Introducing Environmental Noise Conversion as a Method to Analyse and Create Solutions to Enhance Site-Specific Soundscape Experiences

Nikolaj Gerlach

Create - Department of Architecture, Design and Media Technology, 2025

Master's Project

STUDENT REPORT

AALBORG UNIVERSITY

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Semantic profiles of the HEARSEPTION framework, are presented using Microsoft Excel [26], other diagrams of this data are from SurveyXact [124].

Analytical profiles of the physical aspects of the sound, are from SvanPC++ [156], and MatLab [66].

All other diagrams and drawings are made using draw.io [83], unless specifically stated in the description of the image.

Audiofiles were processed and edited in the DAW Reaper [65], by Cuckos, when nothing else is stated.

AALBORG UNIVERSITY
STUDENT REPORT

Create - Department of Architecture, Design and Media Technology
Aalborg University
http://www.aau.dk

Title:
Introducing Environmental Noise Conversion as a Method to Analyse and Create Solutions to Enhance Site-Specific Soundscape Experiences

Theme:
Master's Thesis

Project Period:
Spring Semester 2025

Project Group:
Nikolaj Gerlach

Participant(s):
Nikolaj Gerlach

Supervisor(s):
Dan Overholt

Copies: 1

Page Numbers: 175

Date of Completion:
May 26, 2025

Abstract:

This thesis introduces Environmental Noise Conversion (ENC) as a methodology for analyzing and addressing environmental noise problems through three approaches. The Engineering Approach analyzes the physical characteristics of the acoustic environment. The Soundscape Approach analyses the context and the subjective assessment of the sound. Both approaches are based on the requirements of ISO 12913. The Artistic Approach identifies aspects, techniques and goals for the process of converting the soundscape. The thesis suggests adjustments to ISO 12913 to make soundscape assessment more accessible and practical. The subjective aspects of the sounds are assessed by introducing the model of HEARSEPTION. The model aims to create a standardised holistic assessment tool. ENC is used to analyse a noise problems in an exhibition and create three solutions to address it. The solutions are evaluated using HEARSEPTION, and it is shown how the same data can be used in triangulation with other models, exemplified by the Pleasantness/Eventfulness model. It is concluded that the solutions created are successful in enhancing the soundscape to fit the narrative of the exhibition. ENC is presented as an addition in making soundscape assessment more accessible, especially with further validation of the HEARSEPTION model.

Preface

This master thesis is the final part of the education "Sound and Music Computing" at Aalborg University, Campus Copenhagen. The thesis was planned, conducted and written during the first half of 2025. The aim of the master's thesis is to explore the possibilities of using sounds of the environment to reduce the negative aspects of sounds that could be perceived as bad, unwanted or could be somewhat improved. The project is a culmination of projects conducted during the first 3 semesters, as well as my work as an audio engineer and my artistic practice.

The idea of converting sounds into other sounds began as my first mini project, and was developed during the remainder of my education, culminating in this thesis. The concept of Environmental Noise Conversion was rewritten into an article, with Dan Overholt as my cowriter, in the late summer of 2024. The paper has now been accepted after peer review for publication in "The International Journal of Music, Science, Technology, and Art". Dan Overholt has also throughout my studies been my supervisor in all the different iterations of the project, as well as in this final thesis.

I wanted to do 3 things with this thesis, which in hindsight was a bit ambitious.

1. I wanted to investigate, improve and introduce ENC as a methodology in a real-world setting, using speaker rather than headphones for the converted soundscapes. I wanted to show how often overlooked noise problems could be approached systematically and artistically, and that this could solve problems of different degrees of severity.

2. To enable the scaling of the project, I therefore aimed at making the methodological approach in compliance with ISO 12913 standard. A second reason was to position myself as an in a way that I after sort of soundscape specialist consulting engineer. This is also why I during the semester joined the start-up program at AAU, to push myself in this direction.

3. As I during my internship at 103aps, had developed an analytical assessment model, I wanted to use this model in my thesis. That would require me to further develop the model, so it would be implemented and used.

During the semester I also completed an online course in soundscape composition, from Simon Fraser University, with Berry Truax. I did this as I wanted to get a better insight into how soundscape could be used in compositions. For most of the first month of the semester I was therefore busy studying soundscapes, while I was preparing to present the initial paper on ENC, as part of a conference in Italy. During this time, I also met with some employees of Museum Kolding and discussed how my project could use one of their exhibitions as a case for the implementation of ENC. I had formerly worked with creating sound designs at a museum, and thought that this aspect would further help me in positioning myself as a specialist after my exams. I would like to thank the employees of the museum for letting me play, and explore their work. Likewise, I would like to thank Dan Overholt, for keeping me inspired when I was stuck, and for all the nice things he said to keep my morale up, when the stress of the ambition of the thesis peaked. While learning and working is worthwhile, it wouldn't be fun without the love and support from my girlfriend. Likewise, thank you to my toddler at home for all the hugs, laughs and playful moments.

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Aalborg University, May 26, 2025

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Contents

Part 1

Introduction

There are sounds all around us. Some sounds we notice, others we do not. These sounds are the soundscape. Some soundscapes are dominated by beautiful sounds, others by noise. Noise has a severe effect on our health, general well-being, and productivity, which affects all life forms [1] & [78, pp. 610–632].

This thesis introduces Environmental Noise Conversion (ENC) as a methodology, to analyse why some sounds fit to some situations better than other sounds. It investigates how the sounds of noise can be converted to be perceived differently. When ENC was first introduced by the author in collaboration with Dan Overhot [53], it was mainly philosophical. This thesis aims to improve the initial concept by defining it as a methodology of analysis, and how this analysis can be used to convert soundscapes, to enhance specific contexts.

ENC is presented as a methodology to address all manner of noise problems. from small to large by following the same analytical cross-disciplinary approaches to understand the sounds and context. To accomplish this, the thesis investigates how to understand and enhance the soundscape of an exhibition of a prison cell 5. The exhibition provides an interesting case, as traditional acoustical treatment cannot solve the problem, as the room is the artifact of the exhibition.A second reason for this case is that it has a clear aim in its exhibition design, which makes it easier to evaluate if solutions are successful. While these sounds might seem insignificant compared to problems caused by the noise of traffic, this thesis argues that the analysis of the smaller problems is found the same way as those of more severe problems. Finding solutions through this analysis is similarly achieved, even though the solution might be different, identifying and achieving them could be similar. To understand how the problems of environmental noise are generally assessed, and defined by laws, the thesis investigates the requirements of the ISO 12913 series [152], [153] & [151]. This ISO standard is currently the main document that policy-makers must consult, and how it defines and understands the assessment of soundscapes is a valuable tool, to validate the approaches of the methodology of ENC.

These aims form the research question: *"How can Environmental Noise Conversion, as a methodology, be applied to understand and enhance site-specific experiences of soundscape?"*. The subordinate question: *"How can international standards be used as guidelines to ensure validated data collection"*.

1.1 Theoretical and Methodological Foundation

The first part of the thesis explores the general area of research of noise and soundscape assessment, and how others have used noise as part of an artistic practice 2. This is followed by diving into the theoretical aspects of sound, sound measurement and the requirements and definitions of ISO 12913 3. This section covers both the aspects of sound, and the aspects of how sound is heard, and how it affects emotions. It lastly explores the theoretical context of a modern museum exhibition, and how generally use sound, and are affected by noise. The methodological part of the thesis begins by defining the methodology of Environmental Noise Conversion 4. This is then followed by an elaboration of the methodological requirements of the ISO standards. As a model for collecting holistic data on the subjective experiences of soundscape perception, the thesis introduces the model of HEARSEPTION (or *"Holistic Evaluative Assessment and Rating of Soundscape Experience and Perception - Tuning ISO and Optimizing Normalisation"*.). The model is made by the author to specifically address the issue that no standardised model exists for assessment of soundscapes, and especially not one that is easy to implement, and can be used holistically. That is, it can be used by a multitude of people with different skill sets, in a multitude of different settings. The methodological part of the thesis ends with an introduction to different methods of design, such as masking, that can be used in the iterative process of creating solutions to the noise problem of the exhibition.

1.2 Case Study and Implementation

Part 5 5 introduces the case of "Zelle 2", a preserved Gestapo cell, that is used as the main artifact of a museum exhibition. It explores the setting and context, as well as exploring the noise problem of the exhibition. It explains that it is a modern experience design, where the main narrative elements of the exhibition are made using multimedia, and shows how the noise problem is a common problem.

Parts 6 6 and 7 7 of the Master's thesis presents the implementation of ENC as a methodology. The first part of the implementation analyses the case from the three different aspects of using ENC as a methodology. The first aspect, The Engineering Approach, is used to analyse the physical properties of the room, by following requirements of ISO 12913. It does so by identifying, among other things, sound sources and measuring SPL and RV60. In this part, it is shown that following the requirements of the ISO standards, is not straightforward, and explains why some requirements were not followed, due to, among other things, the quality of the used equipment. The second aspect of ENC, the Soundscape Approach, is then used to analyse the context of the exhibition and how the soundscape is assessed. To get insights into what emotional response would fit with the experience design of the exhibition, an interview with one of the curators, as well as analysing the narrative and other material of the exhibition. It observes the intended mood as sombre, depressing and anxious, made with the intent of relating the guests to the emotions of the prisoners, and guards. But always with respect for the individual stories of the prisoners, and the cell as a historical artifact. To understand how the soundscape is assessed, a lab test using a recording of the soundscape of the cell is made using HEARSEPTION. A second experiment was conducted at the exhibition using HEARSEPTION was conducted, but too few people participated for the data to be valuable. The analysis indicates that it is characterized as neutral, neither stimulation of positive nor negative emotions, and thus not stimulating aesthetic qualities. The final aspect of ENC, "the Artistic Approach", is then used to collect the findings of the previous analysis, and investigate what parts of the physical sound in the room, should be converted, and how, to enhance the mood of the exhibition. It defines a set of design requirements, and tools that should be used to create solutions. It generally aims at using the aesthetic ratings from HEARSEPTION, as goals for the implementation.

The second part of the implementation creates 3 solutions with different aims. One solution is made by abstracting the content of the soundscape based on the found physical aspects. The second solution supports the narrative by transforming the soundscape into rain, using a mixture of samples and a pseudo-physical model of rain. Using the soundscape of the cell to create the synthetic rain, as well as controlling a resonating filter of the sampled rain, to mask the most problematic aspects. The third solution uses music played on a piano tuned to the frequencies of the room, to support the mood, by specific chord progressions and ways of playing. It likewise uses a manipulated version of an impulse response of the room, to create a convolution reverb that enhances the reverberation of the room, to create an atmosphere. The recording of the piano is then used to create a pseudo-generative soundscape.

1.3 Results, Discussion, and Conclusion

The solutions are then evaluated in Part 8 8 in three steps. Firstly, they were implemented within the exhibition, and it was concluded that they all succeeded in masking the soundscape of the cell as they intended. Secondly, the converted soundscapes were self-assesses using part of an evaluation made using HEARSEPTION. The data from HEARSEPTION are triangulated to fit within the framework of the Pleasantness/eventfulness model [8]. It concludes that all the solutions are improvements of the original soundscape. The second evaluation was designed using an online collection of assessment using HEARSEPTION. This assessment showed that all the solutions changed, but only the rain and the piano solution succeeded in changing the aspects of aesthetic as they intended. It argues that the abstracted solution still succeeded, though not as successfully.

In Parts 9 9 and 10 10 ENC as a methodology is discussed and suggestions for improvements are made. It argues that the solutions are not yet ready for implementation, as some aspects, such as sound from guests, are not yet addressed. The thesis argues how ENC makes soundscape assessment more accessible, and addresses some complications of the ISO standard, such as making it difficult to conduct the required measurements without a considerable budget and a team of experts in various fields. It also argues how ENC is an improvement to current methodologies of working with soundscapes, as it supplies a framework that aims at solving problems, rather than addressing them. Finally, it is commented that the methodology, as presented in this thesis, has a primary focus on the Engineering Approach, and that future iterations should be made with focus on the other two approaches. Likewise, it argues that to fully understand if ENC can be used to address noise problems of different scales, different implementations and cases should be conducted.

The final part 11 summarizes the findings and concludes that ENC as a methodology can be used to address environmental noise problems, by following the threefold approach of analysing soundscapes, investigating what aspects of the soundscape can be used to convert it, and use this to connect the converted soundscape to the general desired for mood and context of the specific site. It furthermore concludes that HEARSEPTION as a model of analysis of subjective data on soundscape, works as intended, and has the possibility to be a valuable tool for soundscape assessment in general. The thesis ends by concluding that Environmental Noise Conversion can be used to analyse and create solutions, in a multitude of projects and budgets.

Part 2

Related Research

As this thesis has a broad and cross-disciplinary aim, it relates to multiple research areas. This part provides a general overview of the most important related work.

2.1 Converting the Environment

Environmental Noise Conversion (ENC) was first presented by the author, together with Dan Overholt, in [53]. The paper presents ENC to address noise problems by using aspects of sounds to create new sound. Two prototypes, both based on headphone listening, were presented. Prototype 1 changed environmental sounds into abstract ambient music inspired by Brian Eno's Discreete Music [39]. The second prototype implements ENC as an addition to ANC (Adaptive Noise Cancelling), and converted it using a combination of subtractive synthesis and generative music methods. The introduction of ENC argues that there are 3 general approaches to working with the sounds of the environment. The approaches are Engineering, Soundscape studies, and Artistic. The paper argues that while each approach individually addresses only some problems, combining them discovers new solutions

ENC builds on the theoretical framework that all sounds can be interpreted as music. Russolo was the first to categorise and build specific instruments to produce "noise" as part of his futurist artistic practice [122], & [130]. Cage explored how by changing perspective will make people listen to sound as music, if they expect music [138] & [132]. Pierre Schaefer theorised that as sounds can be recorded, they can be used and manipulated to make music, and expanded the boundaries of what could constitute an instrument [55]. Murray Schafer theorised that if all sounds can be perceived as music, the sounds that society creates are part of a composition he termed soundscape. ENC builds on this and states that we must investigate how environmental sounds, can be used to make better soundscapes by real-time manipulation.

