Acoustics — Soundscape — Part 1: Definition and conceptual framework. https://www.iso.org/standard/52161.html

ISO 12913-2. (2018). Acoustics — Soundscape Part 2: Data collection and reporting requirements. https://www.iso.org/standard/75267.html

ISO 12913-3. (2025). Acoustics — Soundscape Part 3: Data analysis. https://www.iso.org/standard/86955.html

Jennings, P., & Cain, R. (2012). A framework for improving urban soundscapes. Applied Acoustics, 74(2), 293–299. https://doi.org/10.1016/j.apacoust.2011.12.003

Kang, J., & Schulte-Fortkamp, B. (2016). Soundscape and the built environment. In CRC Press eBooks. https://doi.org/10.1201/b19145

Kebapcı, A., & Güner, P. (2020). "Noise Factory": A qualitative study exploring healthcare providers' perceptions of noise in the intensive care unit. Intensive and Critical Care Nursing, 63, 102975. https://doi.org/10.1016/j.iccn.2020.102975

L. K. Kok Msc, Dr. E. Özcan Vieira, & G.L.M. Louwers MSc. (2024). Fulfilling Psychological Needs of Critically Ill Patients Through Soundscape Augmentation [Master Thesis]. Faculty of Industrial Design Engineering, Delft University of Technology. http://repository.tudelft.nl/

LANDR. (n.d.). How to mix music: An easy guide to pro Mixing | LANDR. https://www.landr.com/how-to-mix/

Leech's seven types of meaning in semantics. (2017). In International Journal of Multidisciplinary Research and Development (Vol. 4, Issue 3, pp. 71–72). https://www.allsubjectjournal.com/assets/archives/2017/vol4issue3/4-2-30-733.pdf

Lenzi, S., Spagnol, S., & Özcan, E. (2023). Improving the quality of the acoustic environment in neonatal intensive care units: a review of scientific literature and technological solutions. Frontiers in Computer Science, 5. https://doi.org/10.3389/fcomp.2023.1156693

Lercher, P., & Schulte-Fortkamp, B. (2013). Soundscape of European Cities and Landscapes – Harmonising. Final Conference of Soundscape-COST-TD0804-project. https://doi.org/10.13140/2.1.3030.1127

Louwers, G., Özcan, E., Van Bommel, J., & Pont, S. (2022). Sounds that satisfy: Describing the relationship between sound and need fulfilment. Proceedings of DRS. https://doi.org/10.21606/drs.2022.730

Louwers, G., Pont, S., Gommers, D., Van Der Heide, E., & Özcan, E. (2024). Sonic ambiances through fundamental needs: An approach on soundscape interventions for intensive care patients. The Journal of the Acoustical Society of America, 156(4), 2376–2394. https://doi.org/10.1121/10.0030470

Louwers, G., Pont, S., Van Der Heide, E., Gommers, D., & Özcan, E. (2024). Augmenting soundscapes of ICUs: a Collaborative approach. Proceedings of DRS. https://doi.org/10.21606/drs.2024.792

M. J. van Kekem, Dr. D. J. van Westerloo, Dr. L. Kervezee, & Dr. E. Özcan Vieira. (2025). Towards a Quieter ICU: Mapping Alarms and Exploring Opportunities for SpO2 Alarm Reduction. Technical Medicine Leiden University ; Delft University of Technology ; Erasmus University Rotterdam. http://repository.tudelft.nl/

Mackrill, J., Cain, R., & Jennings, P. (2013). Experiencing the hospital ward soundscape: Towards a model. Journal of Environmental Psychology, 36, 1–8. https://doi.org/10.1016/j.jenvp.2013.06.004

Mascolo, A., Rossi, D., Grimaldi, M., & Guarnaccia, C. (2024). Soundscape Indicators Assessment and Mapping in a University Campus. In Forum Acusticum 2023 (pp. 1039–1045). https://doi.org/10.61782/fa.2023.0511

Moors, A. (2017). Appraisal Theory of Emotion. In Encyclopedia of Personality and Individual Differences (pp. 1–9). https://doi.org/10.1007/978-3-319-28099-8_493-1

Nagahata, K. (2023). A trial of translation of the perceived affective quality attributes for soundscape research to Japanese. Applied Acoustics, 211, 109542. https://doi.org/10.1016/j.apacoust.2023.109542

Özcan, E., Broekmeulen, C. L. H., Luck, Z. A., Van Velzen, M., Stappers, P. J., & Edworthy, J. R. (2022). Acoustic Biotopes, Listeners and Sound-Induced Action: A case study of Operating rooms. International Journal of Environmental Research and Public Health, 19(24), 16674. https://doi.org/10.3390/ijerph192416674

Özcan, E., & Edworthy, J. (2025). Acoustic biotopes of intensive care units: How to listen and act effectively on the sounds of critical care with other listeners in mind. Journal of Critical Care, 92, 155359. https://doi.org/10.1016/j.jcrc.2025.155359

Özcan, E., Misdariis, N., & Monache, S. D. (2025). Sound-driven Design through the lens of four applications for healthcare. In AM '25: Proceedings of the 20th International Audio Mostly Conference (pp. 154–163). https://doi.org/10.1145/3771594.3771609

Özcan, E., Spagnol, S., & Gommers, D. (2024). Quieter and calmer than before: sound level measurement and experience in the intensive care unit at Erasmus Medical Center. NOISE-CON Proceedings, 270(5), 6037–6048. https://doi.org/10.3397/in_2024_3676

Ozcan, E., Van Der Stelt, B., Maljers, I., Jayaram, S., Brenes, S., Van Twist, E., & Kuiper, J. (2023). Nature sounds for the win: Influencing the Pleasantness Perception of PICU Soundscapes (pp. 5139–5146) [Forum Acusticum]. https://doi.org/10.61782/fa.2023.1163

Papadakis, N. M., Aletta, F., & Stavroulakis, G. E. (2024). Issues of translation for the ISO/TS 12913–2:2018 Attributes: Paradox of Equivalence, Non-Equivalence and suggested approaches to Construct Equivalence in Cross-Cultural soundscape research. Applied Acoustics, 225, 110163. https://doi.org/10.1016/j.apacoust.2024.110163

Post Intensive Care Syndroom (PICS) | St. Antonius Ziekenhuis. (n.d.). https://www.antoniusziekenhuis.nl/post-intensive-care-syndroom-pics

RAP-ONE Room Acoustics Simulation Software. (n.d.). [Video]. Soft dB. https://www.softdb.com/products/rapone2/

Russell, J. A., & Pratt, G. (1980). A description of the affective quality attributed to environments. Journal of Personality and Social Psychology, 38(2), 311–322. https://doi.org/10.1037/0022-3514.38.2.311

Schell, C. O., Wärnberg, M. G., Hvarfner, A., Höög, A., Baker, U., Castegren, M., & Baker, T. (2018). The global need for essential emergency and critical care. Critical Care, 22(1), 284. https://doi.org/10.1186/s13054-018-2219-2

Schulte-Fortkamp, B., Fiebig, A., Sisneros, J. A., Popper, A. N., & Fay, R. R. (2023). Soundscapes: Humans and their acoustic environment. In Springer handbook of auditory research. https://doi.org/10.1007/978-3-031-22779-0

Scott, P., Thomson, P., & Shepherd, A. (2019). Families of patients in ICU: A Scoping review of their needs and satisfaction with care. Nursing Open, 6(3), 698–712. https://doi.org/10.1002/nop2.287

Truax, B. (2001). Acoustic communication (2nd ed.). Ablex Publishing.

Van Der Stelt, B. E., & Özcan Viera, E. (2024). Understanding Soundscape Experience, a new approach [Msc Research report]. Delft University of Technology.

Van Kempen, E., Staatsen, B., Van Kamp, I., Centre for Environmental Health Research, & Environment Assessment Agency (MNP). (2005). Selection and evaluation of exposure-effect-relationships for health impact assessment in the field of noise and health (No. 630400001/2005; pp. 2–77). RIVM. https://www.rivm.nl/bibliotheek/rapporten/630400001.pdf

Verpleegafdeling Intensive Care Volwassenen | LUMC. (n.d.). https://www.lumc.nl/patientenzorg/verpleegafdelingen/ic-volwassenen/

wijzijnMEO. (2023, November 29). Wie doet wat. IC Connect. https://icconnect.nl/op-de-ic/wat-kun-je-verwachten/wie-doet-wat/

Woodland, L., Chieng, J., Fenech, B., Lavia, L., Aletta, F., Kang, J., & Mitchell, A. (2024). Development of a conceptual framework for a new international standard on non-acoustic factors. NOISE-CON Proceedings, 270(3), 8269–8276. https://doi.org/10.3397/in_2024_4068

Yu, B., Kang, J., & Ma, H. (2016). Development of indicators for the soundscape in urban shopping streets. Acta Acustica United With Acustica, 102(3), 462–473. https://doi.org/10.3813/aaa.918965

Appendix

Appendix 1 - Project Brief

DESIGN FOR our future

TU Delft

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	van der Stelt	IDE master(s)	IPD ✓ DfI SPD
Initials	B. E.	2nd non-IDE master	
Given name	Babette	Individual programme (date of approval)	
Student number	4440161	Medisign	
		HPM	

SUPERVISORY TEAM

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

Chair	Elif Özcan Vieira	dept./section	HCD/DA
mentor	Magdalena Chmarra	dept./section	HCD/AED
2nd mentor	Prof. Dr. Sesmu Arbous		
client:	LUMC / Adult ICU		
city:	Leiden	country:	the Netherlands
optional comments			

! 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 | Date | Signature

introduction (continued): space for images

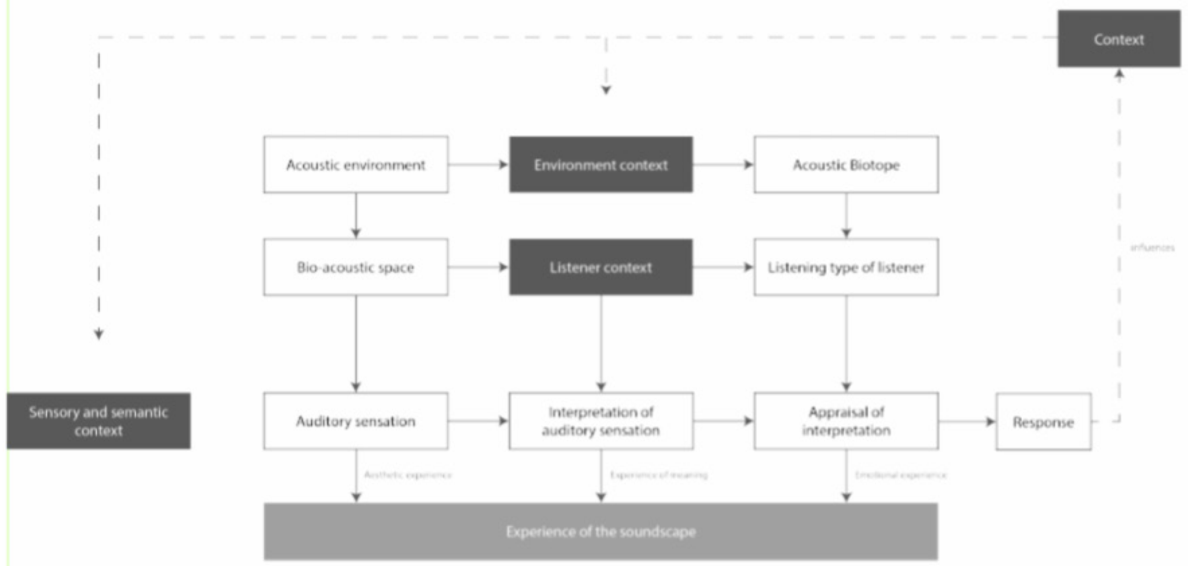

image / figure 1 Framework for Soundscape Experience - a new approach (Previous Criticial Alarms Lab research 2024)

image / figure 2 Leiden's (NL) hospital LUMC - Empty ICU room

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)

Noise pollution in healthcare and especially alarms and has been addressed before mostly through noise mitigation strategies to reduce alarms or unwanted sound events (e.g., speech) [4]. In addition, introducing new sounds in a soundscape has proven itself as a successful way to intervene in the soundscape experience and improve the shared acoustic environment such as nursing homes [5]. Soundscape design for critical care is however a different situation. In the ICU multiple sound users with different relation to the soundscape are present. The soundscape does not belong to a clear single end-user, but is shared by different listeners. To be able to improve the overall soundscape, different user / listener needs should be considered to offer a more long-term solution with a listener-centric approach. Moreover, common practices include designing new sounds or mitigating sounds. A more nuanced approach would consider other design practices as well such as sonic interaction design or participatory design. Thus, sound-driven design approach would be able to cover different design practices and methods.

[4] Özcan, Spagnol, & Gommers (2024). Quieter and calmer than before. Sound level measurement and experience in the Intensive care unit at Erasmus Medical Center. InterNoise 2024, Nantes, France.
[5] Devos, P., et al. (2019). Designing Supportive Soundscapes for Nursing Home Residents with Dementia. International Journal of Environmental Research and Public Health, 16(24), 4904. https://doi.org/10.3390/ijerph16244904

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 consolidated soundscape intervention for the adult ICU of the LUMC (Leiden) to improve the soundscape experience for the different soundscape users / listeners including patients, family and healthcare professionals.

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)

- Literature research has been done in a previous research elective. This research will be used together with state of the art research in the analysis phase towards defining the problem definition further. Using a different approach to soundscape experience determination, that will identify the different listener types present in the ICU, working forwards on earlier research done on auditory biotopes and listener roles.

- Combined with the sound-driven design approach, analysing and designing from four different angles (Designing THE sound, designing WITH sound, designing sound FOR, designing AGAINST sound) and co-creation workshops with experts in the field.

- Iterating and testing will be performed in the field, collaborating with the LUMC hospital in Leiden, NL.

- Designing an intervention or interventions by methods of sound design and recent methods of soundscape intervention, for example soundscape layering, showing improvement in the soundscape experience. The kind of intervention is to be defined after the analysis phase of the design process.

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	13 Dec 2024
Mid-term evaluation	10 Feb 2025
Green light meeting	17 Apr 2025
Graduation ceremony	19 May 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)

Through my entire career and education as an industrial designer, I've become to understand that I have little interest in projects that are executed without an underlying believe that what you're doing would actually be helpful. Instead of 'problem-frosting' projects, I have a great preference for 'problem-solving' projects. As a designer I believe that diving in and determining the exact core of the problem is the only way to design something that would actually matter.

In my master's education I've stumbled upon some projects which would not be working towards a real solution. The Critical Alarms Lab gave me the opportunity to dive into the core of the soundscape issues in the hospital environment, leaving a great opportunity for me to use my during my education developed design skills to design the solution. A problem-solving solution of which I genuinely believe that it would matter, it would really help a lot of people, and it would make a difference to the world.

Appendix 2 - Literature review Soundscape assessment

Understanding Soundscape Experience, a new approach.

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Abstract

Soundscape measurement and soundscape experience determination have been very popular topics over the last years. The current methods proposed by the ISO 12913 series have been seeing users of the same soundscape as the same listeners. In this paper a model is proposed for a new approach in soundscape experience determination, considering the role of the listener exposed to this soundscape. This approach should help designers and decision makers to make interventions in soundscapes that will be beneficial for the different listeners within the same soundscape.

Keywords: Soundscape, Soundscape experience, Acoustic Biotope, Listener types, Listening attention styles, Appraisal

1. Introduction

1.1 Soundscape definition

The concept of the soundscape and the acoustic environment used to be widely interpreted. In 2014, the International Organization for Standardization (ISO) made a standard definition. The acoustic environment is the 'sound at the receiver from all sound sources as modified by the environment' [1]. Kang and SchulteFortkamp elaborated in their book, in which several literature was combined, how the acoustic environment is shared with anyone who occupy the same indoor or outdoor space [2]. The acoustic environment could be shaped and modified by everything in that place as the sound follows its path from the sound source to the receiver, like reflections and absorptions. The acoustic environment can be instrumental measured and described by acoustics and psychoacoustics and the sounds and sound sources can be classified.

The soundscape is most described as a person's perceptual construct of the acoustic environment [2]. The soundscape is not something that can be instrumental measured. Descriptors of a soundscape will reflect meanings and experience. The soundscape is 'the acoustic environment as perceived or experienced and/or understood by a person or people, in context' [1].

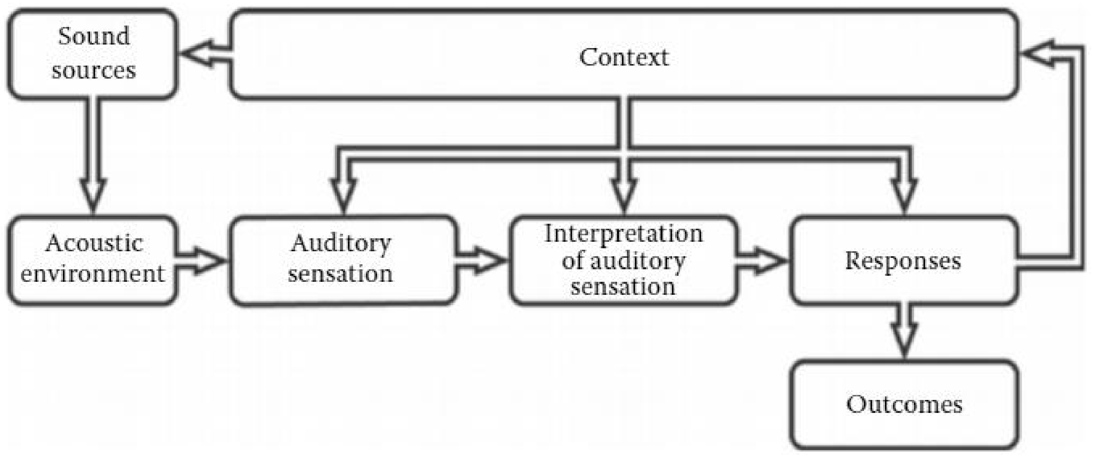


Figure 1 Schematic representation of the soundscape, according to ISO 129131:2014

Sound sources form the acoustic environment. The auditory stimuli will reach the receptors of the ear, which makes it able for the human to detect the acoustic environment. After that the cognitive processes in the mind take place to interpretate the sensed information to give meaning and understanding to it, resulting in the soundscape perception. Internal processing of this will lead to an emotional reaction, which the human can respond to. A behavioural response that can alter the context and change the soundscape [3].

The context influences the soundscape greatly. It includes all nonacoustic components that plays a role in the relationship between the person and activity and place. HerranzPascual and colleagues created a conceptual model of the elements that could be included in this context [4]. In this framework the context, as environmental experience, has been displayed in the cluster 'person', 'place', 'personplace interaction', and 'activity'. Even changing a small thing in the context, could change the environmental experience completely, making it so important to be familiar with it.

1.2 Improving the quality of life

Research about the acoustic environment or soundscapes was at first solely focussed on environmental noise management [2]. Longterm or chronic noise exposure can lead, according to multitude of research, to several health issues [5,6]. Noise exposure has its effects on sleep disturbance, activity performance and concentration. It can lead to annoyance, stress and anxiety which can lead to several somatic and psychosomatic responses, such as high blood pressure, or to cardiovascular or psychiatric disorders. Studies that focus on noise management see sound as a waste product.

Studies that focus on soundscapes see sound as a resource. This approach is focussing on sounds on preference to improve the sound quality. Interest in understanding the human perception and enjoyment of acoustic environment was growing for management of the built environment and designing spaces [2]. Conservating, protecting and creating the soundscape did not only purpose for human health, but as well for enjoyment and the overall quality of life. Research has been shifted in focus on how environmental sounds affect human health and how thee contextual factors contribute to the acoustic quality and human wellbeing [7].

1.3 Soundscape measurement

In 2018, the ISO published a report on data collection and reporting requirements [8]. The report proposed three methods for soundscape measurement, Method A and B dealing with soundscape assessment with questionnaires on site during a soundwalk and Method C being a more narrative interview method used for offsite investigations with residents already familiar with the soundscape [9] [10]. Since then, the report is still under review every five year, since a definite consensus has not been reached yet. Research has been published since then with critique on the accuracy of these methods. Results of method A and B tend to be not completely compatible, meaning an integration or iteration is needed [10,11]. Hong and Jeon underline the importance of identifying perceived sound sources to understand how they relate to the soundscape [12]. It is highlighted that finding the right set of indicators is needed to objectively describe a soundscape [1315]. New approaches are still being developed, like using VR-technique to evaluate the perceived affective qualities [16] and or to validate these in different languages through the Soundscape Attributes Translation Project [1720]. Additionally, there is still a big knowledge gap on literature focused on indoor soundscapes.

From the ISO 12913 series, Method A has been shown to be the far most adopted way of describing soundscapes or soundscape experiences [21]. This method originated from the work of Axelsson and colleagues [22] in which Russell's circumplex model [23] was the foundation for a twodimensional model constructed with 'Pleasantness' and 'Eventfulness' as orthogonal axes. This was adopted in the ISO as the Perceived Affective Qualities scale (PAQs) with two additional axes, resulting in the eight PAQ's (unpleasant, chaotic, calm, eventful, monotonous, pleasant, vibrant and uneventful) [8].

