Patrick Wetzels
Graduation Report

Translating Sound into Light

A Responsive Lighting System Complementing Sonic Ambiances in the ICU

TRANSLATING SOUND INTO LIGHT
A Responsive Lighting System Complementing
Sonic Ambiances in the ICU

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MASTER THESIS
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Erasmus Medical Center
Critical Alarms Lab

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Acknowledgements

This might be an individual project, but I could not have done this alone without the help from some incredible people around me.

First of all my team, my supervisors. Elif, thank you a lot for your knowledge, wise words, discipline and trust in me with this project. You've caught my eye since I've started my bachelor here with Form and Senses/experience, my two favourite subjects. The world of sound is so intriguing and I am very happy to have been able to work and learn aside you in the same field, an honour. Charl, thank you for starting this journey with me. Meeting you as a coach in Lighting Design, I noticed your passion for lighting design caught my attention. Thank you for taking that first step with me in being my mentor and guiding me along this journey. Thank you for checking on me, I appreciate it. Ela, thank you for your knowledge on both topics of sound and light! Also helping me at Erasmus MC, getting places and helping me out with talking to healthcare professionals, etc. Thank you for your support and kindness, I am grateful for that. Thankyou team for guiding me along the way, pushing me when I needed it, listening to me when I doubted myself. Thank you!

I would like to thank my dear friends for helping me in moments when I need it most. You guys know who you are! I appreciate it a lot :) A big thank you to my family who is and were always there for me. It's a journey I could not have done alone. Terima kasih :) And I would like to thank my lovely girlfriend who was always there by my side. Supporting me no matter what, knowing what I needed at all times. I appreciate you and thank you.

Preface

I have been passionate about light and sound for many years. Through photography, I discovered how light can completely transform an atmosphere, shaping how we perceive space and emotion. My fascination with music and speakers taught me the same about sound, how deeply it can affect mood, memory, and presence. For my graduation project, I wanted to explore a meaningful intersection between these two worlds, and this project gave me exactly that opportunity.

Working within the context of the Intensive Care Unit has been a truly eye-opening experience. It's an environment full of complexity, where every design decision is shaped by strict safety requirements and medical protocols. From the start, one of the key constraints was that I could only work with white light as a design parameter. Rather than seeing this as a limitation, I viewed it as a creative challenge: how could I evoke atmosphere, emotion, and comfort using only variations in white light? This question became one of the most fascinating parts of the process.

At the beginning of the project, it was clear that I would be designing a lamp, but not how far I would take it. As the project evolved, I realized that achieving the desired light behaviour required diving deep into coding, electronics, and prototyping. What began as a design concept gradually turned into a highly technical exploration. This process allowed me to bridge creativity and engineering, something that feels very natural to me and aligns perfectly with how I see design.

This project has given me the freedom to explore, learn, and push boundaries between art, technology, and healthcare. It combined everything I'm passionate about: creating meaningful experiences through light and sound while working toward something that could genuinely improve patient well-being. I hope that this project inspires others to explore the endless possibilities of light and sound and to see how, together, they can shape not just environments, but human experience itself.

Abstract

Intensive Care Units (ICUs) are highly technological environments where light and sound strongly influence patient comfort, orientation, and recovery. However, current ICU lighting is static, overly bright, and emotionally disconnected, disrupting circadian rhythms and contributing to stress and disorientation.

This project proposes Komora, a responsive lighting system that translates sound into light to complement existing sonic ambiances developed by Dr. Gijs Louwers. Komora dynamically adapts its brightness and colour temperature to the rhythm and tone of ambient sounds, creating a calm and supportive sensory environment.

The focus was on human-centered design, technical feasibility, and integration into existing ICU infrastructure. Through prototyping and user testing, Komora demonstrated that synchronized light and sound can reduce perceived tenseness, enhance comfort, and support circadian alignment without hindering clinical workflows. By transforming sound into light, Komora shows how subtle, sensory-aware design can improve patient well-being and create more humane, restorative ICU environments.

List of Abbreviations

CAL – Critical Alarms Lab
CRI – Colour Rendering Index
CCT – Correlated Colour Temperature
DB – Decibel
EMC – Erasmus Medical Center
HCD – Human-Centered Design
HCP – Health Care Professional
HREC – Human Research Ethics Committee
IDE – Industrial Design Engineering
ICU – Intensive Care Unit
PICS – Post Intensive Care Syndrome
PSU – Power Supply Unit
TUD – Technical University of Delft

Glossary

AMBIENT LIGHT
Low-intensity background illumination that provides general visibility without focusing on specific areas. In this project, it contributes to the overall atmosphere of the ICU environment.

CIRCADIAN RHYTHM
The natural, internal biological process regulating the sleep–wake cycle, repeating roughly every 24 hours. It is strongly influenced by light exposure and plays a crucial role in patient recovery and well-being.

COLOUR TEMPERATURE (CCT)
A measure of the hue of white light, expressed in kelvins (K). Lower values (warm light) create relaxing atmospheres, while higher values (cool light) promote alertness and concentration.

ICU (INTENSIVE CARE UNIT)
A hospital department providing continuous monitoring and treatment to critically ill patients, characterized by high technological density and sensory intensity.

LED (LIGHT-EMITTING DIODE)
A semiconductor device that emits light when an electric current passes through it. LEDs are used for precise, energy-efficient, and dynamic lighting control.

LUX (LX)
A unit of illuminance that measures how much luminous flux (light) falls on a surface per unit area. One lux equals one lumen per square meter (1 lx = 1 lm/m^2). It indicates how bright a surface appears under a given light source.

SONIC AMBIANCE
A designed auditory environment intended to evoke specific emotional or psychological responses.

SOUNDSCAPE
The acoustic environment as perceived or experienced by people. In the ICU, the soundscape includes both human-generated and mechanical sounds, such as speech, alarms, and ventilation.

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chapter 1

Introduction

Project Background 1.1

This project focuses on designing lightscape that correspond to the existing sonic ambiances developed for the Intensive Care Unit (ICU) at Erasmus MC (EMC) (Figure 1). The aim is to complement these sound environments with lighting that enhances patient comfort and supports recovery. ICUs are typically characterized by artificial lighting and disruptive noise, both of which are known to disturb patients' circadian rhythms and psychological well-being (Lucchini et al., 2023; Simons, 2018).

ICU patients are frequently exposed to insufficient bright light during the day and dimed lighting at night, which affects circadian regulation and sleep quality (Fan et al., 2017, Durrington et al., 2017, Lusczek & Knauert, 2021). Simultaneously, ICU soundscapes consistently exceed WHO-recommended noise levels, leading to stress and psychological distress for both patients and staff (Louwers, 2024, Özcan et al., 2024, Lucchini et al., 2023). For patients, this results in feelings of alienation, disrupted sleep, and increased risks of Post Intensive Care Syndrome (PICS) and delirium (Louwers, 2024, Özcan et al., 2024)

This project builds upon the PhD research of Dr. Gijs Louwers at the IDE Faculty, which focused on developing a set of sonic ambiances to enhance the ICU patient experience. The sonic ambiance types: comfortable, pleasurable or stimulating and their corresponding sound compositions will be used to find the fitting light composition. This project combines sounds and light.

The combination specifically of auditory and visual elements in audiovisual environments have, in a study led to participants feeling significantly more moved compared to when they experience the elements alone (Hosseini et al. (2024)).

The initiative forms part of the broader "Smart ICU" vision proposed by Prof. Dr. Diederik Gommers, head of the ICUs at Erasmus MC. His goal is to create a more supportive, human-centred environment benefiting both patients and healthcare staff. The key stakeholders include Erasmus MC, ICU patients, their relatives, and healthcare professionals (HCPs).

Left Page

Figure 1
ICU room at EMC

Next Page

Figure 2
ICU room at EMC

Design Brief 1.2

The goal of this project is to design, validate and technically integrate a lighting design plan that is congruent with Dr. Louwer's sonic ambiances. This will be tailored to patient's needs, improving their circadian rhythm and psychological well-being in the ICU environment at Erasmus Medical Center. To achieve this goal the project focusses on the following objectives:

To **understand** the current lighting conditions within an ICU box and analyse the surrounding soundscape, enabling design decisions that incorporate these elements. Additionally, to gain a clear understanding of existing ICU lighting systems.

To **develop** lighting principles that can be applied to the sonic ambiances developed by Dr.
Louwers, presented as a 'lighting recipe'. Additionally, to design an integrated sound and lighting system for technical implementation.

To **validate** and test the lighting recipe through patient feedback and evaluation.

To **implement** and apply the designed light and sound system within the ICU setting.

Research Questions 1.3

MAIN RESEARCH QUESTION

How can an integrated lighting and sound system, informed by current ICU conditions and patient feedback, be designed and implemented to complement the sonic ambiances developed by Dr. Louwers within the intensive care environment?

HUMAN

What are the effects of the current lighting system on patients?
How can light affect someone's emotions positively?
How does light affect circadian rhythms and recovery of patients?

SYSTEM

What is the current lighting situation of the ICU?
What are the regulations of an ICU setting regarding light and sound?
What are the main issues of patients regarding current lighting systems?
How to create a light that does not interfere with staff workflow and potentially help it?

PRODUCT

What lighting products exist outside of this project?
How could their technology be used in an ICU setting?
What does the room look like? How can a light be physically implemented in a way that makes sense?
How can sound visually be turned into light?
How can the interaction of the light be made as intuitive for patients and not interfere with workflow of staff?

RESEARCH OBJECTIVES

LIGHTING CONDITIONS ICU AT EMC
Assess and evaluate the lighting conditions within a single-patient ICU room, focusing on the quality, distribution, and intensity of light throughout the day. This includes an examination of the existing lighting system, its technical setup, and the degree of controllability available to both healthcare staff and patients.

SOUND ANALYSIS
Understand the characteristics of the sonic ambiances and explore how they can be translated into corresponding lighting behaviours, identifying overlaps and correlations between auditory and visual parameters.

DESIGN EXPERIMENTS
Building on insights from sonic ambiances, this project will assess how well the designed light ambiances align with creating a comfortable, pleasurable, or stimulating atmosphere. The evaluation will involve participant feedback and be analysed.

This project is valuable as it addresses the disruption of circadian rhythms in the ICU. By restoring natural light cycles and supporting patients' sleep/wake patterns, the lighting design aims to enhance comfort, promote recovery, and contribute to more efficient healing within the intensive care environment.

Project Scope 1.4

STAKEHOLDERS
The key stakeholders in this project are Erasmus MC, adult ICU patients, their relatives, and healthcare professionals (HCPs). Additionally, supervisors from TU Delft's Critical Alarms Lab are involved. Their prior research, particularly on the implementation of sonic ambiances and their effects on patients, provides an essential foundation and background for this project.

PROJECT GOAL
The primary aim is to design the lighting elements that complement the designed sonic ambiances. This combination or "recipe," as one might call it, could be applied to various sonic ambiances to produce specific, desired effects on patient experience and well-being.

TARGET GROUP
The specific target group for this project is adult ICU patients at Erasmus MC.

DESIGN LIMITATIONS
Since the project takes place in a medical setting, there are important design constraints. Only white light can be used, with adjustable parameters limited to CCT (correlated colour temperature) and illuminance levels (brightness). Additionally, all designs must comply with strict healthcare regulations regarding both sound and light, for example, avoiding rapid changes in brightness and maintaining minimum illuminance values.

Methodology 1.5

This project followed the Double Diamond framework, which consists of four phases: Discover, Define, Develop, and Deliver (Figure 3). These can be grouped into two main stages: the Research Phase (Discover and Define) and the Design Phase (Develop and Deliver).

THE RESEARCH PHASE
The discovery phase focuses on understanding the current state of the ICU by reviewing existing literature on sound and light in ICU settings and their effects on patients, as well as identifying key problems and concerns. Additionally, it involves studying and thoroughly understanding Dr. Louwer's research, which will serve as a major foundation for this project.

In the define stage, the design parameters will be established for the lighting essentially developing the "recipe" of light elements that best align with and complement the corresponding sonic ambiance.

THE DESIGN PHASE
The develop phase was about trying to translate the idea of the lighting design into a physical light. For this multiple lo-fi prototypes were made to further develop the project.

The deliver phase focuses on making the intervention feasible by developing a low- and high-fidelity prototype in the mock ICU, followed by testing and evaluating the intervention. Based on the outcomes, further recommendations are provided.

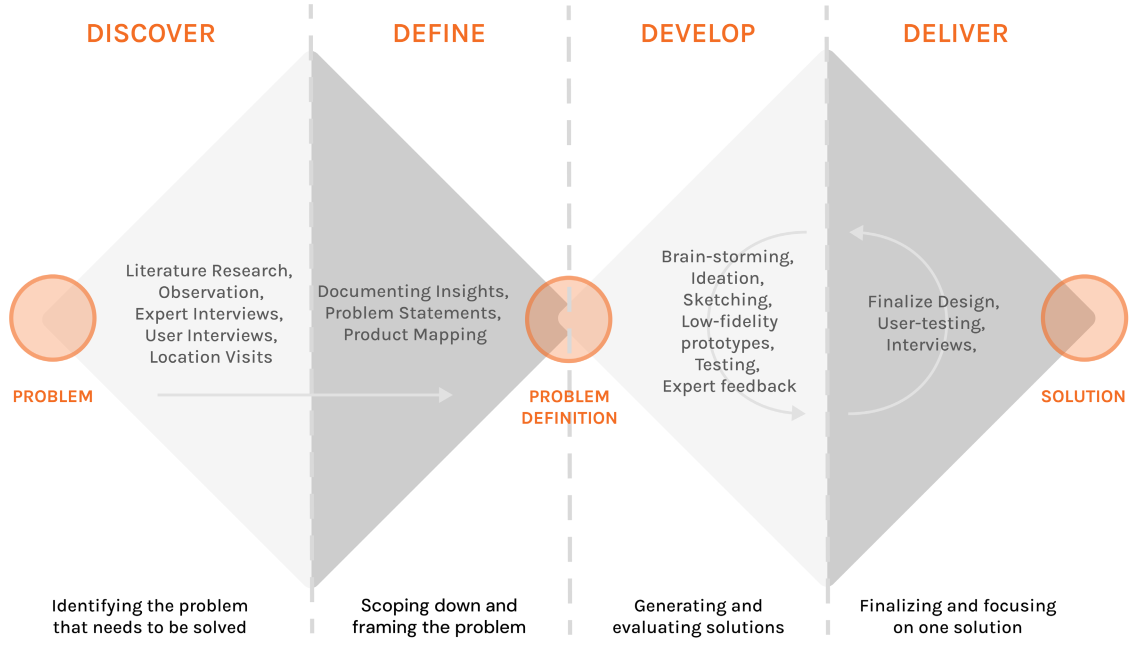


Figure 3
Double Diamond design process and respective methodologies

chapter 2

ICU Context

Sound Context 2.1

The Intensive Care Unit (ICU) is a highly technological and acoustically complex environment, often described as loud, unvaried, and stressful (Figure 4). Measured sound levels frequently exceed 50 dB(A), with peaks reaching 80–100 dB(A), far above the World Health Organization (WHO) recommendation of 30–35 dB(A) (Louwers et al., 2024b; Özcan et al., 2024).

TYPES OF SOUNDS

The ICU soundscape consists of four main categories:

Medical Devices: Alarms, infusion and syringe pumps, ventilators, dialysis machines, and monitoring equipment generate continuous or intermittent beeps and mechanical tones.

Human Activity: Conversations among HCPs, footsteps, doors, and movement of carts contribute to fluctuating background noise.

Patient Sounds: Vocal expressions such as coughing, crying, or moaning reflect discomfort or emotional distress.
Environmental Noise: Ventilation, air-conditioning, and external sounds from corridors or outside the building add a constant background layer.

CHARACTER OF THE ICU SOUNDSCAPE

Patients describe the sound environment as alienating, unvaried, unfamiliar, and disruptive (Van Houwelingen, 2022). The combination of sudden alarms and monotonous mechanical noise creates an atmosphere that is both overstimulating and isolating. Periods of intense activity alternate with sudden silence, resulting in abrupt “on/off” sound dynamics that amplify anxiety and confusion.

EFFECTS ON PATIENTS

Excessive and unpredictable noise functions as a major environmental stressor. It contributes to:

- Sleep disruption and circadian rhythm disturbance, slowing physical recovery.
- Delirium, confusion, and disorientation caused by irregular sensory input.
- Psychological distress, including stress, fear, and feelings of helplessness.

In summary, the ICU soundscape, creates a stressful and unfamiliar environment that hinders patient recovery. Understanding this auditory baseline is vital for designing lighting that complements or mitigates these effects through multi-sensory integration.

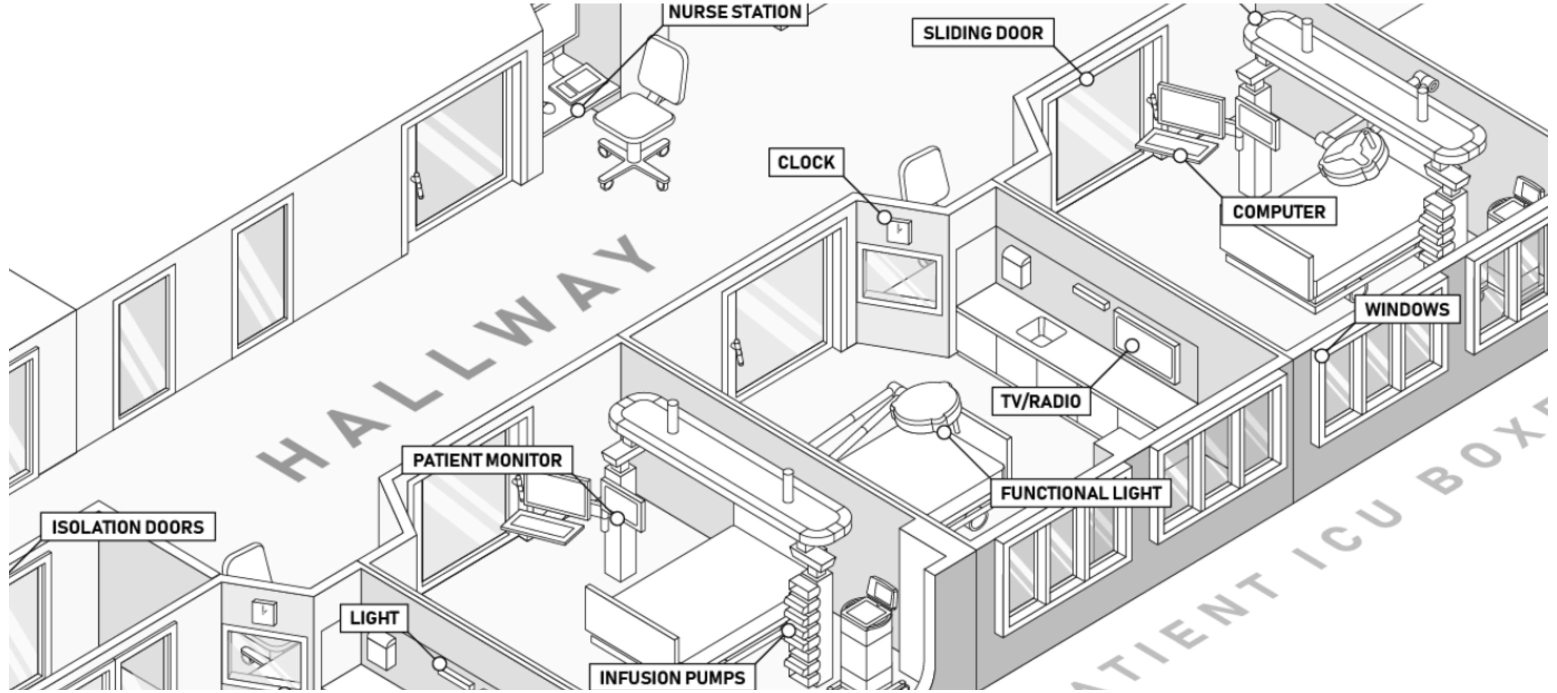


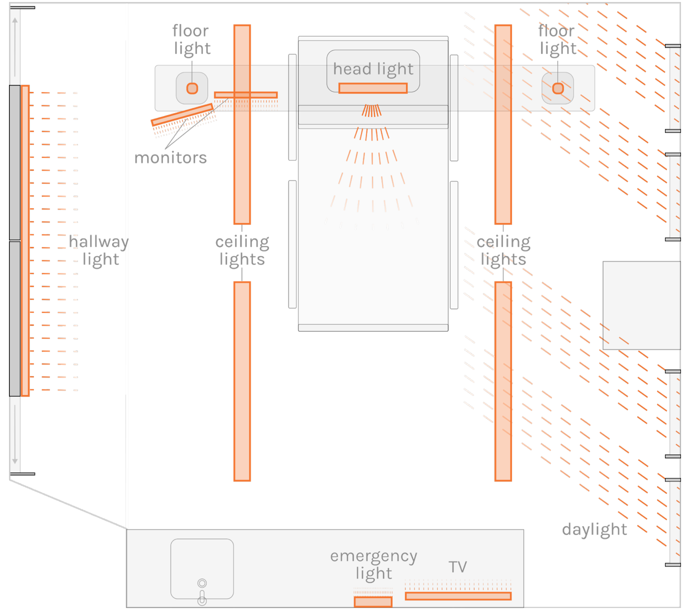
Figure 4
The ICU layout (Louwers et al., 2024)

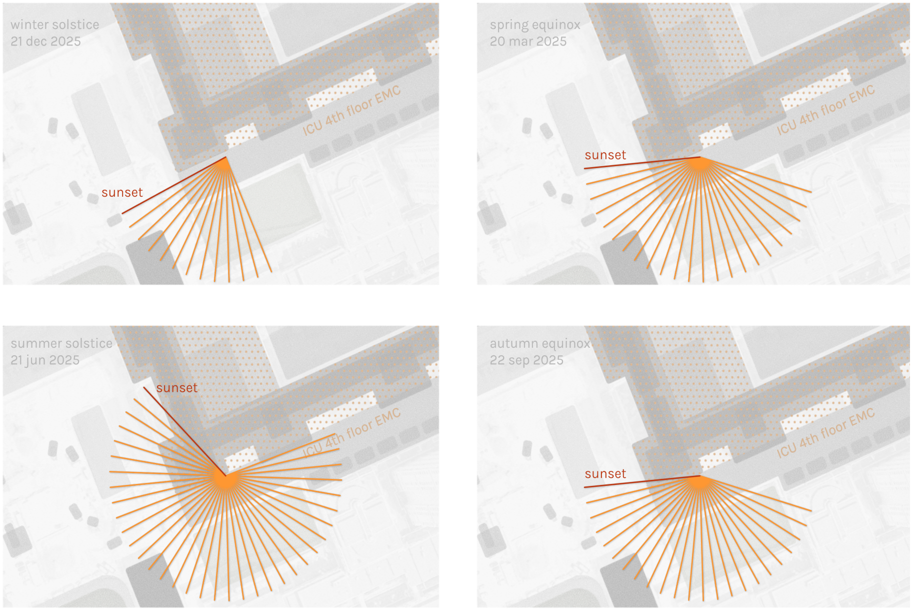
Light Context 2.2

Lighting in the ICU consists of two main types: natural and artificial light (Figure 5). Natural light enters through large windows, with availability depending on the room's orientation within the building: Units A, B, and C receive direct sunlight, while Unit D, located along the interior corridor, does not (Interview Nurse, 2025). Seasonal variations further influence daylight exposure: during winter, shorter days reduce natural light, while in summer, extended evenings provide longer illumination (Figure 6).

Additionally, artificial light in the ICU originates from several sources (Figure 7). The primary and most prominent source is the ceiling mounted LED panels, which provide general illumination. Secondary sources include monitor screens, the television, and the lights integrated into the bridge pendant above the patient's bed. The smallest light source is an emergency light located above the counter.

Figure 5
ICU box at EMC





Left
Figure 7
Floorplan of an ICU box showing the different light sources.

Right
Figure 6
Top view of the EMC ICU department showing the path of the sun from sunrise to sunset.

Patient Journey 2.3

The experience of a critically ill patient in the ICU is shaped by fluctuating cycles of sound, light, and human interaction. These sensory changes structure the patient's perception of time and influence their emotional state, orientation, and recovery (Louwers et al., 2024b; Van Houwelingen, 2022).
The following timeline outlines a typical day in the ICU, combining observed routines and reported sensory experiences (Interview ICU nurse, 2025).

07:30–08:30 | MORNING CARE AND STAFF ARRIVAL
The day begins with the day shift and patient washing routines. This is the most active period, characterized by the presence of multiple HCPs, equipment use, and bright ceiling lighting.

- Sound: Alarms, staff communication, and movement dominate, often exceeding 50–80 dB(A) (Louwers et al., 2024b).
- Light: TL ceiling lights are switched on fully, producing bright, cool illumination that often wakes patients abruptly.
- Experience: Patients feel overstimulated but reassured by human presence and activity.

08:30–12:00 | MEDICAL ROUNDS AND THERAPY
Doctors, physiotherapists, and nurses move between patients. Beds are adjusted, and procedures such as repositioning take place.

- Sound: Continuous staff dialogue and machine alarms; high variability in intensity.
- Light: Strong illumination remains for visibility. Sunlight enters in rooms facing outward; internal units rely solely on artificial light.
- Experience: Busy and noisy—patients may feel safe but also overwhelmed.

11:00–14:00 | VISITING HOURS
Relatives visit, offering emotional relief. The environment is lively yet comforting due to familiar voices.

- Sound: Conversational, social sounds replace mechanical noise as dominant input.
- Light: Natural light peaks around midday, helping orientation.
- Experience: Moments of connection and reassurance; a rare balance between stimulation and comfort.

14:00–16:00 | QUIET HOURS
Visiting ends and staff activity decreases. Machines continue running, but overall sound levels stabilize.

- Sound: Low-level background hum from ventilation and equipment.
- Light: Remains bright or unchanged, despite reduced activity.
- Experience: Patients often feel isolated or bored; lighting no longer reflects the quieter rhythm.

16:00–20:00 | EVENING CARE AND SECOND VISITING PERIOD
Activity increases again with care routines and the evening visiting window.

- Sound: More footsteps, alarms, and conversation peaks.
- Light: Artificial light dominates as natural daylight fades; few systems allow smooth dimming.
- Experience: Sensory variation returns; some patients report relief through social presence.

20:00–07:30 | NIGHTTIME AND REST
After visiting hours, activity drops sharply. The environment quiets, but intermittent alarms and mechanical sounds persist.

- Sound: Reduced overall, though sudden peaks continue (e.g., alarms).
- Light: Lights dim in hallways and some devices switch to night mode, but TL ceiling lights remain overly bright when used.
- Experience: Patients experience partial darkness but frequent awakenings. Sudden light or noise triggers disorientation, anxiety, or delirium, especially in neuro and sedated patients.

Right Page

Figure 8
Melatonin clock

Circadian Rhythms 2.4

TRANSITIONS AND SENSORY IMPACT

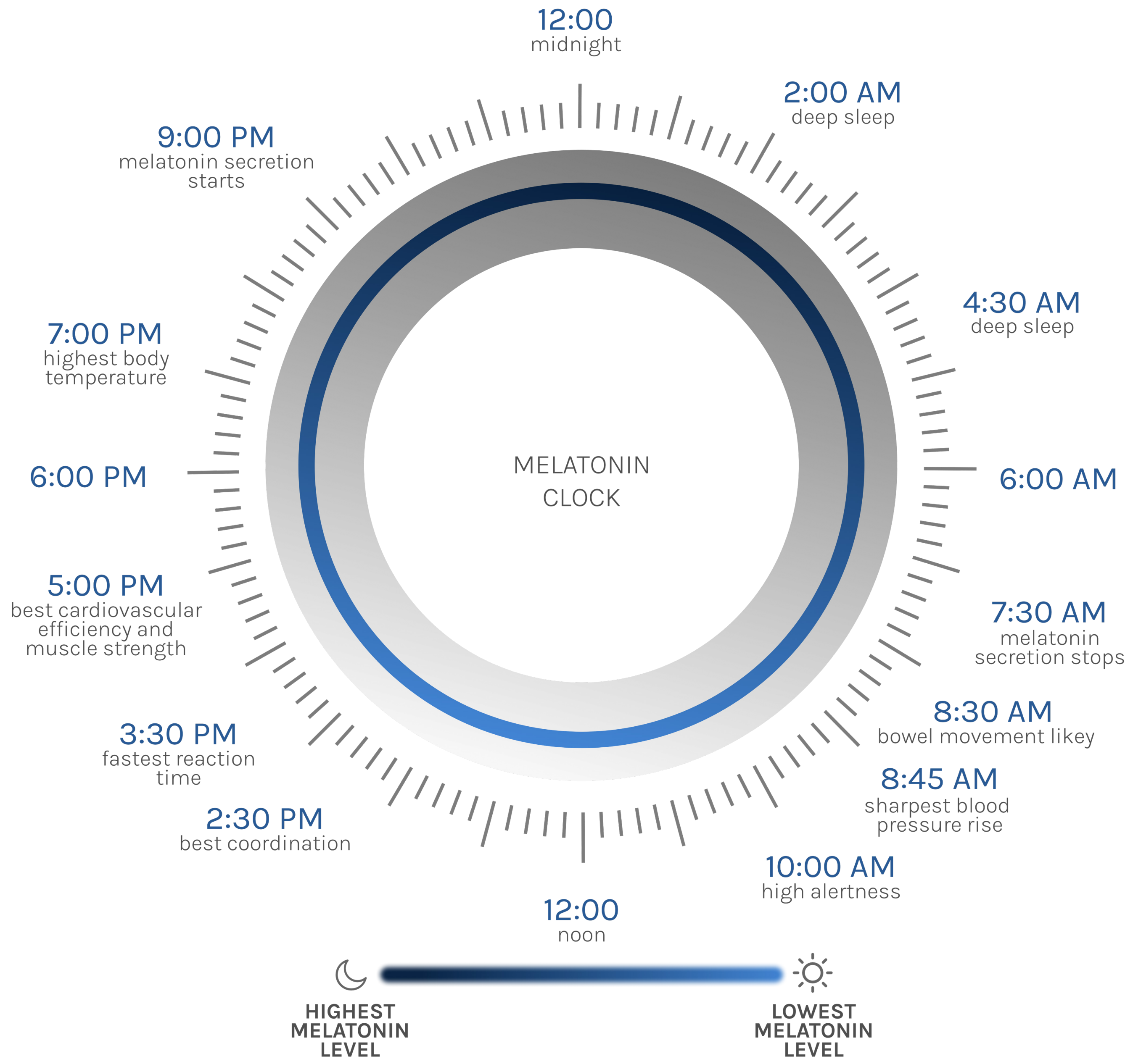
The most psychologically demanding moments occur during transitions, when staff leave, lights are switched off, or sounds abruptly stop (Van Houwelingen, 2022). These shifts create sensory voids associated with loneliness and fear. Gradual light and sound transitions could reduce these effects and support patients' orientation and circadian rhythm.

INTERVENTION MOMENTS

The most suitable moments for introducing light and sound interventions occur during uneventful or resting periods, when patients are alone and environmental stimulation is minimal (Van Houwelingen, 2022). These typically include the quiet hours between 14:00–16:00 and the night period after 20:00, when the absence of human activity and natural light can lead to feelings of isolation, anxiety, or disorientation. Gentle, well-timed sensory interventions during these intervals could help restore orientation, support circadian rhythms, and provide emotional comfort without disturbing rest.

The circadian rhythm is the body's internal 24-hour cycle regulating physiological and behavioural processes such as sleep, hormone secretion, and metabolism. This rhythm is synchronized primarily through environmental cues, with light being the most influential, followed by temperature and sound (Fan et al., 2017; Lusczek & Knauert, 2021).

Light exposure regulates the melatonin clock (Figure 8), a system in which light suppresses and darkness stimulates the release of melatonin, the hormone that signals night and promotes sleep (Cajochen et al., 2005). Bright, cool light in the morning resets this clock by inhibiting melatonin and promoting alertness, while warm, dim light in the evening allows melatonin levels to rise, preparing the body for rest.



CIRCADIAN DISRUPTION IN THE ICU

Critically ill patients in the ICU frequently experience severe disturbances in circadian rhythmicity due to continuous artificial illumination, irregular noise patterns, and the absence of natural light cues (Özcan et al., 2024; Lucchini et al., 2023).
These disruptions lead to desynchronization between the internal biological clock and the external environment, resulting in fragmented sleep, delirium, and delayed recovery (Fan et al., 2017; Durrington et al., 2017).

As outlined in Chapter 2.1 and 2.3, the ICU environment is characterized by excessive noise and unbalanced lighting conditions, both of which misalign the circadian rhythm of patients.

LIGHT AS A CIRCADIAN CUE

Light exposure is crucial for maintaining circadian regulation, yet ICU lighting conditions are often inadequate and mistimed (Lusczek & Knauert, 2021)

- Weak and delayed light–dark cycles: Peak light levels occur late in the day rather than in the morning (Fan et al., 2017).
- Low daytime illuminance: Typical ICU daytime levels remain below 50 lux, far below the 300–500 lux recommended for alertness.
- Continuous illumination: Nighttime light levels (10–400 lux) are sufficient to suppress melatonin, preventing natural sleep onset (Durrington et al., 2017).
- Reduced light perception: Sedated and older patients often receive insufficient retinal stimulation, effectively making them ‘circadian blind’.

As shown in Chapter 2.2, the TL ceiling lights used in ICUs emit bright, cool, and static light that does not adapt to the time of day. Combined with artificial noise and irregular staff activity (Chapter 2.3), these conditions disrupt both biological timing and psychological orientation.

DESIGN IMPLICATIONS

By restoring a structured light/dark rhythm, lighting design can play a pivotal role in supporting circadian entrainment and recovery. A dynamic lighting system that transitions smoothly between bright, cool light during active periods and warm, dim light during rest can reinforce temporal awareness and improve sleep quality.

Regulations 2.5

As this project is primarily concerned with designing a lighting system, only lighting regulations are considered relevant. The focus lies on developing a lighting design solution rather than addressing acoustic factors. The sound design component was previously addressed by Dr. Louwers.

According to the SLL Lighting Handbook, lighting in ICUs and wards must meet strict safety and performance standards to support patient care and staff activities. The maintained illuminance in general bed areas should be at least 300 lx with a uniformity of 0.5 or greater, while the illuminance at the foot of the bed should not fall below 200 lx. These levels provide sufficient lighting for clinical observation and nursing through an appropriate balance of general and task lighting. In clinical areas, lamps must have a CIE colour rendering index (Ra) of at least 80, increasing to Ra 90 or higher for critical procedures to ensure accurate colour assessment of skin, tissue, and fluids (SLL Lighting handbook, 2018, Chapter 17).

According to the ERCO Handbook of Lighting Design by Ganslandt and Hofmann (1992) (Figure 9), the recommended illuminance level for hospital wards is approximately 100 lx. The handbook emphasizes the use of ambient lighting to create a comfortable and functional environment for both patients and staff. Suitable light sources for such applications include tubular (T) and compact tubular (TC) lamps, which provide efficient and uniform illumination across the space.