The general theories of soundscapes, in this thesis are based on the definitions of ISO 12913, but are also closely related, and aware of to the general research in the field. This research has some differences from the definitions of the ISO standard, which will not be elaborated in this paper. Except a general introduction added to the appendix J.0.1.

2.1.1 Previous Conversion

Using the sounds of the environment, as mentioned earlier, is not new. Belgiojoso [12] investigates how different artists used environmental sounds, as part of sound installations in the urban environment, combined with an architectural perspective of urban planning. He mentions artists such as O+A, whose work Lost Neighbourhood (1993) used differently sized tubes to alter zoo sounds and play these recordings in real-time in a city square where such sounds were foreign [12, pp. 66–67]. Contemporary examples of how soundscapes are used in compositions can be especially found in the field of soundscape composition. The main purpose of these is to use the sounds of the environment to create composition, that convey something about the specific soundscape. Truax documents his compositions and discusses and researches his methods and techniques. An example is a paper from 2002 [165], that explains his development of specialization and granulation techniques.

There are many examples of artists that make music of the environment. A famous example is "I'm sitting in a Room" by Alvin Lucier from 1969 [146, pp. 107–108]. Lucier placed a microphone and a speaker in a room, and connected it to tape recorders. One recorded the sound of the room, after a while it played the recording, while the other tape recorder recorded. This process was looped, the more times the loops were made the more enhanced the resonant qualities of the room became the apparent, until they were all that could be heard. More contemporary sound art is works such as "Augmented Aiplanes" by Julie Østengaard [178]. The piece was a site-specific concert which uses the sound from an airport as input to manipulation, that is the basis of a composition. Another example is the works of Jacob Kierkegaard, such as "Though the Wall" [**kirkegaard_through_nodate**]. In this piece, Kierkegaard used sensors to enhance the vibrating qualities of the wall separating Israel and Palestine. The augmented sound was then played inside a concrete wall, that could be experienced in a museum, by guests putting their ears to the wall.

Another approach to sound conversion was the app RjDj. The app included different algorithms to convert the sound captured through the microphone of an iPhone, into different type of music, depending on the algorithm [11, pp. 235–238] & [134, pp. 61–62]. These algorithms could inspire the implementation of conversion methods within the ENC framework.

2.2 Assessing Soundscapes

A different aspect of the thesis is how to assess soundscapes, and especially how it is defined by ISO 12913. There are many methods and papers discussing, and presenting models of research on assessment of soundscapes, such as [8], [139], [177], and [21]. All investigate soundscape assessment with the aim of working toward standardization. The work presented in this thesis assesses the implementation of the standard. This is in the line of research such as that of Engel. et al. [36] that investigates how often research on soundscape assessments follows the requirement of measurements of psychoacoustical parameter of loudness. Their findings show that only 23% of the articles published since the standard was defined measures loudness correctly. Papadakis et al. [113] comment that there is no standardized way of translating an aspect of the standard, which makes them hypothesise that the current form of the ISO standard does not enable cross-cultural implementation. The critique of the language barrier is also explored by Aletta et al. [4] and Fiebig [46], which draws the same conclusions. This aspect of soundscape assessment, and language, is addressed in the creation of the HEARSEPTION model 4.3. In general, the creation of the HEARSEPTION model relates too much research on how and why to use Semantic Differential to assess sound, both for large data gathering and for self-assessment [74], [139], [8], [18], [34], [100] & [154].

The analysis of the thesis, especially in the Engineering Approach, tries to follow the requirements of the ISO 12913 standard. This relates to other research such as Heggie et al. [58]. They argue that the method suggested by the ISO standard, are not standardized, or easy to implement. They propose that the standard is adjusted, as the implementation required is impractical and logistical (close to) impossible, for varying sized practising teams. Axelsson et al. [7] argue the great diversity in methods used for assessment, makes them incomparable. A research project used ISO 12913 to investigate the soundscape of a museum [110], and concluded that aspects, such as SPL, have much less influence on the experience of the visitors, compared to how the content of the soundscape related to the exhibition. They find that enhancing the visitors' feeling of living in a historic period is a valuable sound design goal.

Part 3

Theory and Introduction to the ISO-Standards

This Master's Thesis has two aims. Firstly, an aim of analysing, assessing and enhancing a soundscape of an exhibition using Environmental Noise Conversion as a methodology. Secondly, the thesis is used to investigate how such analysis should be conducted according to international standards. This second aim is to allow the methodology of ENC to solve different types of environmental noise problems. Therefore, the thesis's theoretical and methodological foundation is based on the regulation and standardisation of requirements for soundscape assessment, as presented by the International Organisation of Standardisation (ISO). The introduction of the standard and its theoretical implications are followed by a more general theoretical foundation needed for the cross-disciplinary methodology of ENC. Firstly, an understanding of sound as a physical object that interacts with other objects is established 3.2. Followed by an investigation of the physiological, phenomenological and psychological aspects of the human experience of sound and emotions 3.3. As soundscape investigations are site-specific, a brief introduction to a museological approach to experience design is linked with a more general approach to soundscape theory 3.4. A list of general terms used to describe sound can be found in appendix J.1.

The conversion of the sound is done in the digital domain. That is, the physical sounds are converted to digital sound, before it is analysed, and the conversion and manipulation of the environmental sounds is likewise done digitally. The sound is converted from analogue, into digital, and the other way around. The thesis as a whole would not benefit from diving too deep into the field of digital sound theory, as the aim is creative manipulation rather than exact representation. Instead, when specific methods, theories, and models are used in the implementation of solutions they will be elaborated in those sections. If needed, a general introduction to digital audio theory can be found in the appendix J.2.3.

3.1 Measurements following the ISO standard

ISO 12913 from 2014 [151], was the first attempt to standardise the many opinions and definitions used concerning the term "Soundscape", and a step towards accepting the perception of the acoustic environment as essential for societies well-being [20] & [21]. The standard defines 3 general terms, and how they should be used, and are directly cited here [151]:

1. sound sources: sounds generated by nature or human activity.
2. acoustic environment: sound at the receiver from all sound sources as modified by the environment.
3. soundscape: acoustic environment as perceived or experienced and/or understood by a person or people in context.

The essential part of these definitions is how to make distinctions between what makes a sound, where the sound is present and how these sounds are experienced.

The second aim of ISO 12913 is to define a conceptual framework of soundscape assessment. They do this by defining seven concepts that are intertwined and must be used in the assessment.

1. Sound Source: same as in definition.
2. Acoustic environment: same as definition.
3. Context: Where, who and why the sound is produced, and by whom and why influence how the sound is perceived.
4. Auditory sensation: Psychoacoustics, that is the physical and neurological process of how the sound is computed by the listener.
5. Interpretation of auditory sensation: The individual's experiences and other aspects that influence the unconscious and conscious response to particular sounds.
6. Response: The immediate reaction to the subject's subjective interpretation of the sound.
7. Outcome: The long-term effects of the sound, and its influence on behaviour.

The standard supplies a figure to explain the connectivity of the term, but a paraphrased version of the model has been made for this thesis 3.1. The main adjustment is that the acoustic environment is made as a frame for the experience, with the outcome placed outside the acoustic environment. As the case of the

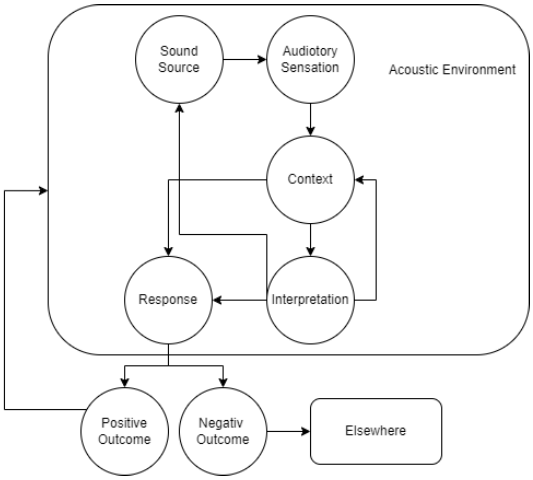

Figure 3.1: Illustration of conceptual framework, paraphrased from [151]

thesis is an exhibition, the aim of the exhibition soundscape should be for visitors to return to the exhibition at other times, or recommend it to others. In the paraphrased model, that would be a positive response. The context defines how a sound is perceived, but as the definition states, the listeners' interpretation is directly related to their understanding of the context, with or without being influenced by the auditory sensation or acoustic environment. The model was adjusted to underline this definition from the standard. A direct link was also made from the interpretation to the sound source. This adjustment is assuming that investigating the sound source can change the context. This is best explained with an example: "imagine you are a sound engineer, and during a concert, the sound of feedback is suddenly rising. Your immediate response is panic, and trying to find out what is causing the problem, so you can stop it. Looking up at the stage, you see the guitarist standing in front of an amplifier using the feedback as part of the music. You relax, and suddenly, you perceive the feedback for its musical qualities rather than its disruptive ones". The acoustic environment is the same, but the auditory sensation and context is thoroughly different. The adjusted model tries to represent visually how concepts are intertwined 3.1.

3.1.1 Data collection and requirements

ISO 12913 defined how to understand soundscapes and discuss soundscapes, and 4 years later ISO 12913-2 [152] was made with requirements for data collection. The standard aims to collect various data according to human perception, acoustic environment and context. It states in the introduction that the primary aim is the human perception, with a secondary aim of physical measurement. In this thesis, it will be argued that the standard forgets this prioritisation, in the manner it defines requirements of measurement.

The standard adds 8 new terms which should be used:

1. Background sounds: Frequent and continuous sounds, form a background in which other sounds are perceived.
2. Foreground sounds: The sounds that dominate the acoustic environment, and can be related to a specific sound source.
3. Descriptor: The terms used to describe the perception of the acoustic environment.
4. Indicator: Terms used to predict descriptors (objective).
5. Local experts: Someone who has day-to-day experience with the acoustic environment and context.
6. Noise: Unpleasant, unwanted and undesirable sounds.
7. Soundwalk: A method of conducting listening experiences.
8. Total sound: All sounds at a given time, of an acoustic environment.

Foreground and background sounds, are commonly used in studies of soundscape, but often with the terms "Keynote Sounds" rather than background [133, p. 272], and "Sound Signals" or "Signal Sounds" as the sounds that require attention [166] & [164]. The ISO emphasises that the choice and use of descriptors and indicators must be adjusted to the context. The standard states that when collection subjective data it should be holistic and cover all auditory sensations, as well as context-based variables such as the general mood, appreciation, and preferences. The standard then supplies an array of requirements for data that must be collected about participants, and measurements that must be conducted. These will be explained in the methodological section 4.2, together with the requirements of data analysis from ISO 12913-3 [153].

3.2 The "Hard" Science of Sound

To address and analyse the noise problems of sound sources in the acoustic environment, an understanding of the physical properties of sound is essential. Physical sound, particularly environmental sounds, are inherently complex dynamic systems, that due to their nature are impossible to calculate exactly. That does not mean we should not strive towards objectivity, but rather, to know when something is close enough to be good enough for the context. The following descriptions are therefore simplified versions of the complex physical phenomena, to create a foundation for making this choice, knowingly, that some aspects will be missing.

3.2.1 Basic Acoustic Properties of Soundwaves

Sounds are longitudinal waves moving through substances. We analyse these waves as the speed of cycles per second (frequency in Hz) and the power or height of the wave (Amplitude). Different substances influence the behaviour of sound waves, with a multitude of factor variables contributing to the specific nature of the interaction. Most often, sound is explained as waves travelling through air, impacting an object. When the object is an ear, it moves to the cochlea where it is processed physiologically [19, pp. 2–3].

The direct sound wave, i.e., the sound from the source, travels "freely" until it impacts something. Parts of the sound wave are reflected, and other parts of it are absorbed by the material [41, pp. 95, 179–182]. The size of the physical waves is defined as wavelength or λ). The longer the sound wave, the lower the oscillation and frequency. Low frequency content is much more difficult to absorb than short wavelengths. Materials have different acoustical characteristics defined by physical aspects such as mass, roughness, and stiffness. But as everything in the natural world, this definition is a simplification, of a much more complex and dynamic system of interaction. Refraction refers to the directional change of the sound wave, caused by the elastic and density properties of the material, that changes the speed of the sound wave. Diffraction, on the other hand, causes change in direction due to impacts of edges, openings, and objects [41, p. 117]. Diffusion properties scatter the soundwaves across a room. How the sound wave is scattered, is defined by aspects such as shape. Diffusion is a common way to make the sonic environment more pleasant, by uniformly distributing the frequencies to fit the human ear. Where acoustical diffusers are used to redistribute the characteristics of sound, absorbers are used to eliminate it. In its most basic explanation, absorbers eliminate soundwaves by allowing the sound waves to move through its surface and slow down the energy of the sound wave until it stops moving and thus disappears [41, pp. 125, 179]. The combined reflection, diffusion, absorption, refraction and diffraction creates the sound of a room, which can be described using reverberation and resonant frequencies.

The energy of soundwaves (simplified) defines how loud a sound is, and is defined in three general aspects that can be measured [101] & [41, pp. 19–32]:

- Sound Power: Measures the acoustic energy of a sound source over time, in Watts (W).
- Sound Intensity: Measures the acoustic energy per unit area in a specific direction from the sound source, in $Watts/m^2$.
- Sound Pressure: Measures local variations in atmospheric pressure, in Pascal (Pa).

Another way of understanding and measuring sound is as vibrations rather than waves, but this aspect of sound will not be used in this thesis, and will not be further addressed. A brief explanation is added to the appendix J.2.1.