In that same study of Axelsson and colleagues [22] there was one extra descriptor named next to 'pleasantness' and 'eventfulness', which was 'familiarity'. It was acknowledged that the state of the individual plays a big role in how the soundscape was perceived, but due to lack of scientific proof how this was connected to the other descriptors, it was not implemented in the model. In 1999, Job and colleagues mentioned 'the psychscape' next to 'the enviroscape' and 'the soundscape' and highlights how the psychological state of the individual influences the individual's perception [24]. In 2013, multiple studies were done under the collaborative name of 'The Positive Soundscape Project'. Cain and colleagues focused mostly on transforming these ideas into a workable model for designers, decision makers and environment planners [25]. Linked to this study, a more explanatory paper was written about the cognitive processes happening when perceiving a soundscape. [26]. It elaborated on behaviour, information, attention and individual differences. Subjects that all influence the soundscape perception but are also poorly measurable and distinguishable in a larger group of participants. Jennings and Cain proposed a different model in 2013 that was focused on the state of the listener [27].

In their study they stated that soundscapes can be measured as the same, but can be perceived very differently by listeners, because this perception is inherently personal and is affected by what a listener, with his own experiences and preferences, brings to the situation. Although this study brought excessive attention to the listener's state and primary activity, the model itself was only theoretical on soundscape engagement and has not been mentioned again often in later studies.

1.4 Initiation and aim for this paper

In 2023, a study was done to explore how soundscape perception at the PICU in the hospital could be influenced by layering with other positive sounds [28]. During the experiment participants were asked to rate the each given soundscape on a scale of unpleasant to pleasant. What was not published is that the same participants were also asked to rate the given soundscapes on vibrancy and calmness and were interviewed to explain their thoughts.
It was expected that plotting the vibrancy and calmness data would give similar results as the plots of the pleasantness ratings. These results however could not be compared at all due to enormous differences in outcome. The outcomes were linked to participants mentioning not to fully understand the meaning and differences of the descriptors 'calmn' and 'dull' and 'vibrant' and 'chaotic', or their Dutch translations 'kalm' and 'saai' and 'levendig' and 'chaotisch'. It was concluded that the data was inusable for analytic comparison.

However, participant's reactions during the experiment themselves were interesting on a different level. Figure 2 will show some the most interesting quotes made by participants during the experiment.

Figure 2 Results of qualitative research in PICU soundscape experience determination

Some of these quotes give a clear picture on why the participant rated a soundscape a specific way. The individual differences, personal preferences, mental and physical state, or job and primary activity was of more influence to the soundscapeperception, than the initial experiment could measure using the descriptors of the soundscape.

Woman, age 5060	"I like to listen to classical music, so for me, these will be rated best immediately"
Woman, age 1825	"I can imagine how the music could be helpful. But I don't like this specific music. So, I will not rate it pleasant.'
Man, age 2530	"The forest sound reminds me of camping. I associate this with the sound of rain falling on a tent, which is a sound I sleep so good on. This calms me immediately"
Man, age 4050 (Diagnosed with brain condition)	"I must quit the experiment. The total of the layering sounds in the eventful soundscapes is too many impulses. Continuing will trigger a seizure."
Woman, age 4050	"When I'm at work at the ICU, part of me is always focused on hearing these alarms. For me the, the music sounds are obstructive, since the music tones and the alarm tones are in same frequency field. So, I hear music, but I think I hear an alarm. I am constantly triggered, therefore rating this fully unpleasant."

Specific for the ICU/PICU situation, the quote of the woman who works at the ICU herself was very interesting. Her state of mind was comparable with the nurses at the PICU, but the other participants could only imagine themselves as being a patient or a family member present there. The preference of the sounds and soundscape can be completely different for doctors, nurses and specialists, than for patients and family members in an PICU, but with the current adopted method all results will be treated the same. The validability of results using this method are therefore questionable and should be discussed.

In this paper, a new approach is explored for determining soundscape perception, while considering the primary activity of the listener and the listener's state. A model is proposed that could be valuable for designers and decision makers, working with complex spaces with soundscapes the people are exposed to have different roles and purposed being there.

2. Understanding Experience

2.1 Framework of Experience

According to Pieter Desmet and Paul Hekkert [29], the circumplex model of Russell [23] could be implemented as well in a framework for product experience, build to understand the humanproduct interaction for product design. According to the theory of this framework, the experience a human being has with a certain product is a unity of three components of experience, the aesthetic experience, the experience of meaning and the emotional experience. The aesthetic experience here is best described as the pleasure to the senses and the experience of meaning and emotion are described as faculties of the mind.

This theory is greatly overlapping with the ISO's framework build for defining the soundscape, see figure 3.

Term in ISO	**Term in PE**	Description	Experience
Acoustic Environment	Product	A phenomenon with physical properties	
Auditory sensation	Aesthetics	Sensory perception	Aesthetic Experience
Interpretation	Meaning	Cognitive processes of understanding what was sensed	Experience of Meaning
Responses	Emotion	Emotional processes of the mind resulting after processing the meaning	Emotional experience

Figure 3 Comparison between ISO terminology and the Framework of Experience theory

Combining the two theories would lead to a combined framework based on the ISO's framework, as shown in figure 4. This combination would hypothesize that in each step on the way of soundscape detection to behavioural response one third of the total soundscape experience would occur.

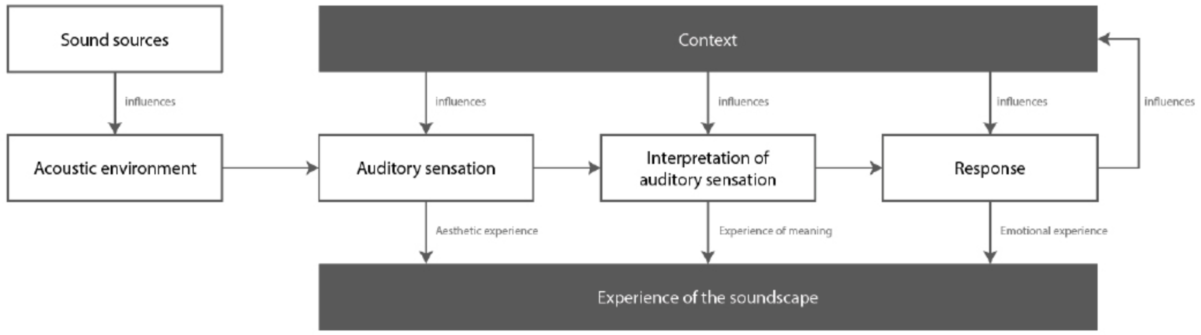


Figure 4 Combination of the ISO Framework and the Framework of Experience

In the current ISO framework, individual differences, preferences, experiences and other emotional influences are visualized to be part of the context. In this iteration, these elements are taken into account when a emotional experience is to be determined.

2.2 Aesthetic Experience

In 2006, Hekkert describes a theory in which evolutionary benefit is embedded in why human beings find things pleasurable [30]. If an aesthetic feature resulted in a better survival rate or reproduction, because it was helpful for detecting danger or finding a mate, it would have been evolved in a feature that was found collectively pleasurable. This would be applicable to all the senses of the human body. We like to look at things that supports navigation, we don't like to smell things that would be poisonous, or we like to hear things that helps to detect signals of danger or supports communication.

Hearing sound itself will play a significant part in the total aesthetic experience. Without interpreting sound and giving meaning to it, sound itself can be nice or annoying. Evolutionary benefits can be separated into 'safety' and 'accomplishment' [31].

The easier it is to be able to recognize a pattern or irregularity, that could lead to the recognition of danger, the more pleasing we tend to like those aesthetic features that provide that. A unity and typicality are what feels safe, and the higher a contrast or peak shift to that what you need to recognize, the easier it is for the senses to recognize that. An example of this can be seen in music. When mixing all the different types of instrument layers we like a perfect blend of all the instrument sounds without overlapping so hard that it makes it hard to recognize one of the other. There is unity in the variety of sounds. [32]

Next to seeking safety, our species have a need for accomplishment. To be able to find food or shelter for example, some initiative was needed to take. And for finding apotential mate for reproduction, you need to stand out and be seen. Aesthetic elements that create high contrast or isolation are found to be pleasurable. In the same example of music this can be seen in the wish to understand the lyrics well. A producer wants to create a bigger contrast in the balance with the vocals and instruments than the instruments with each other. In that way it takes less effort for a listener to recognize the lyrics and makes the song nicer to hear. [33]

The aesthetic elements of a phenomenon can be captured by the receptors of the human senses. After capturing, the mind will process this information and eventually give meaning to it. The timbre or roughness of a sound can tell the mind what type of sound it is. Direction and loudness can tell something about how big of a phenomenon or how close you are to it. And the rhythm or frequency can tell something about the activity or size of the phenomenon producing this sound. Cognitive typicality makes it easier for the brain to process. For evolutionary benefit, recognizable sounds or sound types are smoother processed and categorized and therefore more valued.

2.3 Experience of Meaning

The mental process of giving meaning to a sound, is not fully separated from the process of perception. Note that Desmet [29] also mentioned that the three types of experience are connected and depended on each other.

The human brain has different types of memory stores. The semantic memory refers to the part that holds information about meaning, understanding and other conceptbased knowledge [34]. The aesthetic features of a phenomenon can provide aesthetic experience but is also start the perception processes that will result in recognition. In the semantic memory the recognized information will be described by labels, which are called lexical representations, and will lead to identification.

Meaning attribution can be multifolded [35]. It can be objective, when in sense the label is just describing what it is. But it can also describe a feeling or emotion, on how this phenomenon is affecting the listener. Both the objective and the affective meaning are influencing the experience of meaning. Here context is important. Listeners are not very good in recognizing individual sounds, because the lexical representation can be multilinked. For example, hearing a beeping sound is probably not enough to recognize the sound source. But hearing a beeping sound in the kitchen, while also hearing the humming of the oven, will probably add enough information to recognize the sound as the timer of the oven. The context is also important for the affective meaning. Recognizing the sound of fire can easily give a feeling of warmth and coziness, but adding the context of a burning house will quickly change the affective meaning into danger and fear.

2.4 Emotional Experience

Emotions are affective phenomena evoked in people when a meaningful interaction has occurred. Emotions are functional, for they establish the position of the individual in the environment and where he will be pulled towards to or pushed away from [36,37].
The stimuli caused by a person or situation in question is either easy or difficult to control and in match or a mismatch with the individual's expectations and personal goal, as the Appraisal theory describes it [38]. It is the interpretation of thing, person or situation that causes the emotion, and not the thing, person or situation itself [29]. Although all facets of experience are intertwined, it can make sense that the emotional experience would be placed after the interpretation and experience of meaning in the framework.

This appraisal theory is greatly applicable for sound. Take for example the sound of a train coming into the station. If a person is running to be on time, he probably won't appraise the sound because of the mismatch of the goal to be on time. But if a person is expecting a loved one to arrive, he probably would appraise hearing the sound because of the match of expectation to be with his loved one soon. Another example could be if a person is in coffee bar, like Starbucks and hears people chatting cheerfully. He will appraise the sound if it matches his expectations of a fun social activity with friends, but not if the expectations were to find a quit place to study.

2.5 Reflecting on the combined framework

Looking at the ISO framework, the emotional experience is coming from the behavioural response. The representation of the response, however, could be better visualized as coming after the emotional experience. An individual is present in a certain acoustic environment and sound waves will receive the receptors of the individual's ear. This is the auditory sensation which will be part of the total experience. The cognitive processes in the individual's mind will make sure the sounds are interpretated and the individual knows its meaning. This meaning can be associated with something good or bad and will therefore be part of the total experience. Now the individual knows what the sound is, it can be a match or mismatch with his own expectations which can evoke an emotion. This is the third part of the total experience. The total of this can lead into a behavioural response, that could alter the context the individual is in.

The framework should make space between 'the interpretation' and 'the response' for 'the appraisal'. This is where the listener's state and the primary activity of the listener is considered. Since all users of the same soundscape can hear the same sound and all interpret it in the same way. There is a great chance that they won't all appraise the sound in the same way due to different primary activities, goals and expectations and thus have a different soundscape experience.

3. Listener's role

3.1 Acoustic biotopes

Özcan and colleagues did a case study in 2022 about listeners and soundinduced action [39]. In this study the role of sound in sociotechnical environments likecock pits and Operation Rooms are explored. A listenercentric approach for these complex functional environments is intended to highlight that sound is used as a tool to complete to common task in different ways by different types of listeners.

Next to concept as the acoustic environment and the soundscape, which will refer to all sounds in a specific environment that a certain species is exposed to, the concept of the acoustic biotope was introduced, which will refer to the sounds in a certain functional environment (or sociotechnical habitat) that the same certain species are exposed to. Within an acoustic biotope sounds and listeners will each play a role in a common mission. The mission or the goal can be accomplished by the soundinduced behaviour of the different actors.

3.2 Listener types

This means that within an acoustic biotope different actors are present, which will all listen differently to the sounds present and interact with them in another way. When sounds become a functional element in completing the task, the type of listening attention plays a role in this interaction. Different listener types can be identified, with their own type of listening. Truax categorisation of listener types [40] was used as a basis for identifying five different listening attention styles. Figure 5 is a representation of this new categorisation of listener types with different listening attention styles.

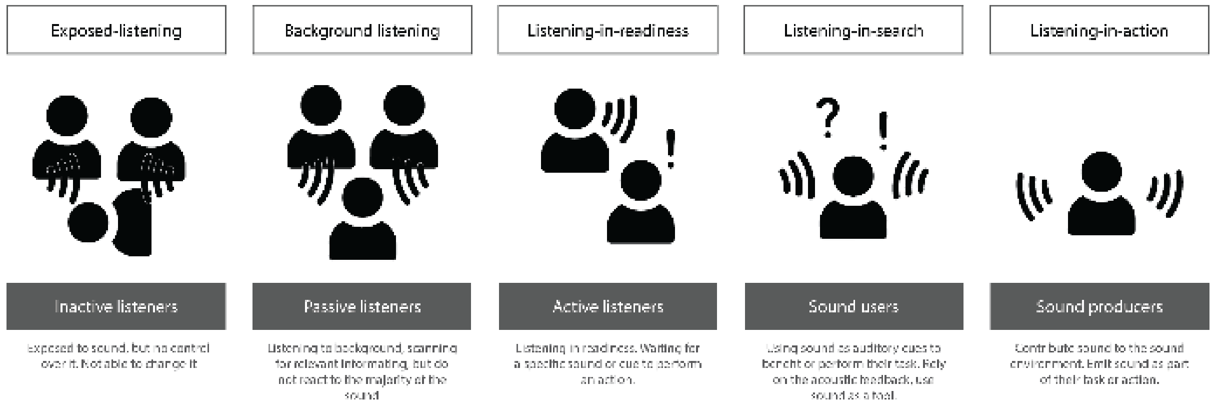


Figure 5 Categorisation of listener types

Within a certain acoustic biotope listener types can be identified in the different actors playing a role in the functional environment. An example has been shown in figure 6.

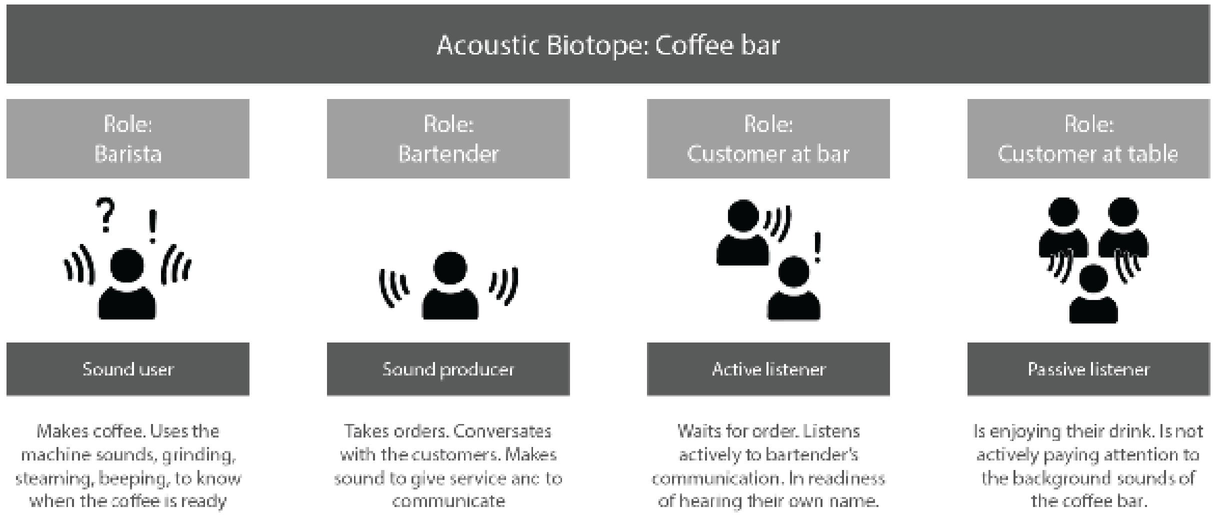


Figure 6 Example "Coffee Bar"

In the acoustic biotope of a coffee bar, the different roles will all have a different interaction with the sounds. Because of the different expectations and goals, the different listeners will appraise the present sounds differently. The steaming sound of a coffee maker will probably be appraised by the barista who uses the sound to perform his/her task and as well will be appraised by the customer who knows his/her order is ready soon. The bartender and the customer who still needs to order, could be bothered by the steaming sound for it hinders their communication. The customers who are already enjoying their order are probably not bothered by the sound at all.

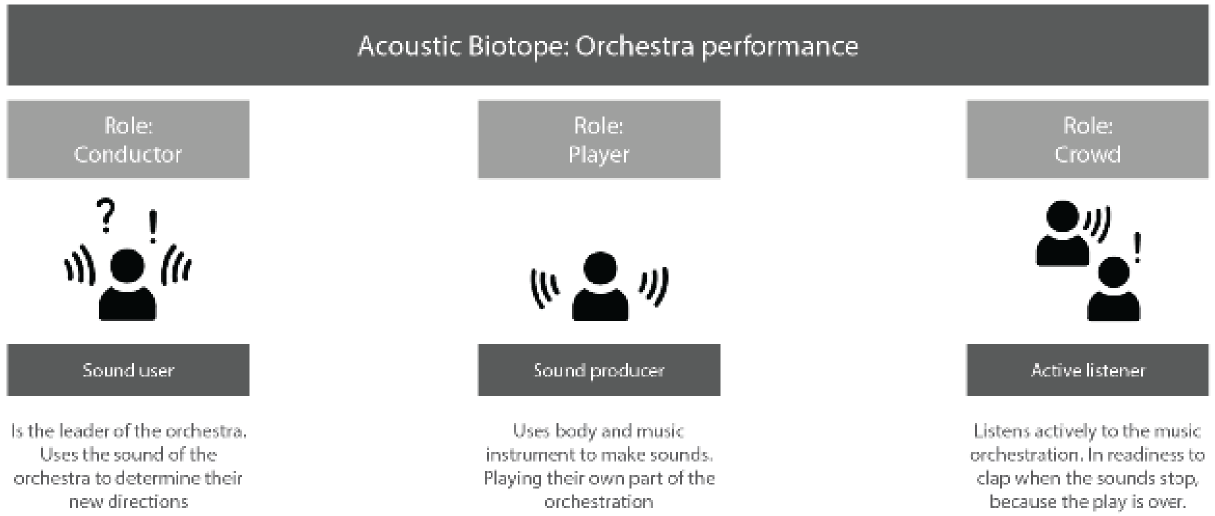


Figure 7 Example "Orchestra performance"

In another example of the acoustic biotope of an orchestra performance, some possible listener types are also identified. In this example there could be much more roles present, think about a security person, the host, the presenter of the show, perhaps there is a bar and people are working there. Each situation is unique. And it is therefore important that for each acoustic biotope, the roles of the listeners are identified for that specific functional environment.

4. Results

With the theories of Desmet and Hekkert's framework of experience and Özcan's acoustic biotopes, a new approach of the soundscape experience determination could be created.

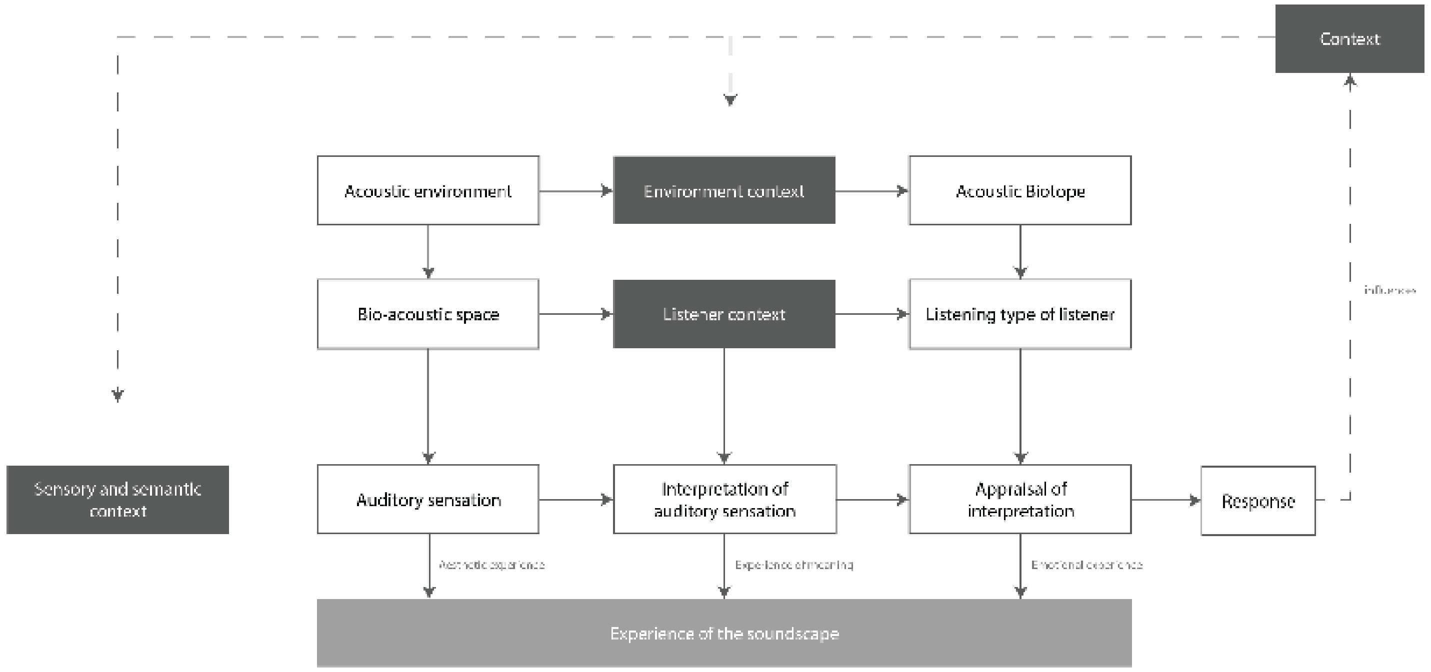


Figure 8 Schematic representation of the perceived soundscape including the acoustic biotope

In this model, the concept of the context has been divided in three subcontexts: the environmental context, the listeners context and the sensory and semantic context.