Together, these standards provide the foundation for defining safe, effective, and comfortable lighting conditions in ICU environments. They serve as key reference points for developing the lighting concept proposed in this project.
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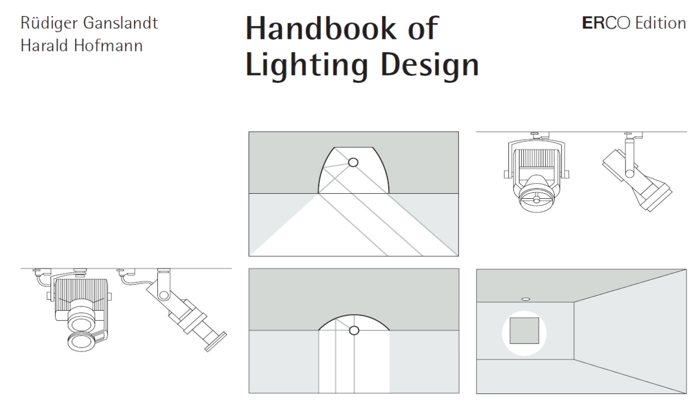

Figure 9
Handbook of Lighting Design (ERCO, 1992)

chapter 3

Sound
Light
Atmosphere
Design Considerations

Research

SONIC AMBIANCES

Dr. Louwers focused on sound design in medical settings, specifically developing soundscape interventions for ICU patients. These soundscape interventions play a central role in this project, as the lightscape interventions are conceptually based on them. To effectively incorporate his work, an in-depth analysis has been conducted.

In one of his studies, Louwers gathered qualitative data on imagined soundscapes designed to fulfill nine fundamental human needs. He combined this qualitative data with quantitative ratings of pleasantness and eventfulness, where eventfulness refers to the density and variety of sound events in time and space. Using hierarchical agglomerative clustering (HAC) and thematic analysis, he identified four clusters of needs that corresponded to four sonic ambiance types: Comfortable, Pleasurable, Stimulating, and Motivating (Louwers et al., 2024). For further research, only the first three sonic ambiances were used, as the Motivating sonic ambiance was found to overlap with the Stimulating one. Therefore, this project focuses on the three primary sonic ambiances: Comfortable, Pleasurable, and Stimulating.

Drawing on earlier sound taxonomies, Louwers further categorized these ambiances into Natural, Human, and Technological sound groups, following the framework established by Axelsson et al. (2010) (Figure 10). This categorization allowed exploration of how different sound types align with fundamental psychological needs within imagined soundscapes (Louwers, 2022).

Eventfulness	Ambiance Type	Natural	Human	Technological
1	Comfortable	Fireplace	Home office	Train compartment
2	Pleasurable	Forest	Terrace	Urban backyard
3	Stimulating	Countryside	Market	City

Left Page

Figure 10
Nine sound compositions within their dedicated categories regarding sound taxonomy and level of eventfulness (Louwers et al. (2025)

The placement of these three sonic ambiances on the pleasantness–eventfulness matrix illustrates how participants perceived each designed soundscape in terms of its affective and sensory qualities (Figure 11). This matrix is derived from the circumplex model of soundscape perception (Axelsson et al., 2010), which describes sound environments along two perceptual dimensions: pleasantness, indicating the degree of positive affect associated with a soundscape, and eventfulness, representing its perceived liveliness and the density of sound events in time and space.

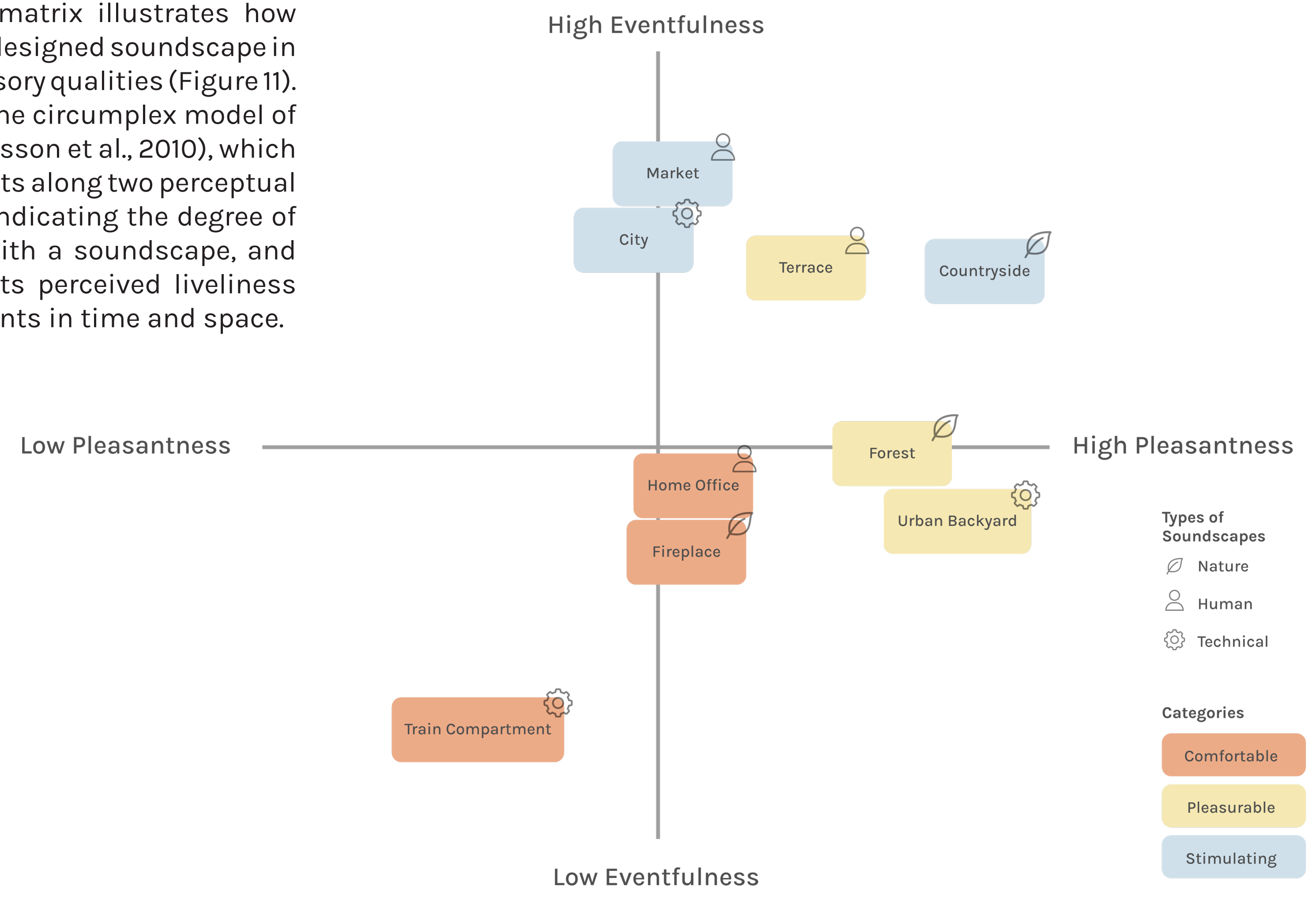

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Figure 11
Placement of the sonic ambiances in their dedicated groups on the pleasantness-eventfulness matrix

When the nine sound compositions were evaluated, their positions on this matrix revealed a distinct gradient across the three ambiance types. Comfortable ambiances (e.g., Fireplace, Home Office, Train Compartment) were perceived as pleasant but uneventful, evoking calmness. Pleasurable ambiances (e.g., Forest, Terrace, Urban Backyard) were positioned higher in both pleasantness and eventfulness, conveying a sense of vitality. Stimulating ambiances (e.g., Countryside, Market, City) occupied the most eventful and energetic region of the matrix, perceived as lively and activating yet still positively balanced.

This gradual increase in eventfulness from Comfortable to Stimulating demonstrates how soundscapes can be deliberately designed to elicit different affective responses while maintaining overall pleasantness. The matrix thereby serves as a conceptual tool linking acoustic design parameters to psychological needs and emotional well-being, providing valuable insights for designing restorative and supportive environments in healthcare contexts (Louwers et al., 2025).

SONIC AMBIANCE ANALYSIS

First, it was necessary to determine which aspects of the sonic ambiances were important to analyse. The initial focus was on creating a frequency spectrum graph to identify the dominant and present frequencies. With this information, it might be possible to explore links between specific frequencies and corresponding light parameters. Additionally, the frequency spectrum allows observation of the distribution of frequencies, meaning whether more are present on either side of the spectrum or how many frequencies are present overall. This analysis can reveal much about the character or atmosphere of the sound: whether it is bass-heavy, treble-heavy, or more centered in the middle range.

Moreover, the number of frequencies present gives an indication of the perceived intensity of the sound. In Louwers' research, the sonic ambiances were rated on a scale of eventfulness, which can directly be rated to this concept of sound intensity. Furthermore, creating spectrograms was relevant to identify the individual elements in the sound. These individual elements can help understand the composition of the sonic ambiance, which consists of multiple of these elements.

FREQUENCY SPECTRUM GRAPHS & SPECTROGRAMS

Sound can be represented visually in several ways, with two of the most common methods being the frequency spectrum graph and the spectrogram. These tools make it possible to analyse the structure, energy, and temporal characteristics of soundscapes.

FREQUENCY SPECTRUM GRAPHS

A frequency spectrum graph shows the strength (amplitude) of different frequencies in an audio signal at a single moment or averaged over time. The x-axis represents frequency (low to high), and the y-axis represents amplitude (loudness). Peaks indicate dominant frequencies, helping identify tonal content, noise levels, or specific sound characteristics.

Figure 11 shows the frequency spectrum of the sonic ambiance Countryside, created using Audacity. This soundscape, rated as highly eventful, displays energy across a wide frequency range, confirming that greater frequency diversity corresponds to higher eventfulness.

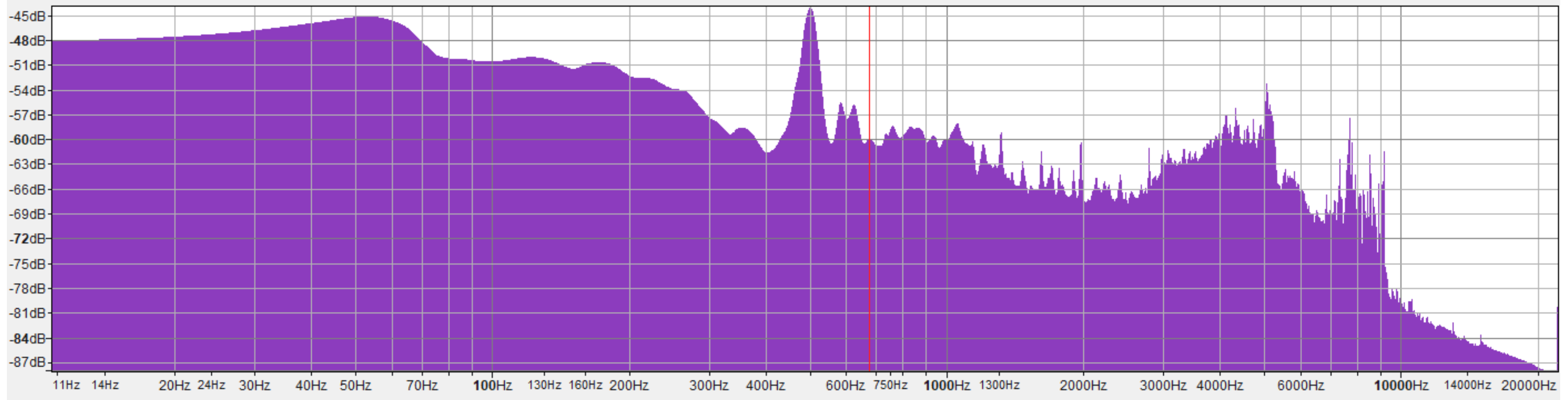

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Figure 12
Frequency spectrum graph of ambient soundscape 'Countryside' (Audacity)

SPECTROGRAMS

A spectrogram provides a time-based visualization of sound. Here, frequency is shown on the y-axis, time on the x-axis, and colour intensity represents amplitude; brighter areas indicating stronger sound energy. This allows distinct sound events to be identified over time, distinguishing foreground from background elements within the ambiance (Figure 12).

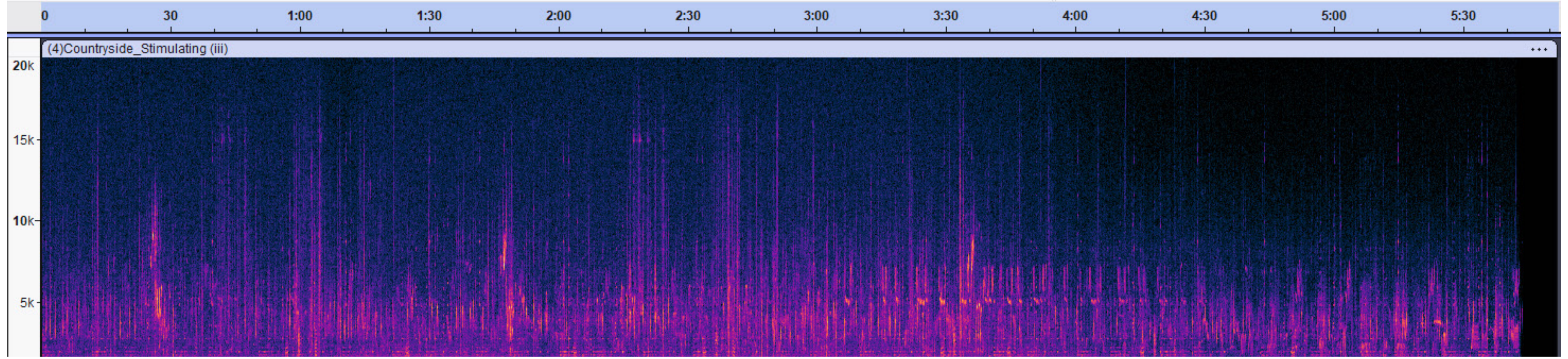
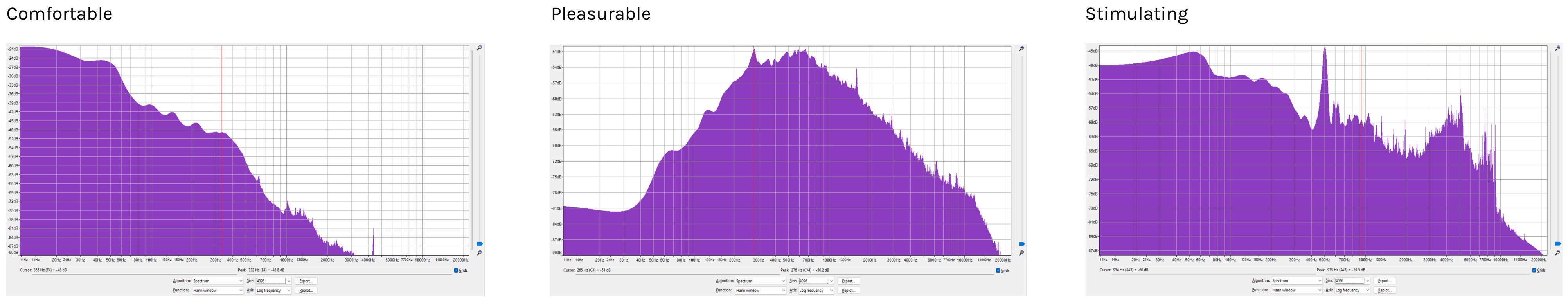


Figure 12
Spectrogram of the sonic ambiance 'Countryside' (Audacity)

APPLICATION IN ANALYSIS

The analysis was divided into two stages:

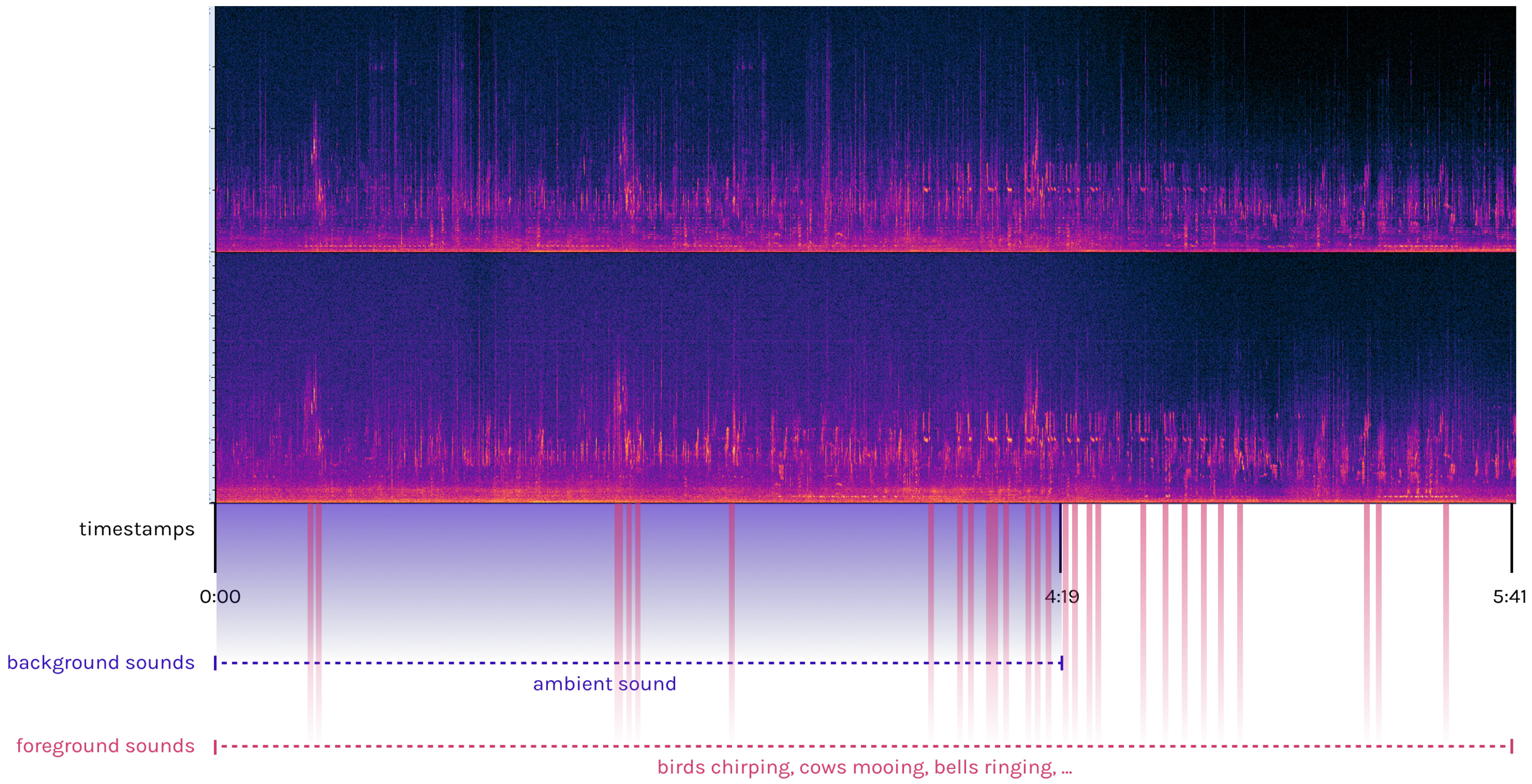
Frequency spectra were used to assess whether each ambiance leaned toward low (bass-heavy), mid (balanced), or high (treble-heavy) frequencies. Comfortable ambiances tended to skew left, pleasurable ones were centered, and stimulating ambiances were broadly distributed (Figure 13).


Comfortable

Pleasurable

Stimulating

Figure 13
Frequency spectra graphs showing the skewing of 3 different sonic ambiances and their ambiance types from left to right comfortable, pleasurable and stimulating.



Spectrograms were used to locate specific sound events (e.g., bird chirps, dove coos) and to differentiate foreground from background activity within each soundscape (Figure 14)

CONCLUSION

The analysis of Louwers's sonic ambiances revealed a clear progression from calm, low-frequency Comfortable sounds to lively, broad-spectrum Stimulating ones. Frequency and spectrogram analysis confirmed that greater spectral density aligns with higher eventfulness. These insights provide a framework for translating auditory qualities into light parameters, where variations in frequency, intensity, and eventfulness inform changes in brightness, colour, and rhythm in the lighting design.

Left Page

Figure 14
Showing the different foreground and background elevments in the countryside soundscape

Light 3.2

FUNCTIONS

The Delft Light Framework draws on the principles established by lighting designer Richard Kelly, who identified three fundamental components of light: ambient, focus, and brilliance (Figure 15). According to Kelly, as discussed in the Handbook of Lighting Design by Ganslandt and Hofmann (1992), the first and most basic form of light is ambient light, which provides general illumination and ensures overall visibility within a space.

The focus component, or focal glow, represents the point at which light becomes an active element in conveying information, directing attention, and supporting visual tasks. The third component, brilliance, refers to the high-angle frequency or texture of light, emphasizing that light can not only highlight information but also embody and express it. In this sense, the light source itself can be perceived as brilliant, with this interplay of brightness and texture adding vitality and atmosphere to prestigious or expressive spaces.

DISTRIBUTION TYPES

Lighting distribution types describe how light is emitted and spread within a space, influencing both visual comfort and atmosphere. Figure 16 illustrates the main distribution types commonly used in interior lighting design.

Direct: Light is directed downward, providing strong, efficient illumination for task areas.
Applications: factories, classrooms, workspaces.

Semi-Direct: Mostly downward light with some upward reflection to soften shadows.
Applications: offices, conference rooms, libraries.

Figure 15
Delft Light Framework showing the three different lighting components (Pont, 2025)

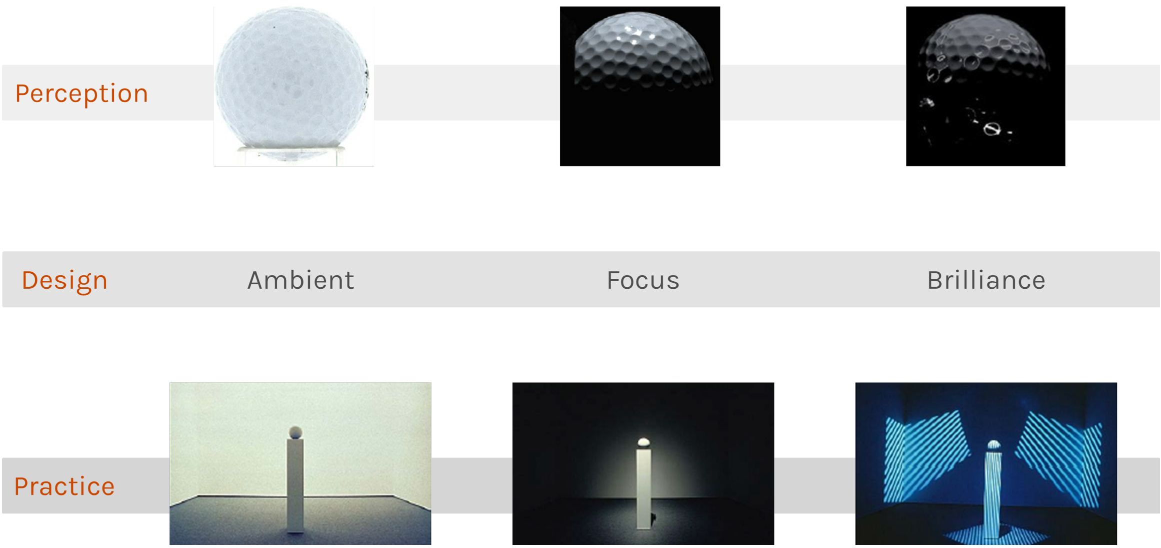
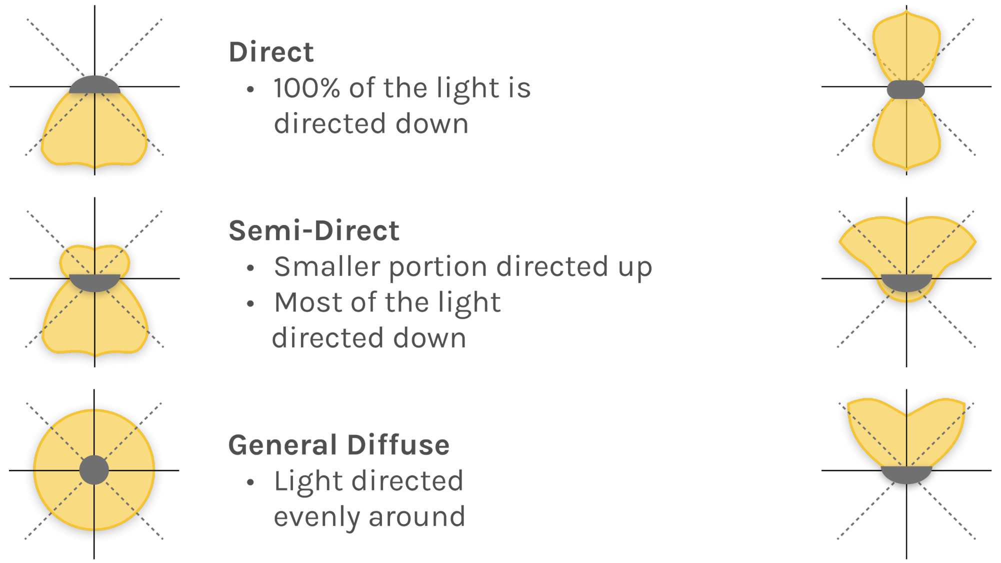


Figure 16
Lighting distribution types (Moustafa et al. (2022)



Direct
- 100% of the light is directed down

Semi-Direct
- Smaller portion directed up
- Most of the light directed down

General Diffuse
- Light directed evenly around

Direct-Indirect
- 50% of the light directed up
- 50% of the light directed down

Semi-Indirect
- Most of the light directed up
- Small portion of the light directed down

Indirect
- 100% of the light directed up

General Diffuse (Omnidirectional): Light is evenly distributed in all directions for balanced, shadow-free illumination.
Applications: lobbies, decorative fixtures, general ambient lighting.

Direct-Indirect: Equal upward and downward light for balanced ceiling brightness and task illumination.
Applications: open offices, classrooms, multipurpose areas.

Semi-Indirect: Primarily upward light with some downward diffusion for soft, glare-free lighting.
Applications: lounges, reception areas, restaurants.

Indirect: All light directed upward, reflecting off ceilings for uniform, glare-free illumination.
Applications: hospitals, offices, hotels, and spaces prioritizing comfort.

FIXTURE TYPES

Lighting fixtures can be categorized based on their method of installation and visual presence within a space (Figure 17).

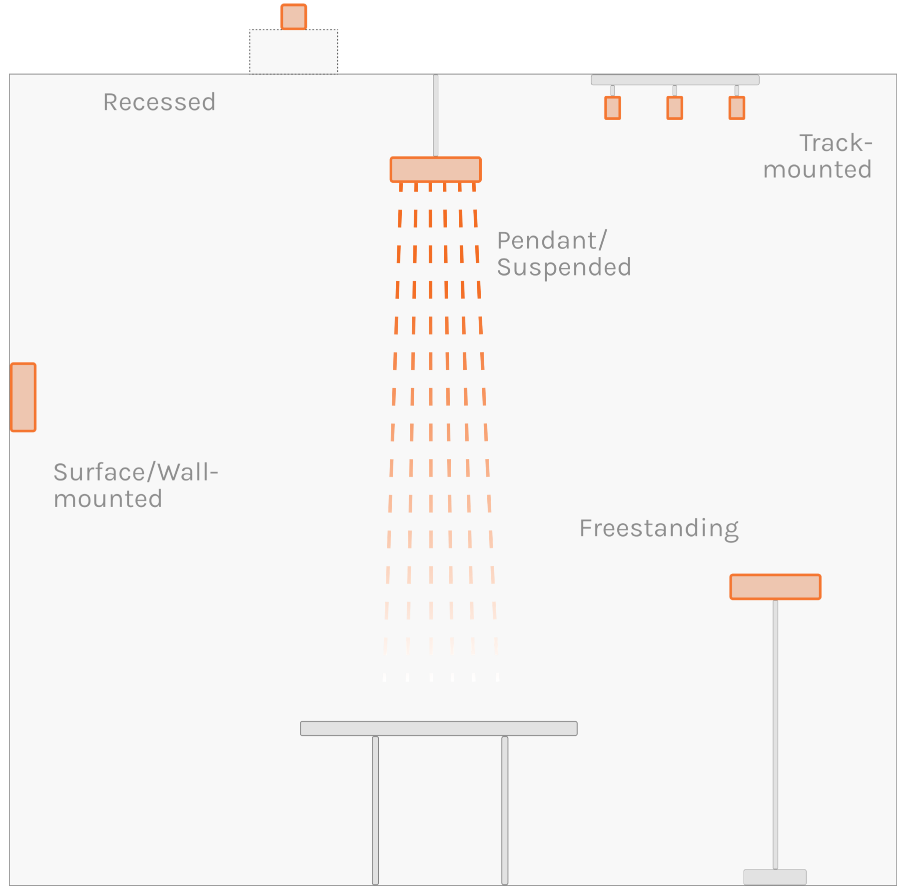


Figure 17
Fixture types

Surface- and wall-mounted fixtures are attached directly to the ceiling or wall, leaving the body visible. These include ceiling domes or bulkhead lights, surface-mounted panels, linear and drum luminaires, as well as wall-mounted sconces, bedhead units, vanity lights, picture lights, and up/down cylinders. Such fixtures are commonly used to provide ambient, task, or accent lighting while maintaining accessibility and ease of maintenance.

Recessed fixtures are built into the ceiling or wall so that the light source is concealed and the body remains hidden from view. This category includes downlights, adjustable or gimbal fittings, wall-wash luminaires, recessed linear lights, and troffers. Recessed lighting is often chosen for its clean, unobtrusive appearance and its ability to deliver focused or uniform illumination.

Pendant or suspended fixtures hang from the ceiling by a cord, rod, or chain. They can be decorative, bowl-shaped, linear, or arranged as multi-light clusters. These fixtures are frequently used to create visual interest or to define specific areas within a space, such as dining tables or work zones.

Track-mounted fixtures are installed on a powered track system, allowing them to be repositioned and aimed as needed. Examples include track spotlights, linear heads, pendant adapters, and monorail systems. This flexibility makes track lighting suitable for environments where lighting needs may change, such as galleries or retail spaces.

Finally, freestanding fixtures are portable and not attached to the architecture. These include floor lamps, arc lamps, desk or task lamps, and bedside lamps. They provide adaptable, localized lighting and are often used to supplement fixed lighting systems for comfort and versatility.

DIFFUSION TYPES

There are many different types of diffusion panels used in lighting design, each serving to soften, direct, or control light in different ways (Figure 18). While options such as egg-crate, clear, ribbed, or micro-perforated diffusers exist, the two most common types used in everyday applications are frosted (opal) diffusers and prismatic diffusers.

FROSTED OR OPAL DIFFUSERS

These translucent panels are designed to scatter light evenly. They create a very soft and uniform illumination, eliminating harsh shadows and direct glare from the light source. This type of diffuser is often chosen for its clean, modern appearance and ability to provide excellent visual comfort. However, because light is spread in all directions, they are generally less efficient than prismatic panels and may reduce brightness on the working

Figure 18
Lighting distribution types (Moustafa et al. (2022)

surface. Frosted or opal diffusers (Figure 19) are commonly used in residential settings, healthcare environments, and architectural applications where comfort and aesthetics are more important than maximum efficiency.

PRISMATIC DIFFUSERS

These use small prism-shaped patterns to control light direction while still diffusing it. This design channels more light downward to the working plane, improving efficiency and maintaining good brightness levels. At the same time, prismatic diffusers help reduce glare at shallow viewing angles, which makes them practical in task-oriented spaces. While they may produce slightly harsher light compared to opal panels and are more utilitarian in appearance, they are highly effective in providing efficient and controlled lighting. Prismatic diffusers are therefore widely used in offices, classrooms, retail environments, and other commercial or institutional settings.

Figure 19
LED strip in an opal diffuser (Maher, 2023) (Maher, 2023)

ICU LIGHTING PROJECT PRECEDENTS

The ‘ICU of the Future’ project, led by the Critical Care Research Group (CCRG) in partnership with The Common Good, reimagines the design of Intensive Care Units to create a more patient-centered and recovery-focused environment. Traditional ICUs have typically been designed by clinicians with an emphasis on medical functionality, often overlooking the psychological and environmental factors that influence patient recovery. This project addresses those issues such as constant noise, lack of natural light, and social isolation by redesigning the ICU space to promote comfort, healing, and well-being (CCRG, 2022).

An interesting aspect of this research is the lighting design, which plays a crucial role in supporting patients’ circadian rhythms and overall mental state. In the redesigned ICU, the lighting concept incorporates panel lighting to ensure even illumination and reduce glare, while LED strips in various colours are integrated along the sides of the room to create a softer, more ambient atmosphere (Figure 20). Additionally, a ceiling panel that mimics the sky provides a sense of connection to the outside world and helps maintain natural light cycles, which are often disrupted in intensive care environments.

Figure 20
ICU of the Future, Critical Care Research Group (CCRG, 2022)

Right Page

Figure 21
Philips VitalSky (Philips, 2019)

Moreover in 2019 Philips has introduced VitalMinds, a new non-pharmacological approach designed to help reduce delirium in Intensive Care Units (ICUs). A key element of this system is VitalSky, a personalized light therapy system (Figure 21).
The VitalSky system simulates natural daylight through a large, glare-free LED ceiling, supporting patients' sleep-wake cycles and providing adaptable lighting for individual needs. It can also display calming nature scenes and will soon include cognitive training features.

Preliminary findings from the VITALITY study at Charité University Hospital in Berlin showed a reduction of 39% in delirium incidence in ICU rooms equipped with VitalSky compared to standard ICU rooms. This shows the potential of improved environmental and lighting design in critical care settings.

Left Page

Figure 22
Mavospec Base Spectrometer (Gossen, 2025)

Right Page

Figure 23
Room layout of a single patient ICU box

CURRENT LIGHTING CONDITIONS ICU

To assess current lighting conditions in the ICU single-patient room, measurements were taken with the Gossen Mavospec Base F521G spectrometer and light meter (Figure 22). This device captures illuminance, spectrum, colour temperature, CRI, flicker, and chromaticity, displaying results on its colour screen. Data can be stored and transferred for computer-based analysis.

In the ICU box, five measurement points (Figure 23) were assessed under four different scenarios: blinds open with artificial lights on (scenario 2), blinds open with artificial lights off (scenario 1), blinds closed with artificial lights on (scenario 3), and blinds closed with artificial lights off (scenario 4), leaving only the emergency lighting on (Figure 24).