The Character of Rooms

To understand the acoustic environment of the case, it seems useful to understand how a room and sound waves interact to create reverberation [41, p. 51]. Reverberation has three main components, the "direct sound", and the "reverberant sound" that is a combination of the scattering and reflection of sound waves from the sound source [119, pp. 283–285]. The third component is the "Early Reflection" which are the reflected sounds that reach the ear 35-100 ms later than the direct sound, and are perceived as part of the sound source [41, p. 60]. The length of the reverberation is known as decay. In the reverberation of a room, specific frequencies behave differently. The resonant frequencies are the ones where the effect of the material and scattering increases specific frequencies in power, compared to the surrounding frequencies, before the beginning of the decay [41, p. 90]. How the frequencies behave and decay can be calculated as RV60, as will be explained in the methodology section F, and is based on Sabines equations, which are briefly explained in the appendix J.2.2.

With this introduction to the physical aspects of sound, we must now understand the context of auditory experiences, and how sound is understood as being processed, interpreted and thus can influence the experience of the soundscape.

3.3 Sound and Emotions

To explore and experiment with how the sound influences the emotions of the visitors of the exhibition, it is necessary to explore what an experience is, and how emotions can be understood. This is done by a brief introduction to human hearing, followed by an introduction to the phenomenological understanding of humans as a conscious being defined by individual experiences. This leads into theories on how and why human emotions are influenced by sound. Lastly, these are combined with neuroscience by presenting the scientific field of psychoacoustics. In general, when working with environmental sound and health, the concept of annoyance is important to analyse and understand. If the case of the thesis was to use ENC to solve environmental issues with an aim of increasing health, it would have been essential, but for this thesis's case of enhancing an experience design the concept will not be elaborated, apart from as a brief explanation in the appendix J.2.4.

3.3.1 The Physical Experience, Critical Bands and Masking

Listening is a complex matter, and only the most important aspects connected to the aim of the thesis are investigated. When soundwaves reach the ear, the sound travels from the outer ear through the ear canal and eardrum and reaches the cochlea. The cochlea consists of approximately, 20000-25000 sensory organs that are very similar to hair. The "hairs" are grouped, and each group has the function of converting vibrations of specific frequencies from the sound waves into electric signals. These electric signals are what we perceive as sound, and they include information on amplitude, timbre, and frequency (among other things) [78, pp. 603–610] & [19, p. 74]. When sound reaches two ears of the same person, a spatial aspect, such as the location of sound sources, is perceived. The range of human hearing allows humans to hear sounds from 0dB, called the threshold of hearing, up to sounds thousands of times as powerful [162, pp. 32–35]. With every increase of 3dB, a sound is doubled in acoustic power, and a 10dB increase doubles the perceived loudness. To represent this physiological function, sound is measured in the logarithmic decibel scale (dB). The exposure to sound throughout our life, even at sensible levels, gradually decreases the number of functioning "hairs" in the cochlea. i.e., the older we get, the less we can hear. The louder our environment, the faster this degeneration happens [78, p. 11] & [31].

Due to the nature of how the ear works, we know that not all frequencies are perceived equally well. We are especially sensitive in the area of 2-4kHz, which is also the normal range of the human voice and intelligibility. When listening to complex signals, the ear combines frequencies together in groups of certain bandwidths, with a centre frequency that dominates the surrounding grouped frequencies. These groups are organized as 24 critical bands, known as Bark bands, which represent how the ear processes the sound. We can approximate the functioning of Bark bands by combining frequencies together logarithmically as they are heard in relation to each other[19, pp. 74–76]. Due to the critical bands and the threshold of hearing differing in frequency areas, the different bands are adjusted accordingly, and is an important aspect of understanding perceived loudness.

Due to this summation and prioritization of sound in bands, masking can occur. The general concept of masking is that sounds that are similar in frequency and timbre, the quietest of these, will be masked by the dominant tone. Additionally, quiet sounds are masked by much louder sounds, even if the content is different due to the power of the sound [19, pp. 78–52], [41, pp. 50–52], [78, pp. 609–610], [35] & [43]. The effectiveness of the masking is closely related to the grouping of frequencies into critical bands, and is one of the basic principles of MP3-compression. The idea being that if parts of a sound are masked, there is no reason to save it, and thereby save less data. Masking can therefore be used as a valuable tool to convert and change perception of soundscapes. Using masking as a method will be elaborated in 4.4.1.

3.3.2 The Subjective Experience

There are many philosophical schools and discussions concerning what it means to be a human, and this thesis will not benefit from going into this debate. Instead, it states that it follows the philosophy of phenomenology. Phenomenology in its most basic form is the understanding of the human experience as being based on subjective perspectives of a world consisting of phenomena. Experiences are therefore always based on previous experiences and always individual. Experiences can be shared, but are not the same individual experience. The consequence of this is that what is true for one person, might not be true for another. And what is true for one person at one period in time, might not be true at a separate moment. When experiences are explained by individuals from a first-person perspective, this is called "Lived Experience". Phenomenology does not claim that knowledge of experience is unattainable, rather it tries to investigate the conditions and mechanisms of phenomena, and use this to explain why something might be experienced in a certain way [175] & [144].

Sound and Emotion

As experiences are individual, it can be difficult to pinpoint exactly why one sound stimulates an emotion and another does not. But this does not mean that there is no research into the field. There are two general schools of such research, one focusing on emotional response to music, which will be described in this section, and one on the individual characteristics of the sound, called psychoacoustics, which will be discussed in 3.3.2.

Juslin and Sloboda present a model trying to explain music and emotion [71] & [70]. They show how particular sounds have specific meanings and associations to individuals, and how these in turn affect the emotions. During their research (built on research from countless others), they combine self-reporting measurements, with physiological measurements such as heartbeat, humidity of skin and dilation of pupils. They state that sound is felt and embodied. In other words, sound induces emotions [51] & [70]. To analyse the complex matter of emotions, they define a few terms that can be used to analyse and understand the process (the following list is revised and paraphrased from [71]):

- Emotion: Affective reactions to phenomena, that are a combination of other components, and create the general state of mental being such as sad, happy etc. In general, they can last from minutes to some hours.
- Mood: The general state of being, not directly connected to specific phenomena.
- Feeling: The subjective conscious experience of emotions and mood.

- Emotional Perception: The emotions that people identify in, for example, music or in others.

To explain how sound affects the above, Juslin et al., have created the BRECVEM framework, that identifies and defines 8 mechanisms [70], [72], [**juslin_how_2010**] & [71]. Each aspect of the BRECVEM mechanisms can be measured cognitively, physiologically and self-consciously. For this project, cognitive and physiological measurements will not be conducted, and these parts of the model are therefore excluded in the following explanation of the mechanisms. The different mechanisms should not be understood as functioning in isolation from one another, but rather as a dynamic, complex system.

- Brain Stem Reflex: When something stimulates basic instincts that require attention, urgency, and awareness. Such as sudden loud noises. This is also what commonly would be known as the Fight/flight mechanism.
- Rhythmic Entrainment: It has been shown that strong rhythm can evoke physiological change, so that the rhythm of the body aligns with that of the sound, and thus embodies the music in the listener. High rhythm is high pulse, which relates to emotional states such as excitement, for example.
- Evaluative Conditions: Associations induced by the music, that create a connection with a specific event or person. e.g., a good friend, a similar piece of music, or a specific product. It could also be the sound of the bell from your hometown that always woke you 2 hours before your alarm.
- Emotional Contagion: When the emotional perception of something is interpreted and the interpretation affects how the listener experiences the sound. For example, someone singing the same song about a breakup, in an expressive happy way, the narrative could be perceived to be positive and vice versa,
- Visual Imagery: When sound and music evoke imagery in the mind's eye. For example, if an abstract ambient music piece gives inner imagery of a wave on a beach, the associations connected to the beach will affect how the music is perceived, even though the imagery and the music only connected in the mind of the listener.
- Episodic Memory: If the sound induces a specific memory, the emotions, or feelings associated with that memory will be considered part of the sound. e.g., A specific sound of a bell, from your hometown, that reminds of when a loved one kissed you for the first time.
- Musical Expectancy: When we hear something, we expect it to behave in a certain way compared to our experience, and it will induce different emotions

if it follows these expectations or breaks them. e.g., If a blues number changes into a black metal number, people would have a notable reaction.

- Aesthetic Judgment: When sound stimulates something that evokes something like awe, admiration or disgust purely based on personal preferences. e.g., Someone likes a house because it is made of yellow bricks, others have preferences for red bricks.

There are naturally many other ways of approaching the complexity of human emotions, but these will not be discussed or used in this thesis. With the BRECVEM model, it is now possible to investigate how the artifacts and narrative of the exhibition are used to stimulate the lived experience of the visitors.

Psychoacoustics

The second aspect of sound, and emotions, is the science of psychoacoustics [103, p. 19] & [135]. Sounds are not perceived in isolation but during a period of time, and the duration and consistency or sudden change in psychoacoustic attributes greatly influence the listening experience [44, p. 173], [36] & [116]. There are 5 general psychoacoustic attributes, for which there is general consensus:

- Loudness: How loud the sound is perceived to be, and is a mixture of factors such as specific frequency combination, masking, duration and their respective amplitude. Frequencies in the critical band are perceived as louder.

- Roughness: How the modulation of the amplitude of the sounds creates harmonic components, that in combination makes the sound elements "unclean", or "distorted". A sine tone would be considered to have very low roughness, whereas a sine tone played through a small speaker at a volume exceeding the speakers' capability would distort the speaker, and thus add roughness to the signal.

- Fluctuation Strength: If the modulation of the amplitude is particularly slow in oscillation, it makes the sound pulse, or fluctuate.

- Sharpness: How spectral distribution and prominence of high-frequency in the sound influences how "thin" or "full" the sound is perceived as being. Sounds with a narrow-band in the high frequencies are generally considered sharp, whereas broadband white noise is wide/dull.

- Tonality / pitch: How we perceive the frequency component, or combination of components, as complimenting or disturbing one another. While many aspects of pitch or tonality are connected to cultural backgrounds, some aspects can be identified, such as if a certain pitch or tone is notable, or if the sound is more related to noise.

3.4 Interaction with Sound in the Context of an Exhibition

As the purpose of using ENC as a methodology is to convert the sounds of an exhibition, this last part of the theoretical section establishes the context of a museum.

The general role of a museum in society is as a cultural institution with the aim of collecting, preservation, studying and presenting culturally important artifacts [22] & [93]. The traditional museum was a place, where visitors were expected to contemplate the artifacts in silence, and all sound was considered disruptive noise. Traditional artifacts of sound would be culturally important artifacts, such as historical recordings [22]. The same is not true for the modern museum. While it still has the same role in society, an additional one has been added. The new role evolved as a way to participate in the cultural movement of "Experience Culture". The general implication of this movement is that modern museums see themselves as a company in competition with other institutions, that compete to attract customers (visitors). In this "New Museology" the product the museum can use to attract and engage visitors is the exhibition. A common way to make the experience more immersive and exciting is by using multimedia installations to evoke emotional engagement with the artifacts and narratives of the exhibition [126], [47], [22] & [86]. As an unintended side effect of multimedia installations and other visitor engagement, e.g., by allowing experience of artifacts through play, is noise. Unintended noise is the byproduct of fans, motors, speakers, or due to the acoustics of rooms designed for silent contemplation [49], [173] & [79]. Successful implementations should enhance the lived experiences, of the majority of the visitors, and make them want to return, or recommend it to others.

The specific problems of sounds in museums and how they relate to and influence, the exhibition's narrative will be further elaborated in 5.

With the cross-disciplinary theoretical background supplied in this part of the thesis, within the framework of soundscape studies, a solid foundation for addressing, assessing and changing site-specific noise problems of a museum is laid. This part has supplied and built a knowledge base on why and what such an investigation could contain. The following methodological part, will elaborate on how such an investigation could be conducted.

Part 4

Methodological Approaches

In the theory section, the general aspects of soundscapes, and sound presented. This section will go into detail on how these theories are used as part of a methodology of Environmental Noise Conversion.

4.1 Environmental Noise Conversion

Environmental Noise Conversion (ENC) is a method devised by the author during the past 3 years of studies, and was firstly presented in a peer-reviewed article co-authored by Dan Overholt [53]. The initial aim was to investigate if it was possible to convert the noise inside a train into ambient music, and reconnect the listener to the environment rather than hiding from it using ANC-Headphones playing loud music. When researching how to reconnect the listener, it seemed apparent to add the perspective from soundscape studies to the initial starting point on technological and compositorial choices. In this Master's thesis, the concept is evolved into a methodology, with the aim of creating an accessible cross-disciplinary methodology to address environmental noise problems, while simultaneously supplying solutions. It does this by:

- Understanding the physical aspects of sound in an environment with the Engineering Approach.
- Investigating the context of the experience of soundscapes, with the Soundscape Approach.
- Using creative manipulation of sound with an artistic reasoning to achieve aesthetic or thought-provoking results, with the Artistic Approach.