Sound sources will form an acoustic environment. All the sounds in that acoustic environment that can be captured by a certain species will form the bioacoustic space. The environmental context will have influence on the acoustic environment and will decide the acoustic biotope. The context of the listener will determine which role this listener plays in the acoustic biotope and which listener type belongs to this role. On the sensory and semantic level of the listeners the earlier framework can be recognized. Sounds of the bioacoustic space will reach the receptors of the ear, forming the auditory sensation. The brain will try to give meaning to this information and all the earlier experiences of the listener will help to interpretate the sounds. The listener type will be influencing the appraisal of this interpretation, which could then lead to a behavioural response, influencing the context.

The total experience of the soundscape for a specific listener will form during this complete sensory and semantic process.

5. Conclusion

The proposed model of a listenercentric approach of soundscape perception could be used in the process of describing a soundscape and determining a soundscape experience. The designer or researcher will use the same techniques and methods as proposed by the ISO 12913 series for data collection and analysis. The designer will however do additional research on the soundscape environment by identifying the different roles and listener types in the acoustic biotope. Analysing the soundscape experience should be done separately for each listener type. Intervention for improvement in the soundscape should be evaluated for each listener. Improvement in the soundscape can only be made if there is improvement in all the soundscape experiences for each listener type.

6. Sources

[1] ISO 129131:2014; Acoustics—Soundscape—Part 1: Definition and Conceptual Framework. ISO: Geneva, Switzerland, 2014.

[2] Kang, J., & SchulteFortkamp, B. (2016). *Soundscape and the built environment*. In *CRC Press eBooks*. https://doi.org/10.1201/b19145

[3] Lercher, P., & SchulteFortkamp, B. (2013). *Soundscape of European cities and landscapes – Harmonising*. Final Conference of SoundscapeCOSTTD0804project. https://doi.org/10.13140/2.1.3030.1127

[4] HerranzPascual, K., Aspuru, I., & García, I. (2010, June 1316) *Proposed conceptual model of environmental experience as framework to study the soundscape*, Inter Noise 2010: Noise and Sustainability, Lisbon, Portugal

[5] Health Council of the Netherlands. Public Impact of large airports. The Hague: Health Council of the Netherlands. 1999. report 1999/14E.

[6] Van Kempen, E., Staatsen, B., Van Kamp, I., Centre for Environmental Health Research, & Environment Assessment Agency (MNP). (2005). *Selection and evaluation of exposureeffectrelationships for health impact assessment in the field of noise and health* (No. 630400001/2005; pp. 2–77). RIVM. https://www.rivm.nl/bibliotheek/rapporten/630400001.pdf

[7] Aletta, F., & Kang, J. (2020). Promoting Healthy and Supportive Acoustic Environments: Going beyond the Quietness. In *MDPI eBooks*. https://doi.org/10.3390/books9783039282739

[8] ISO/TS 129132:2018; Acoustics — Soundscape — Part 2: Data collection and reporting requirements. ISO: Geneva, Switzerland, 2018.

[9] Dunbavin, P. (2018). ISO/TS 129132:2018 – Soundscape – Part 2: Data collection and reporting requirements – what's it all about? *Acoustics Bulletin*, *Vol 43*(No 4), 55–57. https://www.ioa.org.uk/system/files/acoustics_bulletin_julyaugust_2018.pdf

[10] Aletta, F., Guattari, C., Evangelisti, L., Asdrubali, F., Oberman, T., & Kang, J. (2019). Exploring the compatibility of "Method A" and "Method B" data collection protocols reported in the ISO/TS 129132:2018 for urban soundscape via a soundwalk. *Applied Acoustics*, *155*, 190–203. https://doi.org/10.1016/j.apacoust.2019.05.024

[11] Mascolo, A., Rossi, D., Grimaldi, M., & Guarnaccia, C. (2024). Soundscape Indicators Assessment and Mapping in a University Campus. *Forum Acusticum 2023*, 1039–1045. https://doi.org/10.61782/fa.2023.0511

[1] Hong, J. Y., & Jeon, J. Y. (2020). Comparing associations among sound sources, human behaviors, and soundscapes on central business and commercial streets in Seoul, Korea. *Building and Environment*, *vol 186*(107327). https://doi.org/10.1016/j.buildenv.2020.107327

[1] Yu, B., Kang, J., & Ma, H. (2016). Development of indicators for the soundscape in urban shopping streets. *Acta Acustica United With Acustica*, *102*(3), 462–473. https://doi.org/10.3813/aaa.918965

[1] Engel, M. S., Fiebig, A., Pfaffenbach, C., & Fels, J. (2021). A review of the use of psychoacoustic indicators on Soundscape studies. *Current Pollution Reports*, *7*(3), 359–378. https://doi.org/10.1007/s40726021001971

[15] Benocci, R., Afify, A., Potenza, A., Roman, H. E., & Zambon, G. (2023). Toward the definition of a Soundscape Ranking Index (SRI) in an urban park using machine learning techniques. *Sensors*, *23*(10), 4797. https://doi.org/10.3390/s23104797

[16] De Ulhôa Carvalho, M. L., Engel, M. S., Fazenda, B. M., & Davies, W. J. (2024). Evaluating the perceived affective qualities of urban soundscapes through audiovisual experiments. *PLoS ONE*, *19*(9), e0306261. https://doi.org/10.1371/journal.pone.0306261

[17] Aletta F, et al. Soundscape assessment: Towards a validated translation of perceptual attributes in different languages. In: Internoise and noisecon congress and conference proceedings 2020 Oct 12 (Vol. 261, No. 3, pp. 3137–3146). Institute of Noise Control Engineering

[18] Nagahata, K. (2023). A trial of translation of the perceived affective quality attributes for soundscape research to Japanese. *Applied Acoustics*, *211*, 109542. https://doi.org/10.1016/j.apacoust.2023.109542

[19] Papadakis, N. M., Aletta, F., & Stavroulakis, G. E. (2024). Issues of translation for the ISO/TS 12913–2:2018 Attributes: Paradox of Equivalence, NonEquivalence and suggested approaches to Construct Equivalence in CrossCultural soundscape research. *Applied Acoustics*, *225*, 110163. https://doi.org/10.1016/j.apacoust.2024.110163

[20] Aletta, F., Mitchell, A., Oberman, T., Kang, J., Khelil, S., Bouzir, T. a. K., Berkouk, D., Xie, H., Zhang, Y., Zhang, R., Yang, X., Li, M., Jambrošić, K., Zaninović, T., Van Den Bosch, K., Lühr, T., Orlik, N., Fitzpatrick, D., Sarampalis, A., . . . Nguyen, T. L. (2024). Soundscape descriptors in eighteen languages: Translation and validation through listening experiments. *Applied Acoustics*, *224*, 110109. https://doi.org/10.1016/j.apacoust.2024.110109

[21] Aletta, F., & Torresin, S. (2023). Adoption of ISO/TS 129132:2018 Protocols for Data Collection From Individuals in Soundscape Studies: an Overview of the Literature. *Current Pollution Reports*, *9*(4), 710–723. https://doi.org/10.1007/s40726023002836

[22] Axelsson, Ö., Nilsson, M. E., & Berglund, B. (2010). A principal components model of soundscape perception. *The Journal of the Acoustical Society of America*, *128*(5), 2836–2846. https://doi.org/10.1121/1.3493436

[23] Russell, J. A., & Pratt, G. (1980). A description of the affective quality attributed to environments. *Journal of Personality and Social Psychology*, *38*(2), 311–322. https://doi.org/10.1037/00223514.38.2.311

[24] Job RFS, Hatfield J, Carter NL, Peploe P, Taylor R, Morrell S (1999) Reaction to noise: the roles of soundscape, enviroscape and psychscape. In: Internoise. Fort Lauderdale, Florida

[25] Cain, R., Jennings, P., & Poxon, J. (2011). The development and application of the emotional dimensions of a soundscape. *Applied Acoustics*, *74*(2), 232–239. https://doi.org/10.1016/j.apacoust.2011.11.006

[26] Davies, W. J., Adams, M. D., Bruce, N. S., Cain, R., Carlyle, A., Cusack, P., Hall, D. A., Hume, K. I., Irwin, A., Jennings, P., Marselle, M., Plack, C. J., & Poxon, J. (2012). Perception of soundscapes: An interdisciplinary approach. *Applied Acoustics*, *74*(2), 224–231. https://doi.org/10.1016/j.apacoust.2012.05.010

[27] Jennings, P., & Cain, R. (2012). A framework for improving urban soundscapes. *Applied Acoustics*, *74*(2), 293–299. https://doi.org/10.1016/j.apacoust.2011.12.003

[28] Ozcan, E., Van Der Stelt, B., Maljers, I., Jayaram, S., Brenes, S., Van Twist, E., & Kuiper, J. (2024). Nature sounds for the win: Influencing the Pleasantness Perception of PICU Soundscapes. *Forum Acusticum 2023*. https://doi.org/10.61782/fa.2023.1163

[29] Desmet, P. M. A., & Hekkert, P. (2007). Framework of product experience. International Journal of Design, 1(1), 5766

[30] Hekkert, P. (2006). Design aesthetics: principles of pleasure in design. *Psychology Science*, 48(2), 157172

[31] Berghman, M., & Hekkert, P. (2017). Towards a unified model of aesthetic pleasure in design. *New Ideas in Psychology*, *47*, 136–144. https://doi.org/10.1016/j.newideapsych.2017.03.004

[32] LANDR. (n.d.). *How to mix music: An easy guide to pro Mixing | LANDR*. https://www.landr.com/howtomix/#:~:text=Mixing%20is%20the%20practice%20of,to%20prevent%20or%20 solve%20problems.

[33] *How to make space for vocals*. (n.d.). Sage Audio. https://www.sageaudio.com/articles/howtomakespaceforvocals

[34] OzcanVieira, E. (2008). *Product sounds: Fundamentals and application*. https://repository.tudelft.nl/islandora/object/uuid%3A8144d042021f4fa0809b1e5b3b72647b?collection=research

[35] Leech's seven types of meaning in semantics. (2017). In *International Journal of Multidisciplinary Research and Development* (Vol. 4, Issue 3, pp. 71–72). https://www.allsubjectjournal.com/assets/archives/2017/vol4issue3/4230733.pdf

[36] Frijda, N. H. (1986). The emotions. Cambridge: Cambridge University Press

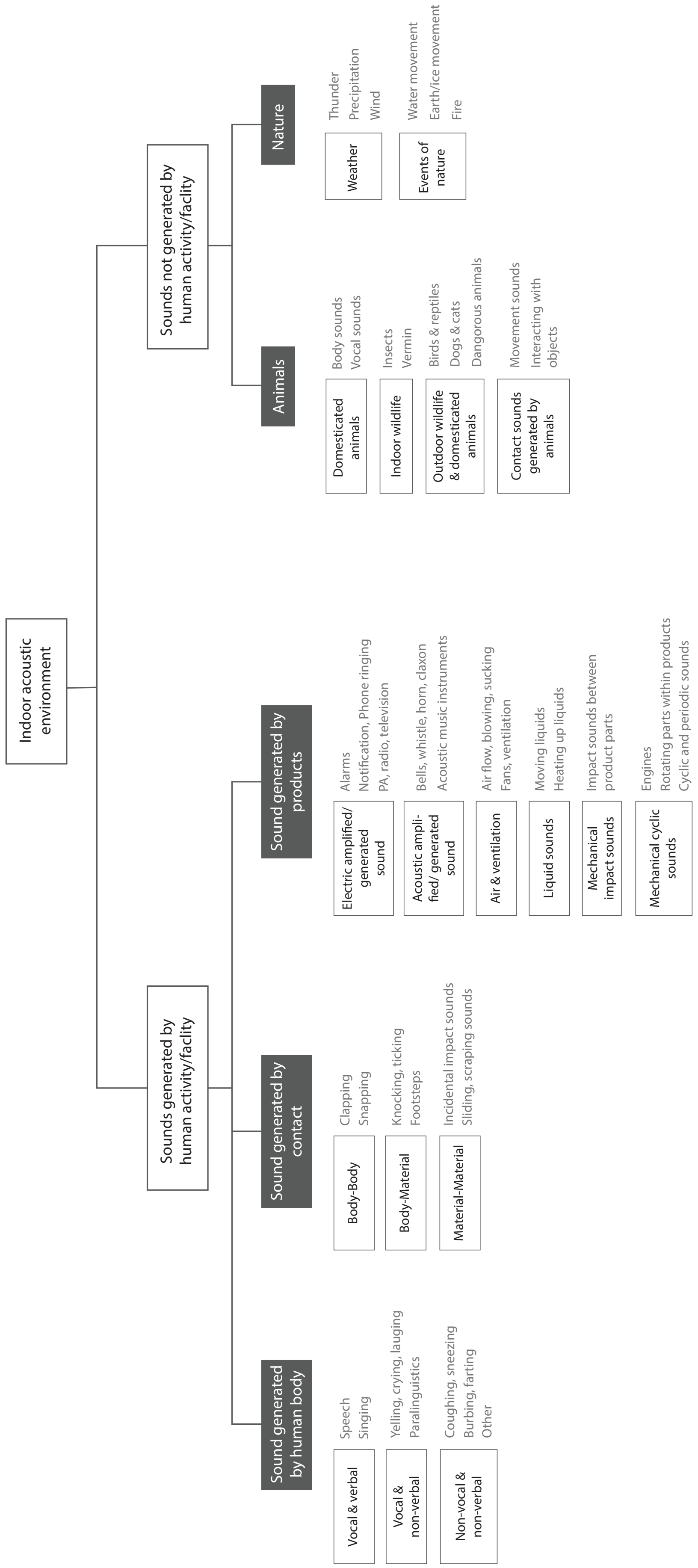
[37] Desmet, P. M. A. (2002). Designing emotions. Unpublished doctoral dissertation, TU Delft, Delft, The Netherlands

[38] Moors, A. (2017). Appraisal theory of emotion. In *Springer eBooks* (pp. 1–9). https://doi.org/10.1007/9783319280998_4931

[39] Özcan, E., Broekmeulen, C. L. H., Luck, Z. A., Van Velzen, M., Stappers, P. J., & Edworthy, J. R. (2022). Acoustic Biotopes, Listeners and SoundInduced Action: A case study of Operating rooms. *International Journal of Environmental Research and Public Health*, *19*(24), 16674. https://doi.org/10.3390/ijerph192416674

[40] Truax, B. Handbook for Acoustic Ecology; Cambridge Street Publishing: Vancouver, BC, Canada, 1999

Appendix 3 - Classification sceme indoor sounds



Appendix 4 - List of sounds (observation list)

Observing sounds in the ICU
Name observer:

Date:
Time:

	0-5	5-10	10-15	15-20	20-25	25-30
Mechanical sound						
Air/ Ventilation room						
Machines cyclic (motor/ fan) sound						
Machines air flow/ sucking/ blowing						
Liquid sounds						
Mechanical impact (sound between product parts)						
Electric amplified/ generated sound						
Red alarms						
Yellow alarms						
Blue alarms						
Pump beeps/alarms						
Ventilator alarms						
Phone ringing/ notifaction						
Television/ Radio/ Music						
Human activity						
Walking/ Movement sound						
Moving/ pushing trolly/ container						
Moving plastic bags (Garbage/ laundry)						
Opening/Closing furniture/ doors						
Getting supplies						
Restock closets						
Other body-material sound						
Other material-material sound						
Human body						
Non-verbal/ Non-vocal (clapping, sneezing)						
Non-verbal/ Vocal (laughing, yelling)						
Verbal/Vocal – Smalltalk						
Verbal/Vocal – Patient related						
Verbal/Vocal – Medical discussion						
Verbal/Vocal – Other						
Nature sound						
Weather/ Nature events						
Animal sounds						

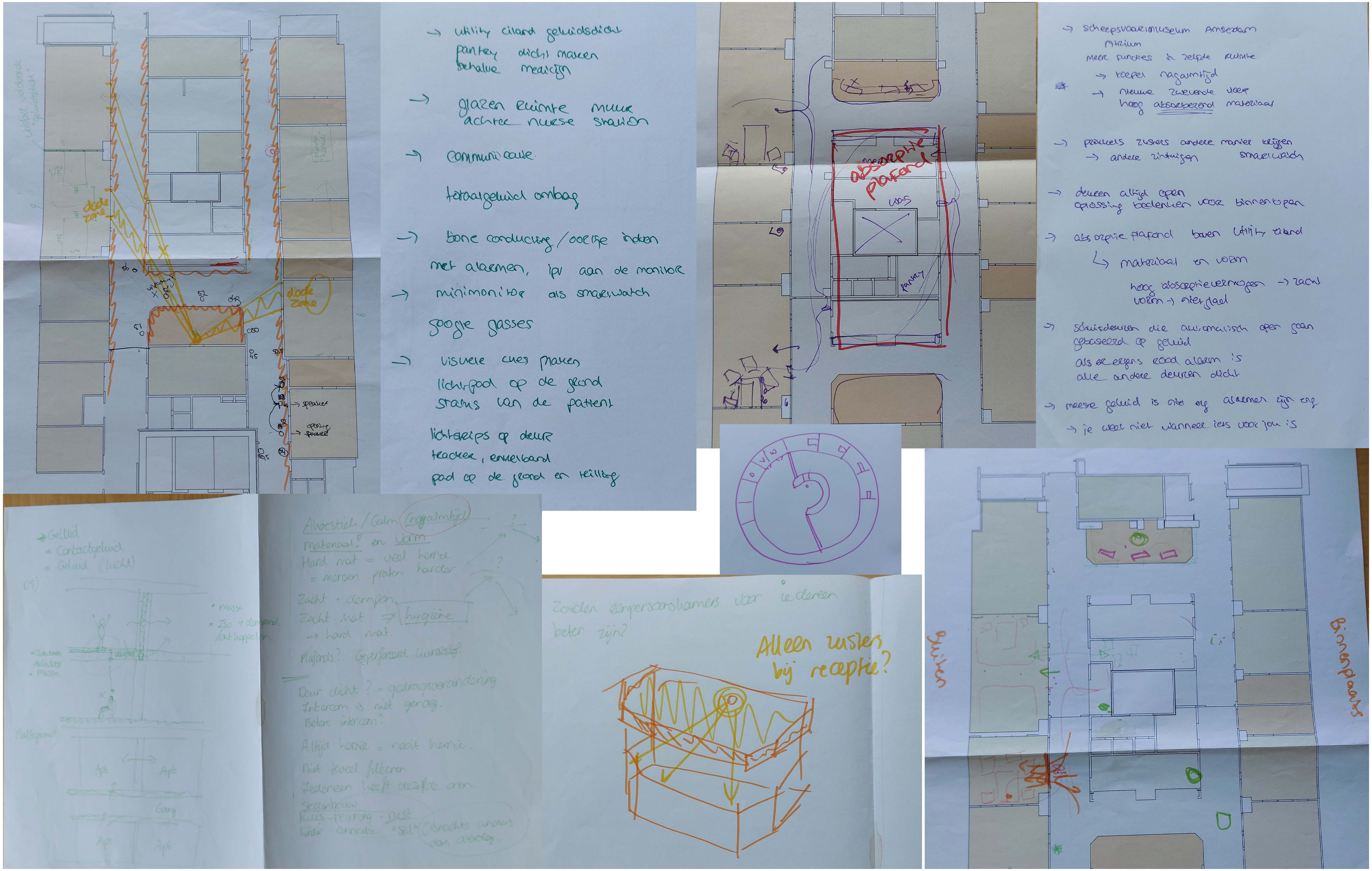
Appendix 5 - Results qualitative research