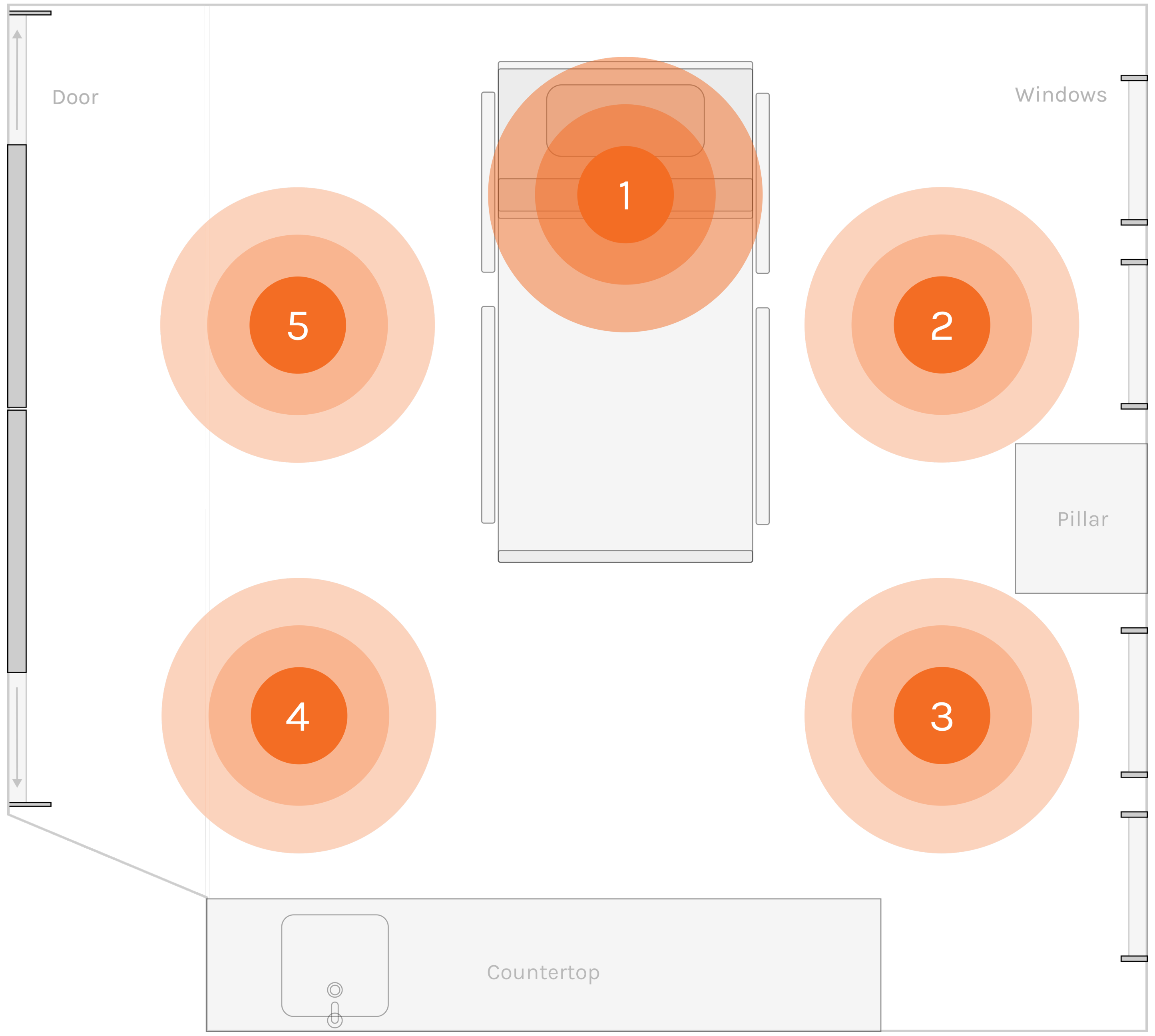
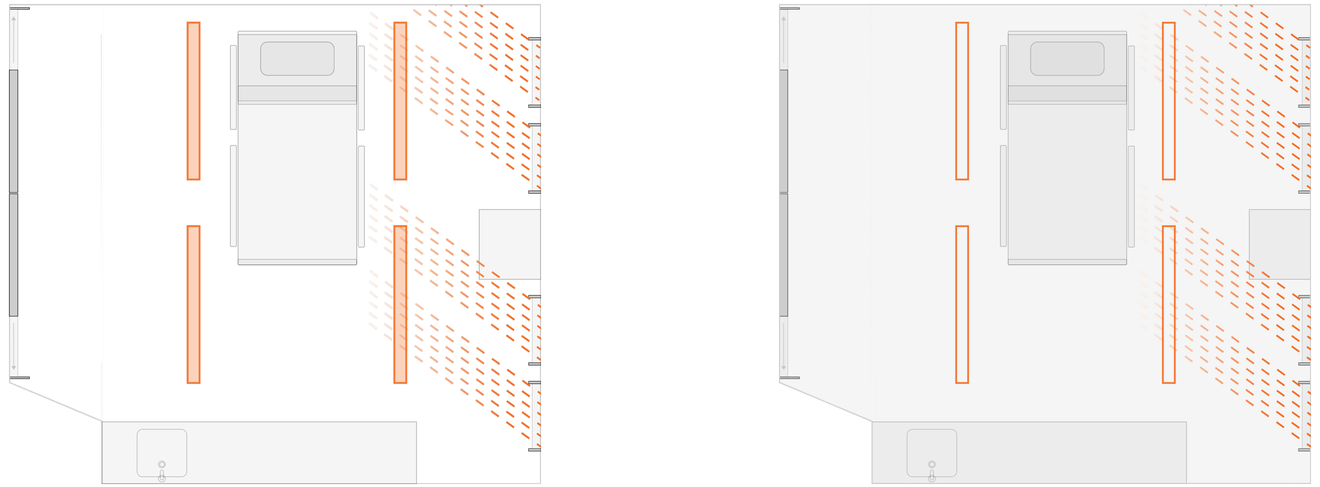


Figure 24
Different lighting scenarios visualized

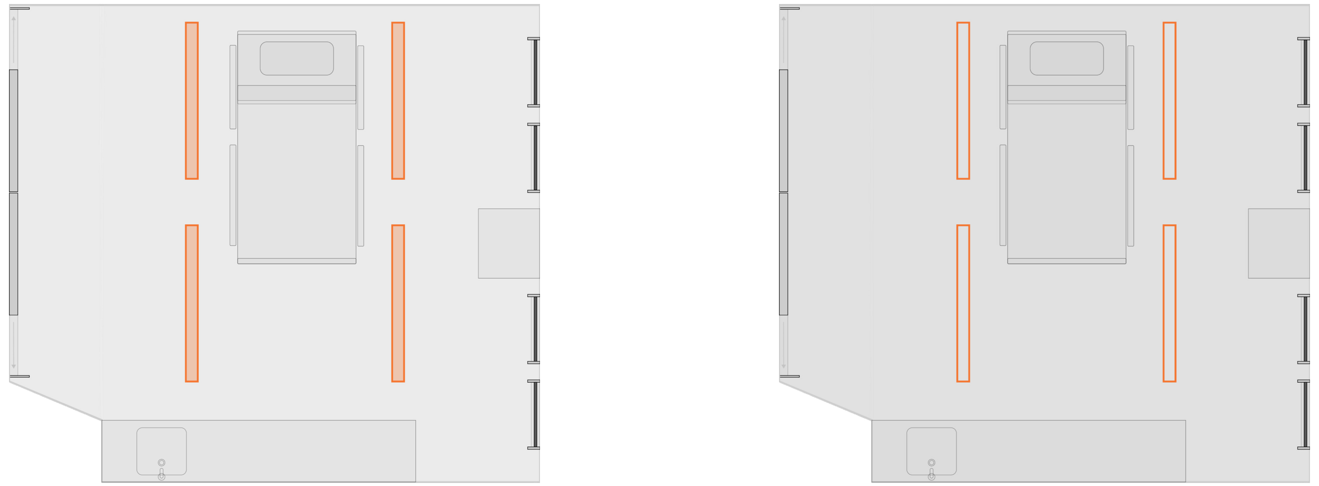
Scenario 1 (lights on, blinds open)

Scenario 2 (lights off, blinds open)



Scenario 3 (lights on, blindes closed)

Scenario 4 (lights off, blinds closed)



By gathering these measurements, a baseline is established for the current lighting conditions, which serves as a foundation for understanding lighting measurements. Measuring at multiple points is essential to capture variations caused by shadows, reflections, and uneven distribution, providing a reliable average of overall illumination rather than depending on a single measurement point.

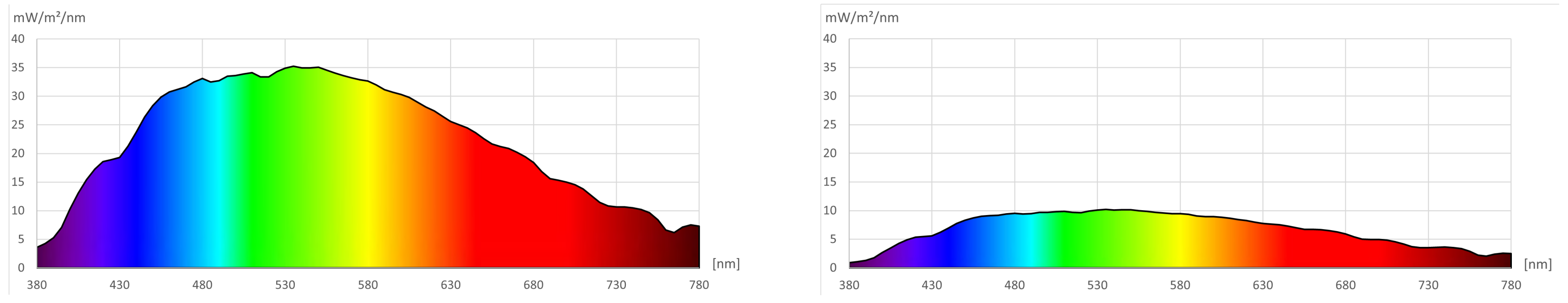
Some notable insights emerged: 3 measurement points could not be collected due to insufficient light levels (Figure 25). Illuminance levels were higher near the windows compared to the opposite side of the room (Figure 26). More sunlight resulted in higher correlated colour temperature (CCT) levels, producing whiter light, while less sunlight combined with more artificial lighting produced lower CCT levels, resulting in warmer-coloured light. Additionally, greater sunlight presence increased the colour rendering index (CRI), while more artificial lighting reduced the CRI due to drops in certain wavelengths (Figure 27). Despite these variations, the CRI RA consistently remained above 80, meeting regulatory requirements. According to regulatory standards (SLL Lighting handbook, 2018, Chapter 17), the general bed area should have at least 300 lx of illuminance, and the foot of the bed should have at least 200 lx. The measurements confirmed compliance with both requirements.

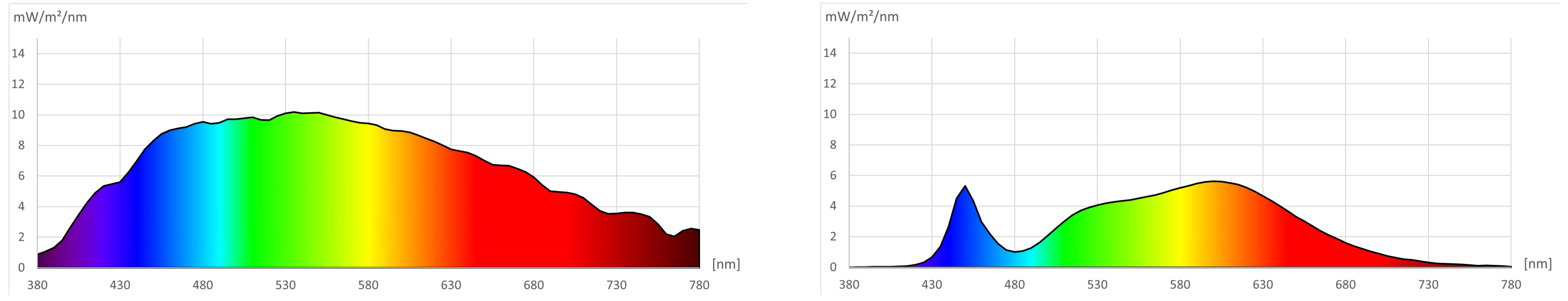
Figure 25
Average measured light levels across different lighting scenarios within the ICU box at Erasmus MC.

Scenario	Type	Details	Illuminance (lx)	CCT (K)	Dominant Wavelength (nm)	CRI RA (R1-R8)	CRI RE (R1-R15)
1	Sunlight + Artificial	Blinds open	1538,24	5007,80	565,00	90,82	86,92
2	Sunlight	Blinds open	1246,71	5537	550	91,7	88,6
3	Artificial	Blinds closed	364,95	3658,60	578,80	83,74	77,34
4	None	Dark - Light off + blindes closed + emerg light on	29,53	4170	570	86,15	81,1

Top
Figure 26
Higher illuminance values near the window than further away

Bottom
Figure 27
Difference in CRI natural light and artificial light





Atmosphere 3.3

In this context, atmospheres refer to the overall sensory and emotional qualities of a space as experienced through perception (Dai & Zheng, 2021). The ICU embodies such an atmosphere: a multisensorial environment shaped by overlapping visual, auditory, tactile, and thermal stimuli. Bright artificial lighting, persistent alarms, physical discomfort, and fluctuating temperatures together define how patients experience this space (Ackley et al., 2024; Nimlyat & Kandar, 2015; Wu et al., 2023).

TYPES OF ATMOSPHERES

In 2008, Ingrid Vogels introduced the concept of Atmosphere Metrics as a systematic method for quantifying the perceived atmosphere of an environment. Her work aimed to capture the subjective qualities of spaces in a structured and measurable way, bridging the gap between environmental design and human experience. The framework is structured around four fundamental dimensions that describe how individuals perceive the atmosphere of a space: coziness, liveliness, tenseness and detachment (Vogels, 2008).

Coziness: Related to terms such as safe, intimate, cozy, and pleasant.
Liveliness: Related to terms such as stimulating, lively, and exciting.
Tenseness: Related to terms such as terrifying, threatening, tense, and oppressive.
Detachment: Related to terms such as business-like, formal, and chilly.

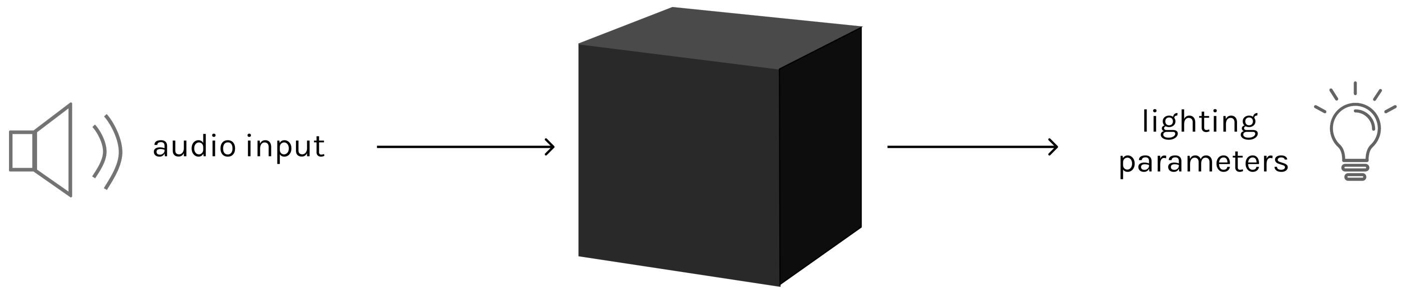
This framework is particularly important for the present project because it provides clear guidelines for linking lighting characteristics to the perceived atmosphere of a space. For example, changes in colour temperature (CCT) and luminance can directly influence how an environment is experienced. Research has shown that an increase in the luminance of white light sources often reduces perceived cosiness and tenseness, while a decrease in luminance can produce the opposite effect. A thesis conducted at TU Eindhoven confirmed these relationships: in essence, warm white light (low CCT) was generally associated with atmospheres that felt cozier, less tense, and less detached than those created by cool white light (high CCT). At the same time, warm white light tended to be perceived as more lively when presented at medium or high intensities. Conversely, cool white light (high CCT) was correlated with atmospheres rated higher on tenseness and detachment, and lower on cosiness (Van Erp et al., 2008).

Design Considerations 3.4

When examining the spectrograms, it becomes clear that different frequency ranges correspond to varying loudness levels, with certain elements of the sound standing out in the foreground while others remain in the background. Translating these auditory characteristics into lighting responses presents an intriguing design challenge. A key aspect of this lighting concept is that it must be adaptable to any type of soundscape.

For this project, this meant developing a system that could process any audio file, analyse it, and extract specific lighting parameters from it (Figure 28). This was brought under the term of finding the 'recipe/lighting recipe'. The first step was finding a method to distinguish foreground sounds from background sounds, followed by identifying when these sound events occur. These dynamic shifts could then be represented visually through changes in light.

To express this distinction between foreground and background, a pendant fixture was chosen. Its ability to direct light both upward and downward allows for semi-indirect, directional lighting, effectively mirroring the layered qualities of sound.

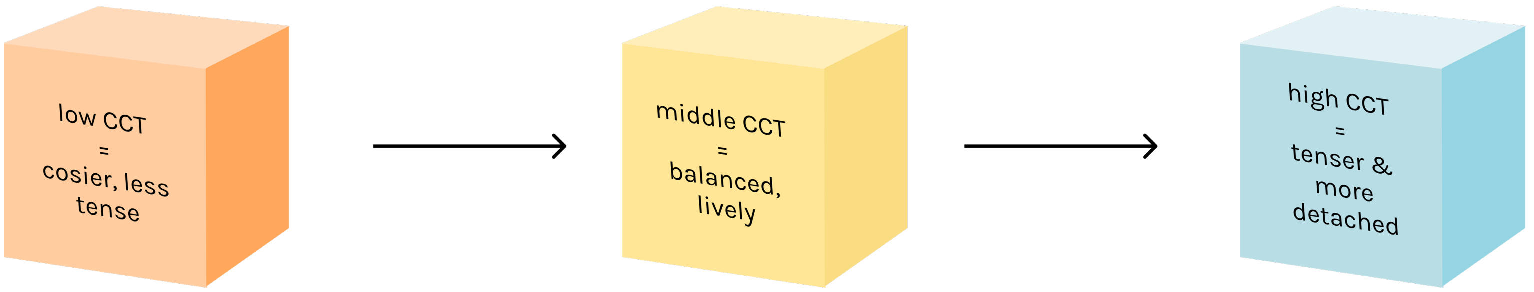


LINKING SONIC AMBIANCE CATEGORIES & CCT

Using this approach, a connection can be established between sonic ambiance categories and lighting parameters. For instance, calm or comfortable soundscapes may correspond to warmer, softer colour temperatures (CCTs), producing a gentle yellow-orange light (Van Erp et al., 2008). Neutral or balanced soundscapes might align with lighter, yellow-white tones, while stimulating or active soundscapes could be represented through cooler, bluish hues, reflecting the energy and brightness of the sound environment (Figure 29).

CONCLUSION

Chapter 3 established a detailed understanding of the sensory and technical foundations underlying the project. By analysing the ICU's existing soundscape, light conditions, and patient experience, as well as exploring the characteristics of the sonic ambiances, this chapter defined how sound can be interpreted and translated into light. This formed a solid foundation for the design development explored in the following chapters.



Left Page

Figure 28
Metaphorical black box representing the 'recipe/lighting recipe'

Right Page

Figure 29
CCT and Perceived Atmosphere

chapter 4

Problem Definition
Final Design Direction
Design Requirements

Design Direction

Problem Definition 4.1

ICU environments are optimized for medical efficiency but neglect the sensory and psychological needs of patients. Constant artificial lighting, irregular noise, and lack of natural cues disrupt patients' circadian rhythms, impair sleep, and contribute to stress and Post-Intensive Care Syndrome (PICS) (Simons, 2018).

While soundscape interventions, such as Louwers' sonic ambiances, have begun to address auditory well-being, light remains static, functional, and emotionally disconnected. Current ICU lighting meets technical standards but fails to support comfort, rhythm, or congruence with sound.

"For the patients, the most difficult thing is that the ceiling lights are still too bright at their most dimmed setting. This disrupts sleep rhythms of patients." - ICU nurse (EMC)

Nurses reported that many patients; particularly those who are delirious, anxious, or on sleep medication, are highly sensitive to light stimuli. Harsh, direct illumination can cause discomfort or even hallucinations, while overly dim or uniform lighting makes care tasks difficult. These insights underscore the need for a lighting solution that supports both patient comfort and staff usability.

Final Design Direction 4.2

The design direction focuses on developing an integrated light and sound system that enhances patient comfort while supporting clinical workflows. The system features a user-friendly interface controlled primarily by healthcare professionals and, where possible, by patients themselves.

Interviews with ICU nurses emphasized the need for adjustable, calm, and well-diffused lighting that can easily switch between bright light for medical procedures and softer illumination for patient rest. Staff reported that current ceiling lighting often remains too bright, even at its lowest setting, and that direct glare can disturb sleep or increase discomfort for sensitive or delirious patients.

These insights guided the development of a dynamic, human-centered lighting solution that adapts to different care contexts. Designed for straightforward integration into existing ICU infrastructure, the system supports the transition toward a "smart ICU" environment, where technology improves both patient well-being and staff usability without adding complexity.

Design Requirements 4.3

Based on the problem definition, context analysis and early explorations, a set of requirements is established to guide the lighting system organised in three categories: desirability, feasibility and viability (Figure 30).

DESIRABILITY
- The lighting must display smooth and calm behaviour.
- The atmosphere must evoke comfort and calmness.
- The user interface should be intuitive and easy to operate.
-

FEASIBILITY
- The system must allow full pixel-level control of the LEDs.
- It must produce accurate white tones.
- It must use an open-source microcontroller for flexible software customization.
- The diffuser must ensure even and uniform light distribution.
- The system should be compatible with existing hospital infrastructure.
- The light should support wireless control for flexibility.

VIABILITY
- The system must be implementable without major infrastructure changes.
- The design should be scalable and adaptable to different ICU layouts.
- Integration must not disrupt existing healthcare workflows.

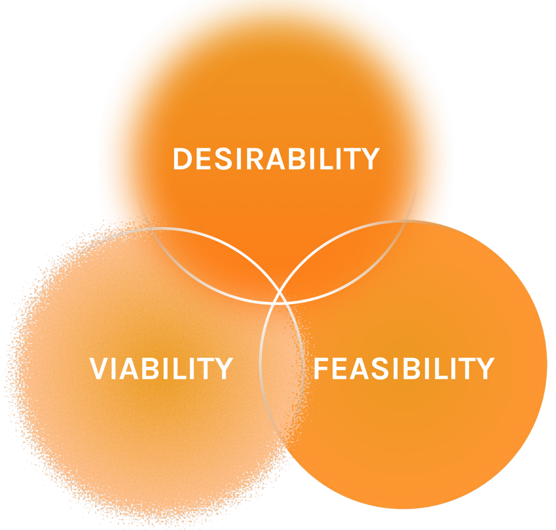


Figure 30
Desirability, feasibility & viability

chapter 5

Design Process

Parallel Paths 5.1

Left Page

Figure 31
Delft Light Framework showing the three different lighting components (Pont, 2025)

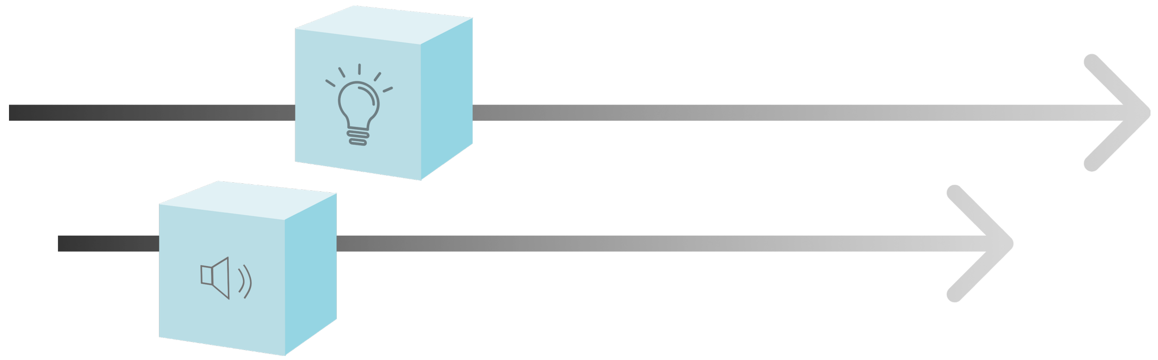
Right Page

Figure 32
Fixture moodboard

At the start of the design process, two parallel paths emerged: the light path and the sound path.

The light path focused on exploring fixtures, light sources, diffusion methods, and lighting effects. Essentially, the physical and visual embodiment of the lamp.

The sound path, on the other hand, involved defining which sonic elements would be translated into light which makes up the 'recipe/light recipe'. These two paths evolved hand in hand, informing and refining each other throughout the process.



The Light Fixture 5.2

INSPIRATION & MOOD BOARD
To gain an understanding of different lighting fixtures and the effects they create, an inspiration phase was carried out. As mentioned earlier, pendant fixtures were initially considered because their semi-indirect lighting direction offered a compelling way to visually represent the distinction between foreground and background sounds. To further develop this idea, a mood board was created (Figure 32), showing various pendant designs and their lighting effects.

Left Page

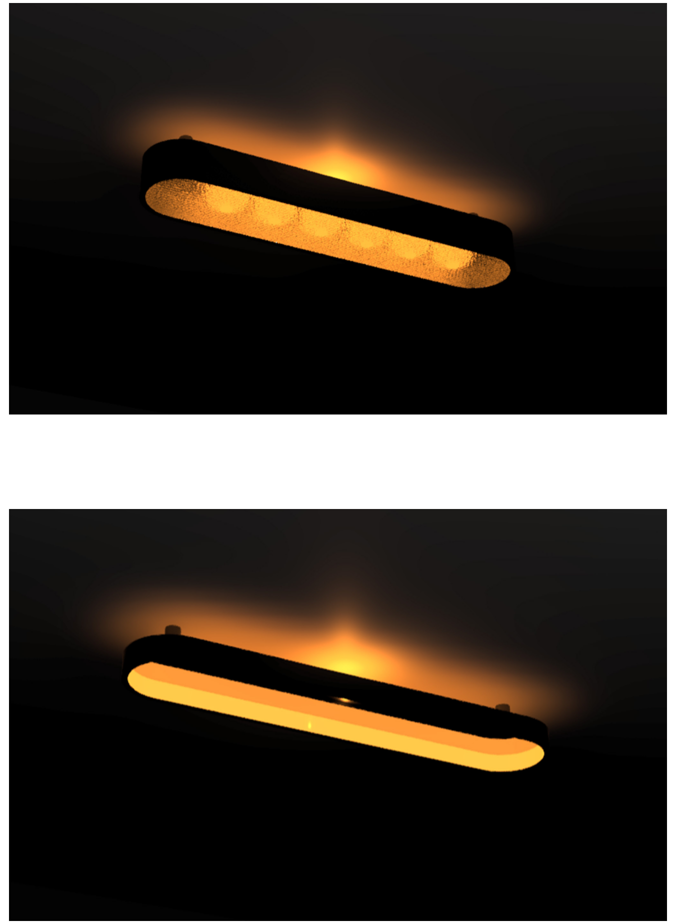
Figure 33
3D render of a pendant light with a semi-indirect lighting distribution

Right Page

Figure 34
Sunne Lamp
(marjanvanaubel, 2023)

From this collection, one design stood out: Sunne by Marjan van Aubel (Figure 34). This is a pendant lamp with a very smooth gradient-like lighting appearance. This pendant stood out for its simplicity and elegant appearance.

VISUALISATION
A quick 3D render was created to visualize how the lighting effect could appear in space (Figure 33). This revealed that using a 2D-light plane allows for dynamic spatial movement, as areas of light can independently brighten and dim over time. This sense of motion directly relates to changes in sound, which are often perceived as movement. Since this project integrates soundscapes, this finding shows a connection between auditory variation and visual rhythm.



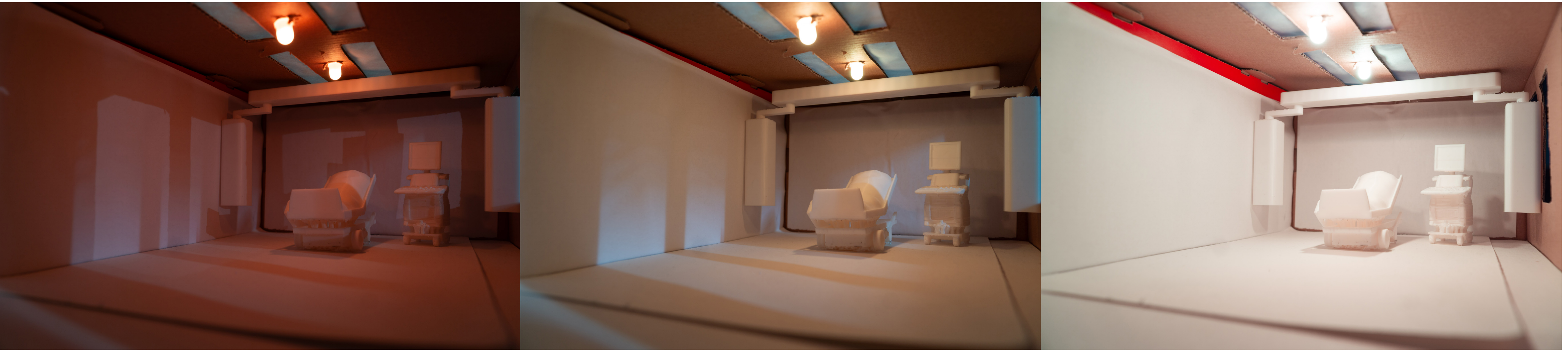
Fixture Placement 5.3

Figure 35
Photos of the shoebox prototype model showing the first colour/light simulations

SHOE-BOX MODEL

Exploring where and how the fixture should be positioned within the space was a crucial step in shaping the overall lighting experience. To study this, a shoe-box model prototype of an ICU room at EMC was built using LED spots from an Arduino kit. Two LED units were mounted on the ceiling of a cardboard box and linked with potentiometer knobs for manual colour and brightness adjustment control to observe how light behaved within the space (Figure 35).

Photographs and observations from this shoebox model highlighted the significant impact of multiple light sources within a space. It became clear that external factors such as daylight and the angle of incoming light strongly influenced the overall ambiance. Even at this early stage, colour variations proved capable of transforming the atmosphere of a space.



COMBINED LAYERS

The initial idea proposed separating foreground and background sounds into two light sources: lighting in the corners for foreground sounds and ceiling lights for background sounds (Figure 36).

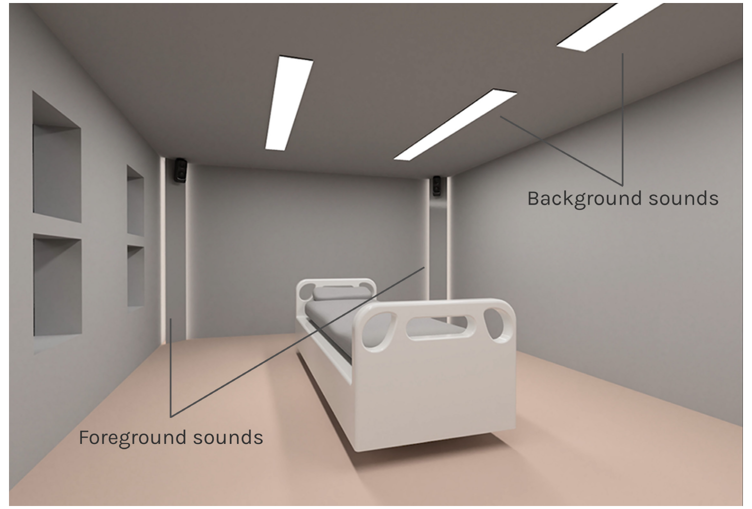
However, this proved impractical in the ICU due to hygiene and infrastructure constraints. The design was therefore refined into a single, ceiling-mounted fixture capable of representing both layers. The background sounds come forward in the base brightness and foreground sounds in the highlights (Figure 37).

FIXTURE FOCUS

At this stage, the priority was to create a technically feasible lighting fixture capable of producing the intended effects. The emphasis was on functionality and performance rather than aesthetics or final form. This phase focused on ensuring the light could behave and respond as required, while visual design details were kept minimal.

Left
Figure 36
Render of lighting concept for foreground and background separation

Right
Figure 37
Connecting background and foreground sounds to light



LIGHT MATRIX

Earlier explorations revealed that movement could be created when light was distributed across a two-dimensional plane. To translate this insight into a tangible design, it was necessary to understand how such a light plane could be constructed. In this project, the chosen form factor for achieving this was a two-dimensional light matrix, a structured arrangement of LEDs.

For this matrix, individual LED control was essential as it provided the freedom to explore dynamic lighting animations and precisely map changes in sound to light behaviour. This prompted an exploration of available programmable LED matrices, such as those offered by Kiwi Electronics (Figure 38). While these provided suitable resolution and control, they exceeded the project's budget and relied solely on RGB LEDs, which were less ideal for achieving natural white tones.

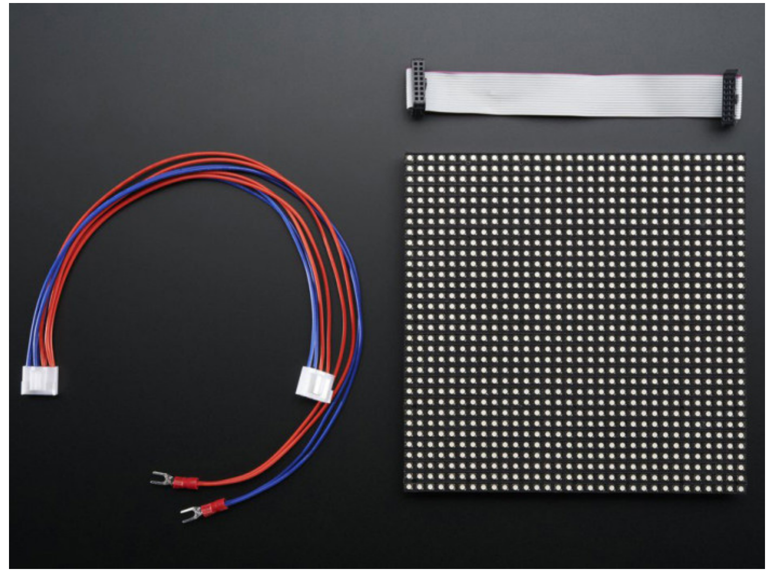


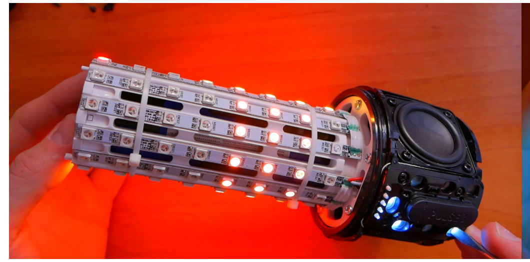
Figure 38
32 x 32 RGB LED Matrix Panel (Kiwi electronics, 2025)

JBL PULSE

To find a more feasible alternative, further investigation was conducted into other lighting products that created dynamic, fluid light patterns. The JBL Pulse speaker stood out for its, lava-like lighting effect (Figure 39), which achieved smooth, ambient motion similar to what was envisioned for this project. Upon examining a disassembly video (Figure 40), it became clear that this effect was created by an array of LED strips placed side by side behind a diffuser, effectively forming a matrix.

Another key insight was that even minimal changes in the distance between the LEDs and the diffuser had a significant impact on light diffusion. When the diffuser was placed just one centimeter closer, individual LED points became more visible, whereas increasing the distance by the same amount produced a much softer, more evenly diffused glow (Figure 41).