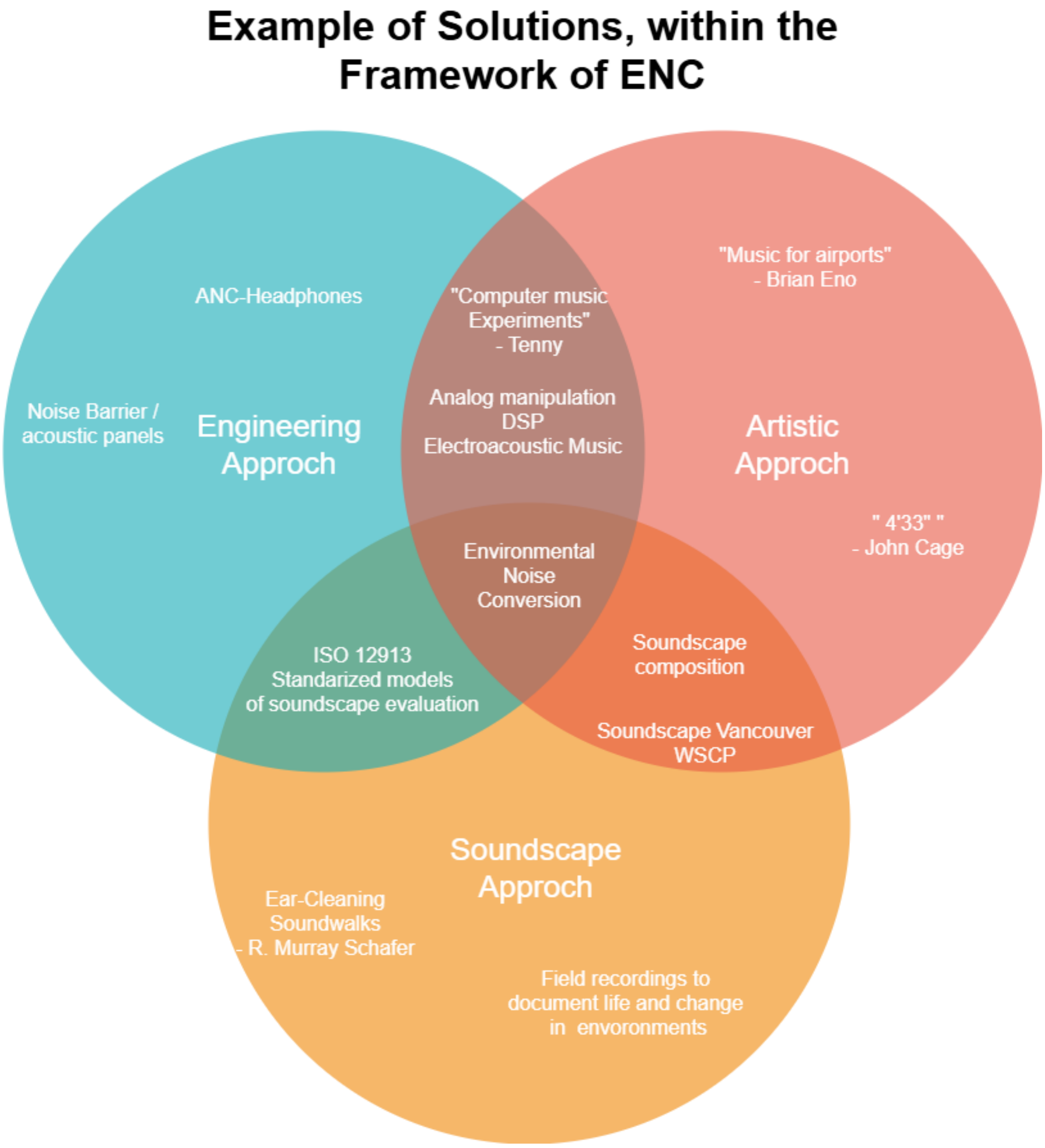

Figure 4.1: Solution of Noise in the Context of ENC

4.1.1 Solutions as Understood within the ENC Methodology

The following section will elaborate how ENC understands the traditional solutions, and how combining them creates new solutions, as shown in the illustration 4.1. A traditional solution, made from the Engineering Approach, is ANC headphones, using phase cancellation of the physical waves to remove unwanted noise [174] & [141]. A traditional methodology to address the problem of environmental noise from the Soundscape Approach is soundwalks. In this method of analysis, participants are asked to listen to, and report how they perceive multiple soundscapes. By comparing the results, aspects of what to change in the environment are discovered [76] & [62]. A combination of these traditional disciplines can be found in ISO 12913, where standardised measurements are defined to enable objective and subjective analysis.

An Artistic Approach to address the sounds of environments can be identified as Brian Eno's original ambient works, exemplified by "Ambient 1: Music for Airports" [38]. The music was created for a specific environment, with the artistic aim of enhancing and connecting listeners to that environment, while accommodating many levels of listener attention [38]. Eno's aim was to create an alternative to Muzak, that traditionally was used as background music at that time, which he found false and lacking in all artistic parameters [80, pp. 210–213]. A combination of the Artistic and Engineering Approaches, could be explorations of algorithmic possibilities in works such as "Computer Music Experiences, 1961-1964" by James Tenney [160], exploring how to synthesise, and thus better understand, the sound of traffic. Combining the Artistic and the Soundscape Approach can be identified in soundscape composition such as "Soundscape Vancouver 1973" [161]. This album combines mixtures of field recordings, that is creatively edited into an artistic interpretation of the soundscape of Vancouver at that specific time, based on the observed soundscape [108].

This explanation is a simplification, as some works of Berry Truax develop techniques, as mentioned in 2.1.1. It could be argued that the techniques are created to solve any problems of environmental noise, but rather to explore specific artistic expression. The same can be said of works such as "En dag på Dyrehavsbakken" [112] from Else Marie Pade in 1952. This work is made of field recordings of an amusement park, and then edited together to make a narrative of the amusement park, supporting a video. But for Pade, the aim was an exploration of technical problems, as with most musique concrète, rather than an exploration of the specific soundscape [6]. The definitions in the example and illustrations are defined by their identified aims.

4.1.2 ENC as a Method of Analysis

While the solutions and artistic works can be placed within ENC, as shown in the previous section. The methodology of ENC used the different approaches as a framework for analysis, and is illustrated in 4.2. Measurements of SPL, calculating the properties of materials or making spectrograms, are examples of analysis methodologies in the Engineering Approach. Methods such as enhanced listening, mapping relationships of the components of the soundscape, or investigating the communicative aspects of specific sounds, are examples of analysis using the Soundscape Approach. Artistic Approaches to analysis, are as varied as the artists themselves, but are based on an aesthetic interest or method used by the artist. These approaches to analysis can be combined in a multitude of ways, but the methodology of ENC argues that by analysing the soundscape from these three approaches, and combining the results inspire holistic solutions. This is conducted, in this thesis, by using:

The Engineering Approach: To investigate the sound source, acoustic environment and some aspects of auditory sensation (Loudness), following the requirements of ISO 12913. The Engineering Approach provides insights into the physical aspects of the problem, and can be used to suggest traditional solutions, such as adding acoustic panels.

The Soundscape Approach: Was used to investigate the context and the individual interpretation, and how this has, consciously or unconsciously, influenced their experience (response and outcome). This was executed by following ISO 12913, and by using the HEARSEPTION evaluation model 4.3, and the BRECVEM model. To get insights into the museum's goals with the exhibition, and challenges related to it, an interview was conducted, and the narrative of the exhibition was analysed.

The Artistic Approach was then used to investigate how to change aspects of the auditory sensation, by adding and converting the soundscape, to better complement the context of the exhibition. The Artistic Approach is then used to create and implement solutions.

After this explanation of how to understand the three approaches of the ENC methodology, the remainder of this part of the thesis specifies how to conduct the analysis and implementation, with a main emphasis on the requirements of the ISO standards.

4.2 Following standards

4.2.1 Data analysis according to ISO

The ISO standard supplies specific theoretical understanding and definitions on how to approach assessment of soundscapes, and defines exactly how and with

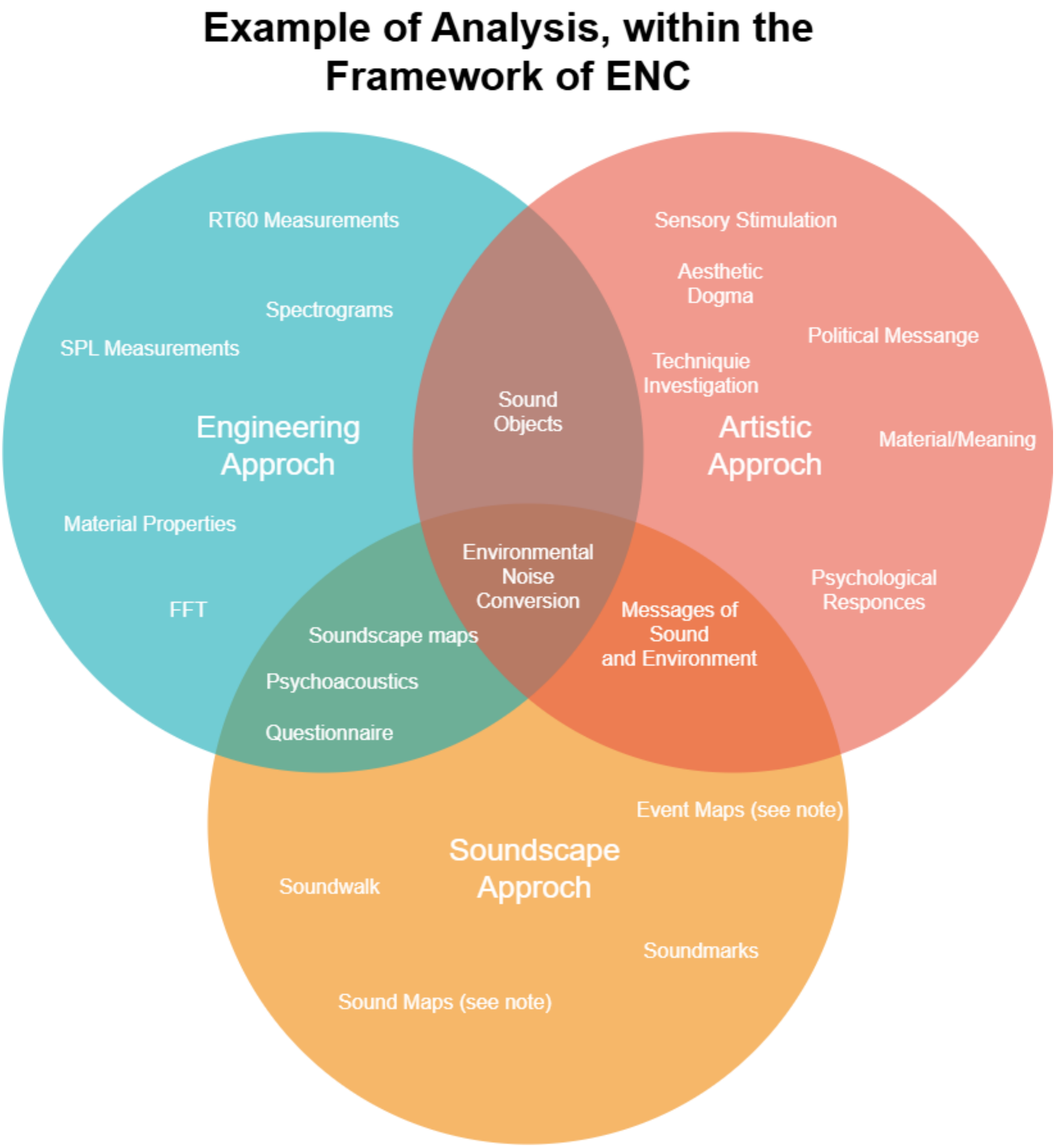

Figure 4.2: Examples of Analysis Using ENC. Different examples of how to draw sounds, such as Noise Maps, and Event maps are suggested by Schafer **[schafer_soundscape_1977]**

what method this assessment should be made.

ISO 12913-3 [153] from 2019 provides clarification and introduction to methodological approaches to data collection of soundscapes. It reminds the reader that soundscape evaluation is holistically and studies the perception of the environment by humans, followed by physical measurements of sound. In general, the standard introduces three types data:

1. Quantitative Measures of Dependence: Measuring and analysing the relationships between variables, and how they influence one another.
2. Parametric Tests: Statistical tests based on general assumptions made from the data.
3. Non-Parametric Tests: Statistical methods that are not based on a specific general assumption.

Due to the often interlinked and complex analysis that is essential to soundscape investigations, the standard reminds the reader to be extra careful to understand the complexity of the analysis, by discussing and minimizing potential confounder factors. To analyse subjective data, the standard suggests the use of models such as the Eventfulness/Pleasantness model [8].

There are some general requirements when designing soundscape assessments in ISO 12913-2 [152], these can be summed up as:

- Sound sources must be identified using taxonomy, and as foreground and background sounds.
- Must include measurements of SPL and LAF, with class-1 measuring device (total sound).
- Must include indicators of loudness.
- Use binaural head microphones.
- Document weather and wind conditions (if relevant), as well as time of year and time of day.
- Provide information on how measurements were conducted, as well as describing the context of the acoustic environment.
- If using soundwalks at least 20 independent observations of each site assessed in similar conditions.
- It must define the setting of the assessment as real, virtual or laboratory.

- To enhance the relevance of the data, the researcher should implement the general idea of triangulation of data (see J.3.1).
- the tests conducted must include descriptors or indicators, that can be used to analyse the following:
  - The overall acoustics assessment: What does the environment sound like?
  - The psycho-psychological assessment: How is the soundscape perceived emotionally?
  - Assessment of the context: How the soundscape and the environment is connected, and does it support or disturb this connection?
  - Design or improvements: Indications of the holistic possibilities in the soundscape.

The series of ISO 12913 also requires subjective assessment to document aspects of the participants, summed as:

- How participants were selected.
- Why the participant was at the given place.
- Relevant information on the participants' experience level with context-based aspects, such as sound and urban planning.
- Age and gender.
- Ability of hearing.
- Indication of attitude towards the sound.
- Information on how the data was gathered.
- The Language of the tests was conducted in.

With this list of general requirements, we can now expand how to comply with them.