Tijdstempel	Wat is uw rol/ werkbeschrijving? (Dokter/Arts, Verpleegkundige, IC assistent, enz..)	Wat is uw geslacht?	Wat is uw leeftijd?	Hoe zou je de IC op dit moment beschrijven?	Welke geluiden/geluidstypes hoor je op dit moment? [Mechanische geluiden/ Machines]	Welke geluiden/geluidstypes hoor je op dit moment? [Alarmen/ Electronische signalen]	Welke geluiden/geluidstypes hoor je op dit moment? [Menselijke activiteit/ beweging]	Welke geluiden/geluidstypes hoor je op dit moment? [Pakken van spullen/ Opruimen van spullen]
21-1-2025 10:50:45	Verpleegkundige	Vrouw	35	Mensen praten in de gangen, Er wordt veel heen en weer gelopen, Het verloopt allemaal soepel, De normale gang van zaken	Een beetje aanwezig	Een beetje aanwezig	Duidelijk hoorbaar	Een beetje aanwezig
21-1-2025 10:57:22	Verpleegkundige	Vrouw	34	Het verloopt allemaal soepel, De normale gang van zaken	Een beetje aanwezig	Niet aanwezig	Gemiddeld	Gemiddeld
21-1-2025 11:35:31	Verpleegkundige	Man	38	Mensen praten in de gangen, Er wordt veel heen en weer gelopen, Het is tamelijk druk, Er gaan veel alarmen af	Gemiddeld	Duidelijk hoorbaar	Duidelijk hoorbaar	Duidelijk hoorbaar
21-1-2025 11:58:39	Verpleegkundige in coordinerende functie	Vrouw	60	Mensen praten in de gangen, Er wordt veel overlegd over de patiënten, Het is tamelijk druk, De normale gang van zaken	Duidelijk hoorbaar	Een beetje aanwezig	Gemiddeld	Een beetje aanwezig
21-1-2025 15:11:10	IC verpleegkundige	Vrouw	31	Mensen praten in de gangen, Er wordt veel overlegd over de patiënten, De patiënten hebben veel zorg nodig, Er wordt veel heen en weer gelopen, Het verloopt allemaal soepel, Het is tamelijk druk, Er is een overdracht/ Er wordt voorbereid voor een overdracht, De normale gang van zaken	Overstemmend/ Overheersend	Overstemmend/ Overheersend	Overstemmend/ Overheersend	Duidelijk hoorbaar
21-1-2025 15:17:25	Verpleegkundige	Man	34	Mensen praten in de gangen, Er gaan veel alarmen af	Duidelijk hoorbaar	Duidelijk hoorbaar	Duidelijk hoorbaar	Duidelijk hoorbaar
21-1-2025 11:23:18	Zorgassistent	Vrouw	38	De patiënten hebben veel zorg nodig, Er wordt veel heen en weer gelopen, Het verloopt allemaal soepel, Het is tamelijk druk	Een beetje aanwezig	Een beetje aanwezig	Gemiddeld	Gemiddeld
21-1-2025 11:30:58	Zorgassistent	Vrouw	22	De patiënten hebben veel zorg nodig, Er wordt veel heen en weer gelopen, Het verloopt allemaal soepel, Er is een overdracht/ Er wordt voorbereid voor een overdracht	Duidelijk hoorbaar	Gemiddeld	Niet aanwezig	Een beetje aanwezig
21-1-2025 10:44:16	Medisch secretaresse IC	Vrouw	30	Erg rustig, Mensen praten in de gangen, De patiënten hebben veel zorg nodig, Er wordt veel heen en weer gelopen, Er gaan veel alarmen af	Een beetje aanwezig	Gemiddeld	Gemiddeld	Niet aanwezig
21-1-2025 12:26:03	Schoonmaken	Vrouw	41	Mensen praten in de gangen, Er wordt veel heen en weer gelopen, Het is tamelijk druk, De normale gang van zaken	Gemiddeld	Gemiddeld	Duidelijk hoorbaar	Gemiddeld
21-1-2025 12:34:42	Teamleiding	Vrouw	60	Mensen praten in de gangen, Er gaan veel alarmen af, De normale gang van zaken	Duidelijk hoorbaar	Duidelijk hoorbaar	Duidelijk hoorbaar	Een beetje aanwezig
21-1-2025 13:40:02	Logistiek medewerker IC	Man	21	Mensen praten in de gangen, Het verloopt allemaal soepel	Een beetje aanwezig	Een beetje aanwezig	Duidelijk hoorbaar	Gemiddeld
21-1-2025 13:30:35	Stagiair Technical Medicine	Vrouw	22	Mensen praten in de gangen, Er wordt veel heen en weer gelopen, De normale gang van zaken	Duidelijk hoorbaar	Een beetje aanwezig	Overstemmend/ Overheersend	Een beetje aanwezig
21-1-2025 13:35:39	Aios	Vrouw	34	Mensen praten in de gangen, Er wordt veel heen en weer gelopen, Het verloopt allemaal soepel	Niet aanwezig	Duidelijk hoorbaar	Duidelijk hoorbaar	Niet aanwezig
21-1-2025 13:42:54	Arts	Vrouw	54	Mensen praten in de gangen, De patiënten hebben veel zorg nodig, Er wordt veel heen en weer gelopen, Het is tamelijk druk, Er gaan veel alarmen af	Een beetje aanwezig	Duidelijk hoorbaar	Gemiddeld	Gemiddeld
21-1-2025 15:19:24	dokter	Man	33	Er wordt veel overlegd over de patiënten, De patiënten hebben veel zorg nodig, Het verloopt allemaal soepel, De normale gang van zaken	Niet aanwezig	Duidelijk hoorbaar	Gemiddeld	Een beetje aanwezig
21-1-2025 15:46:36	Dokter	Man	30	Mensen praten in de gangen, Het is tamelijk druk, De normale gang van zaken	Niet aanwezig	Duidelijk hoorbaar	Duidelijk hoorbaar	Niet aanwezig

Welke geluiden/geluidstypes hoor je op dit moment? [Overleg/ Medisch overleg]	Welke geluiden/geluidstypes hoor je op dit moment? [Geklets/ Gepraat/ Smalltalk]	Welke geluiden hiervan vind je storend?	Welke geluiden hiervan vind je belangrijk om goed te kunnen horen?	Welke geluiden hiervan heb je nodig om je werk goed te kunnen doen?	Welke geluiden hiervan zijn onverschillig voor jou of storen jou niet?	Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Aangenaam/ Prettig (Pleasant)]	Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Kalm/ Rustgevend (Calm)]	Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Rustig/ Statisch (Uneventful)]
Duidelijk hoorbaar	Duidelijk hoorbaar	Geen	Machines	Machines	Small talk menselijke activiteit	4. Eens	1. Helemaal niet mee eens	1. Helemaal niet mee eens
Gemiddeld	Een beetje aanwezig	Geen	Monitor en pompen	Monitoring en pompen	Kletspraat	3. Neutraal	3. Neutraal	4. Eens
Een beetje aanwezig	Duidelijk hoorbaar	Geen	Alarmen	Alarmen	Ongevingsruis	2. Niet mee eens	2. Niet mee eens	2. Niet mee eens
Niet aanwezig	Een beetje aanwezig	Onverwachtse en onbekende geluiden en soms hard praten	Alarmen	Alarmen en belangrijke communicatie	Alarmen die ik kan herleiden en ik weet dat de airco veel herrie maskt maar dat hoor ik niet meer	2. Niet mee eens	2. Niet mee eens	2. Niet mee eens
Overstemmend/ Overheersend	Overstemmend/ Overheersend	Geklets van de zorgassistenten.	Medische apparatuur	Medische apparatuur	Alarmen van de monitor	3. Neutraal	1. Helemaal niet mee eens	2. Niet mee eens
Duidelijk hoorbaar	Duidelijk hoorbaar	Alarmen	Alarmen	Alarmen	Al het overige geluid	3. Neutraal	1. Helemaal niet mee eens	1. Helemaal niet mee eens
Een beetje aanwezig	Een beetje aanwezig	Ik vind niks storend het went wel op ten duur	Dat is voor onze functie niet echt van belang	Nvt	Geen van de geluiden	3. Neutraal	3. Neutraal	4. Eens
Niet aanwezig	Gemiddeld	Niks	Machines	Nvt	Niks	4. Eens	3. Neutraal	3. Neutraal
Niet aanwezig	Een beetje aanwezig	Alarmen en bellen van infusen achter de bali	Collegas die hulp nodig hebben	Collegas die vanaf de gang wat vragen	Pratende collegas	4. Eens	4. Eens	4. Eens
Gemiddeld	Gemiddeld	Niks	Patienten die om hulp vragen	Als je iets hoort vallen of iemand roept je om schoon te maken	-	3. Neutraal	3. Neutraal	3. Neutraal
Een beetje aanwezig	Gemiddeld	Alarmen	Alarmen	Telefoon, Hulpvragen,	Werkgeluiden, tenzij overheersend	4. Eens	2. Niet mee eens	1. Helemaal niet mee eens
Niet aanwezig	Een beetje aanwezig	Geen	Het pakken en opruimen van spullen	Geen	Overleg	3. Neutraal	3. Neutraal	2. Niet mee eens
Gemiddeld	Duidelijk hoorbaar	Geklets	Alarmen en overleg	Alarmen en overleg	Menselijke activiteit en machines	3. Neutraal	1. Helemaal niet mee eens	2. Niet mee eens
Duidelijk hoorbaar	Duidelijk hoorbaar	Praten	Alarmen	Niet specifiek	Beweging	2. Niet mee eens	2. Niet mee eens	2. Niet mee eens
Niet aanwezig	Gemiddeld	Klets	Reke	Relevante alarmen	Uitpakken. Lopen	3. Neutraal	2. Niet mee eens	2. Niet mee eens
Gemiddeld	Duidelijk hoorbaar	geen	alarmen maar zeker ook gezelligheid	alarmen, overleg met collegas, small talk	stoort me allemaal niet	4. Eens	4. Eens	4. Eens
Duidelijk hoorbaar	Duidelijk hoorbaar	Geen	Alarmen	Specifieke alarmen, kritieke grenzen	Mensen, alarmen	3. Neutraal	2. Niet mee eens	2. Niet mee eens

Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Saai/ Eentonig (Monotonous)]	Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Onaangenaam/ Onprettig (Annoying)]	Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Chaotisch/ Hectisch (Chaotic)]	Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Druk/ Dynamisch (Eventful)]	Wat vind je van de geluidsomgeving? Beschrijf voor de onderstaande schalen [Levendig/ Vrolijk (Vibrant)]	Beschrijf voor de onderstaande vragen. [Vind je het luid hier?]	Beschrijf voor de onderstaande vragen. [Vind je het aangenaam hier?]	Beschrijf voor de onderstaande vragen. [Vind je de geluidsomgeving passend voor de IC?]	Beschrijf voor de onderstaande vragen. [Vind je de geluidsomgeving passend voor de activiteiten op dit moment?]	Eventuele uitleg
1. Helemaal niet mee eens	2. Niet mee eens	4. Eens	4. Eens	3. Neutraal	Zeker (Very)	Zeker (Very)	Zeker (Very)	Zeker (Very)	
1. Helemaal niet mee eens	1. Helemaal niet mee eens	1. Helemaal niet mee eens	4. Eens	4. Eens	Een beetje (Slightly)	Zeker (Very)	Zeker (Very)	Zeker (Very)	
2. Niet mee eens	3. Neutraal	3. Neutraal	3. Neutraal	2. Niet mee eens	Gemiddeld (Moderate)	Gemiddeld (Moderate)	Zeker (Very)	Zeker (Very)	
2. Niet mee eens	4. Eens	3. Neutraal	4. Eens	4. Eens	Zeker (Very)	Gemiddeld (Moderate)	Zeker (Very)	Zeker (Very)	
2. Niet mee eens	4. Eens	3. Neutraal	4. Eens	1. Helemaal niet mee eens	Zeker (Very)	Gemiddeld (Moderate)	Gemiddeld (Moderate)	Zeker (Very)	Geluidsspecifiek zijn de nieuwe isolatiekamers nog vrij hol van geluid waardoor alle geluiden versterkt worden.
1. Helemaal niet mee eens	4. Eens	3. Neutraal	4. Eens	2. Niet mee eens	Zeker (Very)	Zeker (Very)	Zeker (Very)	Zeker (Very)	
2. Niet mee eens	2. Niet mee eens	2. Niet mee eens	2. Niet mee eens	3. Neutraal	Een beetje (Slightly)	Zeker (Very)	Zeker (Very)	Zeker (Very)	
3. Neutraal	3. Neutraal	3. Neutraal	3. Neutraal	3. Neutraal	Een beetje (Slightly)	Gemiddeld (Moderate)	Gemiddeld (Moderate)	Gemiddeld (Moderate)	
3. Neutraal	2. Niet mee eens	2. Niet mee eens	4. Eens	4. Eens	Zeker (Very)	Absoluut (Extremely)	Zeker (Very)	Zeker (Very)	
1. Helemaal niet mee eens	2. Niet mee eens	1. Helemaal niet mee eens	5. Helemaal mee eens	5. Helemaal mee eens	Een beetje (Slightly)	Een beetje (Slightly)	Absoluut (Extremely)	Absoluut (Extremely)	
2. Niet mee eens	2. Niet mee eens	2. Niet mee eens	4. Eens	4. Eens	Gemiddeld (Moderate)	Zeker (Very)	Absoluut (Extremely)	Absoluut (Extremely)	
1. Helemaal niet mee eens	1. Helemaal niet mee eens	1. Helemaal niet mee eens	3. Neutraal	4. Eens	Totaal niet (Not at all)	Zeker (Very)	Zeker (Very)	Gemiddeld (Moderate)	
3. Neutraal	3. Neutraal	4. Eens	4. Eens	2. Niet mee eens	Gemiddeld (Moderate)	Een beetje (Slightly)	Zeker (Very)	Zeker (Very)	
2. Niet mee eens	4. Eens	3. Neutraal	4. Eens	4. Eens	Zeker (Very)	Gemiddeld (Moderate)	Zeker (Very)	Zeker (Very)	
2. Niet mee eens	3. Neutraal	3. Neutraal	3. Neutraal	2. Niet mee eens	Zeker (Very)	Een beetje (Slightly)	Zeker (Very)	Gemiddeld (Moderate)	
3. Neutraal	2. Niet mee eens	1. Helemaal niet mee eens	3. Neutraal	3. Neutraal	Een beetje (Slightly)	Zeker (Very)	Zeker (Very)	Zeker (Very)	vaker muziek op zou ik leuk vinden
4. Eens	3. Neutraal	3. Neutraal	4. Eens	2. Niet mee eens	Zeker (Very)	Zeker (Very)	Zeker (Very)	Zeker (Very)	

Appendix 6 - Hardcopy results from SDD Analysis



→ ok alles in vizier
sneller dingen uit zetten/ krapper zetten
op IC loop je heen en weer
voor blind

Je bent de hele tijd verantwoordelijk voor
patient. ook als je niet naast de
patient staat.
op ok, ambu, SEH, ~~staan~~ ben je naast de patient

→ op IC langzaam te stabiliseren
terug naar de balans
op SEH is dat snel, zsm stabiliseren

→ ook afwachtend in handelen
~~voor even aanzien~~'
langere doorlust

→ ok gezonde mensen die je onderuit haalt
IC ga je even uit dat lichaam het niet
zelf kan

→ cultuur ook vanwege logistiek.
alle verdieping in de gang, vooraad
dus moet het nog pakken, niet accuut na
handelen

→ mensen zijn harder, ze hebben altijd gekke
zelfmechanisme vanwege ellende, veel dood
~~je krijgt ook~~
je krijgt ook voor of het slecht gaat of niet
en dan wil je dat er hoe je geluisterd wordt

→ de hiërarchie op de IC anders dan andere plekken ziekenhuis
arts vs. verpleging

arts eindverantwoordelijke → zo wordt je opgeleid
maar op ok en IC is verpleging 'belangrijker'

IC-mentaliteit
→ eigenwijs
→ neerbuigend
→ voorzichtigheid in lichaam zelf laten werken
werkwijze hoe je het aanpakt
zo snel mogelijk oplossen → SEH
zelf afbouwen en dan weer oppakken → OK
langzaam terug naar balans → IC
↳ daarom iemand die onderuit gaat is → dood
gezonde mensen doe je niks
wordt, ie wel weer wakker
IC doe je niks, gaat die dood
↳ op ok kijken ze wel eens wat aan
op IC direct handelen
↳ maar wel traag, klaarzetten
en protocollen

→ IC heeft met
thuis te maken
andere afdelingen niet

gewoon handelen niet de hele tijd hoeven valueren op de IC wordt veel geëvalueerd

→ niet-medisch personeel → prima
medisch concentratie → te veel prikkels
↳ oorzaak alarm fatigue

conflict geluiden medisch noodzakelijk
niet goed voor patient

→ isolatie van utility eiland deuren?

→ licht gebruiken
kleur op de deur

iets mis is automatische de deur open

→ in de kamer geluiden van buitenaf blokken
en dan geluiden toevoegen aan binnen

→ geluidsgordijn
↓ en dan blinde vlek verkleinen
← projectie buiten de kamer
↓ dragen van geluid afzwakken
↓ de gang op afzwakken
dubbel blokken nieuwe kamer in

smartwatch idee

→ gemeten hoe gestresst een persoon is
en dan positieve geluiden in de kamer
en dan stress niveau visualiseren
→ controle bij verpleging

→ audioboek harry potter
→ gepersonaliseerd geluid
→ bouwkundig, is het gepast
alleen staat die deur open
→ minder galmen
→ oordoppen?
→ werken met dode cones van geluid
→ zou patient op 1 zetten
geluid absorberen, niet in bed

→ geluid zusterpost
alleen horen wanneer je
er achter bent

→ wearable, vraag! aandacht! → ongewenst

→ pomp gaat af, waar moet ik heen

→ regelmaat van medicijnen geven

→ deur inham

→ cultuurverandering

– zijn de geluiden van de gang erg
– isolatiemuur om utility eiland

→ acoustische panelen
geluiden stoppen met ontwikkelen

→ laag / indoor festival geluidsdemping
bekijken

→ intercom er uit

→ demp knop

→ mensen alarmen uit laten zetten werkt blijkbaar niet

→ automatisch uitschakelen

→ patienten experience meten op de TU

→ levendig in de kamer
B&B gevoel, er eindelijk wat

→ speel op de gang
→ licht

→ kamers random nurse station
kantoor tuin

→ natuurgeluid in de kamer
of juist wel kunnen verstaan

nieuwe IC designen
gang onaantrekkelijk maken
werkoorsig van ns naar patientenkamer