This discovery revealed that a comparable setup could be built by aligning multiple LED strips in parallel, offering both flexibility and affordability. Since no suitable off-the-shelf solution existed, a custom-built matrix approach was chosen. The technical implementation of this custom setup is discussed further in Chapter 5.5.



Left to Right
Figure 39
JBL Pulse with 'lava-like' effect (JBL, 2017)

Figure 40
Disassembly JBL Pulse (Pavel ES YouTube, 2023)

Figure 41
Diffuser layer (Pavel ES YouTube, 2023)

Translating Sound into Light 5.5

SONIC AMBIANCE CATEGORY & CCT

The initial step in the design process focused on finding a method to translate sound into light. Three categories of sonic ambiances were defined: comfortable, pleasurable, and stimulating (Louwers et al. 2024). Looking back at the Vogel's research, each of these sonics ambiance categories could be associated with different correlated colour temperatures (CCTs) (Figure 42).

CIRCADIAN RHYTHM IMPLEMENTATION

As circadian rhythms play a crucial role in patient recovery, the lighting design needed to support and respect these natural biological cycles. Light is one of the most powerful external cues influencing sleep-wake regulation, directly affecting patients' levels of alertness and restfulness. Therefore, the system was designed to recreate an environment that gently guides patients toward wakefulness during the day and restfulness at night.
Research shows that variations in colour temperature can effectively support these rhythms: cooler, bluish light promotes alertness and concentration, while warmer light tones create a softer, more relaxing atmosphere conducive to sleep (Summer & Summer, 2025). In this context, the lighting concept uses warm light during early morning and evening hours to encourage gradual waking and winding down, neutral white light during general daytime activity, and cool light around midday to promote maximum alertness and orientation.

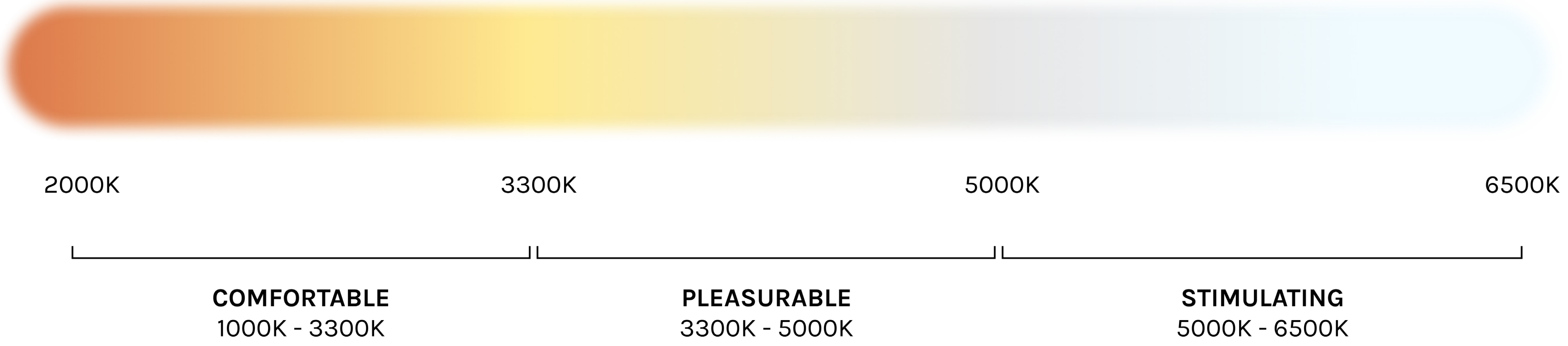


Figure 42
Sonic ambiances and CCT

SOUND ANALYSIS

To identify which sounds the lighting system should react to, finding a method to detect foreground from background sounds is necessary. Several methods for this were explored, including Fourier transforms, spectrograms, and RMS loudness analysis. While the former approaches offered detailed frequency insights, they proved unnecessarily complex for the design goals. The RMS loudness analysis emerged as the most effective and straightforward method.

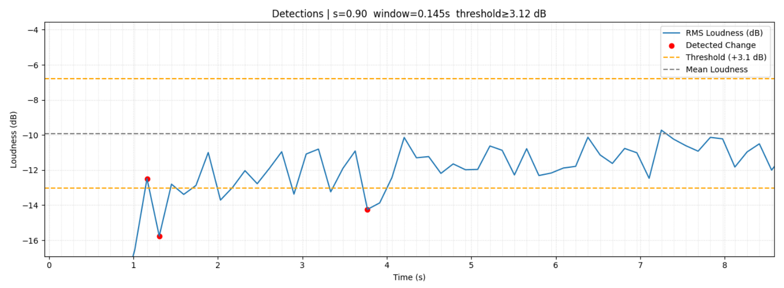
Foreground sounds, those perceptibly louder than their surroundings, were of primary interest, as they best capture the sense of movement or "eventfulness" in a soundscape. For example, a single bird chirp stands out as an event, whereas gradual changes in rainfall intensity do not.

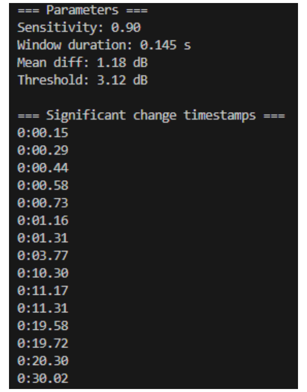
DETECTION PRINCIPLE – RMS LOUDNESS

The detection principle assumes that when loudness within a short time window exceeds the background level by a certain threshold, the event can be qualified as foreground. Both the volume difference and time window parameters vary depending on the sound category under analysis.

The implemented procedure follows these steps:

- The audio is divided into short time windows, and RMS loudness is calculated in decibels. Consecutive windows are compared to identify sharp changes in loudness (Figure 43).
- A sensitivity parameter adjusts both the window size and detection threshold. Higher sensitivity results in shorter windows and lower thresholds, yielding more detected events. To maintain perceptual relevance, a minimum threshold of 3 dB (the just noticeable difference in human hearing) is enforced (McShefferty et al. (2015).
- When significant changes are detected, their timestamps are extracted, marking perceptible shifts in audio dynamics that can be directly translated into lighting cues (Figure 44).





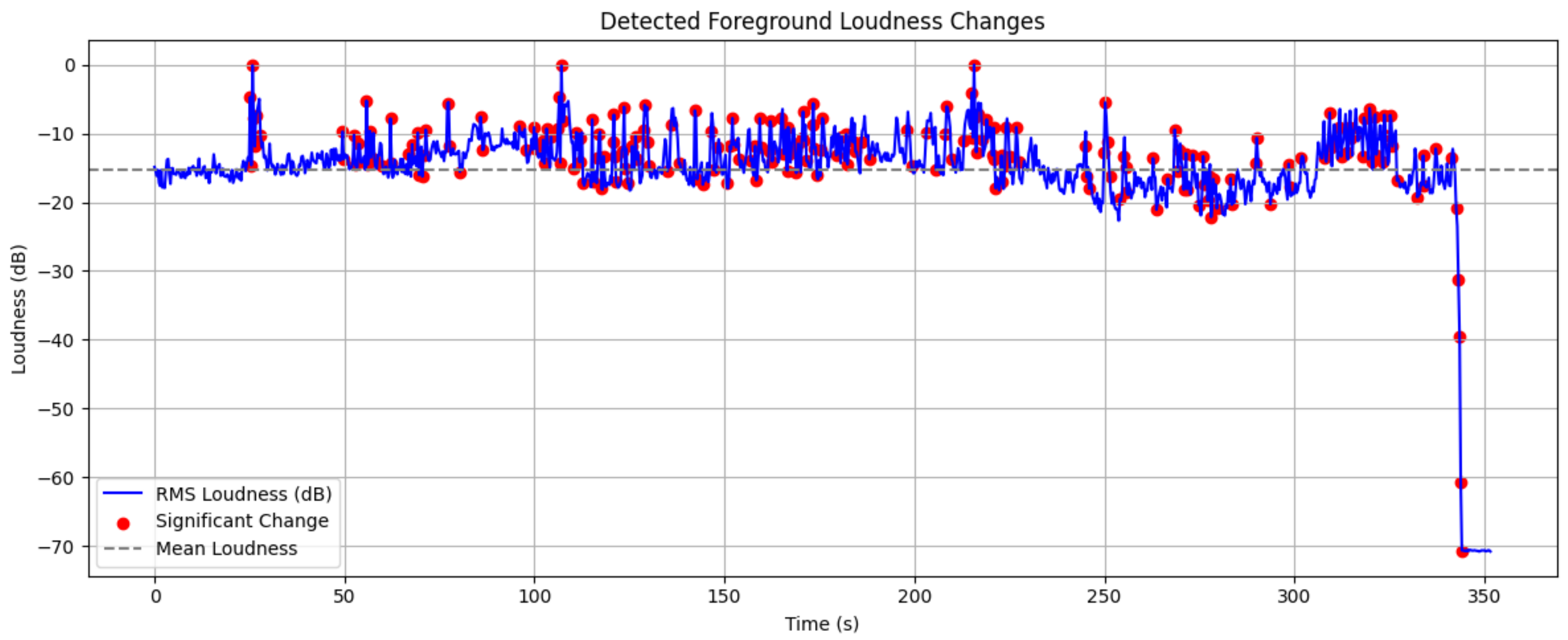
```
=== Parameters ===
Sensitivity: 0.90
Window duration: 0.145 s
Mean diff: 1.18 dB
Threshold: 3.12 dB

=== Significant change timestamps ===
0:00.15
0:00.29
0:00.44
0:00.58
0:00.73
0:01.16
0:01.31
0:03.77
0:10.30
0:11.17
0:11.31
0:19.58
0:19.72
0:20.30
0:30.02
```

Left
Figure 43
Graph of an audio file cut into pieces showing the mean, threshold and detected changes (timestamps)

Right
Figure 44
In code: the detection parameters and a part of the timestamp list

Figure 45
Graph showing RMS loudness with peaks (red dots) identified as timestamps

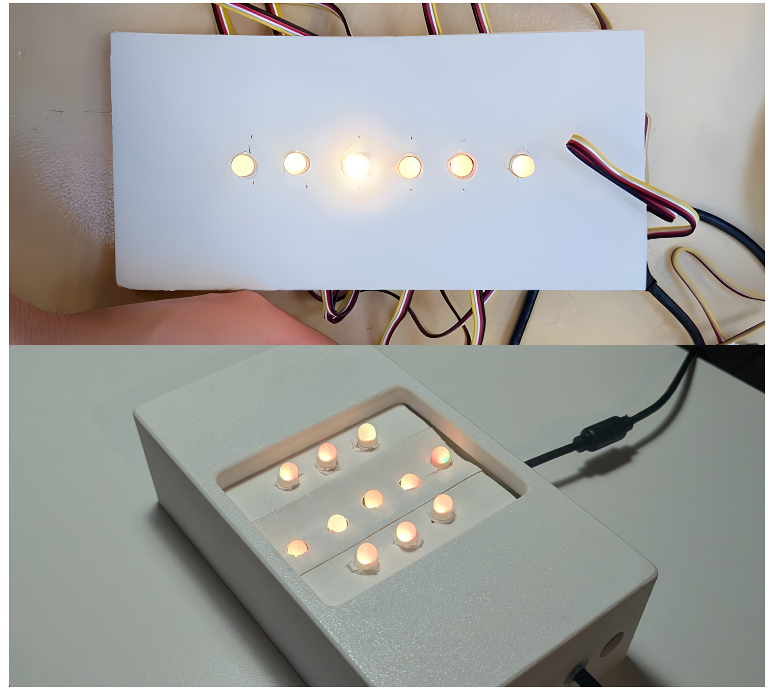
Iterative adjustments to these parameters allowed the system to scale the number of lighting cues according to the soundscape's eventfulness, from calm, "comfortable" ambiances to more "stimulating" ones. Figure 45 below illustrates an example of detected timestamps (shown as red dots) where loudness exceeded the threshold. These timestamps form the foundation of the 'recipe/ lighting recipe' used in the study.



ITERATING LIGHT EFFECTS

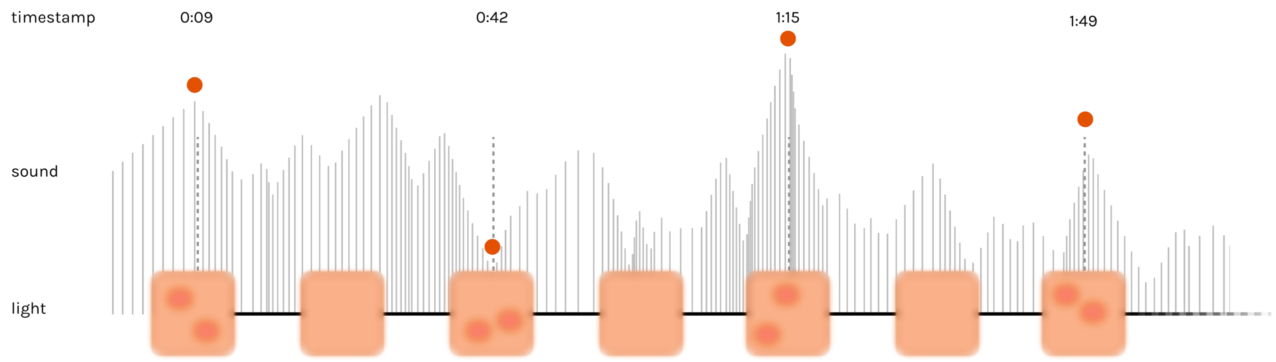
Using Arduino controlled LEDs, simple animations were developed to test how sound events could be visualised. The detected timestamps were used as cues to trigger brightness changes, allowing the light to follow the same timeline as the audio file. During each timestamp, the LEDs smoothly faded from a base brightness to full intensity and back down (Figure 46).

It started out with a single strip of six LED's, later expanded to ten LEDs arranged across a matrix to explore horizontal and vertical movement. Parameters such as the CCT, led brightness, speed of fading and the number of LEDs activated per timestamp were explored. (Figure 47). This exploratory phase revealed the expressive potential of timing and movement in light matrices.



Top & Middle
Figure 46
Six & eleven LED setup

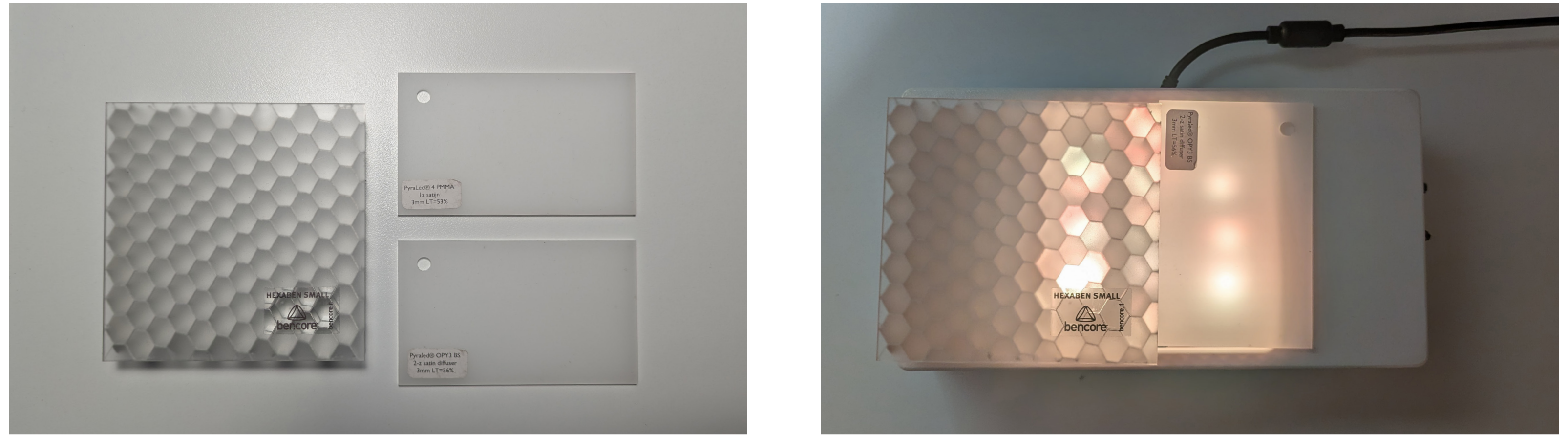
Bottom
Figure 47
Sound & light in the same timeline



Top
Figure 48
Baking paper as a diffuse layer

Bottom
Figure 49
Bencore (left) and PyraLed (right) diffuser samples

DIFFUSION
Diffusion was also experimented with, first using materials such as baking paper (Figure 48) and later with diffuser samples from Bencore and PyraLed (Figure 49). As observed from the JBL Pulse, the diffuse layer plays a crucial role in creating the smooth, seamless appearance of light by blending individual LED points into a continuous surface.



Feedback from ICU nursing staff further reinforced the importance of smooth, glare-free lighting, as visible LED points or harsh contrasts can be uncomfortable for patients, especially those prone to delirium or hallucinations. Based on these insights, opal diffusers were identified as the most effective option, producing the smoothest lighting appearance.

Prototyping revealed that increasing the distance between the LEDs and the diffuser surface significantly improved light uniformity. A spacing of 5 cm was found to be optimal, eliminating visible hotspots while maintaining sufficient brightness (Figure 50).

Top
Figure 50
Comparison of diffusers not spaced (top) and spaced 15mm (bottom)

Scaling to a Full-Scale Prototype 5.5

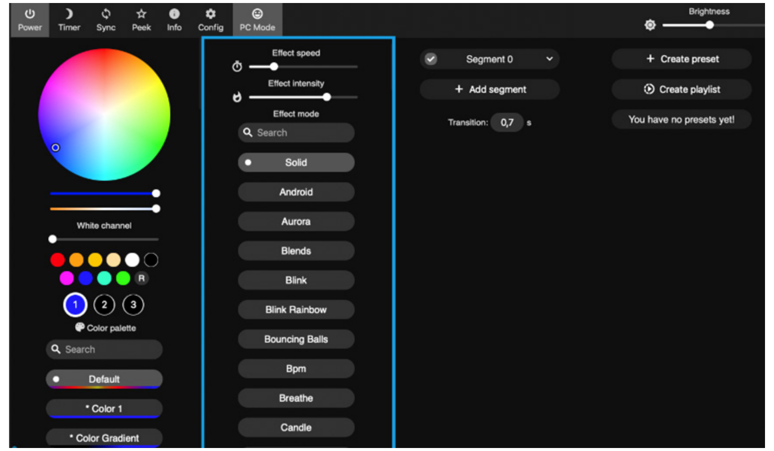
Top Right
Figure 51
WLED Interface

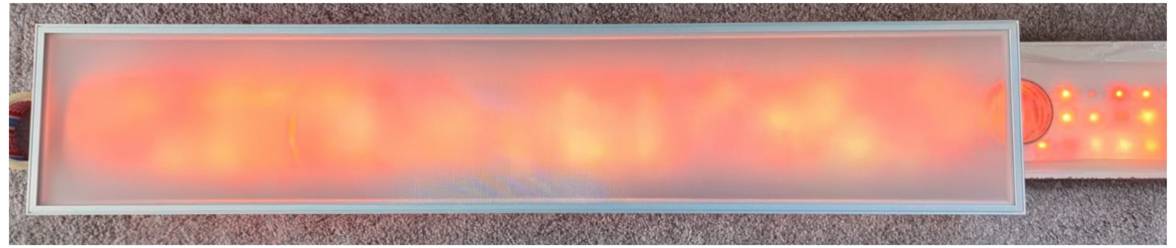
Bottom Left
Figure 52
First large scale prototype using an existing fixture and WS2812B LED strips with a prismatic diffuser

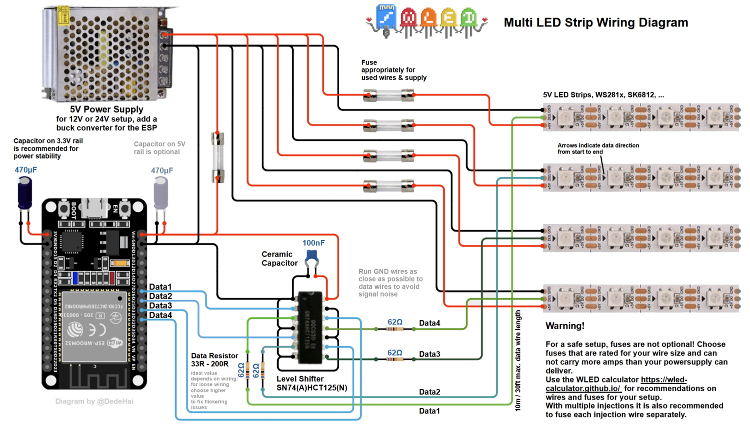
Bottom Left
Figure 53
WLED wiring diagram for 4 LED strips

ITERATION 1 – INITIAL SETUP
The first large-scale prototype focused on testing the feasibility of a programmable light matrix (Figure 52).
This setup used WS2812B addressable RGB LED strips driven by an ESP-32 microcontroller running open source WLED software (Figure 51). The components were powered by a 50 W power supply and mounted into an existing industrial LED panel fixture (Figure 53).

WLED provided a quick way to test dynamic light effects through a built-in web interface, using predefined animations and brightness controls. The circuit followed WLED's reference wiring diagram (Figure 53), which included a level shifter to boost the ESP-32's 3.3 V data signal to the 5 V logic required by the LEDs.





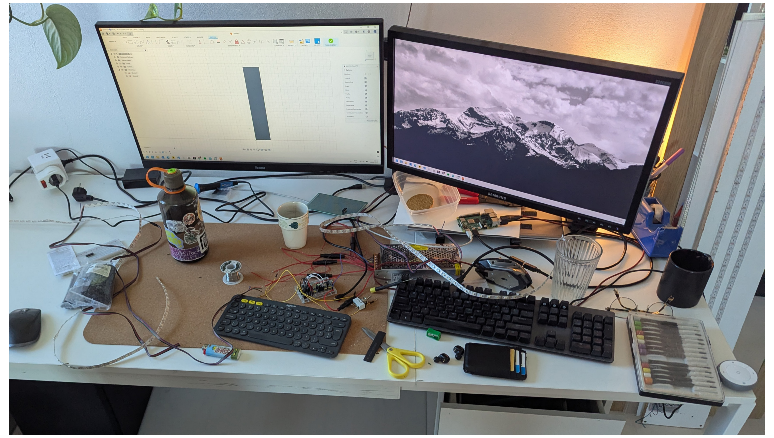


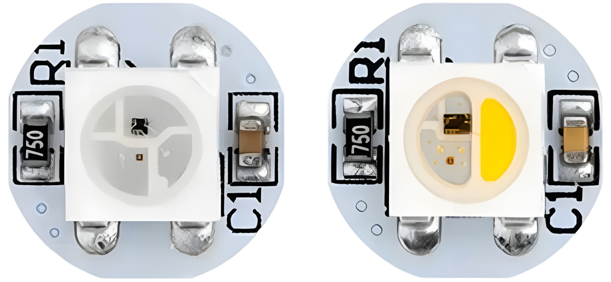
Warning!
For a safe setup, fuses are not optional! Choose fuses that are rated for your wire size and can not carry more amps than your powersupply can deliver.
Use the WLED calculator https://wled-calculator.github.io/ for recommendations on wires and fuses for your setup.
With multiple injections it is also recommended to fuse each injection wire separately.

While this setup allowed rapid testing of colour transitions and motion effects, several key limitations emerged:
- Light quality: the WS2812B LEDs produced white light through RGB mixing, resulting in a noticeably artificial tone which was not desired
- Diffusion: the fixture's prismatic diffuser caused visible LED hotspots, as the light source was positioned too close to the surface.
- Software control: WLED's preset-based animations offered limited lighting control. Individual pixel control was needed.

ITERATION 2 – CUSTOM SOFTWARE AND IMPROVED HARDWARE
To address these issues, the second iteration introduced both hardware and software refinements.

LEDS
The WS2812B LED strips were replaced with SK6812 RGBW strips, which include a dedicated white chip (yellow part in Figure 55). This allowed for accurate, natural white light and variable colour temperature, an essential feature for creating expressive and clinically appropriate lighting. SK6812 RGBW LEDs come in sizes of 30 LEDs/m, 60 LEDs/m or 144LEDs/m. For a decent resolution and not too high price, the middle option of 60LEDs/m was chosen.





Top
Figure 54
Prototyping

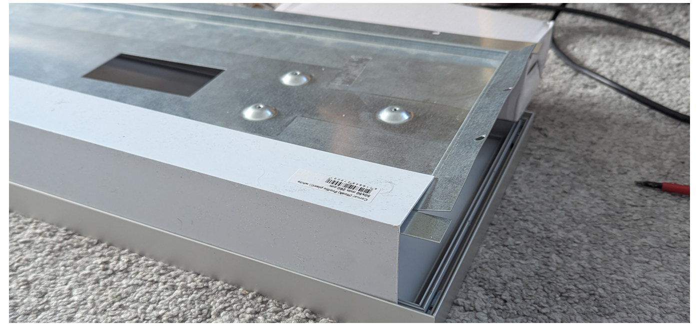
Bottom
Figure 55
WS2812B RGB LED chip (left) & SK6812 RGBW LED chip (right) compared (BFT-LIGHTING, 2025)

Right
Figure 56
5cm spacing & L-shaped profiles

Bottom
Figure 57
Improved diffusion panel

DIFFUSION & FIXTURE

The prismatic diffuser was replaced with an opal diffuser, producing a smooth, uniform light field that eliminated visible hotspots (Figure 57). Testing also revealed that increasing the distance between the LEDs and diffuser by 5 cm provided optimal diffusion without significant brightness loss. The fixture was adjusted accordingly using spacers and covering the sides with plastic L-shaped profiles . (Figure 56)



SOFTWARE TRANSITION

To gain full creative control, the WLED platform was replaced with custom software.

Initially, a Python-based program was developed and uploaded to the ESP-32 to control the LEDs. However, performance limitations caused lag and unsmooth animations. To improve responsiveness, the system was rewritten in Arduino-based C++, allowing for precise timing and smoother transitions.

In parallel, a Raspberry Pi was introduced as a secondary controller. Acting as a compact computer with built-in Wi-Fi and Bluetooth, it hosted a local web server that allowed users to control the lighting wirelessly via a simple webpage.

When a lighting mode was selected, the Pi sent a serial command to the ESP-32, triggering the corresponding light sequence while simultaneously playing the associated audio through Bluetooth-connected speakers.

LIGHTING PARAMETER EXPLORATION

A preliminary lighting recipe was developed to explore how variations in timing, brightness, and colour temperature affect the perceived relationship between sound and light. Through iterative sessions with testees, different parameter combinations were evaluated to identify lighting behaviours that best matched the tone and dynamics of each sonic ambiance; Comfortable, Pleasurable, and Stimulating.

The system detects foreground sound events whenever the audio intensity exceeds the background level by more than 3 dB, converting them into timestamps that trigger light animations (Chapter 5.4). Each ambiance category applies its own sensitivity and timing window, controlling how often light cues occur and how they are expressed.

From these explorations, the main parameters defining the lighting behaviour were established: colour temperature (CCT), base and highlight brightness, fade duration, hold time, number of LEDs per timestamp, and block size. When a cue is triggered the number of LED's determines how many blocks are triggered in random spots and the block size determines of how big each spot is in terms of led amount. These findings formed the foundation for the final lighting recipe in Chapter 6.3.

Left Page

Left
Figure 58
3D-printed casings for
ESP-32 and power supply

Right
Figure 59
Full scale prototype
without diffuser panel

Right Page

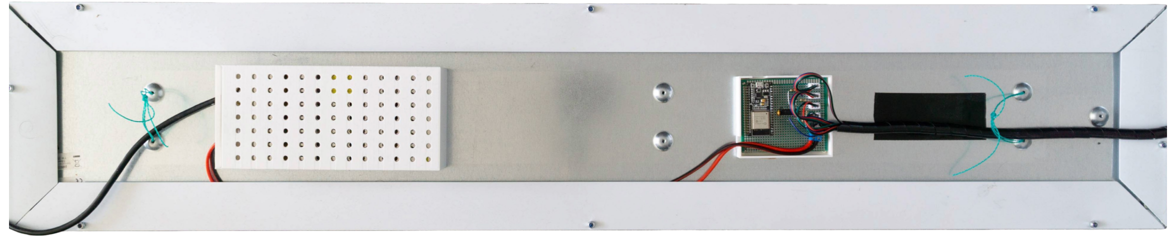
Figure 60
Full scale prototype

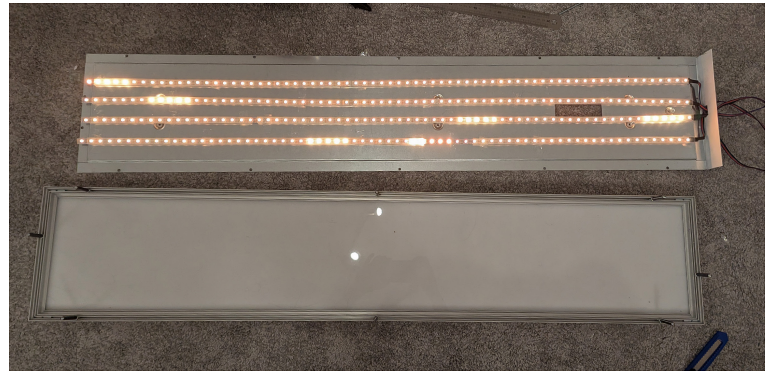
COMPLETE ASSEMBLED PROTOTYPE

The full-scale prototype consisted of four LED strips controlled by an ESP-32 microcontroller, powered by an external supply, and mounted within an adjusted fixture raised by 5 cm to improve light diffusion and reduce glare (Figure 59 & 60). Custom 3D-printed casings were designed to house the microcontroller and power source neatly on the fixture's back panel, ensuring both safety and accessibility (Figure 58). All components were assembled into a fully functional unit capable of running the programmed lighting behaviours. This final prototype was used in the final user testing for evaluation.

CONCLUSION

The two large-scale prototype iterations were instrumental in refining both the hardware and software of the system. The first iteration demonstrated proof of concept but revealed issues with light quality and control, while the second achieved accurate white light, smooth diffusion, and reliable wireless synchronization. These findings directly informed the final implementation of Komora, detailed in Chapter 6.





chapter 6

Main Components
Technical Setup
Lighting Recipe
Interface & Usability
Integration in the ICU Context
Testing & Evaluation

Komora

The final design, named Komora, embodies the integration of light and sound within the intensive care environment (Figure 63). The name is derived from 'Komorebi', the Japanese word describing sunlight filtering softly through the leaves of trees (Figure 62). With the play of light and shadow, moments of brightness appear and fade as the wind moves the branches.
Similarly, Komora translates sonic events into gentle illuminations, allowing light to shimmer and shift in response to sound.

The Komora logo features a clean, sans-serif font and a minimal design inspired by Japanese aesthetics, reflecting the meaning of its name. Its vertical, lantern-like form and soft glowing tones evoke warmth and comfort, in the hopes of offering a subtle contrast to the sterile hospital environment (Figure 61). The design also echoes the gentle light filtering through leaves, evoking calmness and connection to nature within the ICU context.

Left Page

Figure 61
Komora Logo

Figure 62
Komorebi

Right Page

Figure 63
Komora

Right Page

Figure 64
Komora in context

Komora redefines light as an active, responsive element in the sensory landscape of the ICU (Figure 64). By translating sound into calm, lighting behaviour, the system aims to restore a sense of natural variation and comfort within a typically static and environment. In doing so, it reintroduces subtle lighting cues that support patients' circadian rhythms by aligning the light's colour temperature and brightness with the natural progression of the day: cooler, bluish tones in the morning and warmer, softer light toward the evening.

In dialogue with ICU nursing staff, Komora directly addresses current lighting limitations such as excessive brightness, lack of control, and visual discomfort. Its design introduces smooth diffusion, adjustable brightness, and customizable lighting modes that support both patient rest and clinical activity.

Technically, Komora integrates precise LED control, soft diffusion, and a compact fixture that meets hospital hygiene and safety standards. Its minimal form allows seamless installation into existing infrastructure without interrupting workflows. By combining technological precision with sensory awareness, Komora contributes to a more humane, responsive, and circadian-supportive ICU environment.