4.2.2 Taxonomy of Acoustic Environment

ISO 12913 requires the definition of sound sources to follow a specific taxonomy first presented in [21]. The taxonomy should be to include all representation of all possible sound sources. One sound source can be present in more than one place in the taxonomy, and that some aspects are between categories. They claim that the taxonomy is objective and, *"designed to be universal in application"* [21]. When investigating the taxonomy, some problems according to this aim were found. Therefore,

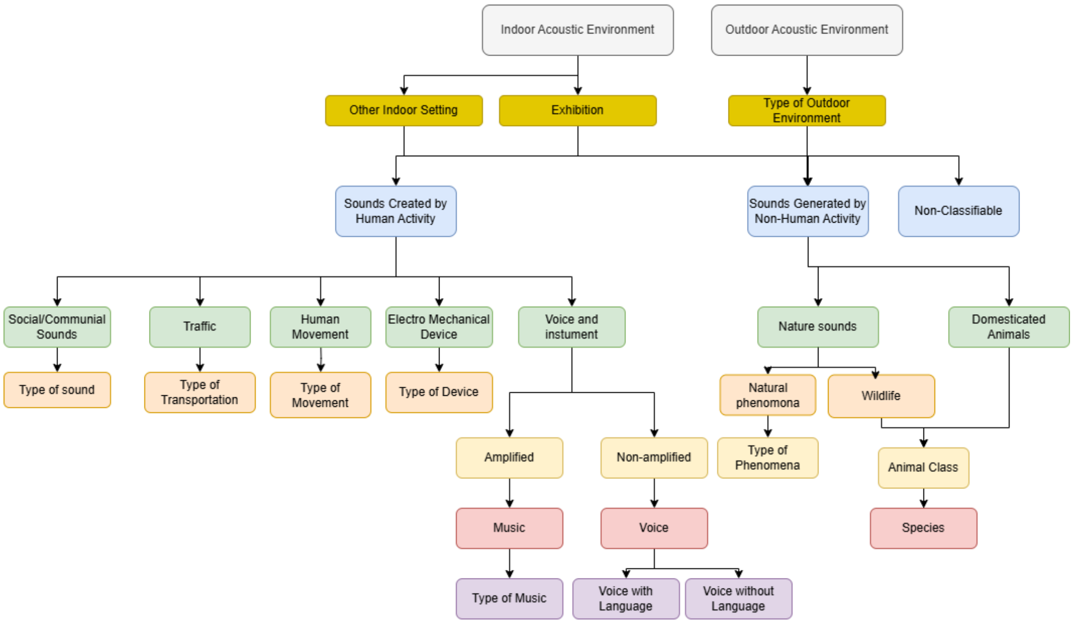

Figure 4.3: Updated Taxonomy of Acoustic Environments, Paraphrase and Revised Model based on [21].

the taxonomy presented in this section is an updated version. The reasoning being that some categories were too specific, to be holistic, some were missing, and some appeared biased. The changes of the taxonomy were made in accordance with theories on how to support multiple users, with different background and different aims of research and information searching [85], [28] & [106].

A few extra dimensions were added to the taxonomy, and the lowest layers were in the original specifically defined, (e.g., in the layer under "Nature", the categories wildlife, wind, water, thunder, and earth/ice movement). Rather than specifying the lowest layer, a more general block was used, as this allows a wider multitude of sounds to be identified. A bias was found in the category voice, which consists of three types, namely speech, singing, and laughter, but that another category of the same layer called "Other Human", was the subcategory laughing. The bias being an unclear definition of human expression. Where would, for example, sobbing be located? Therefore, this layer was changed to "Voice with Language" and "Voice without Language". This change also supports assessment in an exhibition, as "Voice" had the subcategory of "amplified" and "non-amplified", but "other human" did not. In an multimedia installation, it is not improper to imagine all types of human sounds being amplified. The taxonomy will be further discussed in 9.1.1.

4.2.3 Measuring SPL, LAF and Loudness

When measuring SPL, two different methods, equivalent continuous A-weighted and C-weighted measurements, should be conducted in accordance with ISO 1996 [149]. Measurements of LAF are made with an aim of defining changes in the soundscapes, over time, by analysing aspects such as peaks. While there are many rules for how to calculate SPL or LAF from scratch, an easier approach is to make the measurements using a Class-1 Sound Level Meter, that automatically generates the calculations based on the requirements. [25].

While SPL and LAF measure aspects of sound power, Loudness measures how the volume of the sounds is perceived. To measure loudness, it is required to use Zwickers method as presented in ISO 532-1 [150]. The method defines how to convert recorded sounds into data that represents the Bark bands. The method defines how frequencies should be summed, and different predefined values used to adjust the bands in the different steps (the steps are described in the appendix J.3.2. As with measuring and calculating SPL, calculation of loudness can be done by using software, designed to make the correct loudness calculations. For example, the acousticLoudness [88] addition to MATLAB.

The method of measuring SPL, LAF and Loudness in this thesis can thus be defined as using the dedicated professional equipment, that is designed for correct measurements without human interference.

4.2.4 Measuring RT60

As ISO 12913 requires an understanding of the acoustic environment, it seems a valid methodological approach to measure the RT60, to provide insights into the sound of the room. The ISO requirements [148] of measuring RT60 are as follows:

- Must use a class-1 omnidirectional measuring device, in octave and 1/3 octave bands.
- Record an impulse, either Integrated Response (like a sweep), or Interrupted Noise Method (like the rapture of a balloon).
- Measure RT60 using T30 (time of 30dB decay) and multiplying it by 2.
- The microphone must be 1 meter from reflective surfaces.
- The RT60 of the room calculated by combining 3 measurements of impulses of various locations, from 2 different positions, or 2 measurements from 3 positions.

As explained, acoustical measurements are a somewhat hard science, but the reality is that it is based on qualified interpretations of the standard. A reasoning for this is that some rooms are narrow, or have low ceilings, and therefore the 1m distance to surfaces might not be possible for all measurements if they should cover the room. The task is, in that case, to make the measurements as valid as possible in the given situation, and report the reason for these choices as part of the report of the measurement or calculation.

4.3 Evaluation: Locating a Fitting Evaluation Model

ISO 12913 requires in the assessment of soundscape numerous aspects. The physical requirements are covered by the methodologies presented in the previous section 4.2. The standard suggests the use of interviews, soundwalks and the Pleasantness-Eventfulness model, to collect subjective data. As the requirements for this are at least 20 participants, conducting 20 interviews and coding them before getting into the data seems to require an enormous pile of time (as also found by [58]). Furthermore, when speaking with some consulting acoustical engineers (personal communication, Acoustical Engineer, Aug 2024), they replied that the cost of conducting these interviews greatly exceeds the budget of customers. The Pleasantness-Eventfulness model is far easier to implement, but it only covers certain aspects of the emotional response, and cannot be considered holistic. During an internship in a consulting engineering company, to address this issue of a missing holistic evaluation model the author conducted a semi-structured literature review. The review was semi-structured in the sense that it did not report the results into a protocol, but did systematically approach different databases with both block-searches, snowballing and footnote chasing [17]. It concluded that there was no uniform assessment method, but there was a tendency to use Semantic Differential (SD) [36] & [3]). Semantic Differential was also used to create the Pleasantness-Eventfulness model [8].

4.3.1 Semantic Differential

The basic principle of SD is that by using pairs of relevant bipolar adjectives, and asking people to rate concepts on the scale from one word to the other. An example of this could be “Rate your feelings towards your dad on the scale of energetic and lazy”, or “On the scale from powerful to weak, how do you feel?”. By combining multiple ratings, of different word pairs designed using the EPA-framework, the answers indicate the inner attitude, consciously and unconsciously, towards that particular concept under investigation. The EPA-framework has three aspects [120], [111] & [111]:

- Evaluative (such as beautiful-ugly)
- Potency (such as powerful-weak)

- Activity (calm-restless)

One of the strengths of SD is that the rating, on the semantic scale, can be quantified as numerical values. A second strength is that SD has been shown to work cross-cultural, if the words are in the native language of the participants [104] & [120]. The collection of the bipolar pairs, can be shown graphically rating as a Semantic Profile, these can be easily comparable with other semantic profiles, using the same words, and thus discover tendencies. In this thesis, the comparison of profiles is used as an evaluation tool, to provide feedback on the success of the implementations according to their goals.

4.3.2 Semantic Differential in Soundscape Assessment

The next step in using SD as a holistic subjective assessment tool, was to investigate what bipolar words to use. During the literature review, it became apparent that there is no consensus on this. Therefore, it was decided to create a semantic profile from scratch containing the most commonly descriptors. It had the design requirement of including descriptors of all the psychoacoustic properties of sound, as well as containing the descriptors used in other commonly used, but less holist models (such as [8] & [23]). A second review was therefore conducted, to locate, with an aim of clarifying the general descriptors of sound. Among those found were [52], [177], [2], [116] and [100]. One article was found that had an aim of making a unified SD for the assessment of the quality when building wind turbines [139]. While this was made to analyse broadband noise, it did not contain all the psychoacoustic properties, and therefore its model did not fulfil the design requirements.

4.3.3 Introducing HEARSEPTION

Deciding on what words to use was a long process, and will only be explained in the most general form. It was made by collecting the descriptors found in the review, and sorted these to include a balance of words in the following categories:

- Word-class: Based on the 8 word classes of a lexicon on sound descriptors [115].
- The EPA-Framework: Activity, Potency and Evaluation as described previously.
- Key Descriptive Factors: 4 factors of sound descriptors made found in a comprehensive systematic review [74]

- Psychoacoustic properties, time, spatial and aesthetics: That is, a balance of descriptors such as thin (psychoacoustic), periodic (time) and Relaxing (stressful)
- A natural weight of positive, negative and neutral descriptors.

Descriptors were added to the list to express if the soundscape is evaluated as natural or mechanical, following Schafer [133]. As, assessments using Semantic Differential should be done in the native language of the respondents, and in words they understood. Therefore, to prevent the language barrier, all words were added descriptions, defining how it is intended to be understood. Secondly, words were evaluated according to how they would be understood by non-experts. This was done following the design requirements:

- Descriptors should be understood without explanation, or require educational background.
- Definition must be made using common language dictionaries such as [93] & [32].
- Semantic pairs should be of the same word-class and antonyms.
- An equal number of pairs beginning with negative and positive words, in each category.

The final model consists of 23 semantic pairs (the full list, with definitions in English, can be found in appendix C). Each pair of data has a number from 1-23, and by sorting the pairs in that order a general semantic profile is made (see 4.4. The model was named: "Holistic Evaluative Assessment and Rating of Soundscape Experience and Perception: Tuning ISO and Optimizing Normalization" or HEARSEPTION.

It must be mentioned that the model has not been tested or evaluated in the field. This is an issue but the argument for using it is that almost none of the text, found in the review, explained how they had found the bipolar pairs. HEARSEPTION as used in this thesis must therefore be understood as a prototype and iteration of a holistic model, and using it is argued as an improvement compared to copying a semantic profile from a different project, without knowing how and why the terms were collected. Even if the model is shown to have faults, the assessments will still provide usable data of the subjective response to the evaluated soundscapes.

4.3.4 Implementing HEARSEPTION as a Method of Assessment

In the thesis, HEARSEPTION is used by asking test participants to rate what they are listening to. This is done by rating the bipolar pairs in 7 steps. e.g., Ugly-Beautiful, where 1 is ugly and 7 is beautiful. Ratings in steps are recommended by [125, pp. 66–67]. As required by the ISO, and shown in the theory section 3.1, information on the participant should likewise be collected. The rating of the pair can after the evaluation be used in numerous ways. One way is to investigate the ratings of the psychoacoustic properties. Another way is to investigate the evaluative or aesthetic qualities, or the entire semantic profile. The different ratings can then be discussed and compared to the measurements from the room, the BRECVEM model can be used to hypothesis how and why the sound can affect emotions. By sorting the pairs to decrease from lowest to highest rating, they can provide insight into the felt emotions of the visitor in that specific category. A design aim could thus be, as in this thesis,to increase or decrease specific bipolar words.

The model was also made with the aim of triangulation by using closely related terms of other models. In the evaluation section it is shown how the results of HEARSEPTION can be used in the Pleasantness-Eventfulness model 8.2.

With the knowledge of how to analyse, assess and evaluate soundscapes, this section will describe methods of how to convert it.