→ kan dat piepje uit

→ pas aan als zuster binnenloopt

→ koptelefoon met eigen muziek

→ muziektherapie

→ lachtherapie

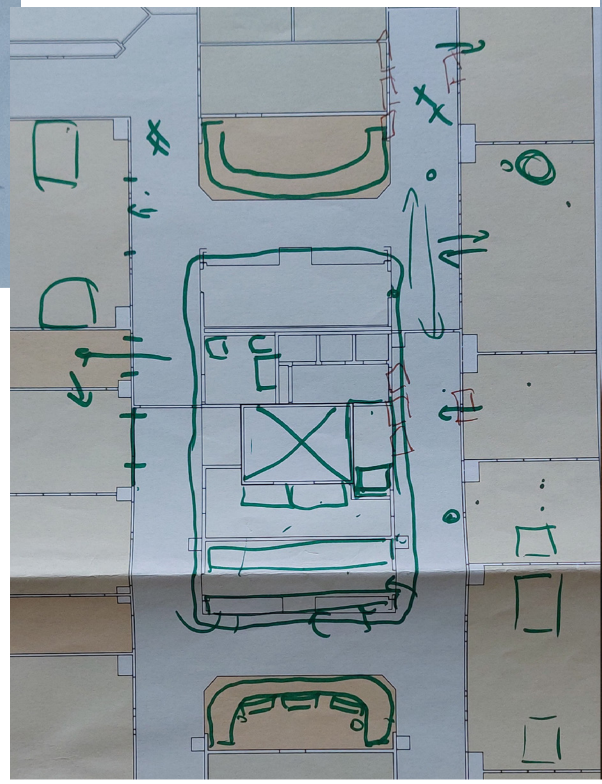
① health issues → patienten → family

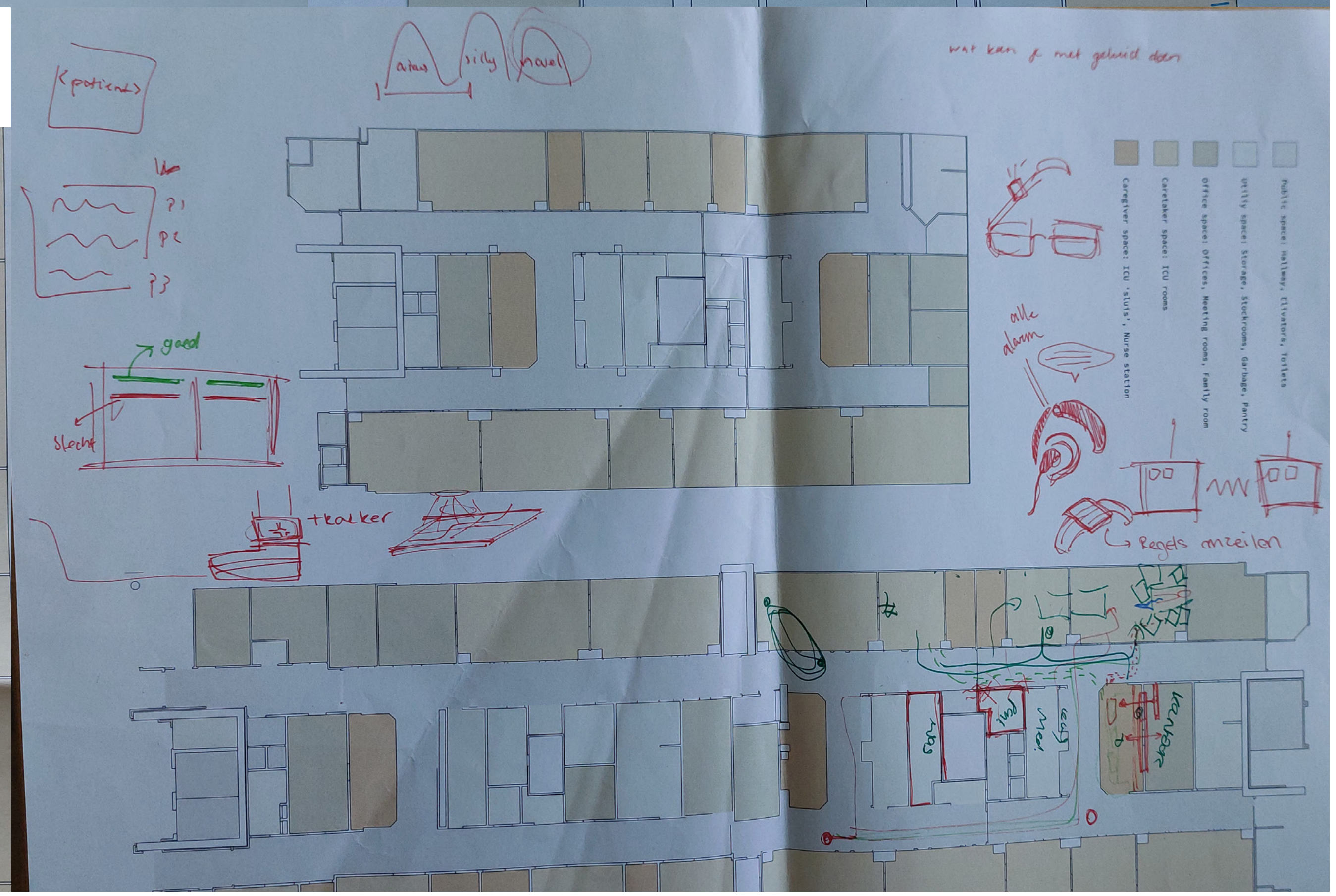
② isolatie alientatie → patienten

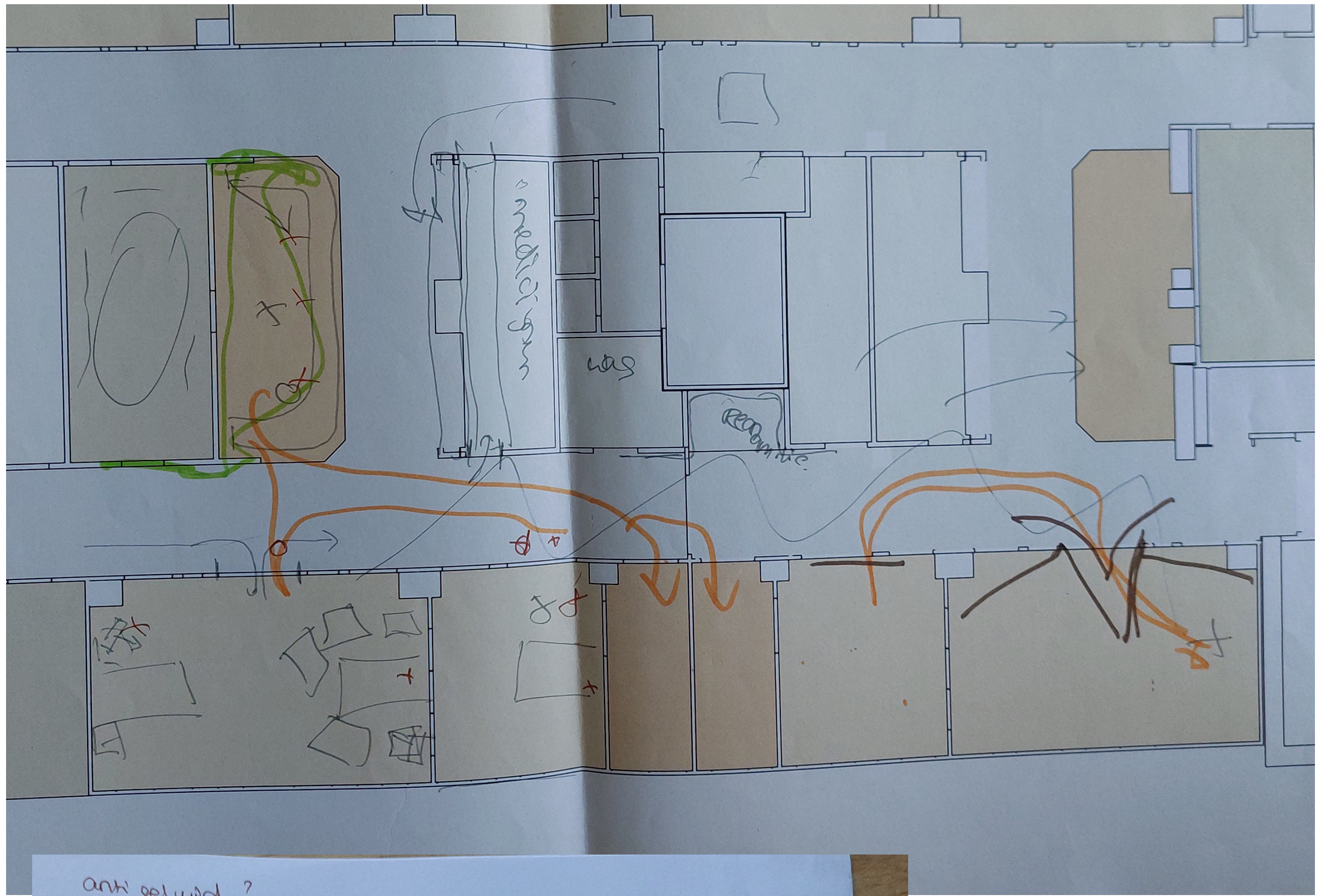
③ alarm fatigue → verpleging

④ sound masking → verpleging

⑤ concentratie → verpleging dokters



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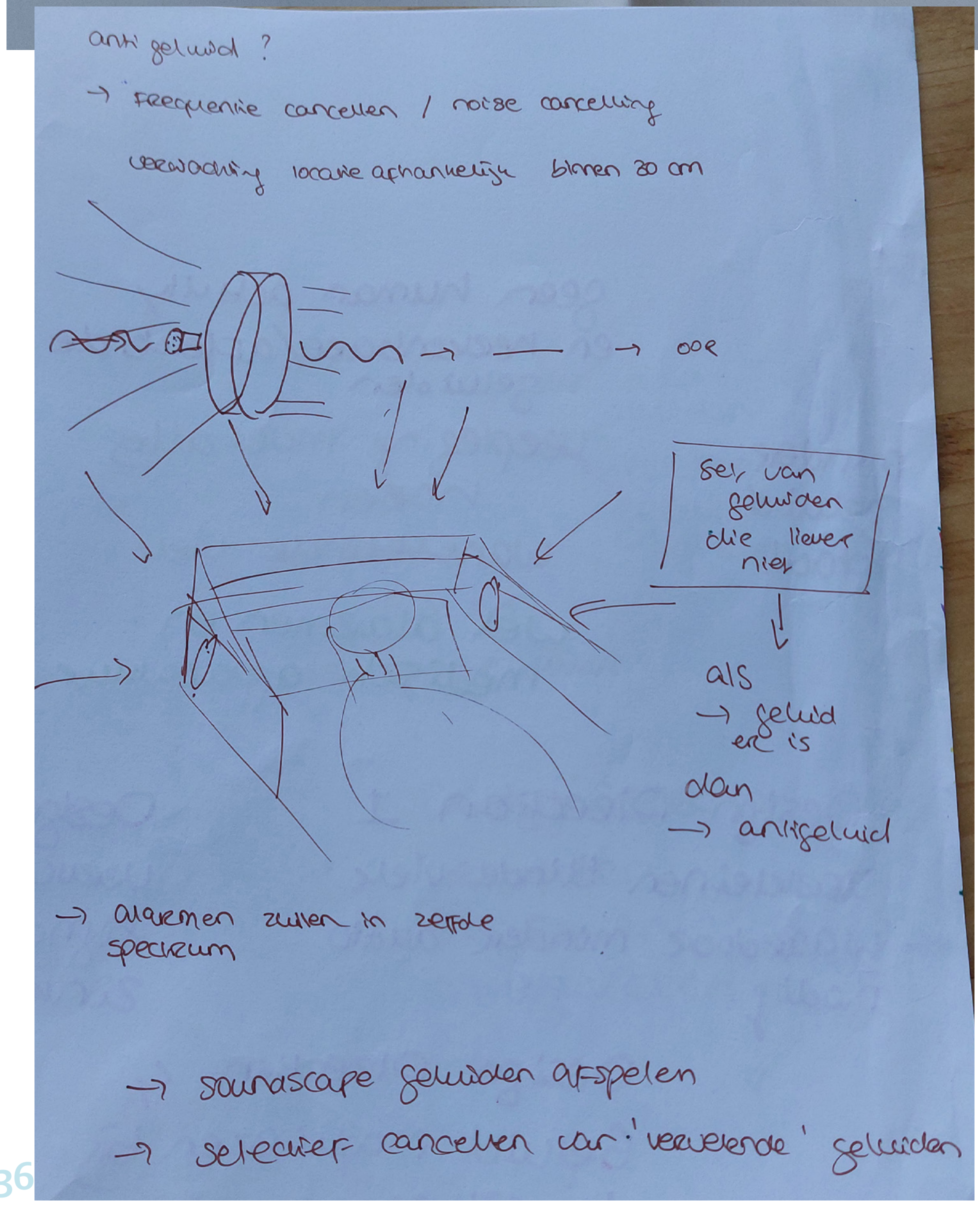
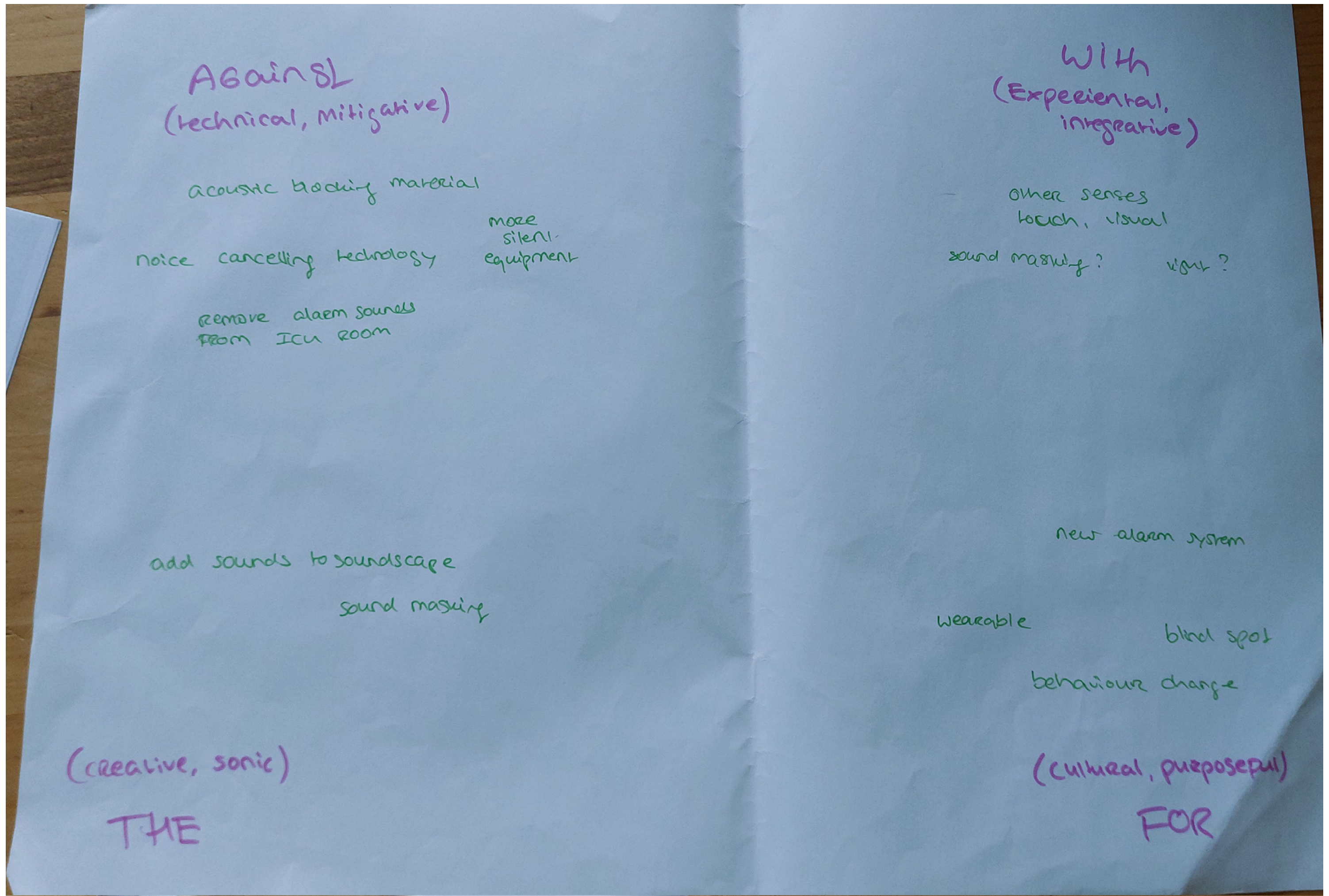
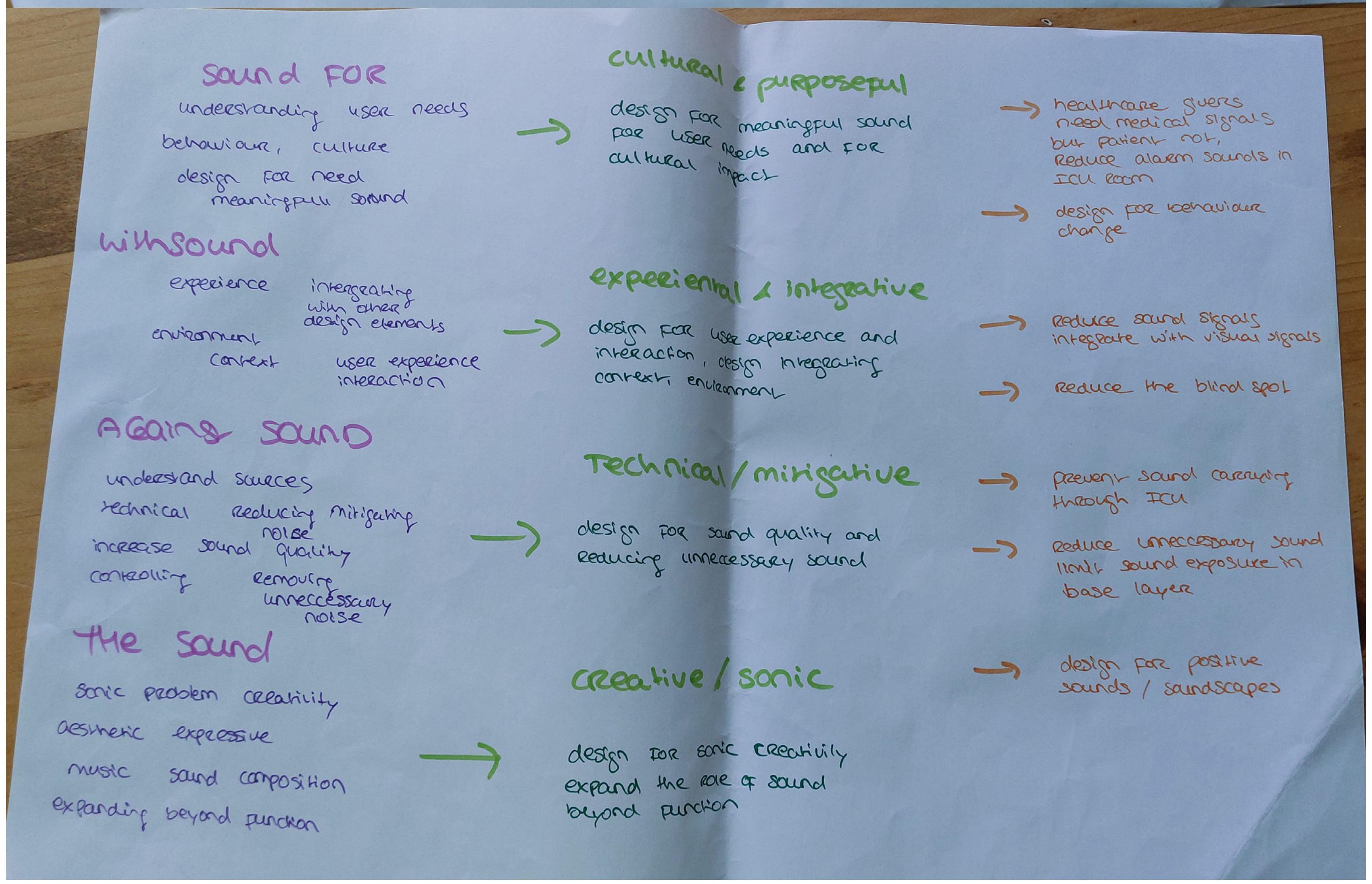
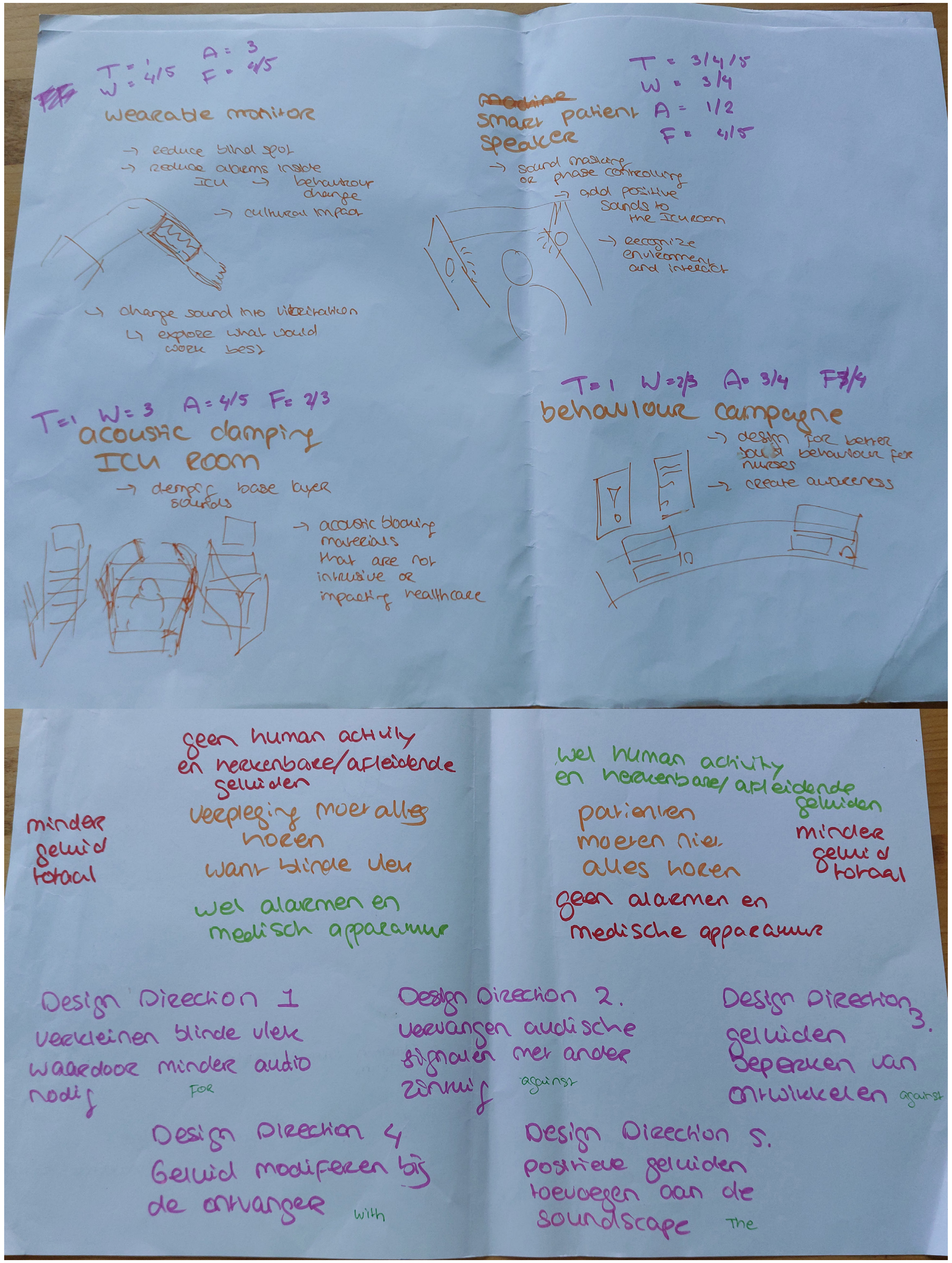

anti geluid ?
→ frequentie cancellen / noise cancelling
verwachting locatie afhankelijk binnen 20 cm
oor
set van geluiden die liever niet
als → geluid er is
dan → antigeluid
→ algemeen zullen in zelfde spectrum
→ soundscape geluiden afspelen
→ selectief cancellen van 'vervelende' geluiden