Main Components 6.1

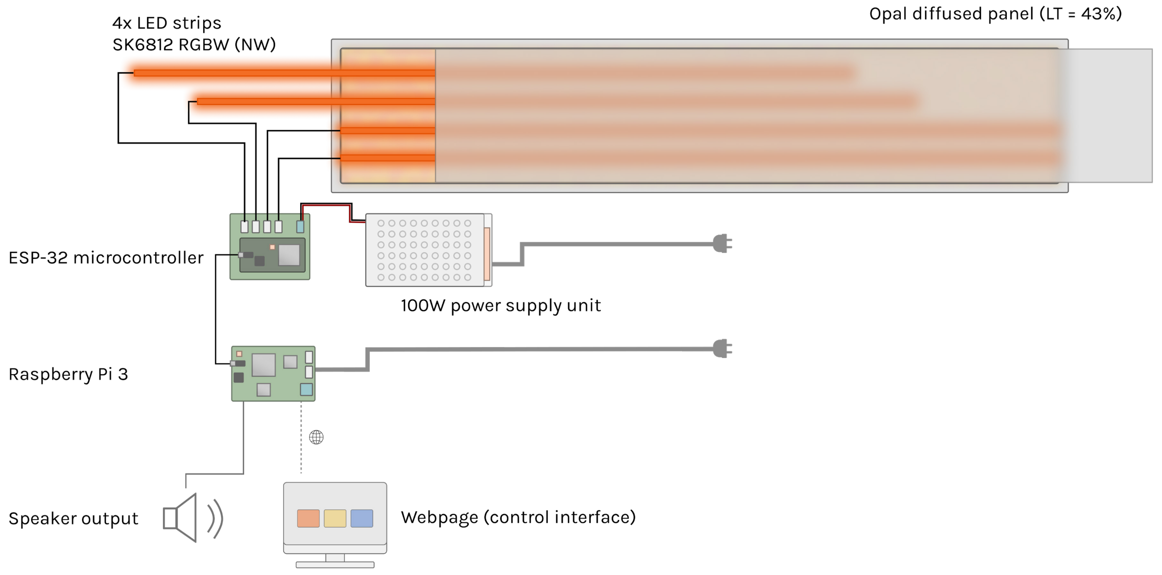
Left Page

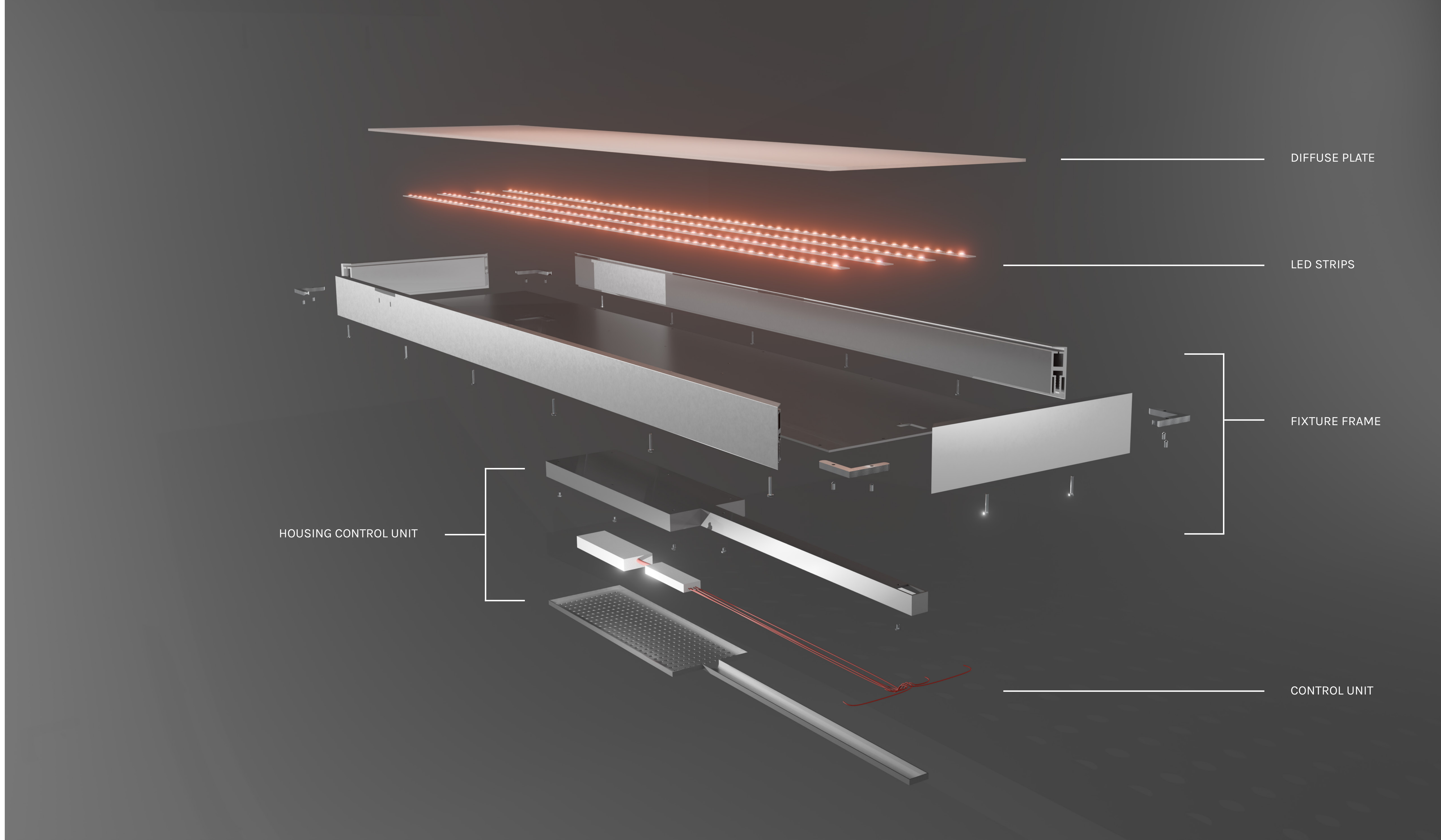
Figure 65
Main components of Komora

Right Page

Figure 66
Exploded view of Komora

The Komora lamp is made of four main components: the fixture, 4 LED strips (SK6812 RGBW), a microcontroller (ESP-32), and a Raspberry Pi (3) (Figure 65).
The fixture is the lamps “main body” and lets light diffuse into the room through the diffuse panel. The 4 LED strips are the source of light. The microcontroller tells the LEDs how and when to light up. The Raspberry Pi works as a minicomputer to host the website (user interface) and sends out an audio signal to external speakers. All of this is powered by a 100W power supply (Figure 66).





Technical Setup 6.2

FIXTURE

The design is based on the earlier prototype fixture but refined for improved visual uniformity, structural integration, and suitability for the ICU context (Figure 67).

In the final version, the fixture features a 5 cm side profile, which defines the optimal distance between the LED matrix and the diffuser. This spacing ensures a uniform light spread and eliminates visible hotspots without compromising brightness. The LEDs are mounted on a flat aluminium base plate. The exterior of the fixture consists of aluminium profiles with slots for mounting screws and a slot for the diffuser plate to slide in. Aluminium brackets in the corners keep the fixture securely assembled.

The diffuser is an opal acrylic panel, selected for producing soft, even light distribution while concealing the individual LEDs. It has a light transmission value of 74%, ensuring smooth and balanced light passthrough. This material offers a continuous lighting effect that complements the sonic ambiances. The edges of the fixture are enclosed by a clean, seamless frame, resulting in a cohesive form that appears minimal and unobtrusive in the ICU environment.

On the top is a housing that keeps the control unit together, mounted to the bottom plate.

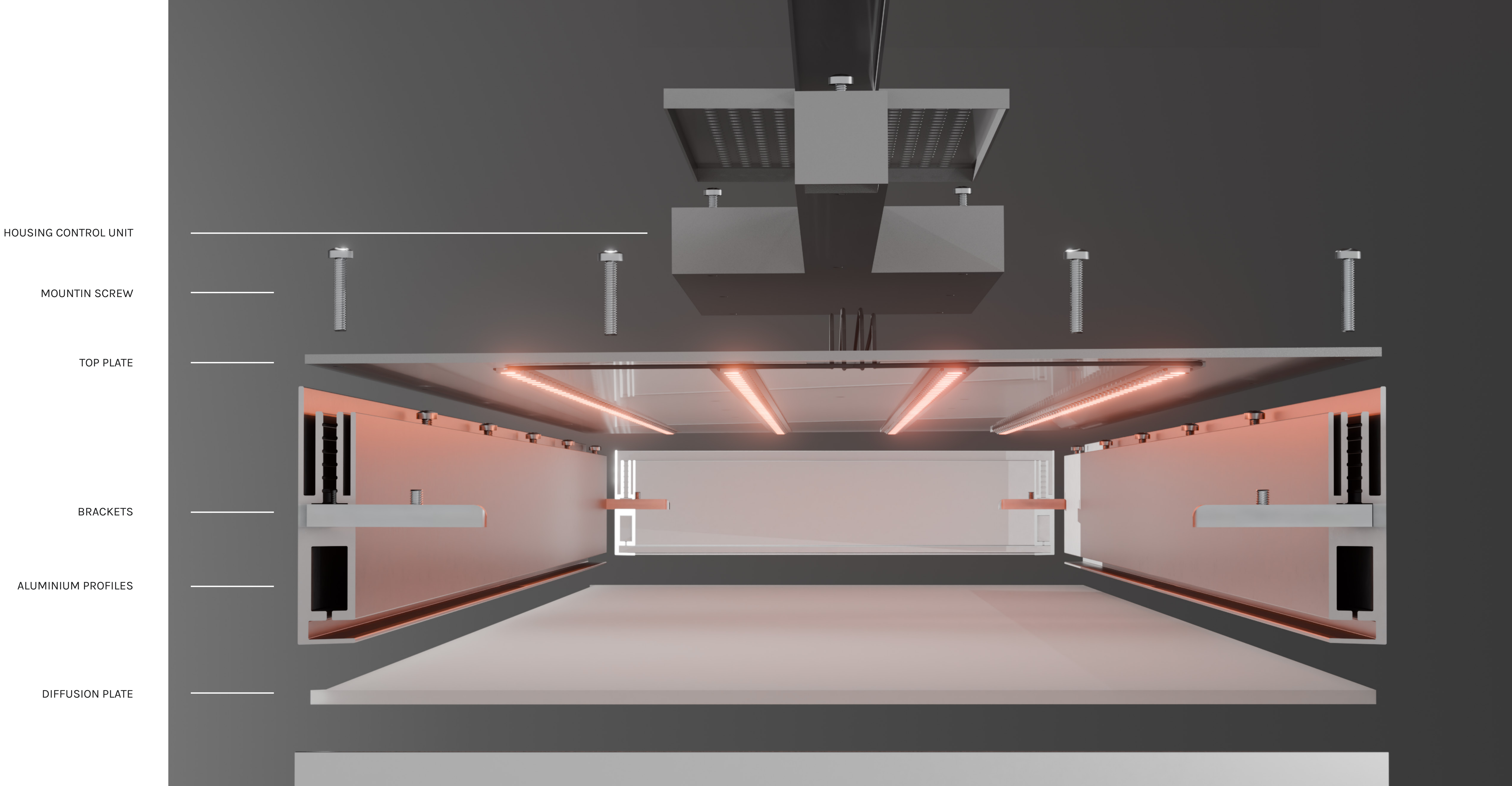


Figure 67
Fixture components

Left Page

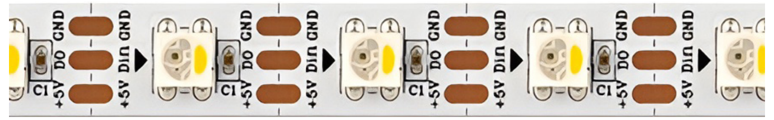
Figure 68
SK6812 RGBW LED strip

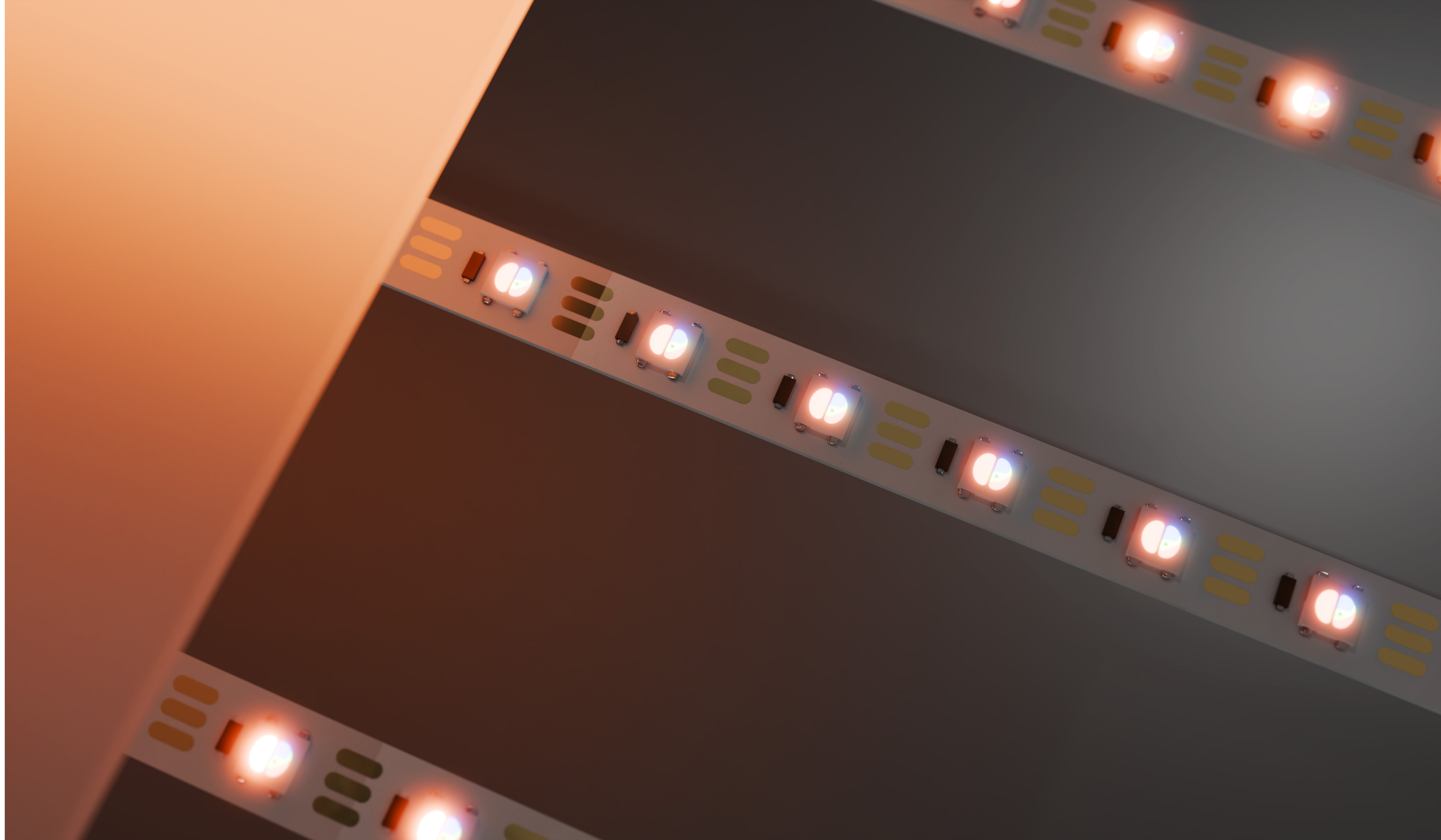
Right Page

Figure 69
Render of SK6812 RGBW
LED strip

SK6812 RGBW LEDS

Komora uses four SK6812 RGBW addressable LED strips (60LEDs/m), each capable of producing both full colour (RGB) and accurate neutral white light due to it's dedicated white diode (Figure 68 & 69). This combination allows for a broad range of colour capabilities and a smooth CCT transition. Addressable LEDs mean that each LED can be individually controlled





Left Page

Left
Figure 70
Custom PCB design

Right
Figure 71
Raspberry Pi 3

Right Page

Left
Figure 72
ESP-32 & Raspberry Pi
flowchart

Right
Figure 73
PCB with JST connectors

ESP-32 MICROCONTROLLER

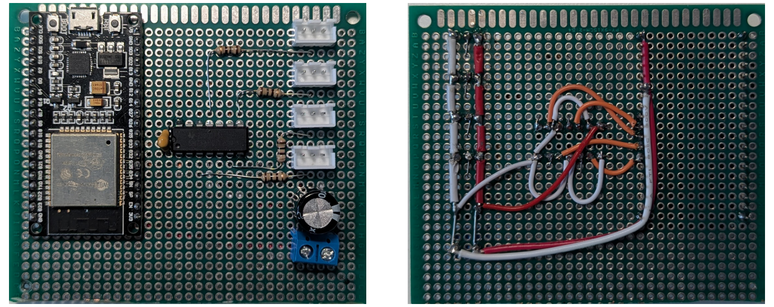
The ESP-32 translates commands from the Raspberry Pi into lighting instructions for the LED strips. It runs Arduino-based C++ code that includes manually pre-programmed timestamp parameters, which serve as cues to trigger the corresponding lighting effects.

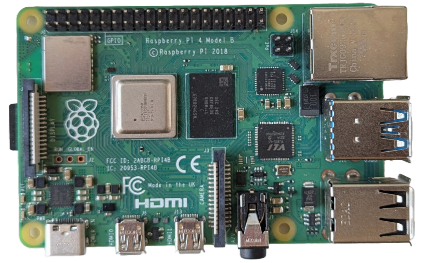
The wiring diagram (Figure 53) is based on the same WLED reference layout used earlier on in the prototyping stage. This setup is soldered onto a custom PCB for stable power distribution and reliable data connections between the controller, PSU, and LEDs (Figure 70). The LED strips are connected to the PCB with JST connectors to facilitate quick and secure attachment or replacement (Figure 73). The operational logic of the ESP32, including how these commands are processed to control the LED behaviour in code, is explained in 'Lighting Recipe' (Chapter 6.3).

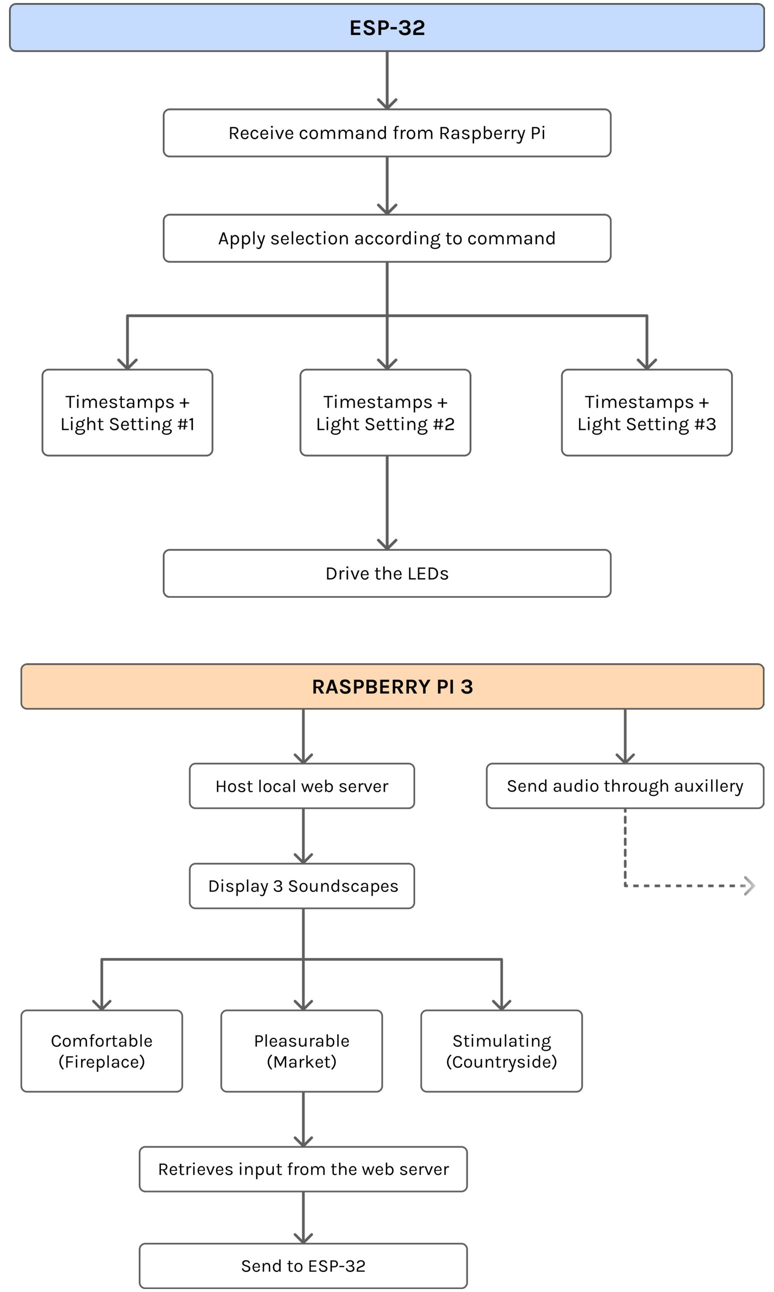
RASPBERRY PI 3

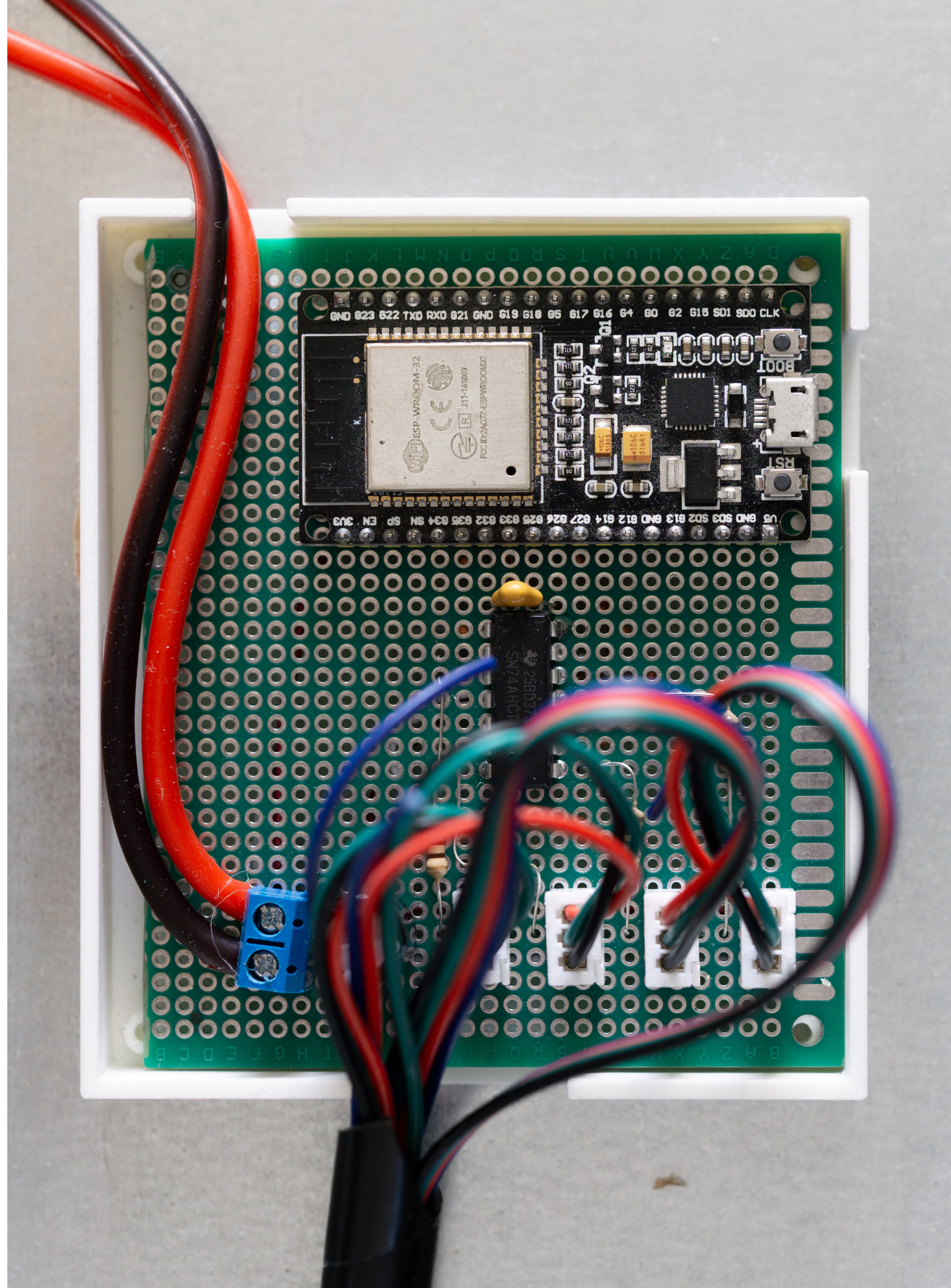
The Raspberry Pi functions as the control hub for Komora. Running on a micro python script, it hosts the local web server (the user interface) and manages audio playback. Through this interface, users can select a lighting program, which sends a command to the ESP-32 via a serial connection while simultaneously triggering the corresponding audio track (Figure 71). Through auxiliary connection with a Sonos Port, audio is then streamed wirelessly to Sonos Era1000 speakers.

Codes of the ESP-32 and Raspberry Pi are to be found in Apendix D & E and flowcharts in Figure 72.









Lighting Recipe 6.3

Left Page

Top
Figure 74
Sensitivity values

Bottom
Figure 75
Relation between sonic ambiances and sensitiviy value

Right Page

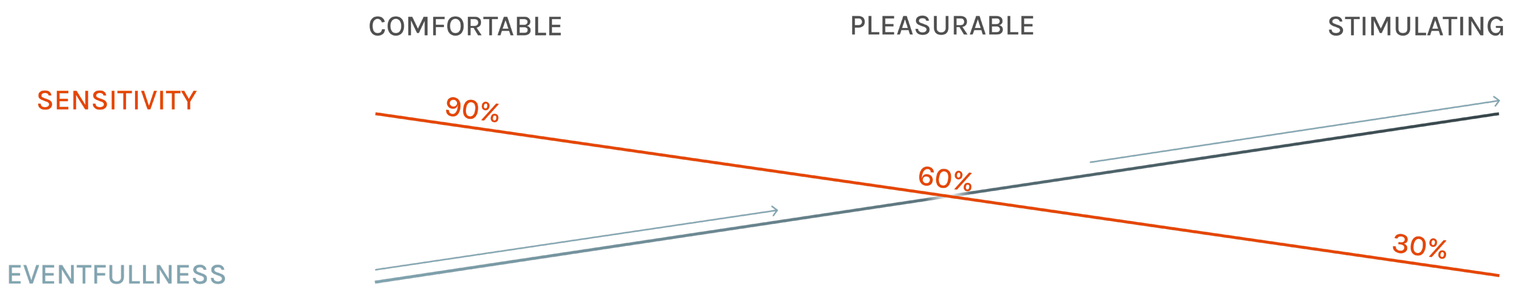
Top
Figure 76
Parameters visualised

Bottom
Figure 77
Relation between sensitivity, window duration and threshold

The lighting recipe defines how sound is translated into light through a set of parameters that describe intensity, colour temperature, speed, and spatial behaviour. Each sonic ambiance: comfortable, pleasurable and stimulating represents its own combination of parameters. For clarity within this project, these lighting modes are referred to as Calm, Neutral, and Alert.

TIMESTAMP ESTABLISHMENT
Komora operates on a timestamp-based lighting system, where sound events exceeding a 3 dB threshold, are converted into light cues. Each sonic ambiance uses its own sensitivity setting (Figure 74) and relation towards the level of eventfulness (Figure 75) determining how frequently light changes occur. These timestamp lists are preprogrammed into the ESP microcontroller.

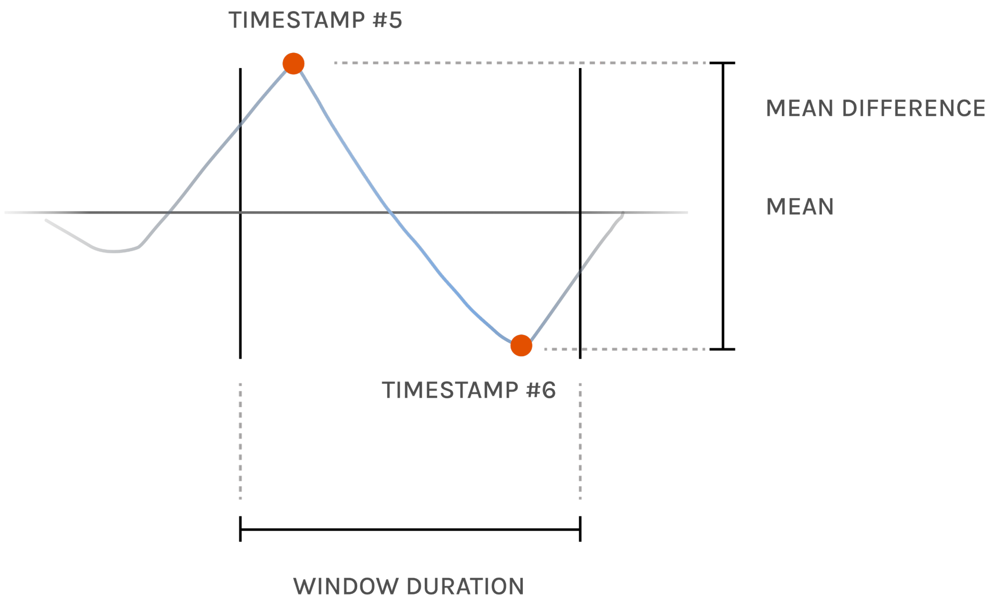
ASPECT	COMFORTABLE	PLEASURABLE	STIMULATING
SENSITIVITY	90%	60%	30%

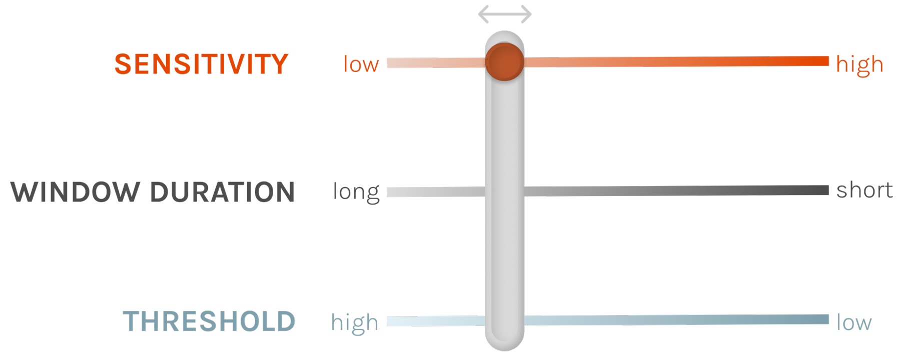


SENSITIVITY
The sensitivity parameter acts as a global control that adjusts how responsive the detection system is. It ranges from 0.0 (strict), detecting only large loudness changes, to 1.0 (lenient), which captures smaller fluctuations. This parameter simultaneously influences both the window duration and detection threshold, functioning as a single 'detection sensitivity knob' (Figure 77).

MEAN DIFFERENCE
The mean difference represents the average absolute change in loudness (in decibels) between consecutive analysis windows. It provides a baseline for assessing how dynamic or stable the sound signal is (Figure 76).

WINDOW DURATION
The window duration defines the length of each segment (in seconds) used for calculating the sound's RMS loudness. Short windows (e.g., 0.05 s) capture quick, fine-grained changes, while long windows (e.g., 1.0 s) smooth over short-term fluctuations. The window duration adapts automatically based on the sensitivity, higher sensitivity results in shorter windows (Figure 77).





Left Page

Figure 78
Lighting parameters

Right Page

Figure 79
Calm, neutral and alert light modes

THRESHOLD

The threshold determines the minimum loudness change (in dB) required to classify a sound event as significant. It is dynamically calculated based on both the average loudness variation (mean difference) and sensitivity: higher sensitivity lowers the threshold (more detections), while lower sensitivity raises it (fewer detections). To ensure perceptual relevance, the threshold never falls below 3 dB.

In summary, tuning the sensitivity parameter automatically adjusts both the window duration and threshold, controlling the system's overall responsiveness to sound dynamics.

LIGHTING PARAMETERS

These timestamps trigger lighting sequences defined by a set of parameters that shape each ambiance's visual behaviour (Figure 78). The lighting recipe defines variations in colour temperature, brightness, transition speed, and LED grouping to reflect the tone of each soundscape. Most parameters increase progressively from Calm to Alert, reflecting a rise in eventfulness and visual energy. The exception is the brightening/dimming speed, which becomes faster in the Alert mode to mirror its more dynamic nature.

Python codes are to the found in Appendix A, B & C.

Aspect	Calm (Comfortable)	Neutral (Pleasurable)	Alert (Stimulating)
CCT Range (K)	1000K	3000K	6500K
Base Brightness	5%	5%	5%
Highlight Brightness	90%	95%	100%
Sensitivity	90%	60%	30%
Number of blocks/timestamp	1	2	3
Block size (LEDs)	4	5	7
Brightening/Dimming speed + hold	3000ms/500ms	2000ms/500ms	1000ms/500ms

COLOUR TEMPERATURE (CCT)

The Calm mode (1000K) produces a warm amber tone, the Neutral mode (3000K) transitions to a balanced yellowish-white, and the Alert mode (6500K) emits a cool, bluish-white tone (blue boost) (Figure 79).

BRIGHTNESS

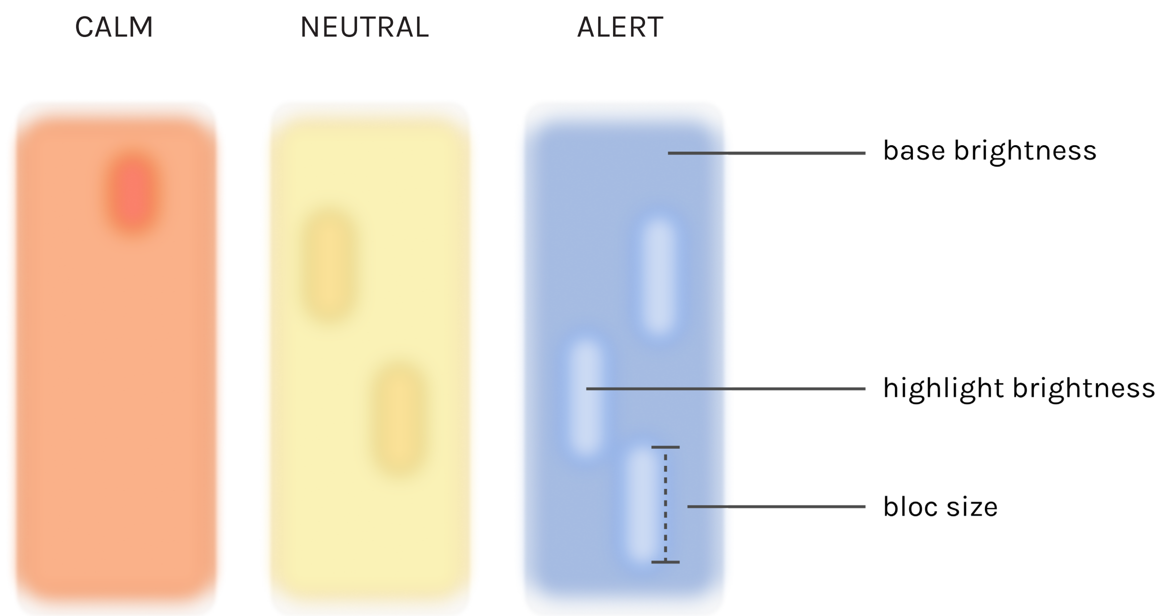
The base brightness remains constant at 5 %, while highlight brightness increases gradually from 90 % to 100 %, reinforcing the sense of intensity.

LED GROUPING

At each timestamp, a random LED block is activated within the matrix. As intensity rises, block size increases (4 to 7 LEDs), while number of blocks per timestamp decreases (3 to 1), resulting in broader but calmer light movements in higher-intensity ambiances.

TRANSITION SPEED

Brightening and dimming times shorten from 3000 ms in Calm to 1000 ms in Alert, producing quicker, more energetic transitions.