4.4 Design, Sound Design and Manipulation in a Museum Setting

This section presents the general methodologies on the conversion process of the implementation section. Two general guidelines are adapted as a general methodology of design. The first "Code Simplicity" [73], is a ruleset of efficient adaptable software design. These can be summed as: Ensure the code is adaptable, for future changes and uses, without complicating it by predicting the future. This is done by using self-explanatory variables, and allow for the most change of the algorithm with the least changes in code. The second general methodology presents a general approach to design, named "The To Don't List" [129]. Summarized, it states: play on your strengths, and combine them; Find the things you like to do the most, and useing your combined skill-set can find unique solutions. It also suggests that a task should not have more than 3 to-dos, and the design process should be circular. That is, create the simplest working solution first (the smallest circle), and expand on this in small steps, always ending with a functional design before adding more steps. The two methodologies can be summed as: "Strive for simplicity, both in design and solutions, and ensure that what is made is reproducible, by people that were not a part of the design process". This Statement of simplicity is the core of

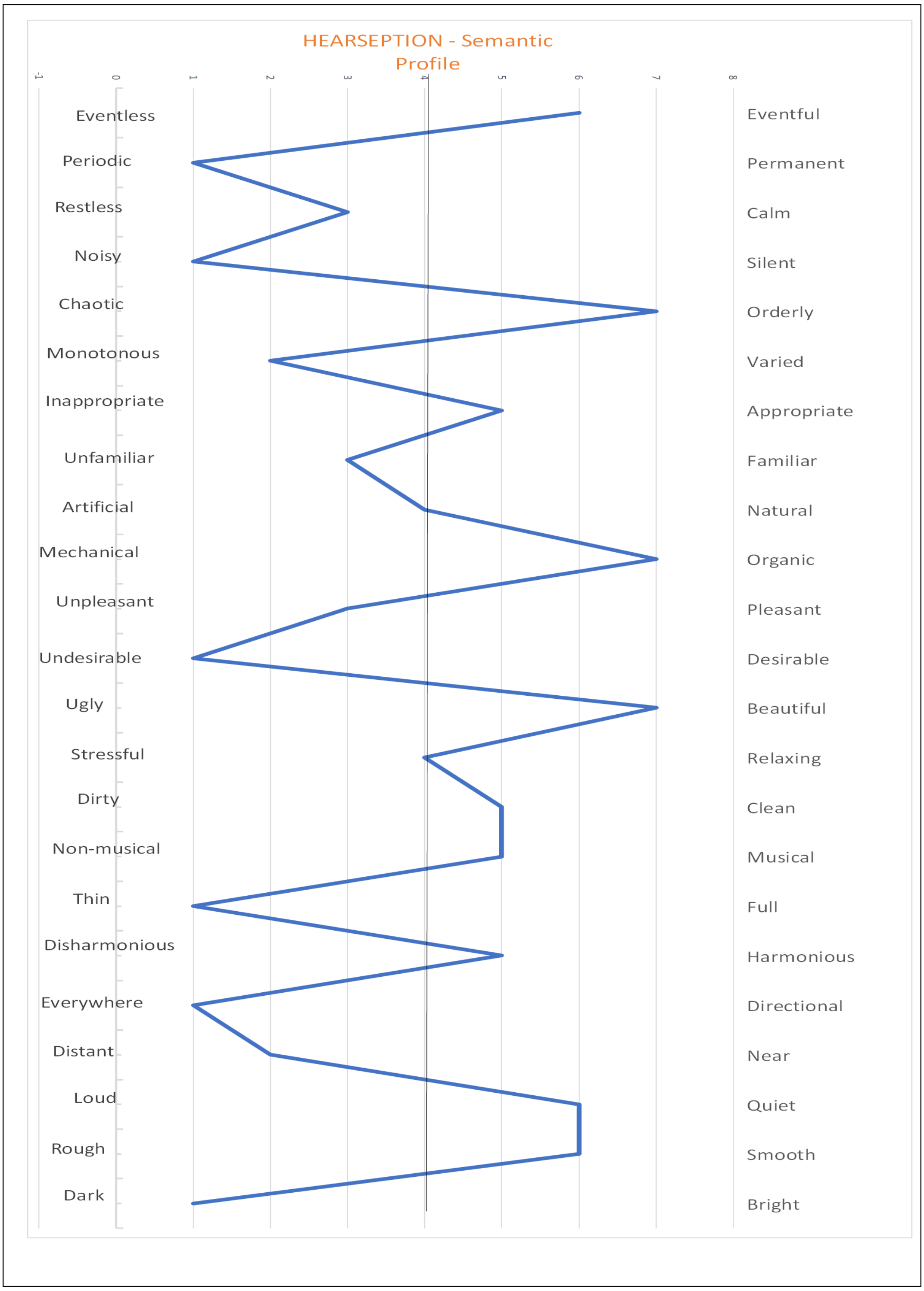

Figure 4.4: Example of Semantic Profile (made with random numbers)

implementing ENC. These general frameworks are supported by the methods of masking, and a specified process of sound design.

4.4.1 Masking as a Method in Sound Design

When investigating how to change sounds, masking is probably both one of the simplest, and one of the most complex solutions, depending on how it is implemented [14], [20] & [35]. When using masking to mask environmental noise, Brown suggests it should be used to [20]:

- Remove unwanted mechanical sounds.
- Introduce natural sounds, such as water.
- Hide unwanted noises made by crowds of people.
- Allow soundmarks and other information important sounds to be heard.

When used specific as a tool for sonic design, originally used in the design of masking in cars, Duroyan et al. [35] presents three strategies based on Fastl and Zwicker [43]. In this thesis the definitions are used, as guidelines of how to approach different aspects of masking techniques:

- Energetic Masking: Masking a specific bark band, by adding something with a higher loudness, to remove one specific part of the sound.
- Sound Dressing: Adding harmonics to the unwanted sound, and in that way change its spectrum and timbre.
- Attention Masking: Adding an entirely new sound to completely replace the unwanted sound.

Masking can therefore be used to either change parts of the sound to allow other sounds to be heard, or change the overall character of the sound, as well as completely hiding the unwanted sound. To create different solutions to the problem of environmental noise of the exhibition, these definitions, are valuable guidelines.

4.4.2 Generative Models and Pseudo-Physical Modeling

As we have seen in the theory part, physical sounds are complicated and can be analysed in numerous ways. The science of synthetically replicating, or trying to replicate, sounds of the physical world is called physical modelling [30] &[145]. Farrell's approach to physically modelling is to make generative models that replicate the complexity of the physical world as we hear it, rather than copying the exact dynamic complex mechanisms [42]. In short, his method is that: "if it sounds right, it is right". This approach, not trying to replicate the exact nature of physical phenomena, but rather to strive for something that sounds right, is called Pseudo-Physical Modelling [30].

Farnell has a specific systematic way of addressing implementations. While he tries to replicate physical models, this thesis tries to use the same approach to the physical world but to convert the sounds. The systematic approach to creating solutions, is used in the thesis as a method of approaching implementation. Farnells structure is as follows:

- Define the aim of the implementation: What should the synthetic sound achieve, in its most basic and simple form?
- Analyse the physical phenomena: Understand what makes sound and how the components interact
- Define what the implementation should do, in accordance with the analysis, and what parts of the physical phenomena aren't necessary to achieve the aim.
- Define the method of synthesis to use to achieve the defined implementation.
- Implement the model.
- Conclude what the model does, and where it can be improved.
- Improve the model, if this is a goal.

This simple structure of implementation, works best if it tackles one problem at a time, and uses previous models as parts of larger, more complex models. This framework will be the foundation of how to create new sounds in the context of the exhibition. We must first, though, understand what is meant by generative music. In the context of music and sound, ideal generative compositions should be considered systems that have no specific starting point, or end, that continually change based, and therefore never are the same. The term was originally coined by Brian Eno, inspired by the KOAN-system [37, p. 253] & [24].

With the theoretical and methodological presented in the last two parts of the thesis, it is now time to investigate the case, and begin the analysis of the problems of environmental noise in the exhibition using the methodology of ENC.

Part 5

Problem Analysis and Case

There were a few reasons for wanting to use a museum exhibition as a case for the implementation of ENC. A main reason was that an exhibition is a controlled environment, which would make the work a bit more straightforward. A second reason was that the curators aimed towards the general mood of the exhibition. This distinguishes an exhibition from, for example, a busy road inside a city, which would allow the implementations to be tailored towards that mood. An additional interesting aspect of the soundscape of Zelle 2, is that the artifact of the exhibition is a room, and therefore traditional acoustical treatment would destroy both the historical artifact that the room is, and the aim of the exhibition. This allows the thesis to investigate and show how ENC can be used to solve problems that traditional methodologies of noise prevention cannot. While making an exhibition more immersive is a valuable goal in itself, the case allowed an exploration of the physical and subjective aspects, with a controlled set of variables. It therefore seemed ideal for an early iteration in the development of the methodology of Environmental Noise Conversion.

5.1 The Case of the Museum, and Conducting an Interview

The first contact with Museum Kolding was made in the fall of 2024. The aim of the thesis of using ENC to convert environmental sounds to enhance an exhibition was explained. It was agreed that an exhibition, that would begin planning in January 2025, would be an ideal case. The plan was to make a soundscape for the exhibition that would relate to the exhibition artifacts of a famous smithy in the 18th century. When January arrived, unforeseen aspects concerning the artifact of the exhibition had sadly postponed the exhibition planning. Therefore, on February 14th, in a meeting at the museum, it was discussed if a different exhibition could be used as a case. It was discovered that an exhibition of a prison cell called "Zelle 2", had an interesting noise problem. The exhibition used multimedia installation to create

Figure 5.1: Image of the Exhibition from the website of the museum [77] *(copied with permission)*

an immersive experience, but the downside of the installation was that it produced noise that was heard as soon as the sound of the installations stopped. A difference between the cases was that the second one was already built. Therefore, ENC would not be included in the planning of the exhibition, and instead of finding design requirements with the curators, they were found by analysing the exhibition material. A consequence of this was that the installation inside the prison cell was made by a third party, which was not involved in the process. To use part of the installation they would need to be involved, but as they were a third party, whose work was paid for and delivered, but exactly how this would work was not agreed upon.

After this meeting, an interview was conducted with one of the curators currently working on the exhibition. The interview was semi-structured [142, pp. 166–200] and made to investigate the general aspects of how the museum usually considered sounds, specific environmental sounds and the evaluation of sounds for the exhibition. The interview was made with the purpose of gathering data on the day-to-day work with sound, from the curators' perspective. This information was used to provide insights into how the museum usually works with sound. The interview was therefore a general interview, and not specific about the exhibition, even though some specifics of the exhibition of "Zelle 2" were discussed.

5.1.1 The Case of Zelle

Located in the region of Southern Denmark in the city of Kolding, next to the old castle, is a reminder of the Nazi occupation of Denmark from 1943 to 1945. The building, "Staldgården", was used by Gestapo as their regional headquarters, and inside the building is located an "untouched" preserved prison cell used to imprison freedom fighters between interrogation. The Exhibition "Zelle 2" (the 2

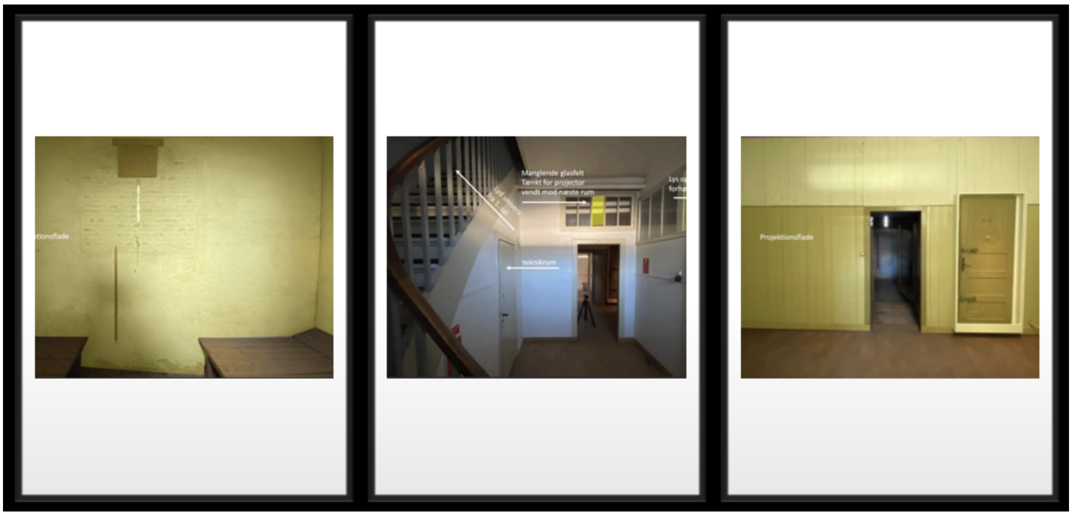

Figure 5.2: Images of the three rooms of the exhibition, yellow is where video is projected. The pictures are from the material supplied by the museum, and can be found in the appendix I.1. Left= inside the cell, as seen from the door (before the glass wall); Middle: The entrance looking towards the cell; Right= from the doorway to the corridor, looking towards the cell.

is pronounced as the German “Zwei”), is an addition to the exhibition “1943 — Gestapo kommer”.

The “Zelle 2” exhibition consists of 3 rooms, as can be seen in 5.2. The rooms are the entrance, a corridor and “Zelle 2”. The entrance and the corridor are completely bare. The walls of the prison cell are made of big stones, and the only light in the room comes from a small slice in the opposite wall, that gives associations to the arrow holes of medieval castles. On both the left and the right side of the cell, wall-to-wall wooden platforms are raised, these were used as the prisoners’ beds and chairs. On all the walls, prisoners have scratched initials and messages during their imprisonment 5.3. A glass wall is constructed inside the cell to contain the guests and preserve the artifact of the room. Above most of this glass containment, a wooden platform is built. On top of this, the multimedia is installed. In the hall and the entrance leading to the cell, speakers have been attached in different places on ceilings and walls, some hidden, some not.

The museum has designed 3 different narratives to create an immersive experience, to convey the story of the cell, its inhabitants and the fates connected to it. The narratives are presented through a multimedia installation that combines projections of video and images on the walls of the 3 rooms, with music, sound effects and lighting of the historical artifacts inside the cell. In addition to the narratives, the museum offers a guided tour of the exhibition with an employee of the museum. In this case, some projections are made in all rooms, creating a mood, but without sound. Sounds move from one speaker to another, and the sound

Figure 5.3: Top: Left=View from the corridor; Right= Projection on writing on the Cell Wall; Bottom: Left= Visitor inside the cell behind a glass wall; Right= 1 of 2, Sleeping platforms inside the cell

design of the narrations was made to enhance spatial immersion. The narrator's voice moves to the scene where the guests are supposed to be, at that specific point in the story. The specifics of the narratives, are used to analyse the mood of the exhibition as part of the analysis of the Soundscape Approach 6.1.

5.1.2 The Case: The "Silence" of a Multimedia Exhibition

A consequence of the experience culture for museums is, as mentioned in 3.4, how multimedia installation have changed the soundscape of the museum experience. Both the sounds of the videos, audio, and active guests, have made the museum into spaces where silence is no longer given. When introducing sound, it is impossible for the sound not to distract some people, no matter how well the sound design is crafted [49]. A positive aspect of the many active sound sources is that they mask the noise from the ventilation components of the multimedia devices. The equipment used in the multimedia installation of "Zelle 2" is no exception in bringing unwanted sounds into the museum. Because of these sounds, the silence of the prison cell has been transformed into a soundscape of multimedia devices. These sounds are unintentional, and in the context of the exhibition narrative they are unwanted, unsupporting, and undesirable. The noise from these devices is particularly notable during the guided tour, as no other sounds are presented in this context. The curators have intentionally left the corridor and the entrance stripped of furniture, posters and other objects. The artifact is the cell, and acoustic panels installed on the walls of the cell would destroy the untouched historical artifact. To investigate how to support the authenticity and narrative of the cell, without interfering with the artifact, implementing the analysis part of ENC is undertaken.