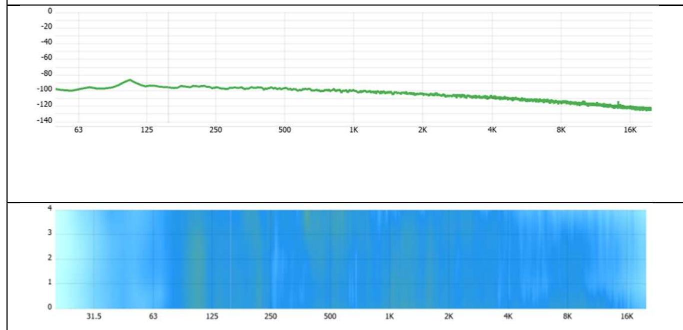

Against
(technical, mitigative)
acoustic blocking material
noice cancelling technology
more silent equipment
remove alarm sounds from ICU room
add sounds to soundscape
sound masking
With
(Experiental, integrative)
other senses touch, visual
sound masking ?
light ?
new alarm system
wearable
blind spot
behaviour change
(creative, sonic)
THE
(cultural, purposeful)
FOR


Sound FOR
understanding user needs
behaviour, culture
design for need meaningful sound
withsound
experience
integrating with other design elements
environment context
user experience interaction
Against sound
understand sources
technical
reducing mitigating noise
increase sound quality
controlling
removing unnecessary noise
The sound
sonic problem creativity
aesthetic expressive
music sound composition
expanding beyond function
cultural & purposeful
design for meaningful sound for user needs and for cultural impact
experiental & integrative
design for user experience and interaction, design integrating context, environment
Technical/mitigative
design for sound quality and reducing unnecessary sound
creative / sonic
design for sonic creativity expand the role of sound beyond function
→ healthcare users need medical signals but patient not, reduce alarm sounds in ICU room
→ design for behaviour change
→ reduce sound signals integrate with visual signals
→ reduce the blind spot
→ prevent sound carrying through ICU
→ reduce unnecessary sound limit sound exposure in base layer
→ design for positive sounds / soundscapes

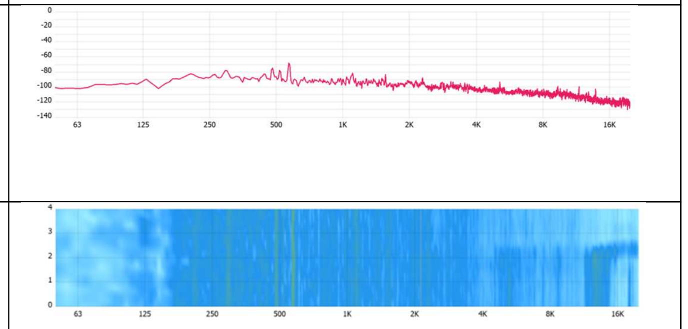


Appendix 7 - Sound measurements

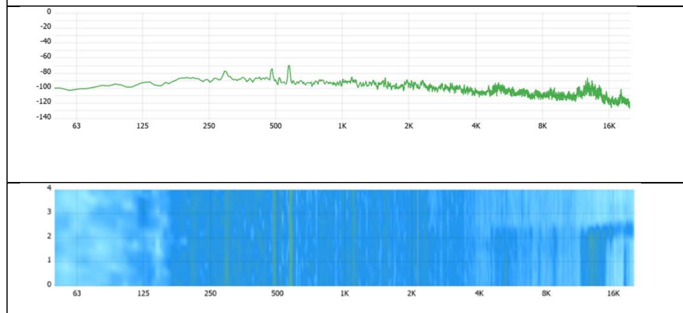
1.1 Ventilatie



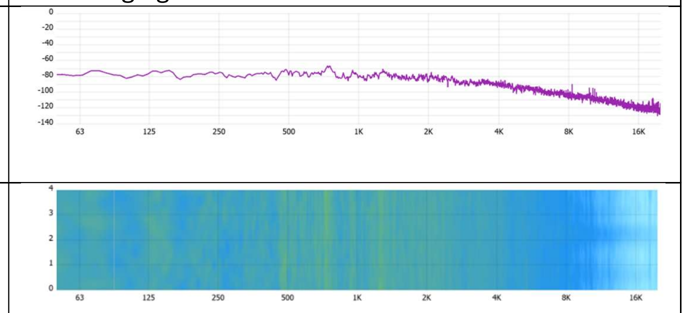
1.2 + 1.4



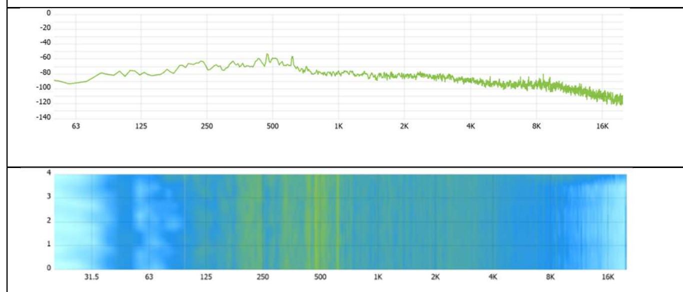
1.2+1.4+1.5



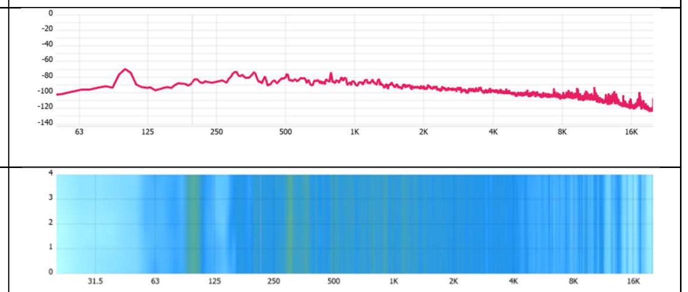
1.7 Afzuiging van MVK



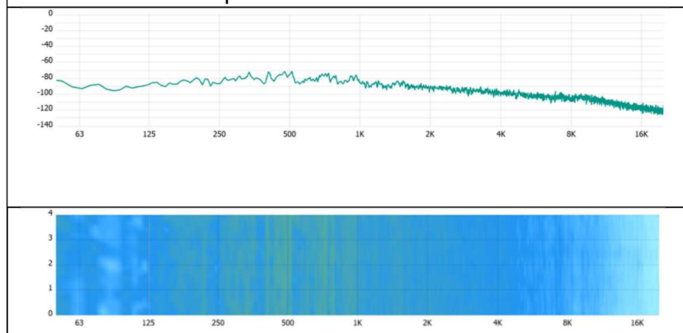
1.8 Etenskar



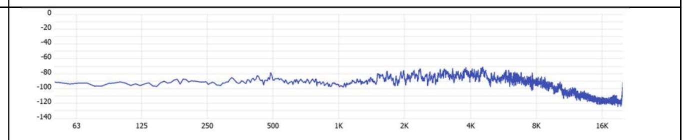
1.11 Koelkast



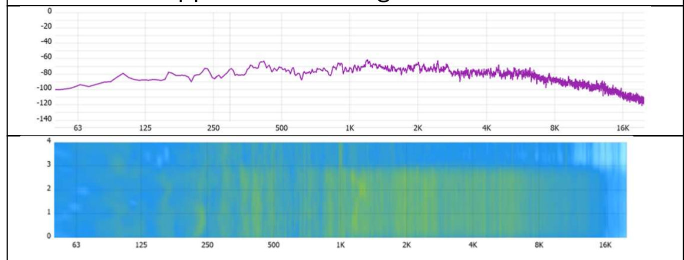
1.11 Koelkast in apotheekruimte



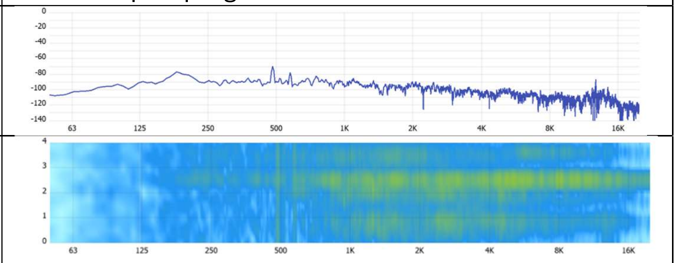
1.15 Ruisende intercom



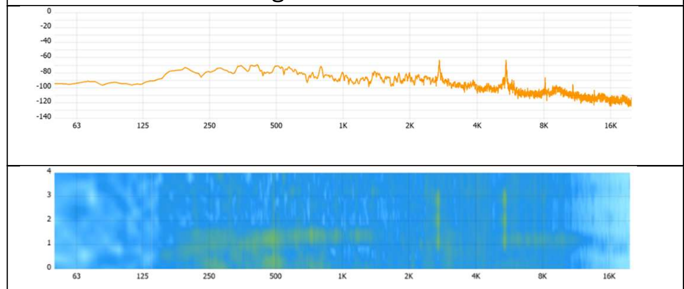
2.4 Koffiezetapparaat in werking



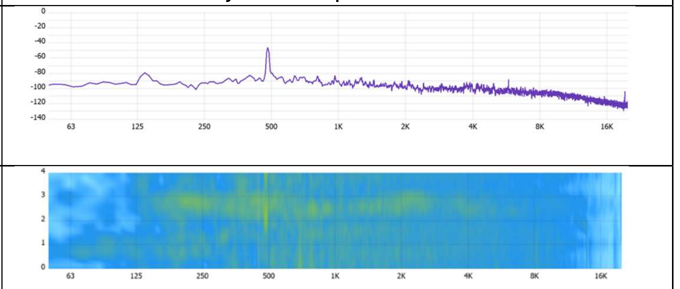
3.4 Infuuspomp signaal



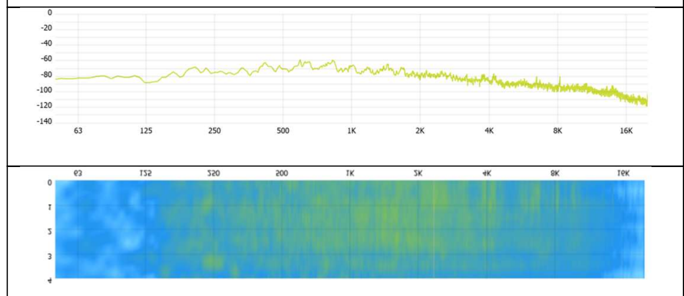
3.11 Reanimatiekar signaal



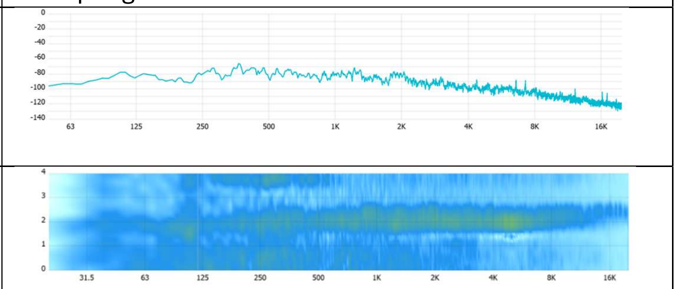
3.13 Geel alarm bij centraalpost



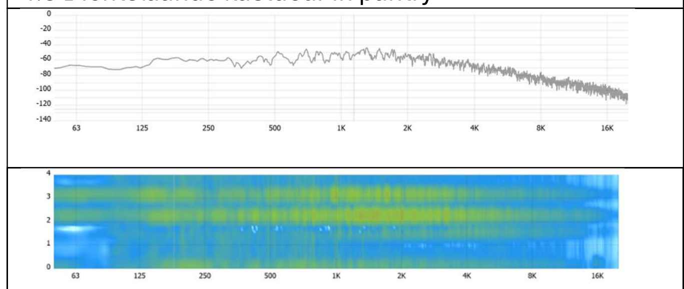
4.4 Rollende koffiekar



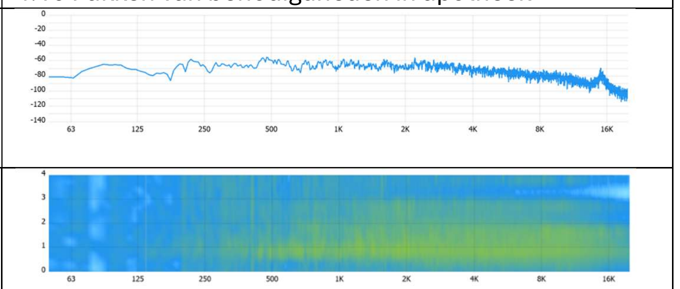
4.5 Opengaande IC-kamerdeur



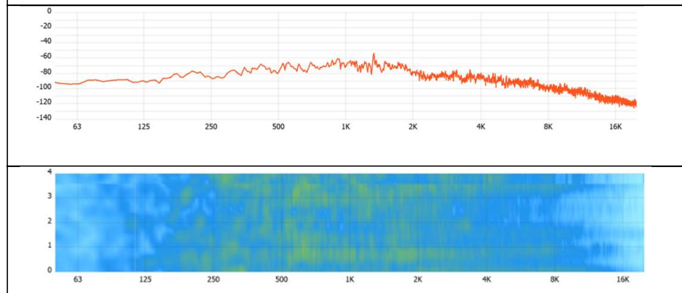
4.8 Dichtslaande kastdeur in pantry



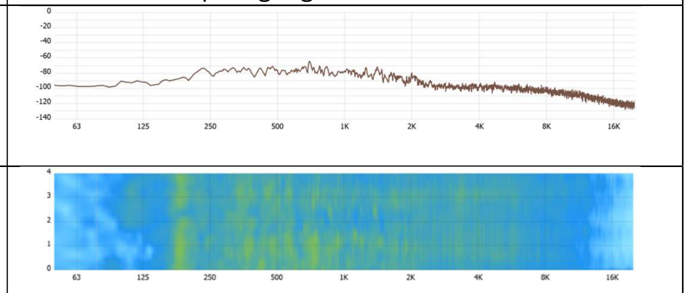
4.10 Pakken van benodigdheden in apotheek



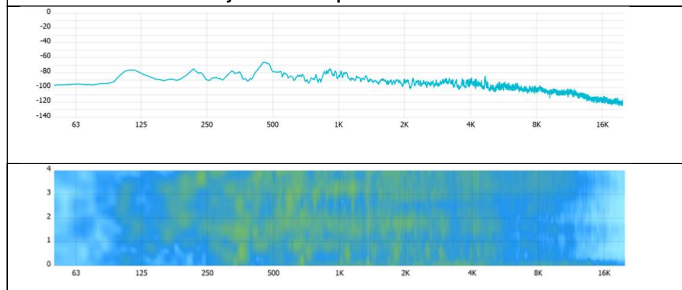
5.3 Gelach in IC-kamer



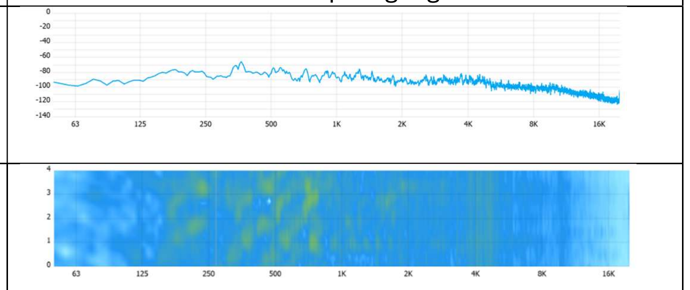
5.6 Small Talk op de gang



5.8 Telefoneren bij centraalpost



5.10 Medische discussie op de gang



Appendix 8 - List of sounds (experience analysis)

IC Geluidscatalogus

Op de IC zijn verschillende geluiden te vinden. Deze catalogus probeert de meeste hiervan in te delen. Geluiden kunnen prettig of onprettig in het oor zijn, maar soms heb je ze simpelweg nodig om goede en veilige zorg te kunnen verlenen. Vul het hokje in wat bij jou voor toepassing is.

#	Naam geluid	Locatie/ Omgeving	Wat vind je van het geluid?			Hoe beïnvloedt dit geluid jouw werk?			Hoe zou een patiënt dit ervaren?		
	Beschrijving van het geluid/ de geluidsbron of de activiteit die het geluid produceert	*De locatie van de geluidsbron*	*Beschrijf de estethiek van het geluid. Hoe klinkt het geluid op zichzelf?*			*Beschrijf de noodzaak van dit geluid om een goede en veilige zorg voor de patiënt te kunnen leveren.*			*Hoe denk je dat een patiënt dit geluid zou ervaren?*		
1.	Mechanische geluiden (continu geluid)		Onprettig/ Irritant	Neutraal/ Onverschillig	Prettig/ Prima	Storend/ Onnodig	Neutraal/ Onverschillig	Noodzakelijk/ Nodig	Storend/ Onprettig	Neutraal/ Onverschillig	Prettig/ Gewensd
1.1	Ventilatie van de ruimte/ Air Conditioning	Complete IC	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.2	Monitor - machine/motor geluid	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.3	Infuuspomp - machine/motor geluid	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.4	Ventilatie monitor - machine/motor geluid	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.5	Ventilatie monitor - lucht flow/ blaas/zuig geluid	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.6	Reanimatie kar - machine/motor geluid	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.7	Gas sample device/ Sample lab - machine/motor geluid	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.8	De voedselkar - machine/motor geluid	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.9	Koffiemachine - machine/motor geluid	In de pantry	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.10	Vaatwasser - machine/motor geluid	In de pantry	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.11	Koelkast - machine/motor geluid	In de pantry	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.12	Computer monitor - machine/motor geluid	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.13	Computer monitor - machine/motor geluid	Bij het zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
1.14	Overige medische apparaten/machines (ECMO, Hart/Long, Nier, etc.) - machine/motor geluid	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
2.	Mechanische geluiden (incidenteel geluid)		Onprettig/ Irritant	Neutraal/ Onverschillig	Prettig/ Prima	Storend/ Onnodig	Neutraal/ Onverschillig	Noodzakelijk/ Nodig	Storend/ Onprettig	Neutraal/ Onverschillig	Prettig/ Gewensd
2.1	Infuuspomp - mechanisch geluid van bewegende onderdelen	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
2.2	Wasmachine - machine/motor geluid	In de waskamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
2.3	Vaatwasser - bij het uitvoeren van een programma	In de pantry	☐	☐	☐	☐	☐	☐	☐	☐	☐
2.4	Koffiemachine - bij het maken van een drankje	In de pantry	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.	Electric ampilified/ generated sound		Onprettig/ Irritant	Neutraal/ Onverschillig	Prettig/ Prima	Storend/ Onnodig	Neutraal/ Onverschillig	Noodzakelijk/ Nodig	Storend/ Onprettig	Neutraal/ Onverschillig	Prettig/ Gewensd
3.1	Rood alarm - monitor	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.2	Geel alarm - monitor	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.3	Blauw alarm - monitor	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.4	Infuuspomp bliebje/alarm	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.5	Ventilatie alarm	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.6	Rinkelende telefoon/ Notificatie	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.7	Televisie/ Radio/ Muziek	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.8	Wasmachine blieb/melding	In de waskamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.9	Vaatwasser blieb/melding	In de pantry	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.10	Overige medische apparaten/machines (ECMO, Hart/Long, Nier, etc.) - blieb/alarm	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.11	Onbekende blieb/alarm/ Onbekende geluidsbron	Complete IC	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.12	Rood alarm - monitor	Bij het zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.13	Geel alarm - monitor	Bij het zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.14	Rood alarm - monitor	Vanuit een andere IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.15	Geel alarm - monitor	Vanuit een andere IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.16	Blauw alarm - monitor	Vanuit een andere IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐

3.17	Infuuspomp bliebje/alarm	Vanuit een andere IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.18	Ventilatie alarm	Vanuit een andere IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.	Menselijke activiteit (Materiaal-materiaal and lichaam-materiaal geluid)		Onprettig/ Irritant	Neutraal/ Onverschillig	Prettig/ Prima	Storend/ Onnodig	Neutraal/ Onverschillig	Noodzakelijk/ Nodig	Storend/ Onprettig	Neutraal/ Onverschillig	Prettig/ Gewensd
4.1	Lopen/ beweging	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.2	Lopen/ beweging	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.3	Duwen/bewegen van een trolley/ container	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.4	Duwen/bewegen van een trolley/ container	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.5	Openen en sluiten van deuren	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.6	Openen en sluiten van deuren	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.7	Openen en sluiten van kastjes	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.8	Openen en sluiten van kastjes	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.9	Spullen pakken/opruimen in kastjes	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.10	Spullen pakken/opruimen in kastjes	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.11	Plastic zakken verplaatsen (afval/de was)	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.12	Plastic zakken verplaatsen (afval/de was)	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.13	Computermuis klikjes	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.14	Computermuis klikjes	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.15	Stoel (rollende) beweging	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.16	Stoel (rollende) beweging	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.17	Stoel hoogte verstellen	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.18	Stoel hoogte verstellen	Op de gang	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.19	Ziekenhuisbed geluid van mechanische onderdelen	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.	Menselijk lichaam geluiden		Onprettig/ Irritant	Neutraal/ Onverschillig	Prettig/ Prima	Storend/ Onnodig	Neutraal/ Onverschillig	Noodzakelijk/ Nodig	Storend/ Onprettig	Neutraal/ Onverschillig	Prettig/ Gewensd
5.1	Non-verbaal/ Non-vocaal (klappen, niezen)	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.2	Non-verbaal/ Non-vocaal (klappen, niezen)	Op de gang/ Bij zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.3	Non-verbaal/ Vocaal (lachen, roepen, joelen)	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.4	Non-verbaal/ Vocaal (lachen, roepen, joelen)	Op de gang/ Bij zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.5	Verbaal/Vocaal – Smalltalk	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.6	Verbaal/Vocaal – Smalltalk	Op de gang/ Bij zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.7	Verbaal/Vocaal – Patiënt-gerelateerd (richting/met de patiënt)	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.8	Verbaal/Vocaal – Patiënt-gerelateerd (richting/met de patiënt)	Op de gang/ Bij zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.9	Verbaal/Vocaal – Medische discussie (zonder patiënt)	Binnen IC kamer	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.10	Verbaal/Vocaal – Medische discussie (zonder patiënt)	Op de gang/ Bij zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.11	Verbaal/Vocaal - Achtergrond gesprek/geluid	Op de gang/ Bij zusterstation	☐	☐	☐	☐	☐	☐	☐	☐	☐
6.	Buitengeluiden		Onprettig/ Irritant	Neutraal/ Onverschillig	Prettig/ Prima	Storend/ Onnodig	Neutraal/ Onverschillig	Noodzakelijk/ Nodig	Storend/ Onprettig	Neutraal/ Onverschillig	Prettig/ Gewensd
6.1	Natuur en geluid van het weer	Buiten het ziekenhuis	☐	☐	☐	☐	☐	☐	☐	☐	☐
6.2	Verkeersgeluiden	Buiten het ziekenhuis	☐	☐	☐	☐	☐	☐	☐	☐	☐
6.3	Dierengeluiden	Buiten het ziekenhuis	☐	☐	☐	☐	☐	☐	☐	☐	☐

Appendix 9 - Sound Catalogue

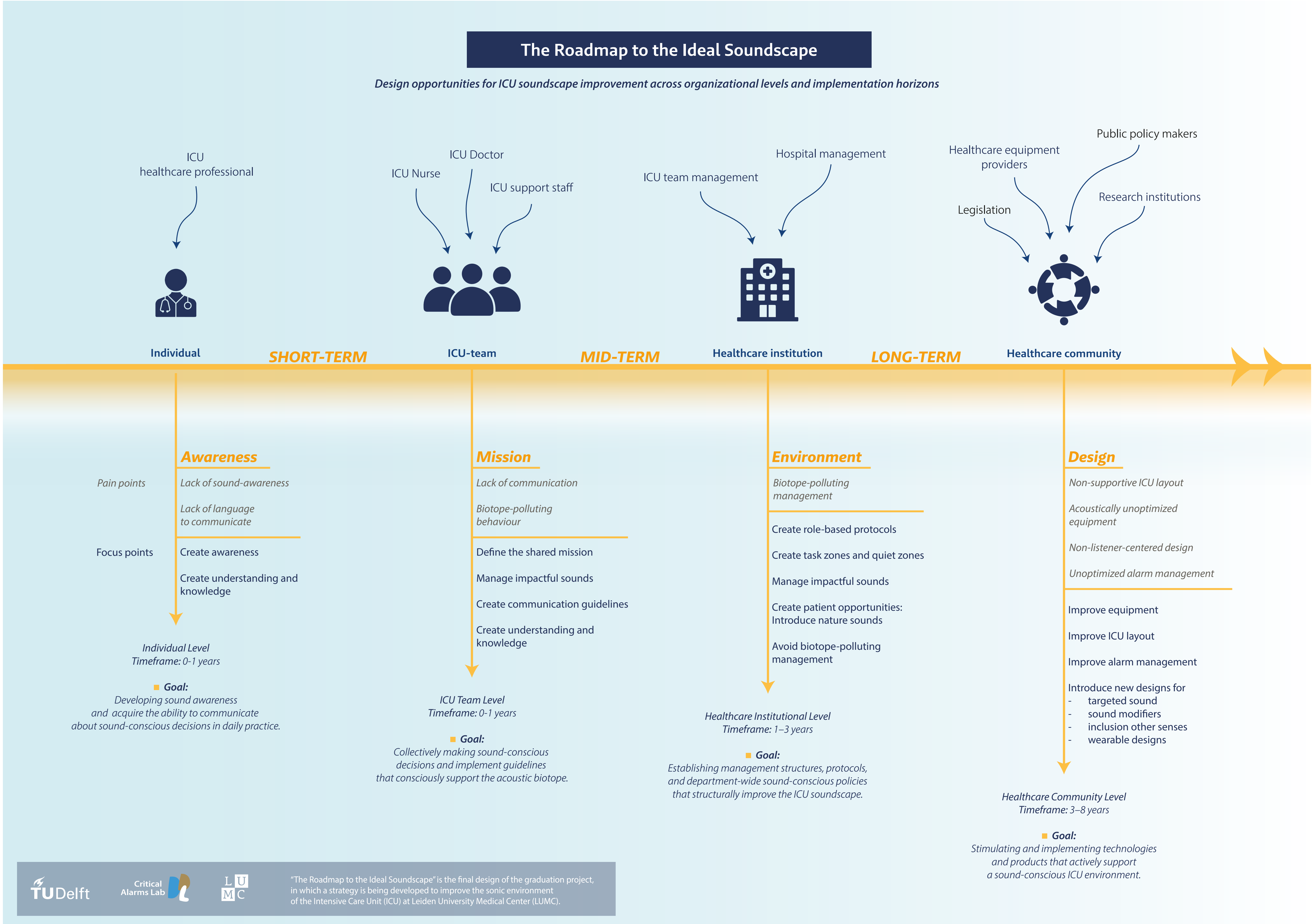
ICU Sound Catalogue

#	Sound name/ Event	Environment *Where is the sound source located?*	Sound description	Measurement data	Physical character *Measured or estimated*	Layering within acoustic environment *Based on observation and physical character*	Acoustic informative value *Auditory cues in the acoustic biotope*	Pollution of the acoustic biotope *Potential pollution risk*
1.	**Mechanical sounds (continous sounds)**							
1.1	Room ventilation/ Air Conditioning	Complete ICU	Continous mechanical sound produced by ventilation/ air conditioning unit	Available	Broadband, wide-spectrum	Masked unless absence other sounds	Zero to minimally infomative	Contributes to background ambient noise
1.2	Monitor - machine motor sound	Inside ICU Room	Continous mechanical sound produced by heart monitor	Available	Tonal over broadband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.3	Infusion pump - machine motor sound	Inside ICU Room	Continous mechanical sound produced by infusion pump	-	Tonal over broadband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.4	Ventilation monitoring - machine motor sound	Inside ICU Room	Continous mechanical sound produced by ventilation monitor	Available	Harmonic over broadband	Part of background, identifiable rythm	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.5	Ventilation monitoring - air flow sound	Inside ICU Room	Repetative air flow hissing sound produced by ventilation	Available	Narrowband, high-frequency dominated	Part of background, identifiable rythm	Medium informative, medical background information	Contributes to background ambient noise
1.6	Reanimation cart - machine motor sound	In Hall	Continous mechanical sound produced by reanimation cart charger	-	Tonal over broadband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.7	Gas sample device/ Sample lab	In Hall	Continous mechanical sound produced by this object	Available	Broadband, wide-spectrum	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.8	The Foodcar	In Hall	Continous mechanical sound produced by this object	Available	Tonal over broadband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.9	Coffee machine - machine motor sound	In Pantry	Continious mechanical sound produced by coffee machine	-	Tonal over broadband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.10	Dishwasher - machine motor sound	In Pantry	Continious mechanical sound produced by dishwasher	-	Tonal over broadband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.11	Refrigerator - machine motor sound	In Pantry	Continious mechanical sound produced by refrigerator	Available	Tonal over narrowband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.12	Computer monitor - machine motor sound	Inside ICU Room	Continious mechanical sound produced by computer	-	Tonal over narrowband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.13	Computer monitor - machine motor sound	At Nurse Station	Continious mechanical sound produced by computer	-	Tonal over narrowband	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
1.14	Additional medical equipment (ECMO, Hart/Lung/, Kidney, etc.) - machine motor sound	Inside ICU Room	Continious mechanical sound produced by additional medical equipement	-	-	Contributes to layer of ambient noise	Minimally informative, contextual relevant information	Contributes to background ambient noise
2.	**Mechanical sounds (incidental sounds)**							
2.1	Infusion pump - mechincal sounds from moving parts	Inside ICU Room	Incidental mechanical sounds produced by body parts moving, produced by infusion pump (loading and unloading medicine)	-	Multi-tonal over broadband	Impactful, volumnous and identifiable	Medium informative, medical background information	Impactful, overpowering other informative sounds, sound-masking
2.2	Washing machine - machine motor sound	In Washing room	Incidental mechanical sound produced by washing machine	-	Broadband, wide-spectrum	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
2.3	Dishwasher - when executing a program	In Pantry	Repetative mechanical and liquid pumping sounds when the dishwasher is on	-	Broadband, wide-spectrum	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
2.4	Coffee machine - producing beverage	In Pantry	Incidental mechanical and liquid sounds when coffee machine is working	Available	Multi-tonal over broadband	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
3.	**Electric ampilified/ generated sound**							
3.1	Red alarm - monitor	Inside ICU Room	Repatitve bleep signal indicating red alarm from heart monitor	-	Tonal	Penetrating pitch, identifiable	Highly informative, meaningful medical information	In case of false activation, habituation
3.2	Yellow alarm - monitor	Inside ICU Room	Repatitve bleep signal indicating yellow alarm from heart monitor	-	Tonal	Penetrating pitch, identifiable	Highly informative, meaningful medical information	In case of irrelevant repetition or false activation, redundancy and habituation, sound-masking
3.3	Blue alarm - monitor	Inside ICU Room	Repatitve bleep signal indicating blue alarm from heart monitor	-	Tonal	Penetrating pitch, identifiable	Medium informative, medical background information	In case of irrelevant repetition or false activation, redundancy and habituation, sound-masking
3.4	Infusion pump beeps/alarm	Inside ICU Room	Bleep signal indicating an empty pump or indicating a preperation signal	Available	Multi-tonal	Penetrating pitch, identifiable	Medium informative, medical background information	In case of irrelevant non-actionable information, habituation, sound-masking
3.5	Ventilator alarm	Inside ICU Room	Repatative set of tones indicating an ventilation alarm	-	Tonal	Penetrating pitch, identifiable	Highly informative, meaningful medical information	In case of irrelevant repetition or false activation, redundancy and habituation, sound-masking
3.6	Phone ringing/ notifaction	Inside ICU Room	Electronic induced musical sound indicating phone call or notification	-	Multi-tonal	Penetrating pitch, identifiable	Highly informative, meaningful communicative information	In case of irrelevant non-actionable information, habituation, sound-masking
3.7	Television/ Radio/ Music	Inside ICU Room	Electronic induced musical and/or vocal sound	-	Mixed spectrum	Recognizable, part of background	Minimally informative, contextual relevant information	Contributes to background ambient noise, sound-masking
3.8	Washing machine beep	In Washing room	Incidental bleep signal indicating the end of a washing cycle	-	Tonal	Penetrating pitch, identifiable	Minimally informative, contextual relevant information	Contributes to foreground sound signals while being medically irrelevant or non-actionable
3.9	Dishwasher beep	In Pantry	Incidental bleep signal indicating the end of a dishwashing cycle	-	Tonal	Penetrating pitch, identifiable	Minimally informative, contextual relevant information	Contributes to foreground sound signals while being medically irrelevant or non-actionable
3.10	Additional medical equipment (ECMO, Hart/Lung/, Kidney, etc.) - beep and/or alarm	Inside ICU Room	Incidental and/or Repatative bleeps produced by additional medical equipment	-	-	Penetrating pitch, identifiable	Medium informative, medical background information	In case of irrelevant repetition or false activation, redundancy and habituation, sound-masking
3.11	Unknown source beeps	Complete ICU	Incidental and/or Repatative bleeps produced by unknown equipment	Available	Tonal	Penetrating pitch, identifiable	Medium informative, medical background information	Contributes to foreground sound signals while being medically irrelevant or non-actionable
3.12	Red alarm - monitor	At Nurse Station	Repatitve bleep signal indicating red alarm from heart monitor	-	Tonal	Penetrating pitch, identifiable	Highly informative, meaningful medical information	In case of false activation, habituation
3.13	Yellow alarm - monitor	At Nurse Station	Repatitve bleep signal indicating yellow alarm from heart monitor	Available	Tonal	Penetrating pitch, identifiable	Highly informative, meaningful medical information	In case of irrelevant repetition or false activation, redundancy and habituation, sound-masking
3.14	Red alarm - monitor	From other ICU room	Repatitve bleep signal indicating red alarm from heart monitor	-	Tonal	Penetrating pitch, identifiable	Highly informative, meaningful medical information	In case of false activation, habituation
3.15	Yellow alarm - monitor	From other ICU room	Repatitve bleep signal indicating yellow alarm from heart monitor	-	Tonal	Penetrating pitch, identifiable	Medium informative, medical background information	High chance of irrelevant repetition or misleading information, redundancy and habituation, sound-masking
3.16	Blue alarm - monitor	From other ICU room	Repatitve bleep signal indicating blue alarm from heart monitor	-	Tonal	Penetrating pitch, identifiable	Medium informative, medical background information	High chance of irrelevant repetition or misleading information, redundancy and habituation, sound-masking
3.17	Infusion pump beeps/alarm	From other ICU room	Bleep signal indicating an empty pump or indicating a preperation signal	-	Multi-tonal	Penetrating pitch, identifiable	Medium informative, medical background information	High chance of irrelevant repetition or misleading information, redundancy and habituation, sound-masking
3.18	Ventilator alarm	From other ICU room	Repatative set of tones indicating an ventilation alarm	-	Tonal	Penetrating pitch, identifiable	Medium informative, medical background information	High chance of irrelevant repetition or misleading information, redundancy and habituation, sound-masking
3.19	Intercom system noise	In Hall	Continious noise feedback from intercom speakers	Available	Mixed spectrum over broadband	Contributes to layer of ambient noise	Medium informative, medical background information	Contributes to background ambient noise, sound-masking
4.	**Human activity sounds (Material-material and body-material sounds)**							
4.1	Walking/ Movement	Inside ICU Room	Impact sound body on floor	-	Impact narrowband	Impactful, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
4.2	Walking/ Movement	In Hall	Impact sound body on floor	-	Impact narrowband	Recognizable, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
4.3	Pushing trolley/ Container	Inside ICU Room	Impact/Rolling squeezing sound material on floor	-	Mixed spectrum over broadband	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
4.4	Pushing trolley/ Container	In Hall	Impact/Rolling squeezing sound material on floor	Available	Mixed spectrum over broadband	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
4.5	Opening/Closing doors	Inside ICU Room	Impact sound from door opening and closing	Available	Impact broadband, mid/high-frequency dominated	Impactful, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
4.6	Opening/Closing doors	In Hall	Impact sound from door opening and closing	-	Impact broadband, mid/high-frequency dominated	Recognizable, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
4.7	Opening/Closing furniture	Inside ICU Room	Impact sound from door opening and closing	-	Impact broadband	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
4.8	Opening/Closing furniture	In Hall	Impact sound from door opening and closing	Available	Impact broadband	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
4.9	Getting supplies/ Restock closets	Inside ICU Room	Variety of impact and ristling sounds materials making contact	-	Broadband, high-frequency dominated	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
4.10	Getting supplies/ Restock closets	In Hall	Variety of impact and ristling sounds materials making contact	Available	Broadband, high-frequency dominated	Impactful, volumnous and identifiable	Minimally informative, contextual relevant information	Impactful, overpowering other informative sounds, sound-masking
4.11	Moving platic bags (Garbage/ Laundry)	Inside ICU Room	Variety of ristling sounds, material making contact	-	Broadband, high-frequency dominated	Impactful, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
4.12	Moving platic bags (Garbage/ Laundry)	In Hall	Variety of ristling sounds, material making contact	-	Broadband, high-frequency dominated	Recognizable, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
4.13	Computer mouse clicks	Inside ICU Room	Incidental mechanical impact between body parts of the computer mouse when clicking	-	Narrowband, high-frequency dominated	Recognizable, masked unless absence other sounds	Minimally informative, contextual relevant information	When repeatedly or intrusively present, annoyance
4.14	Computer mouse clicks	At Nurse Station	Incidental mechanical impact between body parts of the computer mouse when clicking	-	Narrowband, high-frequency dominated	Recognizable, masked unless absence other sounds	Minimally informative, contextual relevant information	When repeatedly or intrusively present, annoyance
4.15	Chair moving and/or rolling	Inside ICU Room	Incidental mechanical sound between wheels of chair and floor	-	Mixed spectrum over broadband	Impactful, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, annoyance
4.16	Chair moving and/or rolling	At Nurse Station	Incidental mechanical sound between wheels of chair and floor	-	Mixed spectrum over broadband	Recognizable, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, annoyance
4.17	Chair changing hights	Inside ICU Room	Incidental mechanical and hissing sound when changing the hights of a desk chair	-	Narrowband, high-frequency dominated	Impactful, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, annoyance
4.18	Chair changing hights	At Nurse Station	Incidental mechanical and hissing sound when changing the hights of a desk chair	-	Narrowband, high-frequency dominated	Recognizable, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, annoyance
4.19	Hospital bed mechanical body part sounds	Inside ICU Room	Incidental mechanical sound when pushing up or down the bed supports or other body parts	-	Narrowband, high-frequency dominated	Impactful, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
5.	**Human body sounds**							
5.1	Non-verbal/ Non-vocal (clapping, sneezing)	Inside ICU Room	Sounds the human body can produce, clapping, sneezing, coughing	-	Broadband	Recognizable, identifiable	Zero to minimally infomative	When repeatedly or intrusively present, sound-masking
5.2	Non-verbal/ Non-vocal (clapping, sneezing)	In Hall/ At Nurse Station	Sounds the human body can produce, clapping, sneezing, coughing	-	Broadband	Recognizable, part of background	Zero to minimally infomative	When repeatedly or intrusively present, sound-masking
5.3	Non-verbal/ Vocal (laughing, yelling)	Inside ICU Room	Sounds the human voice can produce, screeming, yelling, laughing	Available	Mixed spectrum over broadband	Recognizable, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
5.4	Non-verbal/ Vocal (laughing, yelling)	In Hall/ At Nurse Station	Sounds the human voice can produce, screeming, yelling, laughing	-	Mixed spectrum over broadband	Recognizable, part of background	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
5.5	Verbal/Vocal – Smalltalk	Inside ICU Room	Verbal sounds of the human voice, recognizable conversion about personal topics	-	Mixed spectrum over broadband	Recognizable, mixed, identifiable	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
5.6	Verbal/Vocal – Smalltalk	In Hall/ At Nurse Station	Verbal sounds of the human voice, recognizable conversion about personal topics	Available	Mixed spectrum over broadband	Recognizable, part of background	Minimally informative, contextual relevant information	When repeatedly or intrusively present, sound-masking
5.7	Verbal/Vocal – Patient related	Inside ICU Room	Verbal sounds of the human voice, recognizable conversion to a patient or about a patient status	-	Mixed spectrum over broadband	Recognizable, mixed, identifiable	Highly informative, meaningful communicative information	When repeatedly or intrusively present, sound-masking
5.8	Verbal/Vocal – Patient related	In Hall/ At Nurse Station	Verbal sounds of the human voice, recognizable conversion to a patient or about a patient status	Available	Mixed spectrum over broadband	Recognizable, part of background	Highly informative, meaningful communicative information	When repeatedly or intrusively present, sound-masking
5.9	Verbal/Vocal – Medical discussion	Inside ICU Room	Verbal sounds of the human voice, recognizable conversion about medical test results or discussions about a patient's treatment plan	-	Mixed spectrum over broadband	Recognizable, mixed, identifiable	Highly informative, meaningful communicative information	When repeatedly or intrusively present, sound-masking
5.10	Verbal/Vocal – Medical discussion	In Hall/ At Nurse Station	Verbal sounds of the human voice, recognizable conversion about medical test results or discussions about a patient's treatment plan	Available	Mixed spectrum over broadband	Recognizable, part of background	Highly informative, meaningful communicative information	When repeatedly or intrusively present, sound-masking
5.11	Verbal/Vocal - Background talking/ Other	In Hall/ At Nurse Station	Verbal sounds of the human voice, unrecognizable conversation	-	Broadband	Part of background	Minimally informative, contextual relevant information	Contributes to background ambient noise, sound-masking
6.	**Outdoor sounds**							
6.1	Nature/ weather sounds	Outside Hospital	Variety of sounds recognizable from outdoor nature and or weather	-	Broadband, wide-spectrum	Part of background	Zero to minimally infomative	Contributes to background ambient noise, sound-masking
6.2	Traffic sounds	Outside Hospital	Variety of sounds recognizable from outdoor traffic	-	Mixed spectrum over broadband	Part of background	Zero to minimally infomative	Contributes to background ambient noise, sound-masking
6.3	Animal sounds	Outside Hospital	Variety of sounds produced by animals (outdoor)	-	Mixed spectrum over broadband	Part of background	Zero to minimally infomative	Contributes to background ambient noise, sound-masking