Interface & Usability 6.4

Left Page

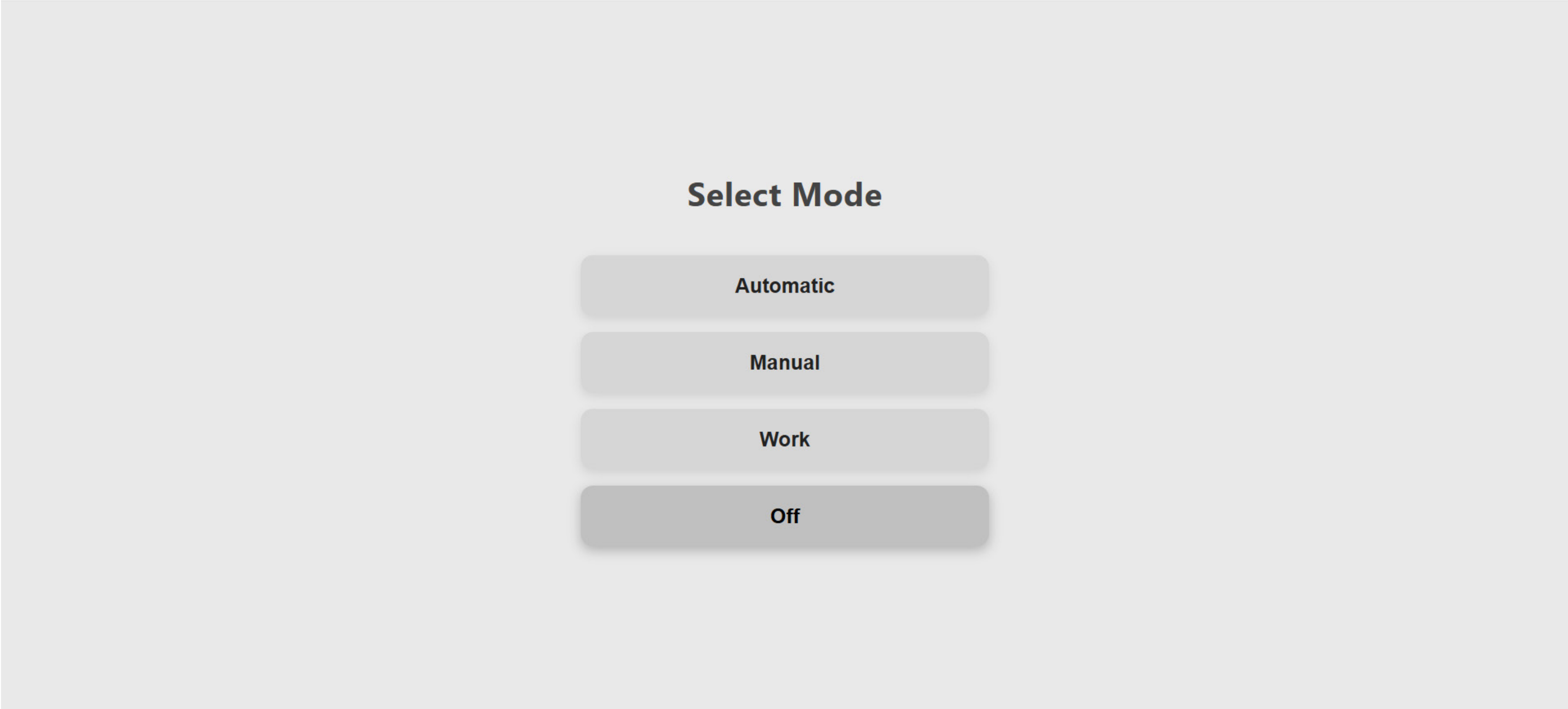
Figure 80
Main web interface of Komora

Right Page

Figure 81
Visual representation of the circadian rhythm with CCT

The lighting interface was designed to provide intuitive, simple, flexible, and context-appropriate control within the ICU. It enables both automated and manual interaction with the lighting system, adapting to the needs of patients and healthcare professionals (HCPs).

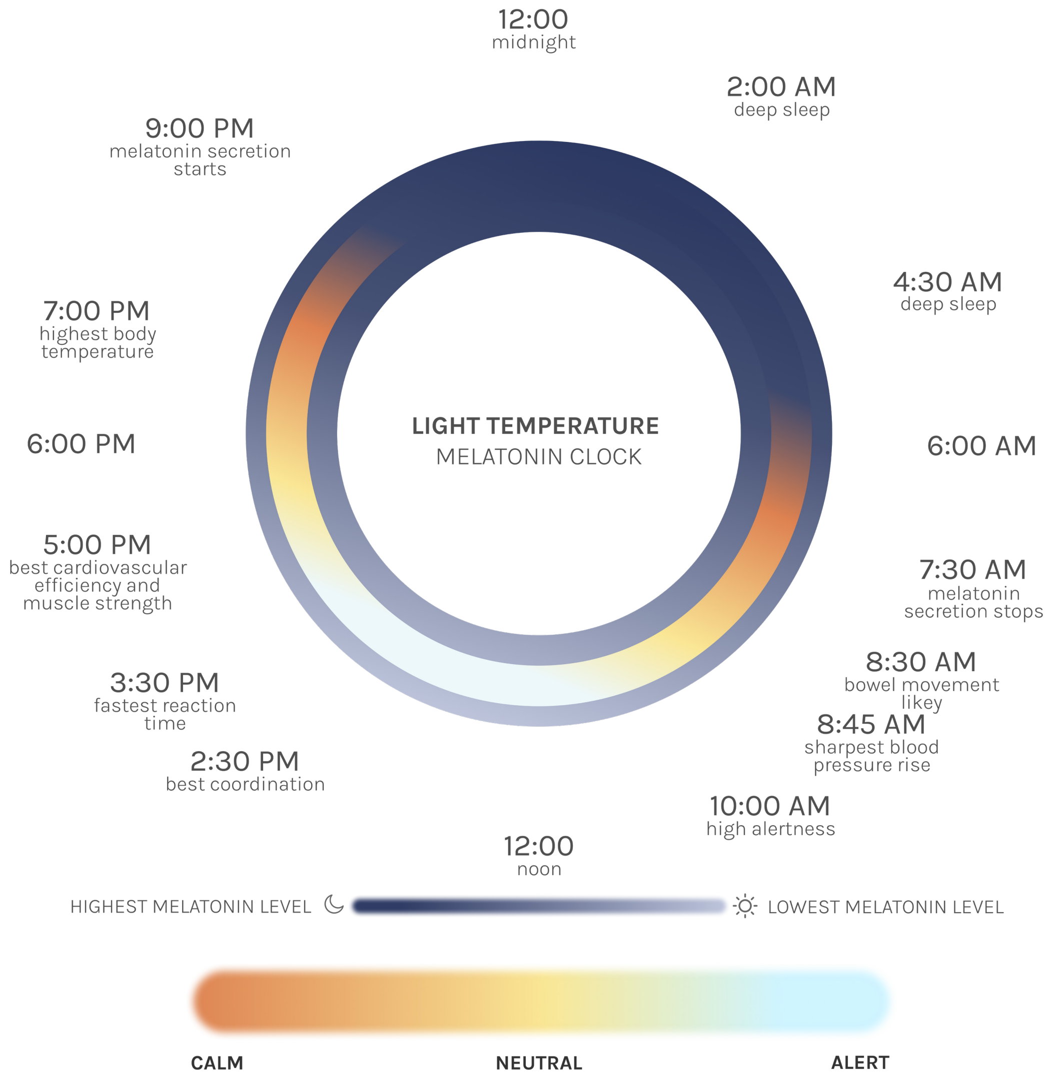
WEB INTERFACE
The web interface offers three main control modes Automatic, Manual, and Work each addressing a specific user scenario, from patient-centred comfort to medical functionality (Figure 80).



AUTOMATIC MODE — CIRCADIAN RHYTHM INTEGRATION

The Automatic Mode operates autonomously, aligning the lighting behaviour with the natural circadian rhythm and the ICU's non-busy hours (see Chapter 2.3). It follows a visual circadian pattern, gradually adjusting colour temperature (CCT) throughout the day, from warm tones in the morning, to neutral midday light, and cooler tones in the afternoon, before returning to warm hues in the evening (Figure 81).

This ensures that patients experience supportive lighting even when HCPs are occupied or when patients cannot interact with the controls. The system's dynamic light shifts promote rest, orientation, and smoother day-night transitions.

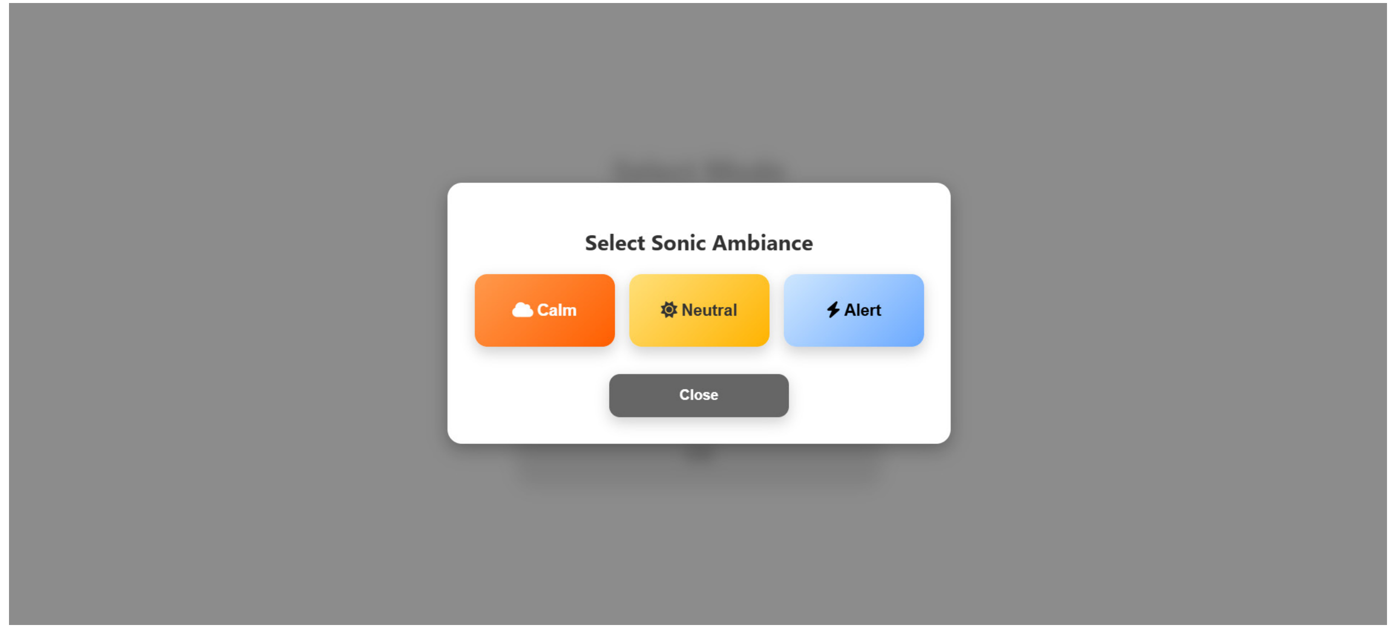


MANUAL MODE

In Manual Mode, users can select between three ambiances: Calm, Neutral, and Alert, corresponding to the sonic ambiances Comfortable, Pleasurable, and Stimulating. Both HCPs and capable patients can access this mode through a bedside tablet or by scanning a QR code on their personal device. This allows for tailored environmental control while maintaining consistency between sound and light design (Figure 82).

WORK MODE

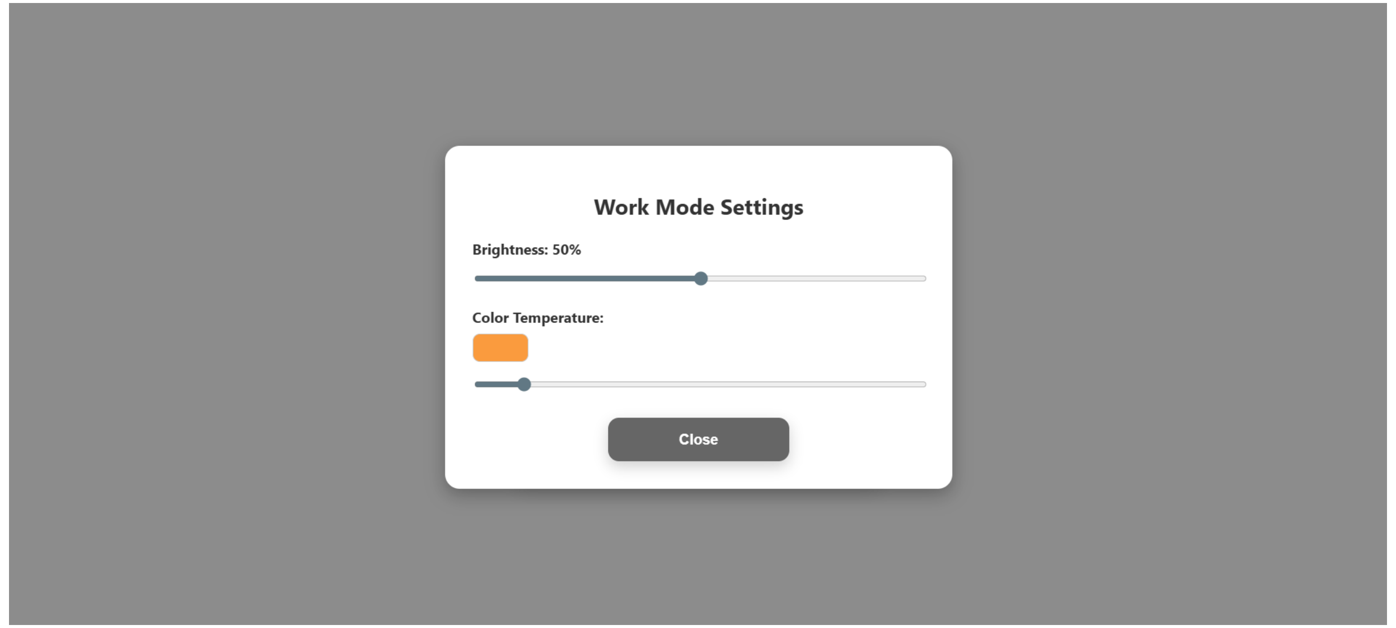
The Work Mode is optimized for medical procedures, offering a static, functional light with both CCT and brightness sliders for fine adjustment. This mode directly addresses nurse feedback requesting an intermediate light level, bright enough for care activities yet soft enough to avoid disturbing patients during rest (Figure 83).



Select Sonic Ambiance

Top

Figure 82
Manual mode



Work Mode Settings

Brightness: 50%

Color Temperature:

Bottom

Figure 83
Work mode

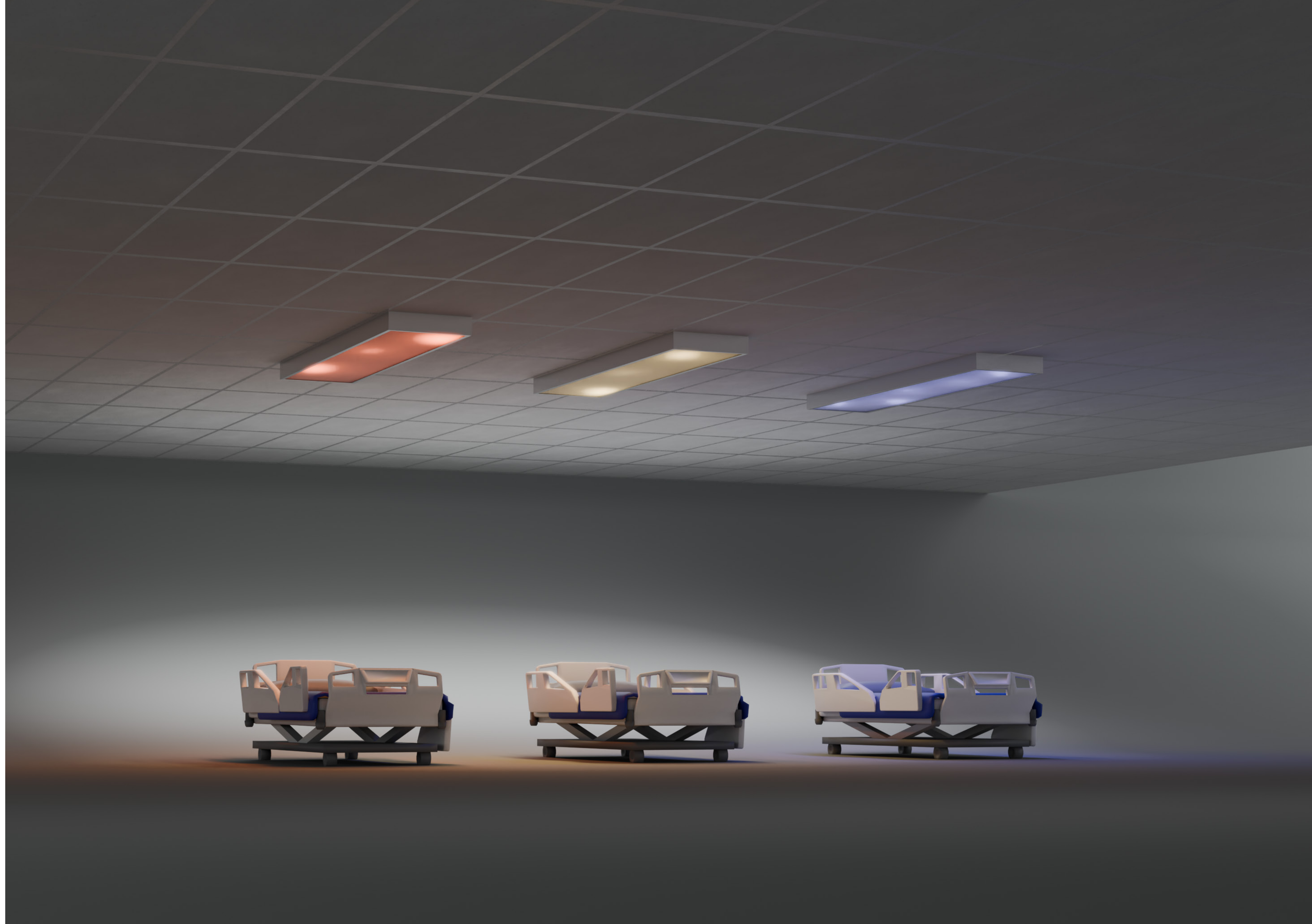
Integration in the ICU Context 6.5

Left Page

Figure 84
Komora placed in the ceiling of a ICU room

Figure 85
Render of Komora in a ICU-like setting

Komora is designed to be installed in the center of the ICU ceiling, replacing one of the existing linear fixtures so that it is positioned directly above the patient (Figure 84 & 85). When a healthcare professional selects a soundscape through the interface, both the corresponding light and audio activate simultaneously. In terms of mounting hardware, Komora will be installed the same as the conventional ceiling fixtures currently installed at EMC. For sound playback, the Raspberry Pi connects via a wired link to a Sonos Port, which streams the audio wirelessly to Sonos Era 100 speakers positioned in the top four ceiling corners of the room. This setup ensures synchronized operation between light and sound while maintaining compatibility with existing ICU infrastructure.



Testing & Evaluation 6.6

Left Page

Figure 86
Experiment setup
(Louwers, 2025)

Right Page

Figure 87
Experiment setup Mock
ICU at IDE

Since this project involves a multisensory design, it is essential to evaluate the overall emotional experience rather than the effect of light alone. Insights from earlier prototypes have shown that different light sources and qualities significantly affect the perceived mood of the environment. Therefore, this testing phase focuses on understanding how the designed lighting interacts with soundscapes to shape emotional responses and comfort levels. By testing these combined effects, the goal is to determine to what extent the lamp contributes to the intended atmosphere and emotional experience.

RESEARCH QUESTIONS

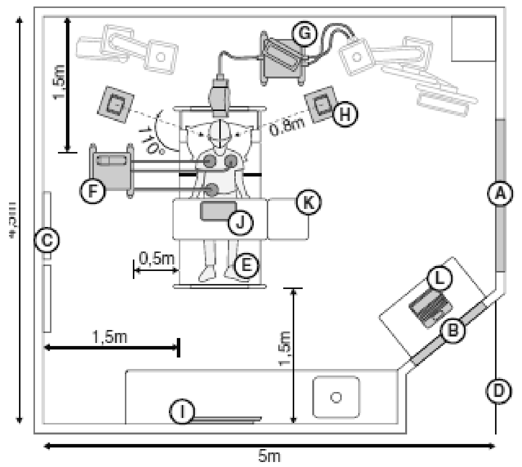
The aim of this study was to explore how lighting, when combined with soundscapes, influences the perceived atmosphere and comfort of an ICU environment.The research focused on understanding whether and how a dynamic lighting intervention can enhance the comfort and emotional wellbeing of individuals exposed to soundscapes designed for intensive care patients.

MAIN RESEARCH QUESTION

How does the addition of lighting to a soundscape influence participants' perceived comfort and emotional response in an ICU-like environment?

SUB-QUESTIONS

- Does the lighting intervention change self-reported mood and affect as measured by the PANAS questionnaire?
- How does the presence of light affect the perceived atmosphere of the environment (e.g., coziness, liveliness, tenseness, detachment)?
- Are there observable physiological differences (e.g., changes in heart rate) between participants exposed to sound only and those exposed to sound plus light?



TEST SETUP

The study was conducted in a controlled, ICU-simulated environment at the Industrial Design Engineering Faculty. Two experimental groups were used in a between-subjects design, with eleven participants per group.

Group A: exposed to the soundscape only condition.
Group B: exposed to the soundscape plus light condition.

The ceiling-mounted linear fixtures were turned off to prevent them from overpowering the prototype lighting, while curtains were opened to allow indirect hallway light into the room (Figure 87).

The speaker setup replicated that of Dr. Louwers' original configuration (Figure 86). Although the goal was to match the same sound pressure level (SPL) as in his setup (41.5 dB), this was not possible due to a higher baseline level in the mock ICU (48.5 dB). During playback, the SPL reached 49.5 dB. After consultation with the supervisory team, it was agreed that levels should remain below 50 dB.

Each participant experienced an exposure block of 5 minutes and 52 seconds (duration of soundscape) under their assigned condition. Lighting levels, spectral characteristics, and audio playback were standardized across sessions. Physiological data (heart rate) were continuously recorded using a Fitbit activity tracker. Participants completed a digital Google Form containing the PANAS questionnaire (Positive and Negative Affect Schedule) and the Vogels Atmosphere Questionnaire after the exposure.

TEST SETUP PROCEDURE

The full session lasted approximately 15 minutes per participant. The procedure was identical across all participants and consisted of the following steps:

PREPARATION

- Participants were randomly assigned to either the sound-only (Group A) or sound + light (Group B) condition.
- The researcher prepared the light and sound system and fitted a heart rate monitor.
- The Google Form questionnaire was opened, and metadata (participant ID, group, age, etc.) were recorded.

ACCLIMATION (1 MINUTE)

- Participants lay down in the test position to rest and acclimate to the environment.
- Heart rate recording was started to collect baseline data.

EXPOSURE (5 MINUTES)

- Group A: exposed to soundscape only.
- Group B: exposed to soundscape with the lighting intervention.
- Heart rate logging continued throughout.

QUESTIONNAIRE (5 MINUTES)

- Immediately after exposure, participants completed the PANAS and Vogels atmosphere questionnaires in the digital form.
- Also heart rate logging stopped and data saved
- Optional comfort rating and adverse reaction questions were also included.

WRAP-UP (2–3 MINUTES)

- Participants were thanked for their time.

DATA

Three categories of data were collected during the experiment:

PHYSIOLOGICAL DATA

- Continuous heart rate data recorded throughout acclimation, and exposure phases.
- Metrics derived: heart rate graph and mean heart rate

SELF-REPORT DATA

- Emotional state: PANAS (20 items, 1–5 scale) providing Positive Affect (PA) and Negative Affect (NA) scores.
- Atmosphere perception: Vogels Atmosphere Questionnaire (4 items, 1–7 scale) measuring coziness, liveliness, tenseness, and detachment.
- Comfort rating (0–100) and optional free-text comments.

DEMOGRAPHIC DATA

- Participant ID, age group, sex

All responses were timestamped and automatically stored in Google Sheets. Heart rate data were synchronized by timestamps to align with exposure periods.

Left Page

Top
Figure 88
Panas positive and
negative emotions

Bottom
Figure 89
PANAS comparison
between Sound Only and
Sound + Light groups

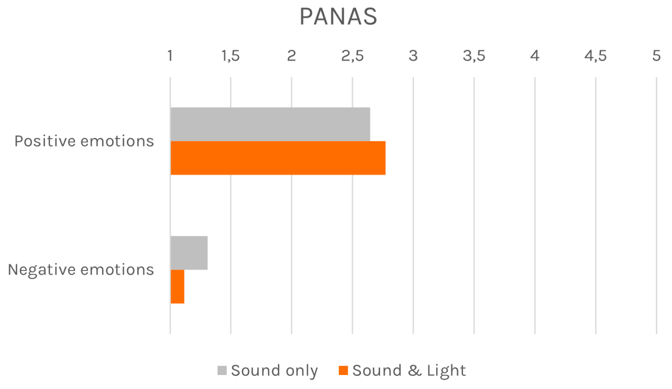
Right Page

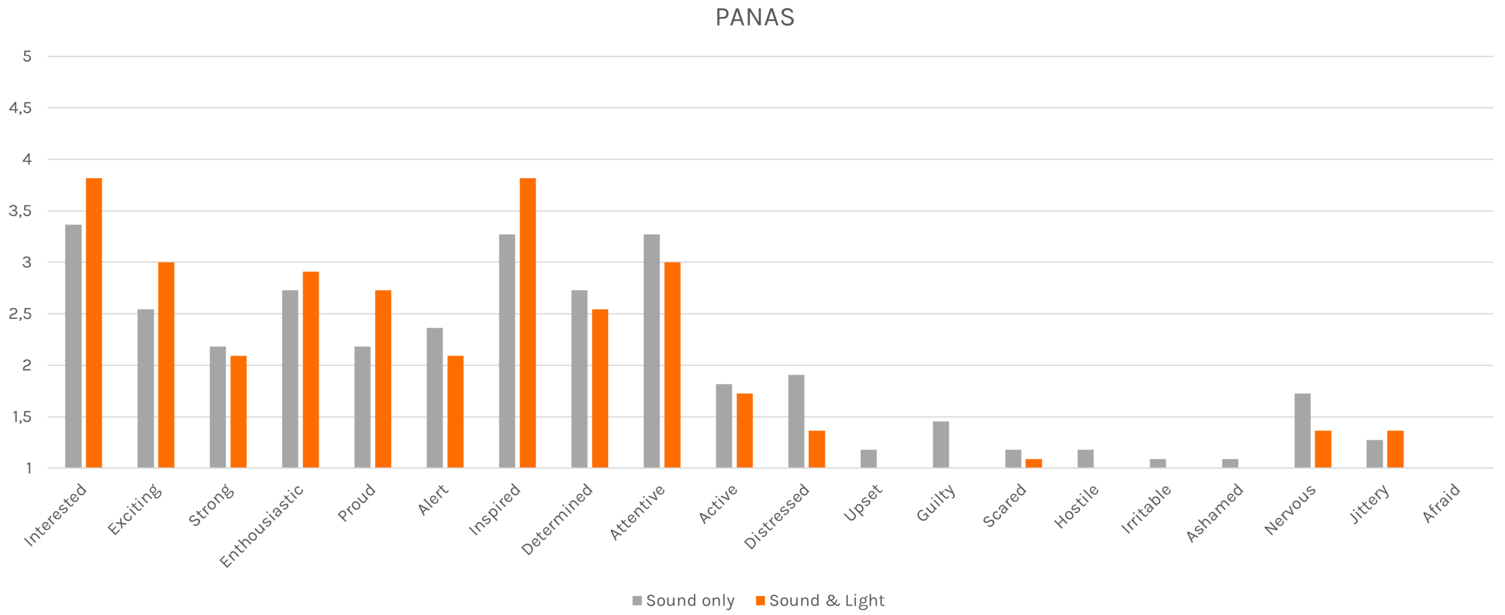
Figure 90
Atmosphere ratings

KEY FINDINGS – QUANTITATIVE

PANAS RESULTS

The PANAS questionnaire showed a slight increase in positive emotional states when light was added to sound. Participants in the Sound + Light condition reported feeling more interested, excited, proud, and inspired compared to the Sound Only group. Negative emotions remained minimal across both conditions, with no significant differences observed (Figure 88 & 89).

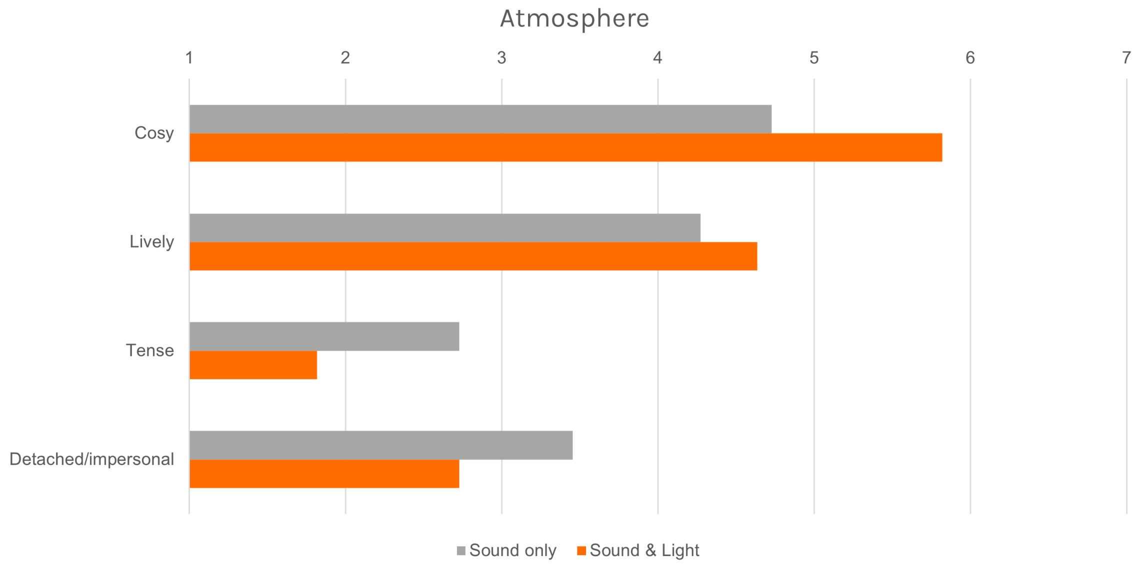




ATMOSPHERE RATINGS

Participants evaluated the environment on the dimensions of cosy, lively, tense, and detached. When light was added, ratings indicated a noticeable shift toward greater comfort and warmth.

Average comfort ratings reflected a clear improvement when light was added to sound. Participants rated the Sound Only condition at approximately 7.8/10, while the Sound + Light condition scored slightly higher at around 8.3/10. This suggests that the addition of light made the environment feel slightly more cosy, less tense, and less detached, while maintaining a similar level of liveliness, indicating an overall enhancement of comfort and atmosphere (Figure 90).

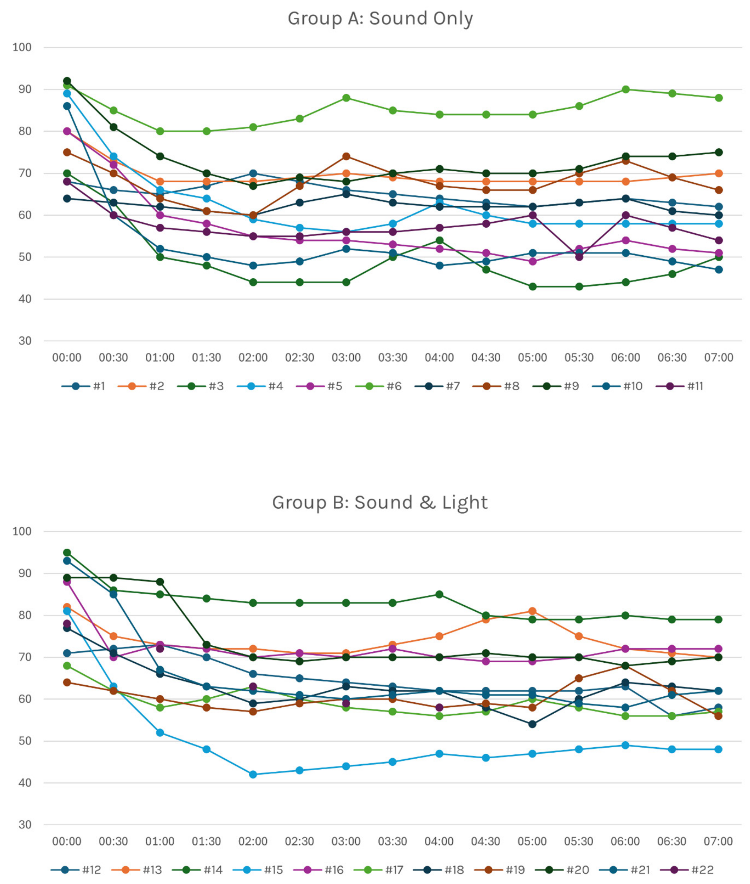


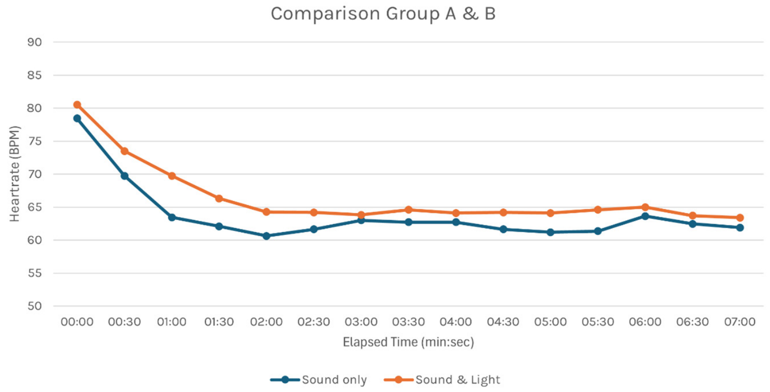
Right
Figure 91
Graph of heart rate trend
Group A & B

Left
Figure 92
Graph of average heart
rate of Group A & B

HEART RATE DATA

Heart rate data did not show a significant difference between the Sound Only and Sound + Light groups, indicating that the lighting addition did not produce a measurable physiological effect. The heart rate trends for both groups are shown in Figure 91 as well as an average from both groups (Figure 92).





KEY FINDINGS – QUALITATIVE

Participants in the Sound Only group often described a sense of visual boredom, noting the lack of visual stimulation in the environment. Many focused on the ceiling or chose to close their eyes to better engage with the sound. The auditory experience was generally perceived as soothing and sleep-inducing, though some mentioned occasional disturbances from unexpected noises. As one participant stated, “Visually the surroundings are very boring, especially if you lay down,” while another noted, “Once I closed my eyes, the sound helped make the room feel cozier.”

In contrast, the Sound + Light group reported greater engagement and focus, frequently describing how their attention shifted naturally between sound and light. Some participants experienced synchronization between breathing and light movement, which contributed to feelings of calm and presence. The combination of stimuli appeared to foster mindfulness, helping participants remain grounded in the moment. However, several commented on a mismatch between the warm orange-yellow light and the rain soundscape, expressing a preference for cooler tones such as blue or green to better align with the auditory atmosphere. As one participant reflected, “The moving lights held my attention,” while another added, “Rain feels more fitting with the colour blue.”

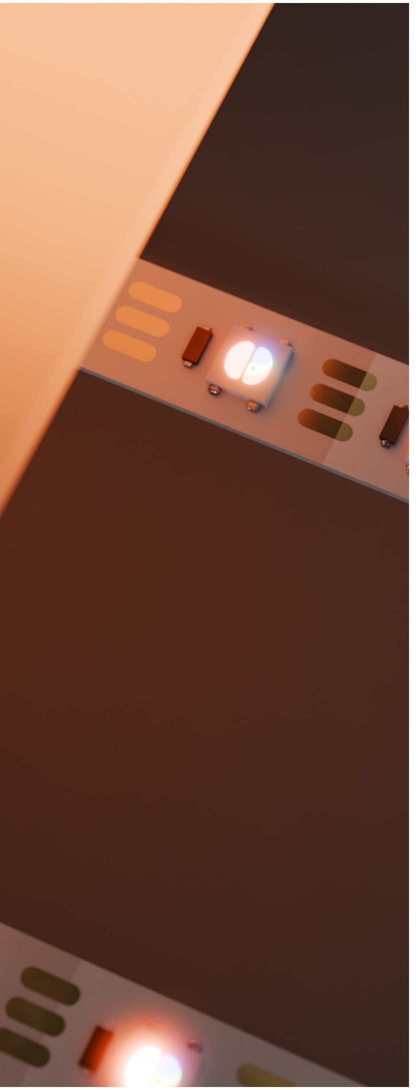
CONCLUSION

Combining light with sound improved participants’ comfort and emotional engagement compared to sound alone. The addition of light created a more inviting and less sterile atmosphere, reducing feelings of tension and detachment. Although no significant differences were found in physiological measures such as heart rate, the emotional and perceptual effects were clearly present. Feedback also highlighted the importance of sound–colour coherence: adopting cooler tones (blue–green) could better match the Fireplace soundscape and further enhance the multisensory experience.

chapter 7

Conclusion

Implications for Healthcare Implementation 7.1



Implementing Komora within ICU environments presents a logical and technically feasible step toward improving patient well-being and staff experience.