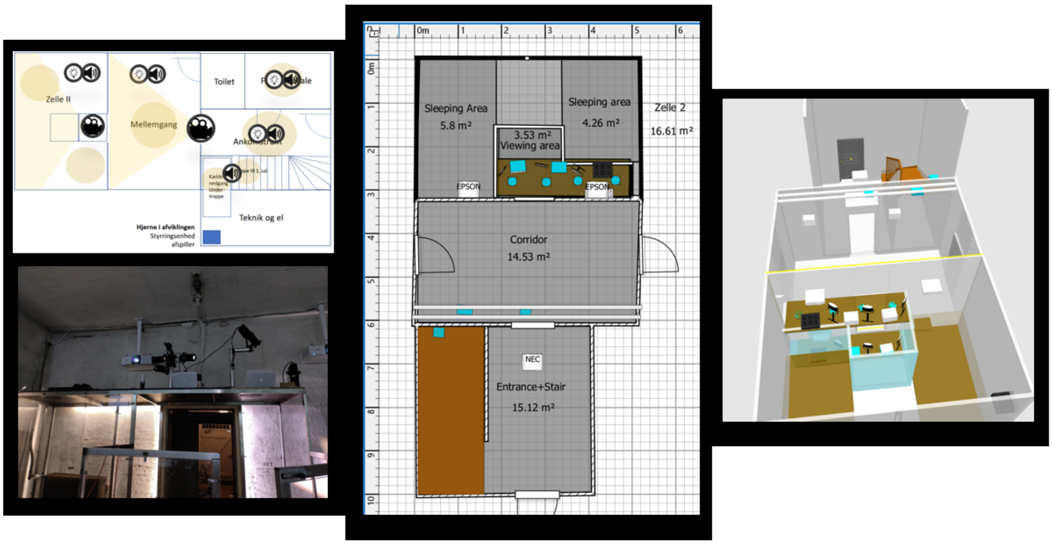

Figure 5.4: Exhibition area and multimedia installation. Top-right corner = original installation plan, supplied by the museum; Bottom-left corner = multimedia installation on top of the viewing area inside Zelle 2; Middle and Right = Rooms and multimedia as noted when visiting the museum (Drawn in Home Sweet 3D).

Part 6

Implementation Part 1: Analysis

Following the methodology of Environmental Noise Conversion, the soundscape of Zelle 2 will be analysed using three different approaches. This aims to establish a holistic perspective of the soundscape that can inform solutions to the noise problem of the exhibition. As the noise is mostly present in the guided tour, this is used as the primary subject of physical measurement. To understand how noise conversion can enhance the exhibition's narrative, the noise characteristics must first be analyzed. After establishing the acoustic environment, the context is analysed. First, by using the material supplied by the museum to clarify the mood and general narrative of the exhibition. This is to provide insights into what the conversions should strive towards. Secondly, the subjective aspects of the noise are assessed in a controlled environment using HEARSEPTION. The found information is then used to explore what and how to convert the soundscape, by defining design requirements in the third and final section of the analysis.

6.1 Analysis: The Engineering Approach

6.1.1 Locating Sound Sources

The first step of implementing ISO 12913 is to identify sound sources according to the taxonomy 4.3, as well as defining foreground and background sounds. Thirteen sound sources, or potential sound sources, were located, and the complete list can be seen in appendix E, and the location of the sound sources are shown in figure 5.4. No sounds from outside the exhibition were observed during the measurements. This could be due to the measurements being conducted on a Monday, where the museum was closed to visitors and noise from other exhibitions. The Sound sources of the 3 rooms differed slightly, and a simplified description of them can be found in 6.1. In the entrance and in the corridor, the projector located in the entrance created a broadband foreground sound. Inside the cell, the PA amplifier created a foreground sound with a notable tonal component. All other sounds appeared as background sounds.

Exhibition room	Sound sources of exhibition room
Entrance	The fan of projector (NEC PA803U)
Zelle 2	Hum with noticeable tonality from PA Amplifier (Monacor PA-9125); Speakers (2xAudac VEX011A and 3xDIY built into the platform-ceiling); Hum from 5xSpotlights; The fans of the two projectors (Epson EB-L53U)
Corridor	a mixture of the soundscape of the two other rooms, but with the projector from the entrance as the foreground sound.

Table 6.1: Simplified description of sound sources. For the complete list, see E

6.1.2 Narrowing the Scope: Rooms

While the experience of all three rooms are part of the experience of the exhibition, it was decided to narrow the analysis to cell. The argument for this is, that to research how to implement the methodology of ENC, does not require the replicated measurements in all rooms, as these measurements would follow the same methodology without bringing new insights to the research question.

6.1.3 The Acoustic Environment of Zelle 2, and Measurement Positions

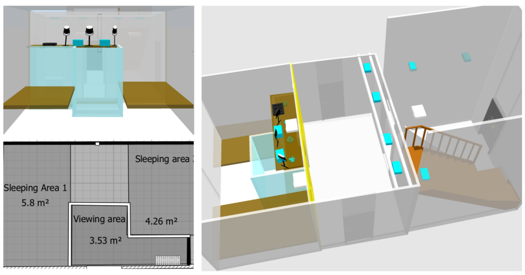

Figure 6.1: 3D drawing of the exhibition rooms, and plan drawing of the viewing area

To understand the behaviour of soundwaves in the rooms, it is important to understand the physical setting that is the rooms. Then RT60 and the general SPL of the soundscape are useful methods to do this. Before this, understanding the general size and shape of the rooms was conducted, and a 3D model of the exhibition space was made to visualize these aspects 6.1. The built viewing area of the cell has some implications on the acoustics of the room. As the purpose of the thesis is to convert the soundscape (as it is heard) it was decided to measure the room from the possible listening position of visitors. In the viewing area, all visitors are surrounded by walls, some of them by a roof of 2 meters and others with one of 3.45 meters. The distance to the walls varies depending on the position, and it must be concluded that the sounds heard from these 3 therefore must vary. Three different listening positions were identified, that should cover the differences of positioning. These can be seen in 6.2.

Measuring Equipment

To allow correct measurements, a Class-1 Sound meter, Svantek 971 calibrated at 1kHz was borrowed from a team of professional acousticians. A secondary recording device, a Zoom H4n Pro, was used to record the soundscape of the exhibition. The microphones were positioned 160 cm above ground. As H4n Pro records using two cardioids shaped microphones, these were positioned at 120 degrees to record as wide soundscape as possible (240 degrees). The stereo track, when used for analysis, was downmixed to mono following standardized recommendations [169]. The microphones were positioned at about 45 degree angle upwards, aiming at the centre of the room. An overview of the measurements can be seen in figure 6.2.

The recordings were conducted in the early spring of Denmark, the 10th of March 2025, between 10:30-13:00. The temperature outside began at 5.3 degrees Celsius, and moved to 11.2. Inside the exhibition, it changed from approximately 15-18 degrees Celsius. The humidity began at 73.8% and ended at 54.9. There was no rain, and no clouds. and the wind was between 3.0-4.2 m/s [33].

RT60, and Resonant Frequencies of the Exhibition

To measure the RT60 of the rooms, impulses were made using the Interrupted Noise Method, by bursting balloons. Before recording anything, the multimedia installation was turned off, as these would interfere with the measurement. The impulses were recorded both with the Zoom Recorder and the Svantek 971 device. 13 balloons and the Svantek device were borrowed from 103aps, to conduct this specific measurement. It was decided to conduct recording of impulses from the three found listening positions in the viewing room. The impulses would be of 2 impulses for each position. In this way, there would be the required 6 recordings with a Class-1 Measurement Device. As the WAV files recorded with the Svantek device, only work with the dedicated SvanPc+ Software[156], the impulses were simultaneous recorded with the Zoom Recorder. This was to supply WAV files, that could at a later time be used to create an impulse response reverb of the cell if this would be needed. When returning the recording devices, and changing data from the devices to a computer, it was noticed that the Svantek 971 had not been

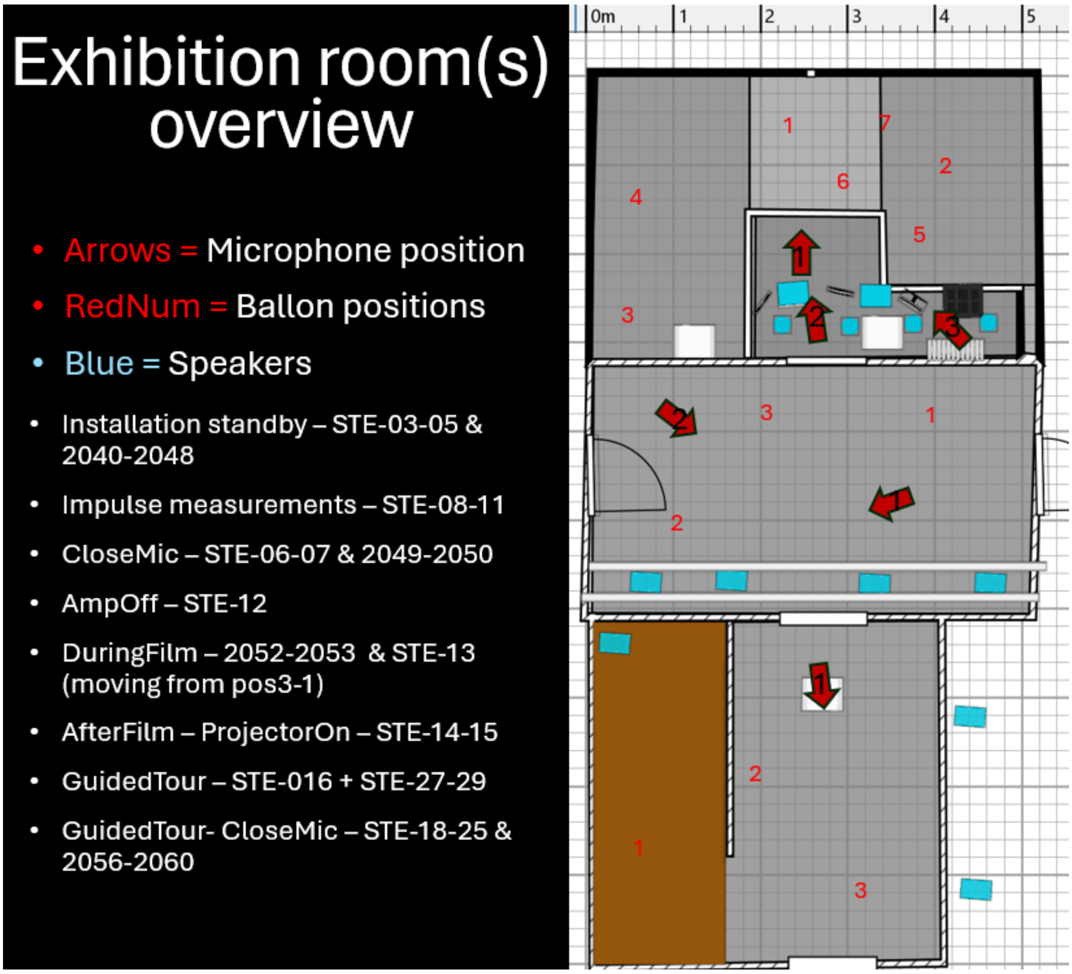

Figure 6.2: Measurement overview

set up correctly. As a consequence, it had not recorded anything when used in the RT60 mode. It was considered to redo the entire recording, but due to both the logistics and cost, it was decided that the Zoom recording would be sufficient. Therefore, the recordings from the Zoom recorder were used instead, which had recorded the impulses from position 1 and 2.

When recording from the listening positions, it was not possible to comply with the requirement of 1m to all closest surface. This was due to the viewing area in some places only being $83 cm$wide, with $2m$ between the floor and “roof”.

The recording of the impulses were imported into the REW - Room EQ Wizard Software [98]. This software calculates all the parameters of the impulse following ISO 3382. The data of the 1/3 octave band measurements of RT30 was then used to calculate RT60 according to the standard, using Microsoft Excel. The results can be seen in 6.3. In the frequency areas of 50-1600Hz a relatively similar decay of 2.3 seconds was detected. The frequencies of 2kHz and above slowly decline to the last measured frequency of 10kHz at 0.61 seconds. The exception to the similarity in the low frequency components were the 1/3 octave band of 100Hz, with a decay of 3.34 seconds. This could indicate one of the resonant frequencies of the room. To get an approximation of the resonant frequency of the room, the software "amroc-THE Room Mode Calculator" [91], by Andreas Melcher was used. In this browser-based software, the dimensions of the room were inserted, along with the general RT60 of 2.35 were added. But the software appeared to work better for traditional treated rooms, and did not supply any usable information. This was decided as it indicated 23 resonant frequencies from 33-367Hz, with an additional 50 less resonant, but still dominating frequencies.

To calculate an overall RT60 for the room, the standard uses the average of the bands from 400Hz to 1250Hz. This gave a result of a RT60 of 2.35 seconds. This is a long reverberation time for a small room. For comparison, a classroom in Denmark is by law required to have an average of the bands between 125hz-4kHz of 0.6 seconds, to allow comprehension (Zelle 2 has 2.23) [118]. In general, the longer the reverberation time, the more difficult it is to comprehend speech.

6.1.4 SPL, LAF and Loudness

To better understand the acoustic environment and soundscape, measurements of SPL, LAF and loudness are required by ISO 12913. The measurements made in this thesis used the Svantek Sound Meter and the dedicated SvanPC++ software. Measurements were made of SPL in different weightings in 1/3 octave bands. The graph presented as figure 6.4, shows the summed results from the SvanPC++ software [155] of the SPL measurement as presented in of “Zelle 2”, in position 1.