ICU Sound Catalogue

#	Sound name/ Event	Sound event occurence	Experience - Sound Aesthetics			Experience - Need/ Necessity			Experience - Patient's perspective		
		Based on frequency observations	*Unpleasant/ Annoying*	*Neutral/ Indifferent*	*Pleasant/ Fine*	*Disturbing/ Unnecessary*	*Neutral/ Indifferent*	*Necessary/ Needed*	*Disturbing/ Unnecessary*	*Neutral/ Indifferent*	*Pleasant/ Wanted*
1.	**Mechanical sounds (continous sounds)**										
1.1	Room ventilation/ Air Conditioning	5. Always present	0,0%	45,5%	54,5%	9,1%	81,8%	9,1%	36,4%	63,6%	0,0%
1.2	Monitor - machine motor sound	5. Always present	18,2%	63,6%	18,2%	0,0%	90,9%	9,1%	27,3%	72,7%	0,0%
1.3	Infusion pump - machine motor sound	5. Always present	27,3%	45,5%	27,3%	9,1%	72,7%	18,2%	27,3%	72,7%	0,0%
1.4	Ventilation monitoring - machine motor sound	5. Always present	10,0%	70,0%	20,0%	0,0%	80,0%	20,0%	30,0%	70,0%	0,0%
1.5	Ventilation monitoring - air flow sound	5. Always present	10,0%	40,0%	50,0%	0,0%	60,0%	40,0%	44,4%	55,6%	0,0%
1.6	Reanimation cart - machine motor sound	5. Always present	10,0%	60,0%	30,0%	0,0%	80,0%	20,0%	11,1%	77,8%	11,1%
1.7	Gas sample device/ Sample lab	5. Always present	0,0%	77,8%	22,2%	0,0%	70,0%	30,0%	12,5%	75,0%	12,5%
1.8	The Foodcar	5. Always present	30,0%	60,0%	10,0%	18,2%	54,5%	27,3%	11,1%	77,8%	11,1%
1.9	Coffee machine - machine motor sound	5. Always present	9,1%	63,6%	27,3%	18,2%	63,6%	18,2%	20,0%	70,0%	10,0%
1.10	Dishwasher - machine motor sound	5. Always present	0,0%	72,7%	27,3%	0,0%	81,8%	18,2%	10,0%	80,0%	10,0%
1.11	Refrigerator - machine motor sound	5. Always present	9,1%	63,6%	27,3%	0,0%	81,8%	18,2%	10,0%	80,0%	10,0%
1.12	Computer monitor - machine motor sound	5. Always present	0,0%	72,7%	27,3%	9,1%	72,7%	18,2%	30,0%	60,0%	10,0%
1.13	Computer monitor - machine motor sound	5. Always present	0,0%	72,7%	27,3%	9,1%	72,7%	18,2%	25,0%	62,5%	12,5%
1.14	Additional medical equipment (ECMO, Hart/Lung/, Kidney, etc.) - machine motor sound	5. Always present	27,3%	36,4%	36,4%	20,0%	50,0%	30,0%	54,5%	45,5%	0,0%
2.	**Mechanical sounds (incidental sounds)**										
2.1	Infusion pump - mechincal sounds from moving parts	3. Occasional present	27,3%	63,6%	9,1%	0,0%	90,9%	9,1%	70,0%	30,0%	0,0%
2.2	Washing machine - machine motor sound	3. Occasional present	27,3%	54,5%	18,2%	36,4%	54,5%	9,1%	36,4%	54,5%	9,1%
2.3	Dishwasher - when executing a program	3. Occasional present	9,1%	63,6%	27,3%	18,2%	63,6%	18,2%	22,2%	66,7%	11,1%
2.4	Coffee machine - producing beverage	3. Occasional present	36,4%	36,4%	27,3%	18,2%	63,6%	18,2%	22,2%	66,7%	11,1%
3.	**Electric ampilified/ generated sound**										
3.1	Red alarm - monitor	2. Limited present	45,5%	18,2%	36,4%	9,1%	18,2%	72,7%	77,8%	22,2%	0,0%
3.2	Yellow alarm - monitor	3. Occasional present	36,4%	36,4%	27,3%	0,0%	27,3%	72,7%	77,8%	22,2%	0,0%
3.3	Blue alarm - monitor	3. Occasional present	63,6%	18,2%	18,2%	27,3%	36,4%	36,4%	88,9%	11,1%	0,0%
3.4	Infusion pump beeps/alarm	2. Limited present	54,5%	18,2%	27,3%	18,2%	18,2%	63,6%	88,9%	11,1%	0,0%
3.5	Ventilator alarm	2. Limited present	36,4%	45,5%	18,2%	0,0%	27,3%	72,7%	77,8%	22,2%	0,0%
3.6	Phone ringing/ notifaction	3. Occasional present	36,4%	36,4%	27,3%	45,5%	27,3%	27,3%	62,5%	37,5%	0,0%
3.7	Television/ Radio/ Music	3. Occasional present	18,2%	54,5%	27,3%	18,2%	63,6%	18,2%	0,0%	55,6%	44,4%
3.8	Washing machine beep	3. Occasional present	9,1%	54,5%	36,4%	36,4%	45,5%	18,2%	25,0%	50,0%	25,0%
3.9	Dishwasher beep	3. Occasional present	9,1%	54,5%	36,4%	27,3%	54,5%	18,2%	25,0%	62,5%	12,5%
3.10	Additional medical equipment (ECMO, Hart/Lung/, Kidney, etc.) - beep and/or alarm	3. Occasional present	40,0%	30,0%	30,0%	10,0%	10,0%	80,0%	88,9%	11,1%	0,0%
3.11	Unknown source beeps	3. Occasional present	60,0%	40,0%	0,0%	30,0%	30,0%	40,0%	77,8%	22,2%	0,0%
3.12	Red alarm - monitor	2. Limited present	54,5%	27,3%	18,2%	27,3%	9,1%	63,6%	40,0%	60,0%	0,0%
3.13	Yellow alarm - monitor	3. Occasional present	45,5%	36,4%	18,2%	18,2%	18,2%	63,6%	40,0%	60,0%	0,0%
3.14	Red alarm - monitor	2. Limited present	63,6%	18,2%	18,2%	27,3%	9,1%	63,6%	60,0%	40,0%	0,0%
3.15	Yellow alarm - monitor	3. Occasional present	54,5%	27,3%	18,2%	18,2%	18,2%	63,6%	60,0%	40,0%	0,0%
3.16	Blue alarm - monitor	3. Occasional present	72,7%	18,2%	9,1%	36,4%	9,1%	54,5%	50,0%	50,0%	0,0%
3.17	Infusion pump beeps/alarm	2. Limited present	80,0%	20,0%	0,0%	55,6%	11,1%	33,3%	90,0%	10,0%	0,0%
3.18	Ventilator alarm	2. Limited present	60,0%	40,0%	0,0%	33,3%	22,2%	44,4%	80,0%	20,0%	0,0%
3.19	Intercom system noise	4. Frequently present									
4.	**Human activity sounds (Material-material and body-material soun**										
4.1	Walking/ Movement	4. Frequently present	0,0%	70,0%	30,0%	0,0%	80,0%	20,0%	55,6%	44,4%	0,0%
4.2	Walking/ Movement	4. Frequently present	10,0%	60,0%	30,0%	0,0%	80,0%	20,0%	44,4%	55,6%	0,0%
4.3	Pushing trolley/ Container	3. Occasional present	40,0%	40,0%	20,0%	20,0%	70,0%	10,0%	75,0%	25,0%	0,0%
4.4	Pushing trolley/ Container	3. Occasional present	50,0%	30,0%	20,0%	20,0%	70,0%	10,0%	50,0%	37,5%	12,5%
4.5	Opening/Closing doors	2. Limited present	0,0%	80,0%	20,0%	10,0%	80,0%	10,0%	62,5%	37,5%	0,0%
4.6	Opening/Closing doors	2. Limited present	0,0%	80,0%	20,0%	10,0%	80,0%	10,0%	50,0%	50,0%	0,0%
4.7	Opening/Closing furniture	4. Frequently present	10,0%	70,0%	20,0%	0,0%	90,0%	10,0%	50,0%	50,0%	0,0%
4.8	Opening/Closing furniture	4. Frequently present	0,0%	80,0%	20,0%	10,0%	80,0%	10,0%	37,5%	62,5%	0,0%
4.9	Getting supplies/ Restock closets	4. Frequently present	0,0%	80,0%	20,0%	0,0%	90,0%	10,0%	50,0%	50,0%	0,0%
4.10	Getting supplies/ Restock closets	4. Frequently present	0,0%	80,0%	20,0%	10,0%	80,0%	10,0%	37,5%	62,5%	0,0%
4.11	Moving platic bags (Garbage/ Laundry)	3. Occasional present	0,0%	70,0%	30,0%	0,0%	80,0%	20,0%	62,5%	37,5%	0,0%
4.12	Moving platic bags (Garbage/ Laundry)	3. Occasional present	0,0%	70,0%	30,0%	0,0%	80,0%	20,0%	50,0%	50,0%	0,0%
4.13	Computer mouse clicks	2. Limited present	10,0%	60,0%	30,0%	0,0%	90,0%	10,0%	37,5%	50,0%	12,5%
4.14	Computer mouse clicks	2. Limited present	20,0%	50,0%	30,0%	10,0%	70,0%	20,0%	37,5%	50,0%	12,5%
4.15	Chair moving and/or rolling	2. Limited present	20,0%	50,0%	30,0%	0,0%	80,0%	20,0%	37,5%	62,5%	0,0%
4.16	Chair moving and/or rolling	2. Limited present	10,0%	60,0%	30,0%	0,0%	80,0%	20,0%	37,5%	62,5%	0,0%
4.17	Chair changing hights	2. Limited present	10,0%	60,0%	30,0%	0,0%	80,0%	20,0%	37,5%	62,5%	0,0%
4.18	Chair changing hights	2. Limited present	10,0%	60,0%	30,0%	0,0%	80,0%	20,0%	37,5%	62,5%	0,0%
4.19	Hospital bed mechanical body part sounds	3. Occasional present	20,0%	60,0%	20,0%	20,0%	70,0%	10,0%	42,9%	57,1%	0,0%
5.	**Human body sounds**										
5.1	Non-verbal/ Non-vocal (clapping, sneezing)	2. Limited present	40,0%	20,0%	40,0%	40,0%	40,0%	20,0%	62,5%	37,5%	0,0%
5.2	Non-verbal/ Non-vocal (clapping, sneezing)	2. Limited present	40,0%	20,0%	40,0%	30,0%	50,0%	20,0%	62,5%	37,5%	0,0%
5.3	Non-verbal/ Vocal (laughing, yelling)	3. Occasional present	70,0%	20,0%	10,0%	60,0%	30,0%	10,0%	75,0%	25,0%	0,0%
5.4	Non-verbal/ Vocal (laughing, yelling)	3. Occasional present	60,0%	30,0%	10,0%	50,0%	40,0%	10,0%	87,5%	12,5%	0,0%
5.5	Verbal/Vocal – Smalltalk	3. Occasional present	60,0%	20,0%	20,0%	50,0%	40,0%	10,0%	50,0%	25,0%	25,0%
5.6	Verbal/Vocal – Smalltalk	3. Occasional present	20,0%	60,0%	20,0%	20,0%	70,0%	10,0%	42,9%	57,1%	0,0%
5.7	Verbal/Vocal – Patient related	3. Occasional present	10,0%	40,0%	50,0%	10,0%	40,0%	50,0%	22,2%	11,1%	66,7%
5.8	Verbal/Vocal – Patient related	3. Occasional present	0,0%	50,0%	50,0%	0,0%	50,0%	50,0%	22,2%	22,2%	55,6%
5.9	Verbal/Vocal – Medical discussion	2. Limited present	30,0%	40,0%	30,0%	20,0%	50,0%	30,0%	55,6%	44,4%	0,0%
5.10	Verbal/Vocal – Medical discussion	2. Limited present	10,0%	50,0%	40,0%	10,0%	60,0%	30,0%	44,4%	55,6%	0,0%
5.11	Verbal/Vocal - Background talking/ Other	4. Frequently present	20,0%	50,0%	30,0%	20,0%	60,0%	20,0%	25,0%	50,0%	25,0%
6.	**Outdoor sounds**										
6.1	Nature/ weather sounds	1. (Almost) Never present	0,0%	10,0%	90,0%	0,0%	100,0%	0,0%	0,0%	50,0%	50,0%
6.2	Traffic sounds	1. (Almost) Never present	10,0%	50,0%	40,0%	10,0%	90,0%	0,0%	30,0%	60,0%	10,0%
6.3	Animal sounds	1. (Almost) Never present	0,0%	30,0%	70,0%	0,0%	100,0%	0,0%	30,0%	40,0%	30,0%

Appendix 10 - Roadmap poster



Appendix 11 - Evaluation results

Evaluation session

Participant #	Gende	Age	Function	Experience	Feedback points (original)	Feedback point
1	26	M	Intern Technical Medicine	1 week	Denk uitgebreid veel onderdelen van IC geluid inbegrepen, dus dat is mooi. Hoe detailleerd wil je gaan?	Extensive research and analysis
					Denk uitgebreid veel onderdelen van IC geluid inbegrepen, dus dat is mooi. Hoe detailleerd wil je gaan?	Detailing and concrete actionability
					Quiet zones is moeilijk van technische alarmen die cruciaal zijn. Dus voor wie is deze zone bedoeld? Patient of zorgverlener?	Execution will be challenging
					Quiet zones is moeilijk van technische alarmen die cruciaal zijn. Dus voor wie is deze zone bedoeld? Patient of zorgverlener?	General comment
					Vrij brede aspecten. Wil je hier in verdiepen of is dat nog niet de bedoeling	General comment
2	25	V	Basisarts (General physician)	7 months	[Introduce nature sounds] Goed!	General postive feedback
3	29	M	ANIOS (Non-resident physician)	4 years	[Commucation guidelines][Create task and quiet zones] Erg belerend om professionals op te leggen waar en wanneer te praten	Actionability without being patrionizing will be challenging
					[Introduce nature sounds] Zorg voor mogelijkheid dat patient zelf kan kiezen welke geluiden hij hoort	Implementation Suggestion
					[Design] Belangrijk op IC LUMC dat de juiste alarmen bij de juiste mensen komen, nu worden ze vaak gehoord door mensen die het niet hoeven te horen en niet gehoord door degene die het moeten horen. Vb: Normale bel van een kamer hoort iedereen op de IC. Noodbel is zachter en moeilijker te horen in de artsenkamer	General comment
					[Improve equipment] Persoonlijke seinen waar hulpbellen op komen	Implementation Suggestion
4	37	V	AIOS (Resident physician}	2,25 years	Persoonlijk had ik al wel wat awareness, dus de fase overgeslagen t.o.v. de roadmap	General comment
					Breder dan dit project: Om beslissingen te nemen over geluid moet er een gevoel van autonomie/invloed zijn, lastiger: op IC hebben we heel veel passagere mdw. stage, opleiding etc, eigenaarschap	Decide ownership
					Breder dan dit project: Om beslissingen te nemen over geluid moet er een gevoel van autonomie/invloed zijn, lastiger: op IC hebben we heel veel passagere mdw. stage, opleiding etc, eigenaarschap	Continuity risk
					Aandacht voor het thema	General postive feedback
					Inbedding in breder concept van bandwith/human factors	Extensive research and analysis
					Korte naar lange termijn	Informative value poster
					Delft mogelijk onderspit in alle thema's die om onze aandacht/input vragen	[Unclear feedback]
					Veel passagere mdw. op IC. Wie is de 'owner' van dit proces. Ervaren mensen zeggenschap/invloed	Decide ownership
					Veel passagere mdw. op IC. Wie is de 'owner' van dit proces. Ervaren mensen zeggenschap/invloed	Continuity risk
5	35	V	Fellow IC	1,5 years	Veel dingen goed met duidelijke afspraken te verbeteren bijv. zones, afspraken [xx] verbouwing, bepaalde ondersteunende taken	General postive feedback
					Niet per se veel tijd nodig maar wel belangrijk dit als prioriteit te stellen	Realistic implementation
					Evt. dedicated breakroom, en alarmen niet in gedeelde ruimtes	Implementation Suggestion
					Evt. beter patienten op te splitsen in ruimtes -> postop vs. Intox vs. Slapend	Implementation Suggestion
					Goede inventarisatie soort geluiden (hoe dit wordt ervaren en dus waar aan gewerkt moet worden)	Extensive research and analysis
					Suggestie natuurgeluiden ook goed. Bijv. VR of oordopjes etc. ook veel literatuur over op [xx].	General postive feedback
					Suggestie natuurgeluiden ook goed. Bijv. VR of oordopjes etc. ook veel literatuur over op [xx].	Implementation Suggestion
					Veel dingen denk ik pas op hele lange termijn pas haalbaar (layout IC, nieuwe monitor systemen en draagbare device etc)	Realistic implementation
6	29	V	Onderzoeker (PhD)	4-5 years	[Create awareness] Door wie?	Decide ownership
					[Create understanding and knowlegde] Hoe?	Detailing and concrete actionability
					Wie zorgt ervoor dat de awareness wordt gecreateerd?	Decide ownership
					[Healthcare equipment providers] Belangrijk! Fabrikanten spelen een grote rol hierin.	General postive feedback
					[Public policy makers] Eisen/requirements opstellen zorgt ervoor dat fabrikanten ervoor worden gedwongen of geluidsdichte rooms	Implementation Suggestion
					Tips: Meer concrete voorbeelden of stappen	Detailing and concrete actionability
7	27	V	Onderzoeker (PhD)	3 years	Wie is hoofdverantwoordelijk voor dit probleem? En wie zorgt ervoor dat de awareness uitgedragen wordt.	Decide ownership
					Ik weet niet zeker of het haalbaar is gerichte ruimtes voor bepaalde gesprekken te vormen	Realistic implementation
					Goed aan veel verschillende aspecten gedacht. Ik denk dat er erg samengewerkt moet worden met de fabrikanten om alarmen te beperken	Extensive research and analysis
					Goed aan veel verschillende aspecten gedacht. Ik denk dat er erg samengewerkt moet worden met de fabrikanten om alarmen te beperken	Implementation Suggestion
					Toevoegen verantwoordelijke	Decide ownership
8	26	M	Onderzoeker (PhD)	1 year	Denk dat er aan groot samenspel/tegelijkertijd gebeurd is tussen individu en team en management. Dat wordt nu misschien nu minder duidelijk.	[Unclear feedback]
					Praktische 1ste stap/stappenplan ontbreekt. Waar moet iemand die dit wil aanpakken nu beginnen?	Detailing and concrete actionability
					Tijdlijnen zijn goed.	Informative value poster
					Focus op grootste leverage zou handig zijn -> Waar ligt de meeste waarde met de minste inzet	Include potentential benefit
9	28	V	ANIOS (Non-resident physician)	<1 year	Realistische roadmap. Veel van de beschreven problematiek is herkenbaar.	Realistic reflection
					Doelen zien er haalbaar uit	Realistic implementation
					Goede en haalbare doelen. Realistisch tijdframe	Realistic implementation
					Vooral op individueel en ICU team level nog wel wat vaag. Wat er nu wat ons als persoon verwacht wordt	Detailing and concrete actionability
10	26	M	Co-assistent	0,5 year	Zinnig om na awareness bijeen te komen en knelpunten te bespreken. Hieruit plan van omgang met afspraken maken	General postive feedback
					Alarmen getarget maken op de ontvanger met regelgeving en aansprakelijk waardoor fabrikanten dit niet willen maken	Realistic implementation
11	34	V	AIOS (Resident physician}	2 years	Ruimte waar artsen kunnen werken, zonder dat daar ook verpleging luncht, koffiedrinkt of overdraagt	Implementation Suggestion
					Alarmen die alleen bij degene komt die het nodig heeft, zou heel fijn zijn	General postive feedback
12	25	M	Co-assistent	2 weeks	[Create understanding and knowlegde] [Lack of communication] Ik denk dat deze doelen haalbaar zijn in het eerste jaar. De grootste valkuil is denk ik dat mensen na een korte tijd weer in hun oude patronen vallen. Een wekelijkse reminder zou kunnen helpen	Continuity risk
13	33	V	Basisarts (General physician)	2 years	[Create awareness] Misschien de soundmap ook delen, zijn mensen er zich van bewust dat daar veel lawaai is.	General comment
					[Biotope-polluting behaviour] Moeilijk voor te stellen wat dit precies is	Informative value poster
					[Create task zones and quiet zones] Sterk punt, als hier ruimte voor is	General postive feedback
					[Create patient opportunities, Include nature sounds] Ook goed idee, kan meditatief werkn	General postive feedback
14	24	M	Co-assistent	2 years	Goede representatie! Zelf vanuit mijn eigen ervaring merk ik dat mijn pomp alarmen erg storend zijn, als ze niet zsm worden uitgezet. Dit is iets wat (wakkere) patienten ook benoemen	Realistic reflection
					Goede representatie! Zelf vanuit mijn eigen ervaring merk ik dat mijn pomp alarmen erg storend zijn, als ze niet zsm worden uitgezet. Dit is iets wat (wakkere) patienten ook benoemen	General comment
					[Wearable designs] Lijkt me zeer nuttig! Als de verpleegkundige een eigen pieper heeft met de alarmen op zijn/haar kamer, is de reactiesnelheid op alarmen veel adequater, denk ik!	General postive feedback
					[Wearable designs] Lijkt me zeer nuttig! Als de verpleegkundige een eigen pieper heeft met de alarmen op zijn/haar kamer, is de reactiesnelheid op alarmen veel adequater, denk ik!	General comment