Current ICU conditions are often characterized by excessive noise, harsh lighting, and sensory monotony which are factors that can contribute to disorientation and slow down recovery. Komora responds to these challenges through an integrated system that synchronizes light with sound, creating a calmer, more human-centered environment.

Its design as a standalone lamp ensures easy integration without altering the existing infrastructure or workflow. Installation can occur quickly, as Komora requires only power, wireless connectivity to operate and simple mounting hardware. Because the lighting behaviour is software-driven, it allows flexibility in future adjustments and updates. With technical validation and patient testing, hospital-wide implementation could feasibly begin within 12–18 months.

From a production standpoint, the current prototype demonstrates functional viability but would need to transition to medical-grade hardware for real-world use. Unlike consumer LED strips, the production version would rely on certified, professional lighting components and dedicated lighting controllers designed for continuous use, offering a longer expected lifespan. The final product would also be simplified (in comparison the current proof of concept), performing only essential light behaviours derived from the sonic ambiances.

Financially, budget is not a limiting factor, as noted by Prof. Dr. Diederik Gommers (Chairman of the Dutch Union for Intensive Care), provided that the design does not require structural changes to the ICU. Maintenance would involve only software updates rather than physical intervention. In this sense, Komora represents a low-risk, high-impact addition to ICU environments. It would align technological feasibility with clinical and emotional needs and ultimately offer a scalable path toward sensory-centered healthcare design.

Limitations & Recommendations 7.2

While Komora shows strong potential, several limitations must be addressed before clinical implementation. The current prototype serves as a proof of concept, developed with accessible components suitable for experimentation but not for long-term medical use. Future iterations should employ certified, medical-grade hardware to ensure safety, reliability, and compliance with hospital standards.

During prototyping, colour temperature (CCT) values were converted into RGB values combined with a white diode intensity factor, but these were not verified for spectral accuracy. To improve precision, spectrometer testing is recommended to confirm the actual CCT output. In the Alert mode, a “blue-boost” was applied because the 6500 K setting did not produce a sufficiently blue tone. Increasing the CCT value further was ineffective, meaning the current light output no longer accurately represents 6500 K. Future work should therefore include recalibration and validation of colour rendering and CCT accuracy.

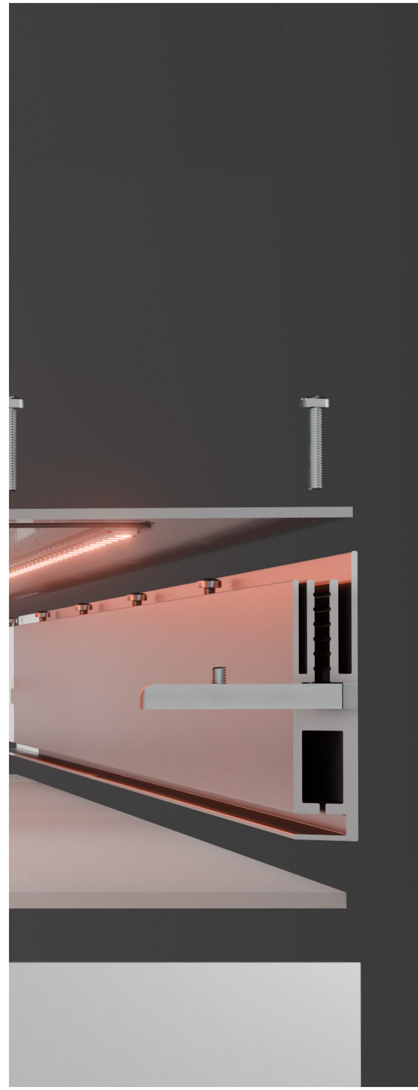
After the main user testing, an additional attempt was made to evaluate the fit between CCT and sonic ambiance. However, due to time constraints, not enough results were present to have a clear outcome. It is therefore recommended that future studies execute this properly to strengthen the concept.

Validation so far has been primarily qualitative, based on staff interviews and environmental observations. Future research should include quantitative evaluation of patient outcomes, such as circadian rhythm alignment, sleep quality, and stress levels, through controlled trials comparing Komora lighting with standard ICU conditions.

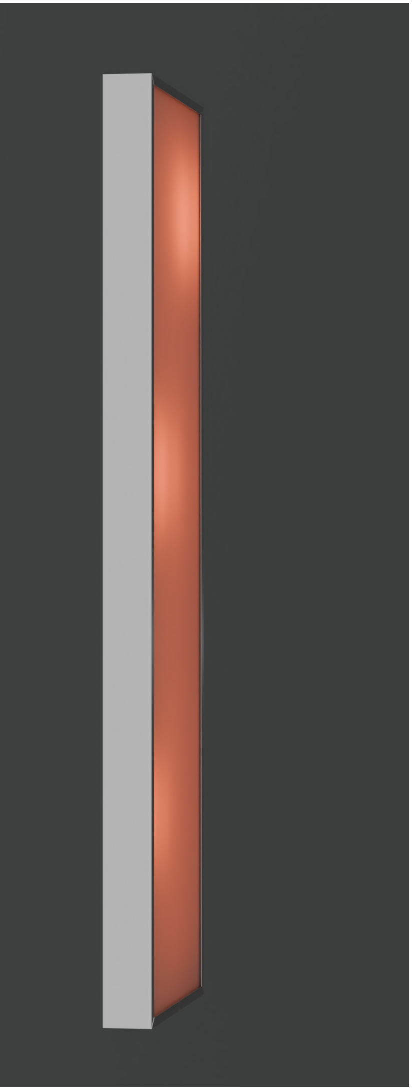
Feedback from ICU staff confirmed the benefits of diffuse, low-intensity lighting and supported the Work-Light Mode, which allows manual control of colour temperature and brightness for night-time care. However, dynamic lighting should remain subtle, as excessive movement or colour variation may disturb sensitive patients.

Testing was limited to the Comfortable soundscape due to time constraints. Further evaluation across all sonic ambiances, as well as integration with existing ICU control systems, is recommended.

In summary, Komora presents a strong conceptual and technical foundation. With further validation, calibration, and refinement, it has clear potential to enhance patient recovery, staff well-being, and the overall ICU environment.



Conclusion 7.3



HUMAN
The existing ICU lighting environment often exposes patients to bright, cold, and unvarying illumination that disrupts circadian rhythms, increases stress, and contributes to disorientation. Patients frequently experience overstimulation from the TL lights, particularly when lying on their backs facing the ceiling for extended periods. Komora addresses these issues by introducing soft, diffused, and dynamically adaptive lighting that mirrors natural rhythms of brightness and colour temperature.

Scientific research and field feedback emphasize that light strongly influences mood, alertness, and physiological recovery. Warmer tones (around 2700–3000K) promote relaxation and support sleep, while cooler tones (5000–6500K) help maintain alertness during daytime hours. Komora leverages these principles by adjusting colour temperature and intensity in correspondence with sound dynamics and time of day, subtly guiding patients' wake-sleep cycles.
The circadian-sensitive design encourages a more natural rhythm of rest and recovery. Staff observations further confirm that reducing nighttime brightness improves patient calmness and reduces the incidence of agitation and delirium. By respecting both emotional comfort and biological regulation, Komora contributes to a more humane and restorative care environment.

SYSTEM
The current ICU lighting setup relies predominantly on ceiling-mounted TL fixtures offering limited adjustability. These systems produce consistent brightness levels that can be distressing for patients and suboptimal for staff during night shifts. Regulations require sufficient illumination for care procedures, yet few systems balance clinical needs with patient comfort.

Komora introduces a dual-mode operation: a soft ambient mode driven by sonic input, and a manually controlled work-light mode for clinical tasks. This integration respects hospital standards while enhancing functionality. Its compatibility with existing infrastructure ensures seamless integration. This means no rewiring, no additional ceiling mounts, and minimal interference with hospital equipment.

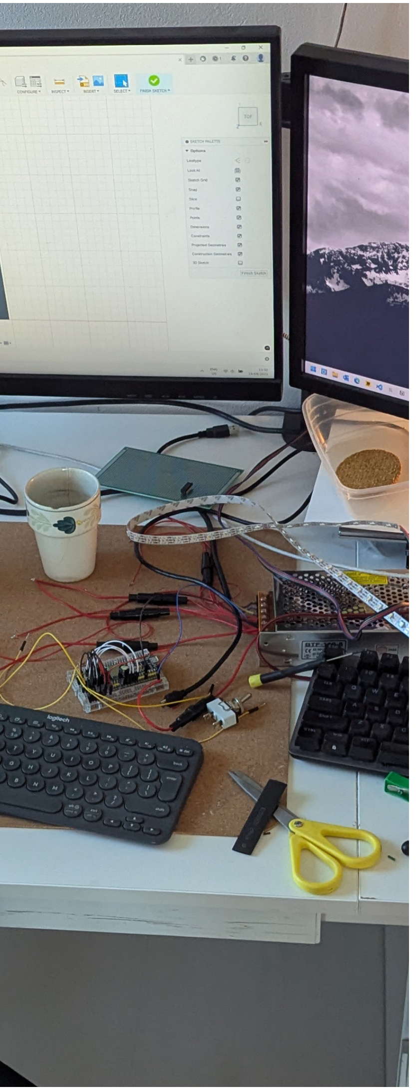
Nurses' feedback highlighted usability concerns regarding remote controls, battery failures, and inconsistent dimming. Komora resolves these through a centralized, reliable control interface and automatic adjustments linked to environmental context. Over time, the system could connect to the hospital's digital infrastructure for synchronized light management across ICU units.

By aligning with both technical feasibility and regulatory compliance, Komora demonstrates a pragmatic path toward sensory-conscious critical care.

PRODUCT
Current market lighting systems for ICUs, such as Philips' custom fixtures, focus on reliability and quality but lack the dynamic, emotionally adaptive dimension Komora provides. While Philips uses bespoke LED modules, Komora's design shows that similar principles can be achieved through modular, open-source systems allowing flexibility and iterative development.

The prototype validated how sound can drive light behaviour, linking auditory ambience to luminous dynamics in real time. This translation of sound intensity into light parameters (brightness, colour temperature, and speed) creates a visual extension of Louwers' sonic ambiances. The result is a coherent sensory system rather than two isolated experiences. The eventual production version of the lamp would use medical-grade materials and enclosed construction for easy cleaning and compliance with hygiene standards. Professional-grade LEDs and control systems would ensure uniformity, reliability, and longevity.

The user interaction prioritizes simplicity: automated behaviour for patients and minimal manual override for staff. In this way, Komora becomes both a functional light source and a therapeutic environmental tool, contributing to emotional comfort without compromising medical care.



Overall Project Conclusion 7.4

MAIN RESEARCH QUESTIONS
The research question asked:
'How can an integrated lighting and sound system, informed by current ICU conditions and patient feedback, be designed and implemented to complement the sonic ambiances developed by Dr. Louwers within the intensive care environment?'

Through research, prototyping, and user validation, the project demonstrated that an integrated light–sound system can indeed enhance the ICU environment. Komora translates the emotional and temporal qualities of sound into responsive lighting patterns, creating an environment that feels more alive, personal, and comforting.

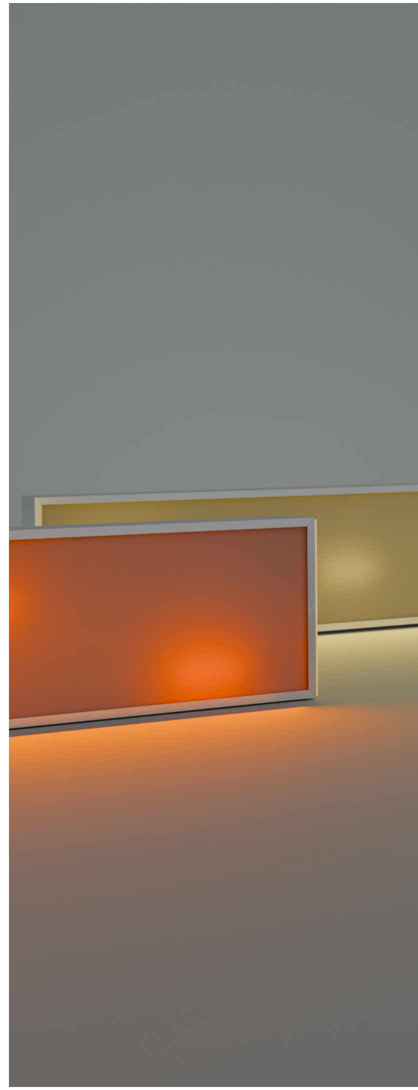
The findings reveal that successful integration depends on three principles: sensory balance, technical adaptability, and human-centered design. The system must respect circadian alignment, fit seamlessly into existing workflows, and remain adaptable through software refinement.

Ultimately, Komora shows that multi-sensory design can bridge the gap between technical performance and emotional experience in healthcare. By turning sound into light, it introduces an empathetic layer to ICU design, one that responds not only to functional needs but also to human presence.

Komora proves that multi-sensory integration can be a viable and impactful approach to improving ICU environments. By merging the sonic ambiances developed by Dr. Louwers with a complementary lighting system, this project demonstrates how coordinated sound and light can foster a more restorative and human-centered atmosphere within critical care settings.

Built around technical feasibility, emotional awareness, and clinical practicality, Komora demonstrates that even small, targeted interventions, like a single adaptive lamp, can profoundly influence patient experience. Its design requires no architectural changes, no complex maintenance, and aligns with both hospital needs and medical regulations.

As a proof of concept, Komora opens the path for future interdisciplinary research and collaboration between designers, engineers, and medical professionals toward ICU environments that heal not only the body, but also show more care towards the mental and emotional aspect of people involved.



Reflection 7.5

It's surreal for me that this journey that I started in 2012 is coming to an end. As a kid I had the privileged opportunity to live in 3 different countries across the entire world for over 10 years. I have learned to live in different cultures, be different cultures and take these with me everywhere I go. Coming into the Netherlands the switch was challenging. Moving across different schools and cities things around me constantly changed but what remained constant was my family and the fact that this academic journey was still going. So that is what I did for many years. In the end choosing industrial design as a study was the best choice for me. I felt that this study has pushed the right buttons to grow intellectually but also as a person. Especially this project was a confronting one. Individual projects are not my strong suit. I like being around people thinking and creating together because that's when I have the feeling that ideas get places than rather stay fixated in one place as design is not only about me and my own perception. It's about others, so I would like to create with others to do my best in that part. So it was challenging at times but I have learned a lot and look back at it positively.

Over the years I have grown interest an passion for combining technology and art. I started my professional photography career at this university I have had the opportunity to create and learn so much. For me photography was a space where I could express my ideas. In photography it's all about lighting, how it looks in the frame, where it is coming from, what the colour is, etc. The same goes for sound, I deeply enjoy listening and creating music. I can spend hours listening to music through some good speakers, just for the feeling it can give me.

A while back I purchased a set of IKEA ambient lights which could change colour, I dispersed them across my room. I started to listen to music with them on as well. That's when it clicked. The combination was very soothing. Since then I know how powerful light and sound combined can be, what it can do to your emotions, thoughts, feelings. This was the basis for my graduation project. After following the course Lighting Design coordinated by Charl, I reached out to him to see if we could come up with a project together. After talking to him about my interests he suggested I reach out to Elif. I've had 2 courses throughout the entire curriculum of the bachelor and masters which were my favorite: Form & Experience and Form & Senses. Both coordinated by Elif! I reached out and we came up with this project. The perfect combination of both worlds or art and design. I have had the wonderful opportunity to work with my supervisors to create something meaningful and beautiful at the same time. For me this meant that I was able to be creative and technical at the same time which is perfect. I really believed in what I was doing and making. The feeling I got from it gave me a lot of motivation. This is something that I would like to continue to pursue in my career as I believe meaningful design is the future.

Starting this project with an idea than actually going through the whole process of how we can actually make this work was very rewarding. Having this massive black box of this 'lighting recipe' concept was very challenging in the beginning as it was all up to me to make sense out of it. But in the end finding the idea to make this work was a very rewarding moment. At some point the prototype of the lamp reached a point where it was a single unit. Just one object with a power cord sicking out. Finally coming to this moment was a very nice one. Made it feel complete. Elif, Charl and Ela, it was an honour to work and think besides you. You all pushed me well. At times difficult but I always tried to see the positive of it. I really thank you for your wise words. Thank you Elif, Charl and Ela. I appreciate you!

I hope you enjoyed reading my report :)
Patrick

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Appendix A - Timestamp calculation python code (comfortable)

```
import numpy as np
import librosa
import matplotlib.pyplot as plt

# === Audio file path ===
audio_path =  “C:/Users/…

# === Load audio (preserve original sampling rate) ===
y, sr = librosa.load(audio_path, sr=None)

# === Single sensitivity knob (0 = strict/few detections, 1 = lenient/many) ===
s = 0.9
s = float(np.clip(s, 0.0, 1.0))

# === Map sensitivity -> window duration (seconds) ===
W_MIN, W_MAX = 0.05, 1.00  # bounds in seconds
window_duration = W_MAX - s * (W_MAX - W_MIN)
window_length = max(2, int(sr * window_duration))
hop_length = window_length

# === Loudness per window (RMS in dB) ===
rms = librosa.feature.rms(
    y=y,
    frame_length=window_length,
    hop_length=hop_length,
    center=False
)[0]
if rms.size < 2:
    raise ValueError(“Not enough frames—try a longer audio clip or a shorter window.”)

rms_db = librosa.amplitude_to_db(rms, ref=np.max)

# === Changes between consecutive windows ===
diffs = np.abs(np.diff(rms_db))
mean_diff = float(np.mean(diffs)) if diffs.size > 0 else 0.0

# === Map sensitivity -> threshold (with 3 dB minimum) ===
threshold = 3.0 + (1.0 - s) * mean_diff
threshold = max(3.0, threshold)

# === Print diagnostics ===
print(“=== Parameters ===”)
print(f”Sensitivity: {s:.2f}”)
print(f”Window duration: {window_duration:.3f} s”)
print(f”Mean diff: {mean_diff:.2f} dB”)
print(f”Threshold: {threshold:.2f} dB\n”)

# === Detect significant changes ===
significant_indices = [i + 1 for i, d in enumerate(diffs) if d >= threshold]
timestamps = np.arange(len(rms_db)) * window_duration

# === Helper: seconds -> mm:ss.ss ===
def sec_to_min_sec(seconds: float) -> str:
    m = int(seconds // 60)
    ssec = seconds % 60
    return f”{m}:{ssec:05.2f}”

# === Print timestamps ===
print(“=== Significant change timestamps ===”)
for idx in significant_indices:
    print(sec_to_min_sec(idx * window_duration))

# === Optional plot ===
plt.figure(figsize=(12, 5))
plt.plot(timestamps, rms_db, label=’RMS Loudness (dB)’)
if significant_indices:
    plt.scatter([timestamps[i] for i in significant_indices],
                rms_db[significant_indices], color=’red’, label=’Detected Change’)
plt.axhline(np.mean(rms_db), color=’gray’, linestyle=’--’, label=’Mean Loudness’)
plt.title(f”Detections | s={s:.2f}  window={window_duration:.3f}s  threshold≥{threshold:.2f}
dB”)
plt.xlabel(“Time (s)”)
plt.ylabel(“Loudness (dB)”)
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```

Appendix B - Timestamp calculation python code (pleasurable)

```
import numpy as np
import librosa
import matplotlib.pyplot as plt

# === Audio file path ===
audio_path =  “C:/Users/…

# === Load audio (preserve original sampling rate) ===
y, sr = librosa.load(audio_path, sr=None)

# === Single sensitivity knob (0 = strict/few detections, 1 = lenient/many) ===
s = 0.7
s = float(np.clip(s, 0.0, 1.0))

# === Map sensitivity -> window duration (seconds) ===
W_MIN, W_MAX = 0.05, 1.00  # bounds in seconds
window_duration = W_MAX - s * (W_MAX - W_MIN)
window_length = max(2, int(sr * window_duration))
hop_length = window_length

# === Loudness per window (RMS in dB) ===
rms = librosa.feature.rms(
    y=y,
    frame_length=window_length,
    hop_length=hop_length,
    center=False
)[0]
if rms.size < 2:
    raise ValueError(“Not enough frames—try a longer audio clip or a shorter window.”)

rms_db = librosa.amplitude_to_db(rms, ref=np.max)

# === Changes between consecutive windows ===
diffs = np.abs(np.diff(rms_db))
mean_diff = float(np.mean(diffs)) if diffs.size > 0 else 0.0

# === Map sensitivity -> threshold (with 3 dB minimum) ===
threshold = 3.0 + (1.0 - s) * mean_diff
threshold = max(3.0, threshold)

# === Print diagnostics ===
print(“=== Parameters ===”)
print(f”Sensitivity: {s:.2f}”)
print(f”Window duration: {window_duration:.3f} s”)
print(f”Mean diff: {mean_diff:.2f} dB”)
print(f”Threshold: {threshold:.2f} dB\n”)

# === Detect significant changes ===
significant_indices = [i + 1 for i, d in enumerate(diffs) if d >= threshold]
timestamps = np.arange(len(rms_db)) * window_duration

# === Helper: seconds -> mm:ss.ss ===
def sec_to_min_sec(seconds: float) -> str:
    m = int(seconds // 60)
    ssec = seconds % 60
    return f”{m}:{ssec:05.2f}”

# === Print timestamps ===
print(“=== Significant change timestamps ===”)
for idx in significant_indices:
    print(sec_to_min_sec(idx * window_duration))

# === Optional plot ===
plt.figure(figsize=(12, 5))
plt.plot(timestamps, rms_db, label=’RMS Loudness (dB)’)
if significant_indices:
    plt.scatter([timestamps[i] for i in significant_indices],
                rms_db[significant_indices], color=’red’, label=’Detected Change’)
plt.axhline(np.mean(rms_db), color=’gray’, linestyle=’--’, label=’Mean Loudness’)
plt.title(f”Detections | s={s:.2f}  window={window_duration:.3f}s  threshold≥{threshold:.2f}
dB”)
plt.xlabel(“Time (s)”)
plt.ylabel(“Loudness (dB)”)
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```

Appendix C- Timestamp calculation python code (stimulating)

```python
import numpy as np
import librosa
import matplotlib.pyplot as plt

# === Audio file path ===
audio_path = “C:/Users/…

# === Load audio (preserve original sampling rate) ===
y, sr = librosa.load(audio_path, sr=None)

# === Single sensitivity knob (0 = strict/few detections, 1 = lenient/many) ===
s = 0.3
s = float(np.clip(s, 0.0, 1.0))

# === Map sensitivity -> window duration (seconds) ===
W_MIN, W_MAX = 0.05, 1.00  # bounds in seconds
window_duration = W_MAX - s * (W_MAX - W_MIN)
window_length = max(2, int(sr * window_duration))
hop_length = window_length

# === Loudness per window (RMS in dB) ===
rms = librosa.feature.rms(
    y=y,
    frame_length=window_length,
    hop_length=hop_length,
    center=False
)[0]
if rms.size < 2:
    raise ValueError(“Not enough frames—try a longer audio clip or a shorter window.”)

rms_db = librosa.amplitude_to_db(rms, ref=np.max)

# === Changes between consecutive windows ===
diffs = np.abs(np.diff(rms_db))
mean_diff = float(np.mean(diffs)) if diffs.size > 0 else 0.0

# === Map sensitivity -> threshold (with 3 dB minimum) ===
threshold = 3.0 + (1.0 - s) * mean_diff
threshold = max(3.0, threshold)

# === Print diagnostics ===
print(“=== Parameters ===”)
print(f”Sensitivity: {s:.2f}”)
print(f”Window duration: {window_duration:.3f} s”)
print(f”Mean diff: {mean_diff:.2f} dB”)
print(f”Threshold: {threshold:.2f} dB\n”)

# === Detect significant changes ===
significant_indices = [i + 1 for i, d in enumerate(diffs) if d >= threshold]
timestamps = np.arange(len(rms_db)) * window_duration

# === Helper: seconds -> mm:ss.ss ===
def sec_to_min_sec(seconds: float) -> str:
    m = int(seconds // 60)
    ssec = seconds % 60
    return f”{m}:{ssec:05.2f}”

# === Print timestamps ===
print(“=== Significant change timestamps ===”)
for idx in significant_indices:
    print(sec_to_min_sec(idx * window_duration))

# === Optional plot ===
plt.figure(figsize=(12, 5))
plt.plot(timestamps, rms_db, label=’RMS Loudness (dB)’)
if significant_indices:
    plt.scatter([timestamps[i] for i in significant_indices],
                rms_db[significant_indices], color=’red’, label=’Detected Change’)
plt.axhline(np.mean(rms_db), color=’gray’, linestyle=’--’, label=’Mean Loudness’)
plt.title(f”Detections | s={s:.2f}  window={window_duration:.3f}s  threshold≥{threshold:.2f}
dB”)
plt.xlabel(“Time (s)”)
plt.ylabel(“Loudness (dB)”)
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```

Appendix D - ESP-32 python code

```cpp
#include <Adafruit_NeoPixel.h>
#include <math.h>
#include <vector>
#include “BluetoothSerial.h”

BluetoothSerial SerialBT;

// ---------------- STRIP CONFIG ----------------
#define NUM_STRIPS 4
const int DATA_PINS[NUM_STRIPS] = {26, 25, 33, 32};
const int NUM_LEDS[NUM_STRIPS]  = {70, 70, 70, 70};

const int MAX_LEDS = NUM_LEDS[0] + NUM_LEDS[1] + NUM_LEDS[2] +
NUM_LEDS[3];

// ---------------- LIGHT PROFILES ----------------
struct LightParams {
  int base_brightness;
  int full_brightness;
  int fade_time;
  int hold_time;
  int cue_leds;      // how many blocks per cue
  int block_size;
  int kelvin;
  bool blue_boost;   // apply extra blue boost
  std::vector<unsigned long> timestamps;
  unsigned long total_time;
};

LightParams profile1, profile2, profile3;
LightParams* currentProfile = nullptr;

// Active fades
struct Fade { int start_led; int size; unsigned long t0; };
std::vector<Fade> active_fades;

// Strips
Adafruit_NeoPixel* strips[NUM_STRIPS] = {
   new  Adafruit_NeoPixel(NUM_LEDS[0],  DATA_PINS[0],  NEO_GRBW  +
NEO_KHZ800),
    new  Adafruit_NeoPixel(NUM_LEDS[1],  DATA_PINS[1],  NEO_GRBW  +
NEO_KHZ800),
   new  Adafruit_NeoPixel(NUM_LEDS[2],  DATA_PINS[2],  NEO_GRBW  +
NEO_KHZ800),
   new  Adafruit_NeoPixel(NUM_LEDS[3],  DATA_PINS[3],  NEO_GRBW  +
NEO_KHZ800)
};

// ---------- Colour Utilities ----------
void kelvin_to_rgb(int kelvin, uint8_t &r, uint8_t &g, uint8_t &b) {
  float t = kelvin / 100.0;
  if (t <= 66) r = 255;
  else r = (uint8_t)constrain(329.6987 * pow(t - 60, -0.1332), 0, 255);

  if (t <= 66) g = (uint8_t)constrain(99.47 * log(t) - 161.12, 0, 255);
  else g = (uint8_t)constrain(288.12 * pow(t - 60, -0.0755), 0, 255);

  if (t >= 66) b = 255;
  else if (t <= 19) b = 0;
  else b = (uint8_t)constrain(138.52 * log(t - 10) - 305.04, 0, 255);
}

uint32_t rgb_to_rgbw(uint8_t r, uint8_t g, uint8_t b,
                     uint16_t brightness16, int kelvin, bool blue_boost) {
  uint8_t w = min(r, min(g, b));
  if (kelvin < 3000) w = (uint8_t)(w * (kelvin / 3000.0));

  r -= w; g -= w; b -= w;
  float scale = brightness16 / 65535.0;
  r = (uint8_t)(r * scale);
  g = (uint8_t)(g * scale);
  b = (uint8_t)(b * scale);

  // ☒ Extra blue boost for stimulating profile
  if (blue_boost) {
    b = min(255, (int)(b * 15));
  }

  w = (uint8_t)(w * scale);
  return strips[0]->Color(r, g, b, w);
}

// ---------- Helpers ----------
void set_led(int idx, uint32_t color) {
  for (int si = 0; si < NUM_STRIPS; si++) {
    if (idx < NUM_LEDS[si]) {
      strips[si]->setPixelColor(idx, color);
      return;
    }
    idx -= NUM_LEDS[si];
  }
}

void flush() {
  for (int si = 0; si < NUM_STRIPS; si++) strips[si]->show();
}

void fadeToBlack(int duration_ms) {
  int steps = max(1, duration_ms / 20); // ~50 FPS
  for (int step = 0; step <= steps; step++) {
    float factor = 1.0 - (float)step / steps;
    for (int si = 0; si < NUM_STRIPS; si++) {
      for (int pi = 0; pi < NUM_LEDS[si]; pi++) {
        uint32_t c = strips[si]->getPixelColor(pi);
        uint8_t r = (c >> 16) & 0xFF;
        uint8_t g = (c >> 8) & 0xFF;
        uint8_t b = (c) & 0xFF;
        uint8_t w = (c >> 24) & 0xFF;
        r = (uint8_t)(r * factor);
        g = (uint8_t)(g * factor);
        b = (uint8_t)(b * factor);
        w = (uint8_t)(w * factor);
        strips[si]->setPixelColor(pi, strips[si]->Color(r, g, b, w));
      }
      strips[si]->show();
    }
    delay(duration_ms / steps);
  }
}

// ---------- Animation State ----------
unsigned long start_time;
int ts_index = 0;
uint8_t r_base, g_base, b_base;

void startProfile(LightParams* p) {
  currentProfile = p;
  ts_index = 0;
  active_fades.clear();
  kelvin_to_rgb(p->kelvin, r_base, g_base, b_base);
  start_time = millis();
}

// ---------- Setup ----------
void setup() {
  Serial.begin(115200);
  SerialBT.begin(“ESP32-Lights”);
  Serial.println(“BT ready. Pair to ‘ESP32-Lights’”);

  for (int i=0; i<NUM_STRIPS; i++) {
    strips[i]->begin();
    strips[i]->show();
  }
```

```
// ---------------- Profile 1 (Comfortable) ----------------
profile1.base_brightness = 15;
profile1.full_brightness = 255;
profile1.fade_time = 3000;
profile1.hold_time = 500;
profile1.cue_leds = 1;
profile1.block_size = 4;
profile1.kelvin = 6500;
profile1.blue_boost = false;
profile1.timestamps = {
  150, 290, 440, 580, 730, 1160, 1310, 3770, 10300, 11170, 11310,
  19580, 19720, 20300, 30020, 36110, 36690, 55970, 73520, 91930, 92080,
  92220, 94690, 94980, 97150, 97300, 103820, 104550, 105710, 107160,
  110350, 115420, 130360, 131230, 137610, 137750, 140650, 140800,
  141380, 141520, 142100, 144710, 144860, 147030, 147180, 148770,
  160950, 161240, 170960, 172550, 177340, 180670, 180820, 180960,
  181400, 182410, 183570, 183720, 183860, 186330, 186470, 190100,
  194590, 194740, 200830, 201120, 211270, 213300, 213440, 216340,
  218370, 226930, 229970, 230120, 232730, 232870, 234180, 242590,
  254770, 256800, 257090, 257230, 264630, 264770, 275940, 293920,
  295950, 296090, 296240, 311460, 313200, 323500, 325670, 329880,
  332780, 332920, 334520, 336260, 338290, 338870, 339740, 340460,
  340610, 340900, 341190, 343800, 343940, 345390, 347420, 349160,
  349890, 351190
};
profile1.total_time = profile1.timestamps.back() + 2000;

// ---------------- Profile 2 (Pleasurable) ----------------
profile2.base_brightness = 15;
profile2.full_brightness = 255;
profile2.fade_time = 2000;
profile2.hold_time = 500;
profile2.cue_leds = 1;
profile2.block_size = 4;
profile2.kelvin = 3000;
profile2.blue_boost = false;
profile2.timestamps = {
  860, 2150, 11180, 21500, 22790, 23220, 37410, 39560, 42570, 43000,
  44290, 46870, 47730, 48160, 50310, 50740, 67510, 72670, 99330,
  111800, 114380, 118250, 118680, 122550, 122980, 124270, 128570,
  129000, 133730, 134160, 139320, 144910, 196080, 243380, 262730,
  263590, 269610, 290250, 294550, 310030, 313040, 325940, 326370,
  332820
};
profile2.total_time = profile2.timestamps.back() + 2000;

// ---------------- Profile 3 (Stimulating) ----------------
profile3.base_brightness = 15;
 profile3.full_brightness = 255;
 profile3.fade_time = 1000;
 profile3.hold_time = 500;
 profile3.cue_leds = 2;   // two blocks per cue
 profile3.block_size = 7;
 profile3.kelvin = 10000;
 profile3.blue_boost = true; // ☒ cold blue tint
 profile3.timestamps = {
   25030, 25740, 26460, 27890, 55770, 62210, 76510, 77940, 106540,
   109400, 112970, 115120, 115830, 121550, 122980, 124410, 125840,
   128700, 130130, 135850, 138000, 142290, 143000, 146580, 147290,
   151580, 161590, 171600, 173030, 173750, 175890, 198060, 198770,
   203060, 208070, 209500, 213070, 215930, 218080, 223800, 225230,
   226660, 227370, 249540, 250250, 250970, 251680, 255970, 268130,
   275990, 306020, 308170, 308880, 309600, 310310, 311740, 332480,
   342490, 343200, 343920
 };
 profile3.total_time = profile3.timestamps.back() + 2000;

 Serial.println("Waiting for Bluetooth command: 1/2/3 or r");
}

// ---------- Loop ----------
void loop() {
 // Handle Bluetooth commands
 if (SerialBT.available()) {
   char cmd = SerialBT.read();
   if (cmd == '1') { startProfile(&profile1); Serial.println("Start Light 1"); }
   if (cmd == '2') { startProfile(&profile2); Serial.println("Start Light 2"); }
   if (cmd == '3') { startProfile(&profile3); Serial.println("Start Light 3"); }
   if (cmd == 'r') {
     fadeToBlack(1000);   // smooth fade out in 1 second
     currentProfile = nullptr;
     Serial.println("Reset (fade to black)");
   }
 }

 if (!currentProfile) {
   delay(10);
   return;
 }

 unsigned long elapsed = (millis() - start_time) % currentProfile->total_
time;

 if (elapsed < 50 && ts_index >= currentProfile->timestamps.size()) {
   ts_index = 0;
   active_fades.clear();
 }

 // Trigger cue blocks
 if (ts_index < currentProfile->timestamps.size() &&
     elapsed >= currentProfile->timestamps[ts_index]) {

   unsigned long now = elapsed;
   std::vector<int> busy;
   for (auto &f : active_fades) {
      for (int led = f.start_led; led < f.start_led + f.size; led++) busy.push_
back(led);
   }

   int blocks_added = 0;
   int attempts = 0;
   while (blocks_added < currentProfile->cue_leds && attempts < 200) {
     int start_led = random(MAX_LEDS - currentProfile->block_size);
     bool free = true;
     for (int b : busy) {
       if (b >= start_led && b < start_led + currentProfile->block_size) {
         free = false; break;
       }
     }
     if (free) {
           active_fades.push_back({start_led,  currentProfile->block_size,
now});
        for (int led = start_led; led < start_led + currentProfile->block_size;
led++) busy.push_back(led);
       blocks_added++;
     }
     attempts++;
   }

   ts_index++;
 }

 // Reset to base color
 uint32_t baseColor = rgb_to_rgbw(r_base, g_base, b_base,
                          currentProfile->base_brightness*257,
                          currentProfile->kelvin,
                          currentProfile->blue_boost);
 for (int si=0; si<NUM_STRIPS; si++) {
   for (int pi=0; pi<NUM_LEDS[si]; pi++) {
     strips[si]->setPixelColor(pi, baseColor);
   }
 }

 // Apply fades
 std::vector<Fade> still;
 for (auto &f : active_fades) {
   unsigned long t = elapsed - f.t0;
   if (t < 2*currentProfile->fade_time + currentProfile->hold_time) {
     float factor;
      if (t < currentProfile->fade_time) factor = 0.5*(1 - cos(M_PI*(t/(float)
currentProfile->fade_time)));
       else if (t < currentProfile->fade_time + currentProfile->hold_time)
factor = 1.0;
     else {
       float td = t - currentProfile->fade_time - currentProfile->hold_time;
       factor = 0.5*(1 + cos(M_PI*(td/(float)currentProfile->fade_time)));
     }
     uint16_t b16 = currentProfile->base_brightness*257 +
                  (uint16_t)((currentProfile->full_brightness-currentProfile-
>base_brightness)*257*factor);
     for (int led = f.start_led; led < f.start_led+f.size; led++) {
     set_led(led, rgb_to_rgbw(r_base,g_base,b_base,b16,currentProfile-
>kelvin,currentProfile->blue_boost));
     }
     still.push_back(f);
   }
 }
 active_fades = still;

 flush();
 delay(1);
}
```

Appendix E - Raspberry Pi Code

```
from flask import Flask, request, render_template_string
import serial, os, pygame

app = Flask(__name__)

# ---------------- CONFIG ----------------
SERIAL_PORT = "COM7"
BAUD_RATE = 115200

# Try to open serial once at startup
try:
   ser = serial.Serial(SERIAL_PORT, BAUD_RATE, timeout=1)
   print(f"☒ Connected to ESP32 on {SERIAL_PORT}")
except Exception as e:
   print(f"☒☒ Could not open {SERIAL_PORT}: {e}")
   ser = None

AUDIO_FILES = {
   "1": r"C:\\Users\\pretz\\Desktop\\(1)Fire_Comfortable (i).wav",
   "2": r"C:\\Users\\pretz\\Desktop\\(8)Market_Pleasurable (ii).wav",
     "3":  r"C:\\Users\\pretz\\Desktop\\(4)Countryside_Stimulating  (iii).
wav"
}

pygame.mixer.init()

# ---------------- HTML ----------------
MAIN_PAGE = """
<!DOCTYPE html>
<html>
<head>
     <meta    name="viewport"    content="width=device-width,    initial-
scale=1.0">
 <title>Sonic Ambiance Control</title>
   <link   rel="stylesheet"   href="https://cdnjs.cloudflare.com/ajax/libs/
font-awesome/6.5.0/css/all.min.css">
 <style>
  body {
    font-family: 'Segoe UI', Arial, sans-serif;
    background: #e9e9e9;
    margin: 0;
    height: 100vh;
    display: flex;
    align-items: center;
    justify-content: center;
    overflow: hidden;
    color: #333;
  }

.container {
  text-align: center;
  width: 100%;
  max-width: 400px;
  padding: 20px;
  transition: filter 0.3s ease, opacity 0.3s ease;
}

h1 {
  margin-bottom: 40px;
  color: #444;
  letter-spacing: 0.5px;
}
/* ---------- HOME BUTTONS (GREYSCALE) ---------- */
.btn {
  display: block;
  width: 100%;
  margin: 16px 0;
  padding: 18px;
  font-size: 20px;
  font-weight: 600;
  border: none;
  border-radius: 12px;
  cursor: pointer;
  transition: transform 0.15s, box-shadow 0.15s, background 0.15s;
  color: #222;
  background: #d6d6d6;
  box-shadow: 0 4px 10px rgba(0,0,0,0.1);
}

.btn:hover {
  transform: translateY(-1px);
  box-shadow: 0 6px 14px rgba(0,0,0,0.15);
  background: #cfcfcf;
}

.btn:active { transform: translateY(0); opacity: .95; }

/* Off button with exact color #C0C0C0 */
.off {
  color: #000;
  background: #C0C0C0;
  box-shadow: 0 4px 12px rgba(0,0,0,0.25);
}
.off:hover {
  background: #b8b8b8;
  box-shadow: 0 6px 16px rgba(0,0,0,0.3);
```

```
}

/* ---------- MODALS ---------- */
.overlay {
  position: fixed;
  top: 0; left: 0;
  width: 100%; height: 100%;
  background: rgba(0, 0, 0, 0.4);
  backdrop-filter: blur(6px);
  display: none;
  align-items: center;
  justify-content: center;
  z-index: 100;
}

.modal {
  background: white;
  border-radius: 16px;
  padding: 30px;
  width: 90%;
  max-width: 500px;
  box-shadow: 0 6px 20px rgba(0,0,0,0.3);
  text-align: center;
  animation: fadeIn 0.25s ease;
}

@keyframes fadeIn {
  from { opacity: 0; transform: scale(0.96); }
  to { opacity: 1; transform: scale(1); }
}

.grid {
  display: grid;
  grid-template-columns: repeat(auto-fit, minmax(150px, 1fr));
  gap: 16px;
  margin-top: 20px;
}

/* ---------- MANUAL MODE COLORS (KEEP OLD) ---------- */
.card {
  border-radius: 14px;
  padding: 30px 10px;
  cursor: pointer;
  font-size: 18px;
  font-weight: bold;
  color: white;
  border: none;
  box-shadow: 0 6px 15px rgba(0,0,0,0.18);
```

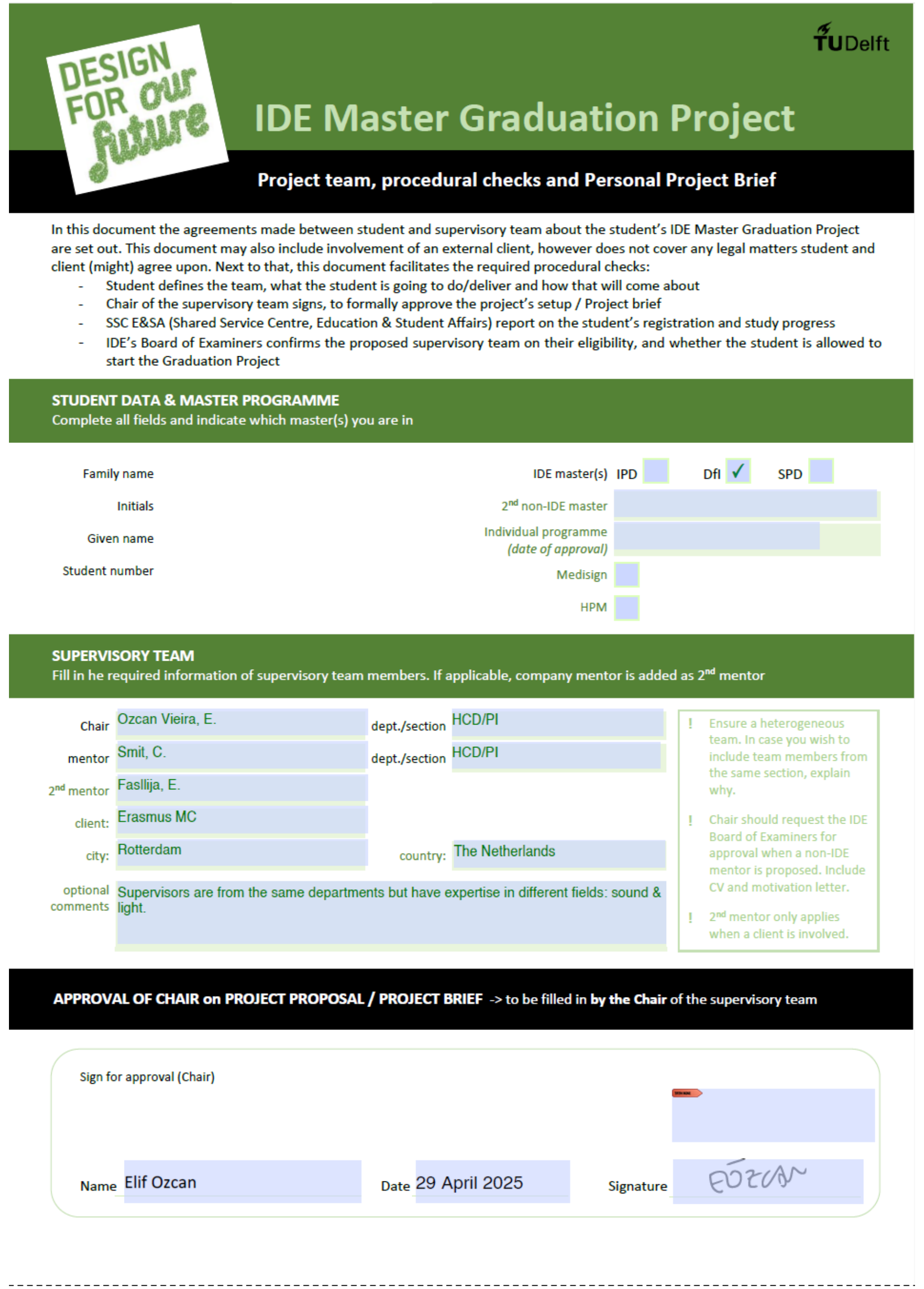
```
      transition: transform .15s, box-shadow .15s;
    }

      .card:hover { transform: translateY(-2px); box-shadow: 0 8px 20px
rgba(0,0,0,0.15); }

    .calm { background: linear-gradient(135deg, #ff9a4d, #ff5e00); }
    .neutral { background: linear-gradient(135deg, #ffe07a, #ffb300); color:
#333; }
      .alert { background: linear-gradient(135deg, #cfe7ff, #6aa9ff); color:
#000; }

    .close-btn {
      margin-top: 30px;
      width: 100%;
      max-width: 200px;
      height: 48px;
      background: #666;
      border: none;
      border-radius: 12px;
      color: white;
      font-size: 16px;
      font-weight: bold;
      cursor: pointer;
      box-shadow: 0 6px 15px rgba(0,0,0,0.18);
      transition: transform .15s, box-shadow .15s;
    }
    .close-btn:hover { transform: translateY(-1px); box-shadow: 0 8px 18px
rgba(0,0,0,0.22); }

    /* ---------- WORK MODE ---------- */
    .slider-container {
      display: flex;
      flex-direction: column;
      gap: 24px;
      margin-top: 20px;
      text-align: left;
    }

    label {
      font-weight: bold;
      color: #333;
      margin-bottom: 8px;
      display: block;
    }

    input[type=range] {
      width: 100%;
```

```
      height: 6px;
      border-radius: 3px;
      background: #ddd;
      outline: none;
      cursor: pointer;
      transition: background 0.3s;
    }

    input[type=range]:hover { background: #ccc; }

    /* Color preview blob */
    #colorPreview {
      width: 60px;
      height: 30px;
      border-radius: 8px;
      margin-top: 8px;
      margin-bottom: 10px;
      border: 1px solid #ccc;
      transition: background-color 0.2s linear;
    }
  </style>
</head>
<body>
  <div class=”container” id=”mainContainer”>
    <h1>Select Mode</h1>
    <form method=”POST” action=”/select”>
          <button  class=”btn”  name=”choice”  value=”auto”>Automatic</
button>
     <button type=”button” class=”btn” id=”manualBtn”>Manual</button>
      <button type=”button” class=”btn” id=”workBtn”>Work</button>
      <button class=”btn off” name=”choice” value=”r”>Off</button>
    </form>
  </div>

  <!-- Manual Mode Modal -->
  <div class=”overlay” id=”manualOverlay”>
    <form method=”POST” action=”/select” class=”modal”>
      <h2>Select Sonic Ambiance</h2>
      <div class=”grid”>
        <button class=”card calm” name=”choice” value=”1”><i class=”fas
fa-cloud”></i> Calm</button>
       <button class=”card neutral” name=”choice” value=”2”><i class=”fas
fa-sun”></i> Neutral</button>
        <button class=”card alert” name=”choice” value=”3”><i class=”fas
fa-bolt”></i> Alert</button>
      </div>
                                        <button      type=”button”      class=”close-btn”
onclick=”closeManual()”>Close</button>
```

```
    </form>
  </div>

  <!-- Work Mode Modal -->
  <div class=”overlay” id=”workOverlay”>
    <div class=”modal”>
      <h2>Work Mode Settings</h2>
      <div class=”slider-container”>
        <div>
     <label for=”brightness”>Brightness: <span id=”brightnessValue”>50</
span>%</label>
          <input type=”range” id=”brightness” name=”brightness” min=”0”
max=”100” value=”50”>
        </div>

        <div>
          <label for=”temperature”>Color Temperature:</label>
          <div id=”colorPreview”></div>
               <input  type=”range”  id=”temperature”  name=”temperature”
min=”2000” max=”6500” value=”4000” step=”10”>
        </div>
      </div>
  <button type=”button” class=”close-btn” onclick=”closeWork()”>Close</
button>
    </div>
  </div>

  <script>
    const mainContainer = document.getElementById(‘mainContainer’);
    const manualBtn = document.getElementById(‘manualBtn’);
    const manualOverlay = document.getElementById(‘manualOverlay’);
    const workBtn = document.getElementById(‘workBtn’);
    const workOverlay = document.getElementById(‘workOverlay’);
    manualBtn.addEventListener(‘click’, () => {
      manualOverlay.style.display = ‘flex’;
      blurBackground(true);
    });

    workBtn.addEventListener(‘click’, () => {
      workOverlay.style.display = ‘flex’;
      blurBackground(true);
    });

    function closeManual() {
      manualOverlay.style.display = ‘none’;
      blurBackground(false);
    }
```

```
    function closeWork() {
      workOverlay.style.display = ‘none’;
      blurBackground(false);
    }

    function blurBackground(state) {
      if (state) {
        mainContainer.style.filter = ‘blur(6px)’;
        mainContainer.style.opacity = ‘0.5’;
      } else {
        mainContainer.style.filter = ‘none’;
        mainContainer.style.opacity = ‘1’;
      }
    }

    // Live slider updates
    const brightnessSlider = document.getElementById(‘brightness’);
   const brightnessValue = document.getElementById(‘brightnessValue’);
    brightnessSlider.oninput = () => {
      brightnessValue.textContent = brightnessSlider.value;
    };

    // Color temperature slider with color blob
    const tempSlider = document.getElementById(‘temperature’);
    const colorPreview = document.getElementById(‘colorPreview’);

    function kelvinToRGB(k) {
      const t = (k - 2000) / (6500 - 2000);
      const warm = { r: 255, g: 147, b: 41 };
      const cool = { r: 200, g: 230, b: 255 }; // bluish white
      const r = Math.round(warm.r + (cool.r - warm.r) * t);
      const g = Math.round(warm.g + (cool.g - warm.g) * t);
      const b = Math.round(warm.b + (cool.b - warm.b) * t);
      return `rgb(${r},${g},${b})`;
    }

    function updateColorPreview() {
      const k = parseInt(tempSlider.value);
      colorPreview.style.backgroundColor = kelvinToRGB(k);
    }
    tempSlider.oninput = updateColorPreview;
    updateColorPreview();
  </script>
</body>
</html>
“””
# ---------------- Serial + Audio ----------------
def send_char(c: str):
```

```
    if not ser or not ser.is_open:
        print(“ESP32 not connected, command skipped”)
        return
    try:
        ser.write((c + “\\n”).encode())
        ser.flush()
        print(f”Sent to ESP32: {c}”)
    except Exception as e:
        print(f”Error sending to ESP32: {e}”)

def play_audio(choice: str):
    if choice in AUDIO_FILES and os.path.exists(AUDIO_FILES[choice]):
        try:
            pygame.mixer.music.stop()
            print(f”Playing audio: {AUDIO_FILES[choice]}”)
            pygame.mixer.music.load(AUDIO_FILES[choice])
            pygame.mixer.music.play()
        except Exception as e:
            print(f”Failed to play audio: {e}”)
    else:
        print(f”No audio file for choice {choice}”)

def stop_audio():
    pygame.mixer.music.stop()
    print(“Audio stopped”)

# ---------------- BEEP BEEP BOOP BOOP----------------
@app.route(“/”, methods=[“GET”])
def index():
    return render_template_string(MAIN_PAGE)

@app.route(“/select”, methods=[“POST”])
def select():
    action = request.form.get(“choice”, “”)
    print(f”User selected: {action}”)

    if action in [“1”, “2”, “3”]:
        stop_audio()
        send_char(action)
    elif action == “r”:
        stop_audio()
        send_char(“r”)

    return render_template_string(MAIN_PAGE)
# ---------------- Main ----------------
if __name__ == “__main__”:
    app.run(host=”0.0.0.0”, port=5000)
```



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

Initials

Given name

Student number

IDE master(s) IPD ☐ DfI ☑ SPD ☐

2nd non-IDE master

Individual programme *(date of approval)*

Medisign ☐

HPM ☐

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

Chair: Ozcan Vieira, E. dept./section: HCD/PI

mentor: Smit, C. dept./section: HCD/PI

2nd mentor: Fasllija, E.

client: Erasmus MC

city: Rotterdam country: The Netherlands

optional comments: Supervisors are from the same departments but have expertise in different fields: sound & light.

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

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

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

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

Sign for approval (Chair)

Name: Elif Ozcan Date: 29 April 2025 Signature: EÖzcan

CHECK ON STUDY PROGRESS
To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ____ EC

Of which, taking conditional requirements into account, can be part of the exam programme ____ EC

★	YES	all 1st year master courses passed
☐	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

G. Janse Digitally signed by G. Janse Date: 2025.06.16 10:56:52 +02'00'

Name: G. Janse Date: 16-6-2025 Signature:

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO	☐	Supervisory Team not approved

Comments:

Based on study progress, students is ...

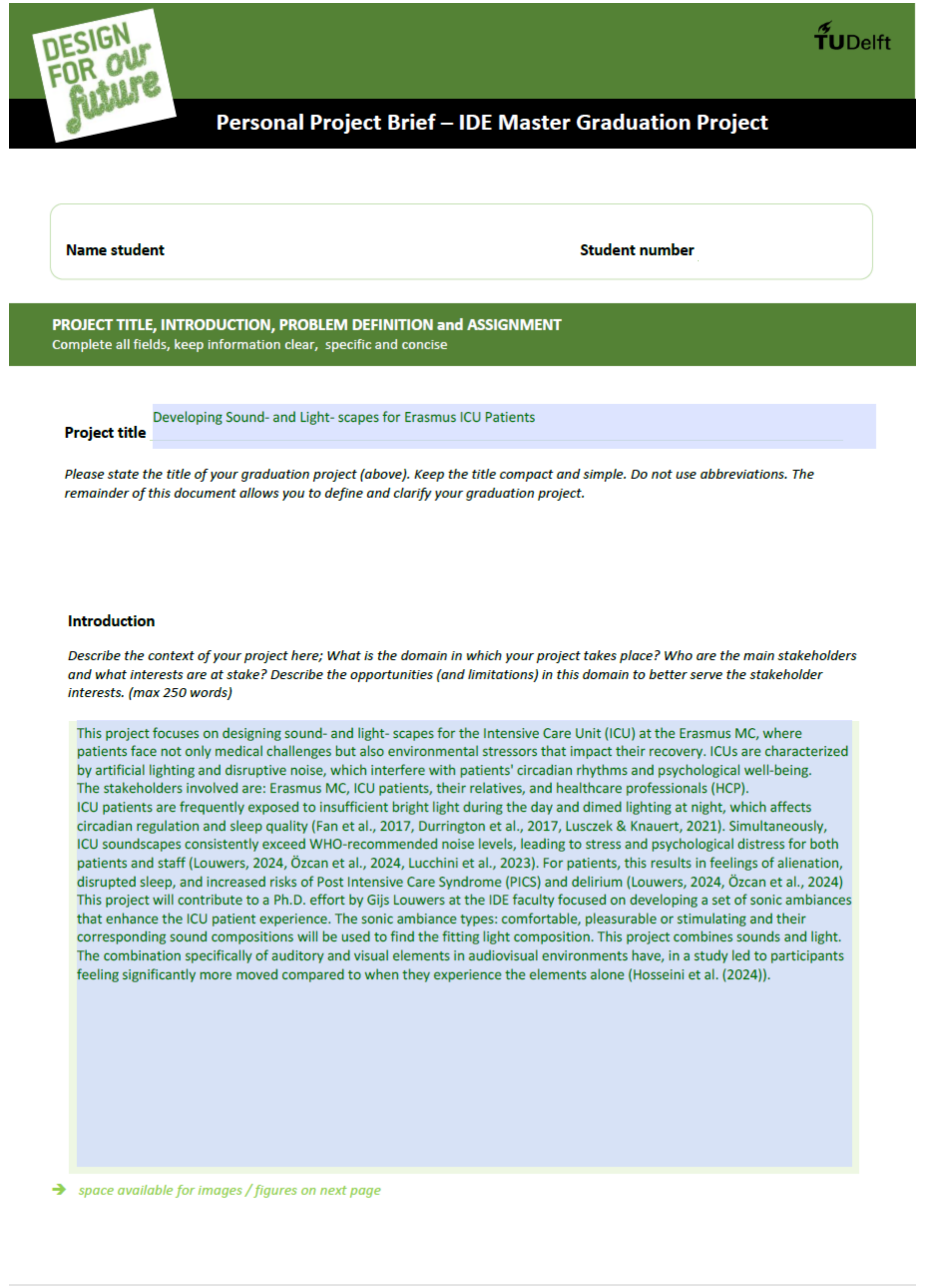
★	**ALLOWED** to start the graduation project
☐	**NOT** allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Monique von Morgen Digitally signed by Monique von Morgen Date: 2025.07.01 11:29:52 +02'00'

Name: Monique von Morgen Date: 1/7/2025 Signature:



TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student **Student number**

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

Project title Developing Sound- and Light- scapes for Erasmus ICU Patients

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

Introduction

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

This project focuses on designing sound- and light- scapes for the Intensive Care Unit (ICU) at the Erasmus MC, where patients face not only medical challenges but also environmental stressors that impact their recovery. ICUs are characterized by artificial lighting and disruptive noise, which interfere with patients' circadian rhythms and psychological well-being.
The stakeholders involved are: Erasmus MC, ICU patients, their relatives, and healthcare professionals (HCP).
ICU patients are frequently exposed to insufficient bright light during the day and dimed lighting at night, which affects circadian regulation and sleep quality (Fan et al., 2017, Durrington et al., 2017, Lusczek & Knauert, 2021). Simultaneously, ICU soundscapes consistently exceed WHO-recommended noise levels, leading to stress and psychological distress for both patients and staff (Louwers, 2024, Özcan et al., 2024, Lucchini et al., 2023). For patients, this results in feelings of alienation, disrupted sleep, and increased risks of Post Intensive Care Syndrome (PICS) and delirium (Louwers, 2024, Özcan et al., 2024)
This project will contribute to a Ph.D. effort by Gijs Louwers at the IDE faculty focused on developing a set of sonic ambiances that enhance the ICU patient experience. The sonic ambiance types: comfortable, pleasurable or stimulating and their corresponding sound compositions will be used to find the fitting light composition. This project combines sounds and light. The combination specifically of auditory and visual elements in audiovisual environments have, in a study led to participants feeling significantly more moved compared to when they experience the elements alone (Hosseini et al. (2024)).

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

introduction (continued): space for images

image / figure 1 Erasmus MC ICU rooms

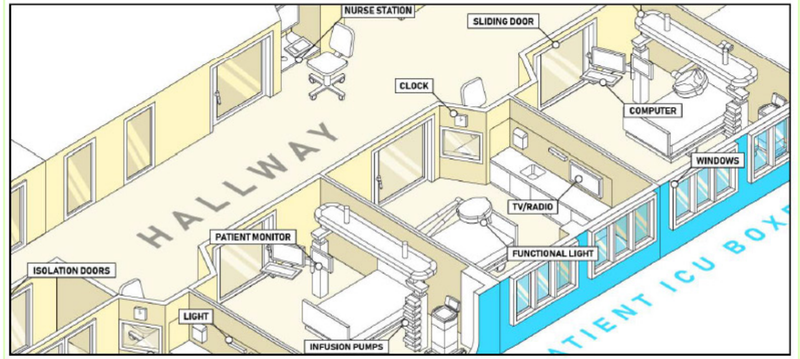
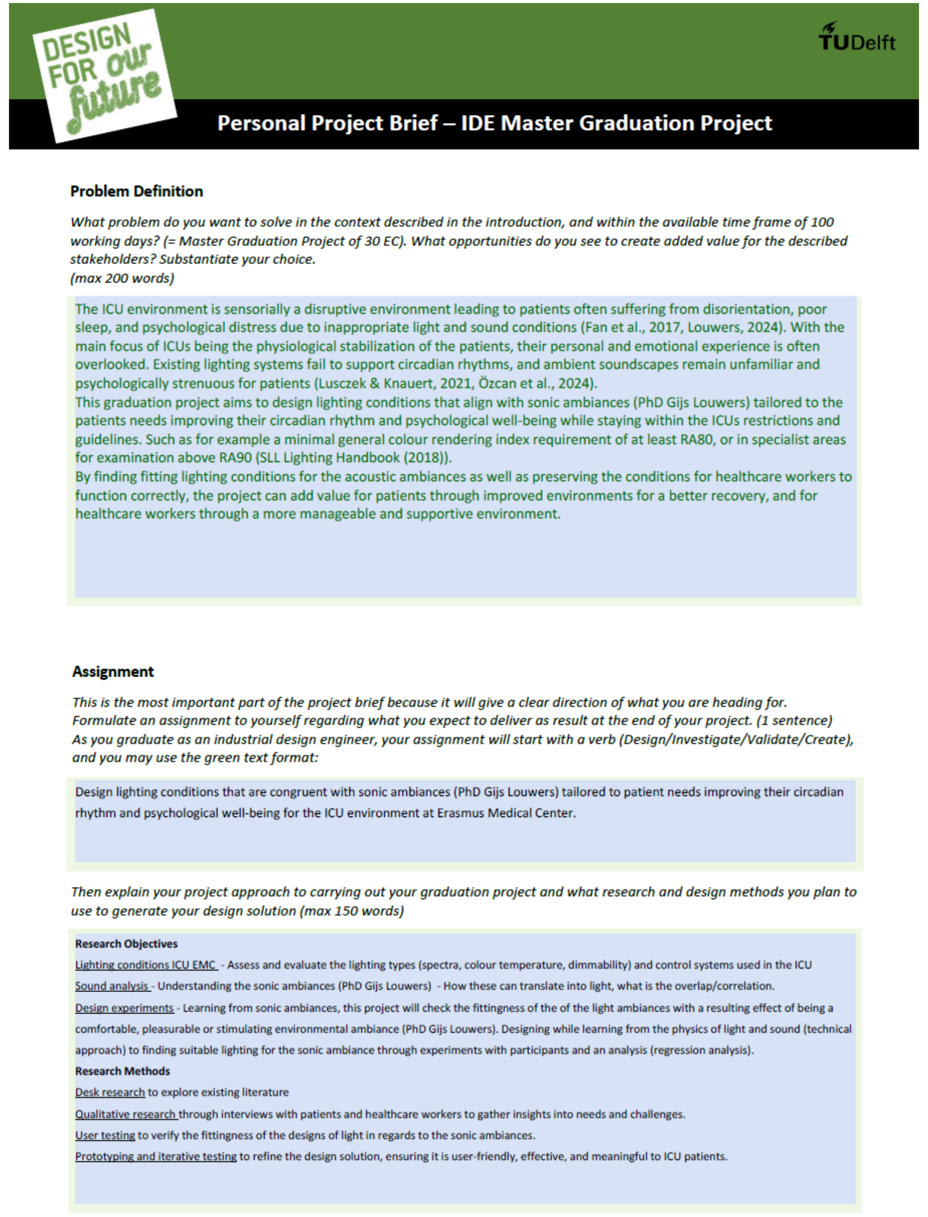


image / figure 2 ICU floor plan highlighting various sections and their corresponding soundscape (Louwers et al., n.d.).



Personal Project Brief – IDE Master Graduation Project

Problem Definition

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

The ICU environment is sensorially a disruptive environment leading to patients often suffering from disorientation, poor sleep, and psychological distress due to inappropriate light and sound conditions (Fan et al., 2017, Louwers, 2024). With the main focus of ICUs being the physiological stabilization of the patients, their personal and emotional experience is often overlooked. Existing lighting systems fail to support circadian rhythms, and ambient soundscapes remain unfamiliar and psychologically strenuous for patients (Lusczek & Knauert, 2021, Özcan et al., 2024).
This graduation project aims to design lighting conditions that align with sonic ambiances (PhD Gijs Louwers) tailored to the patients needs improving their circadian rhythm and psychological well-being while staying within the ICUs restrictions and guidelines. Such as for example a minimal general colour rendering index requirement of at least RA80, or in specialist areas for examination above RA90 (SLL Lighting Handbook (2018)).
By finding fitting lighting conditions for the acoustic ambiances as well as preserving the conditions for healthcare workers to function correctly, the project can add value for patients through improved environments for a better recovery, and for healthcare workers through a more manageable and supportive environment.

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 lighting conditions that are congruent with sonic ambiances (PhD Gijs Louwers) tailored to patient needs improving their circadian rhythm and psychological well-being for the ICU environment at Erasmus Medical Center.

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)

Research Objectives

Lighting conditions ICU EMC - Assess and evaluate the lighting types (spectra, colour temperature, dimmability) and control systems used in the ICU

Sound analysis - Understanding the sonic ambiances (PhD Gijs Louwers) - How these can translate into light, what is the overlap/correlation.

Design experiments - Learning from sonic ambiances, this project will check the fittingness of the of the light ambiances with a resulting effect of being a comfortable, pleasurable or stimulating environmental ambiance (PhD Gijs Louwers). Designing while learning from the physics of light and sound (technical approach) to finding suitable lighting for the sonic ambiance through experiments with participants and an analysis (regression analysis).

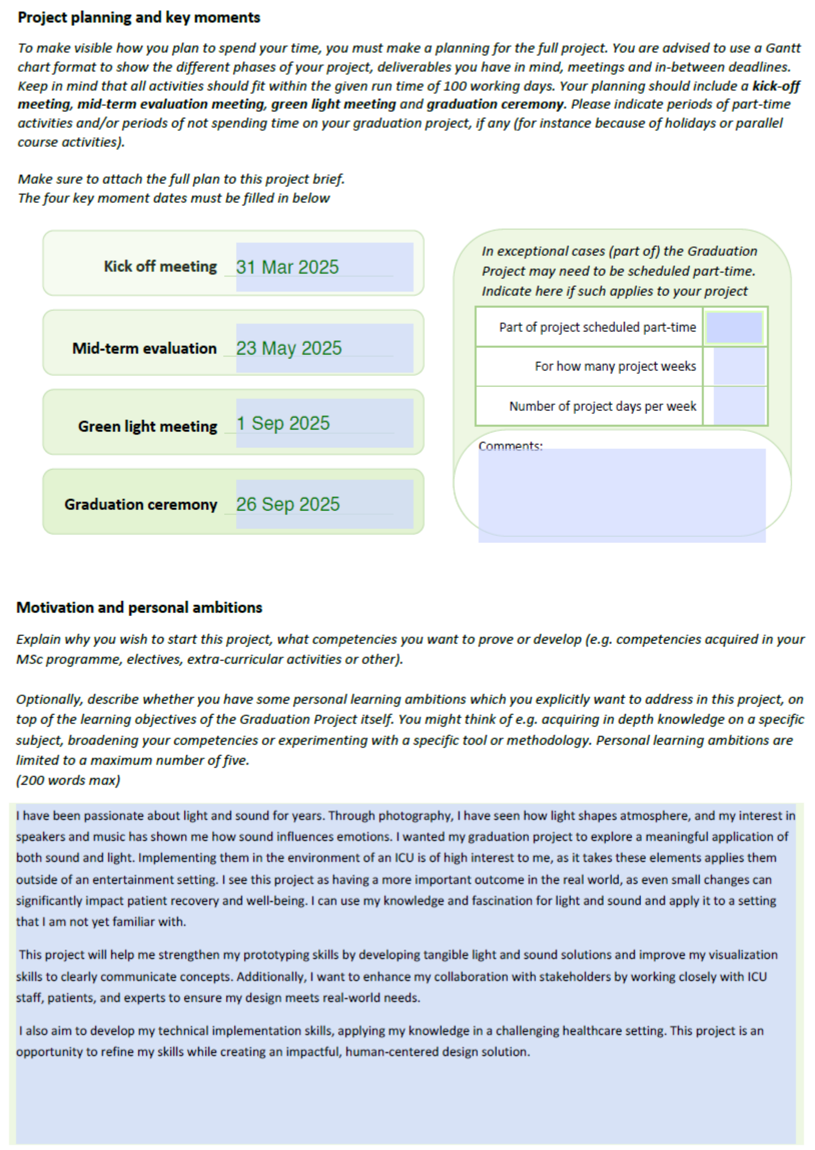
Research Methods

Desk research to explore existing literature

Qualitative research through interviews with patients and healthcare workers to gather insights into needs and challenges.

User testing to verify the fittingness of the designs of light in regards to the sonic ambiances.

Prototyping and iterative testing to refine the design solution, ensuring it is user-friendly, effective, and meaningful to ICU patients.



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	31 Mar 2025
Mid-term evaluation	23 May 2025
Green light meeting	1 Sep 2025
Graduation ceremony	26 Sep 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)

I have been passionate about light and sound for years. Through photography, I have seen how light shapes atmosphere, and my interest in speakers and music has shown me how sound influences emotions. I wanted my graduation project to explore a meaningful application of both sound and light. Implementing them in the environment of an ICU is of high interest to me, as it takes these elements applies them outside of an entertainment setting. I see this project as having a more important outcome in the real world, as even small changes can significantly impact patient recovery and well-being. I can use my knowledge and fascination for light and sound and apply it to a setting that I am not yet familiar with.

This project will help me strengthen my prototyping skills by developing tangible light and sound solutions and improve my visualization skills to clearly communicate concepts. Additionally, I want to enhance my collaboration with stakeholders by working closely with ICU staff, patients, and experts to ensure my design meets real-world needs.

I also aim to develop my technical implementation skills, applying my knowledge in a challenging healthcare setting. This project is an opportunity to refine my skills while creating an impactful, human-centered design solution.