The 1/3 octave bands show the measured Z-weighted SPL. Z-weighting shows the SPL as it is present in the room, and not as it is perceived by listeners. The

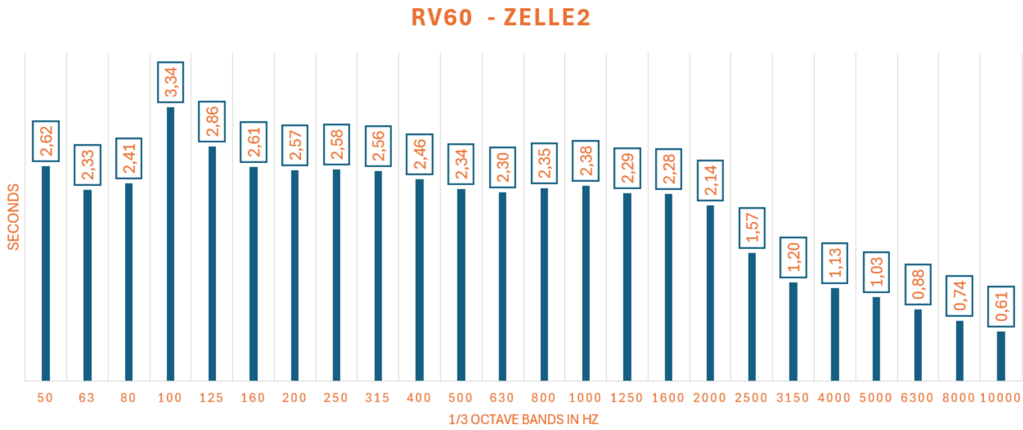

Figure 6.3: Combined measurements of RT60 of Zelle 2, in 1/3 octave bands in seconds

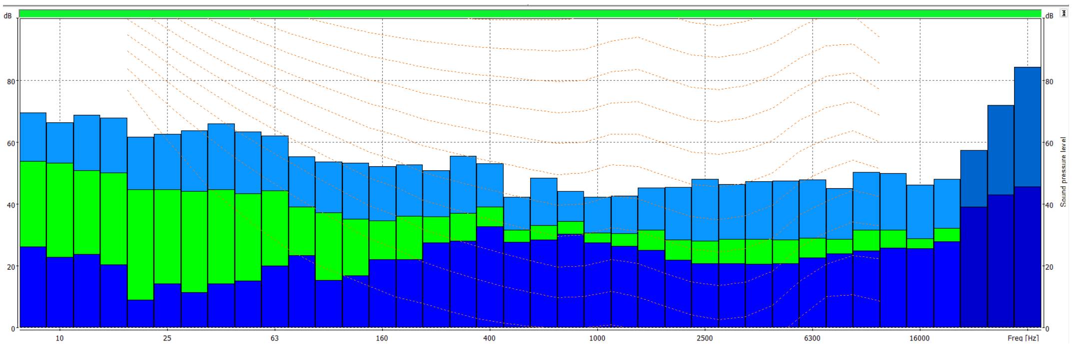

Figure 6.4: SPL of the soundscape of Zelle 2, from listening position 1, as show in 1/3 octave bands in SvanPC++

Room	LAeq in dB	LCeq in dB	LAmin in dB	LAmax in dB	Length in sec.
Zelle 2, 1	43.0	53.7	39.1	57.4	19
Zelle 2, 2	46.7	70.0	40.0	68.6	24
Zelle 2, 3	47.7	60.1	39.0	57.3	3

Table 6.2: SPL of Exhibition

orange dotted lines in the graph show the Equal loudness contour grid 6.4. That is, they do not show the measured loudness, but they indicate how the different octave bands are perceived. The graph shows the measurement with a y-axis of 0dB to 100dB, the x-axis represents the 1/3 octave bands in a bar chart, from 8hz-20kHz. What is needed to comply with the ISO standard is the C and A-weighted overall measurements of the acoustic environment. These are shown together with the A-weighted min and max values in table 6.2. All the graphs from SvanPC++ can be seen in appendix G. Some mistakes were made during the recording, as the time of the measurements are fairly short. All of them are under a minute.

Investigating the data, the measurement of position 2 in the cell, has a much higher LCeq than the two other measurements, as is also seen in the LAmax. The reason could be the recording of a sound not present in the other two measurements. For the purpose of investigating the differences of the listening positions, some general aspects can be found. A LAeq from 43.0 in the first position, where there is no platform, does make sense, when considering the behaviour of sound waves. That the LAeq is loudest in position 3 also makes sense, as this is completely encapsulated by walls and the platform ceiling, and is positioned directly beneath the amplifier. The LAmin also shows that the soundscape is consistent without pauses of silence.

When investigating the Weighted 1/3 octave bands, it is shown that sound is present in all the bands, which is a characteristic of broadband noises. That the mid and low frequencies are louder correlates with how the behaviour of the RT60 graph 6.3. That the low frequencies are more present also explains why the C-weighting is generally higher than the A-weighting. The spectrum of the soundscape is investigated further in 6.1.5.

A Fatal Problem with the Analysis of Loudness and LAF

It was not possible to get the correct analysis of either loudness and LAF. The reason was inexperienced use of the Svantek 913 Sound Meter. When the measurements were conducted, it was made without thoroughly understanding how the sound meter worked, and it was thus not set up correctly. Firstly, as mentioned, the RT60 measurements were not stored as they should have been. The same was true for the LAF values. It was expected that the meter would record all the relevant data, as it is daily used by a company of professional acousticians. When extracting and analysing the data it became clear, that what is expected of a measurement of soundscape by ISO 12913-3, includes data that is not normally in the day-to-day measurements of the acoustical engineers, the device was borrowed from, such as LAF.

The same is true for the requirements of loudness. When measuring loudness, the Svantek 913 sound meter had some complications. As mentioned earlier, the WAV files recorded by the device are only read correctly by the SvanPC++ software. This software cannot calculate loudness, and therefore these measurements cannot be used. Calculating the loudness of the Zoom recordings is a complex task. This is due to the Zoom Recorder using a preamp and not being calibrated for SPL. It should be possible to convert the sound recorded with the Zoom recorder using the SPL from Svantek as reference. But it was not possible to find a toolbox, library, or software to do this. It was deemed that the time required to make an algorithm to do this, could be better used elsewhere. This decision was based on that the recording was not made with a Class-1 device, and would therefore still not comply with the requirements of the ISO standard. That it was not possible to make the correct measurement has two implications. Firstly, that one must know the equipment before using it. And secondly, an indication of the difficulties of complying with the ISO standard. The ideal situation would be to use a Class-1 Binaural Sound Meter that either, calculates loudness, or stores the files in a way, to allow them to be extracted. But this kind of Class-1 equipment is out of the budget of this project, and it has not been possible to borrow.

6.1.5 The Spectrum of the Soundscapes

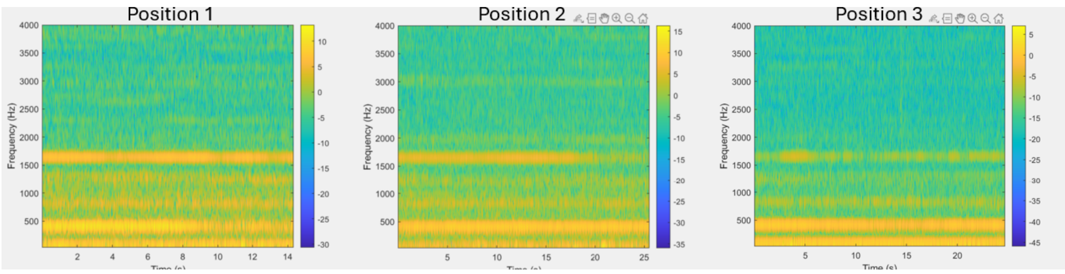

Figure 6.5: Spectrograms from all positions

To get some insights into the frequency content of the soundscapes, they were analysed as spectrograms. Spectrograms provided visual representations of the audio, in both the time and the frequency domain. The X-axis shows the time, the Y-axis the frequencies, and the colour represents the amplitude/magnitude at that particular point. The purpose of using a spectrogram in this thesis was to investigate the broadband sounds of the soundscape to find potential tonal components.

Position	Fundamental Frequency	Fundamental Frequency dB
1	358Hz	399.5Hz
2	398Hz	399.9Hz
3	163Hz	400Hz

Table 6.3: Fundamental frequencies, calculated from MATLAB

The spectrograms were made in MATLAB [89], and designed to analyse broadband sounds. They were calculated using a normalized -24LUFSi version of the recordings. When analysing the sound in the digital domain using FFT, changing how often FFT is calculated influences what the analysis finds. More instances of FFT increases the detection of frequency components, with the cost of precision in the time domain. As the purpose is to locate the frequencies, a larger FFT was ideal. For analysis of broadband sounds, a smoothly curved window, such as a hann window, was recommended by [147]. The complete setting of the spectrogram computation can be seen in fig 6.6. As the aim of the implementation is to change what is heard, the audio was filtered to only contain the most dominant frequencies from 20Hz-5000Hz. To find the fundamental frequency of the soundscape, the mean of the pitch function from MATLAB was used as an estimation. As the spectrogram function in MATLAB shows frequencies from 0-20kHz, it was rewritten to allow easier interpretation of the relevant frequency area. To supply an indication of the fundamental frequency heard by the listener, the fundamental frequency was found by converting all the samples logarithmically before using the pitch function.

The results are shown in table 6.3, and the 3 spectrograms can be seen in figure 6.5. The tonal component of the amplifier can be heard especially around 400Hz, varying slightly in the different listening positions. The third position exhibits a lower fundamental frequency, which corresponds with what is heard when listening at that location. This is most likely due to being directly beneath the foreground sounds from the amplifier, and contained in a smaller space, but could be due to the recording being too short. The spectrograms show the presence of tonal component in the area 1550-1750Hz, that is most audible in position 1. That it is most audible in position 1, indicates the changed acoustics due to the build of the viewing area. Other tonal components are centred in the area of 750Hz, and 1.2 kHz.

These measurements form the foundation of the understanding of the acoustic environment. To investigate how these sounds are perceived, the analysis from the Soundscape Approach, can begin.

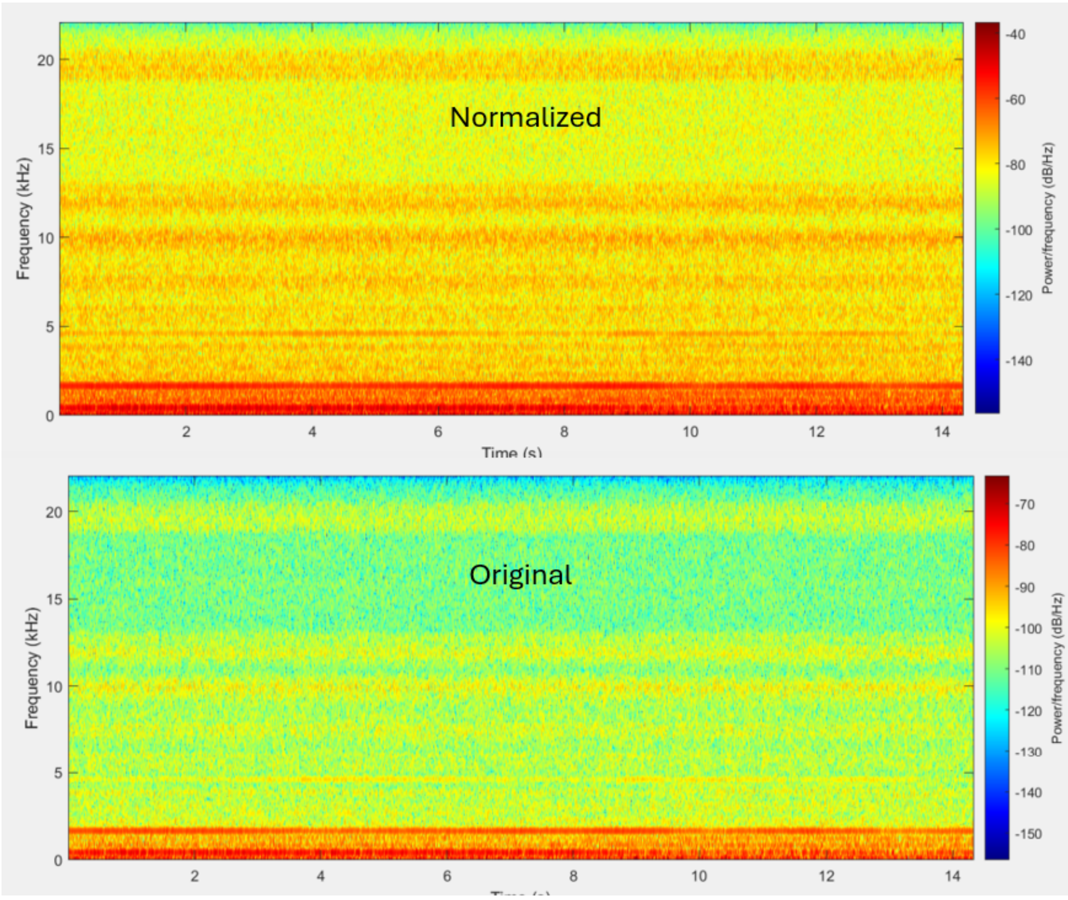

Figure 6.6: Spectrogram of Zelle 2, position 1, normalized and original recording

6.2 Analysis: The Soundscape Approach

The next step in following the standard is to investigate the context, the auditory sensation and the interpretation of the auditory sensation. The context is investigated by looking into the narrative and the interview with the curator. The interpretation of, and the auditory sensation, is investigated with a lab experiment using the HEARSEPTION model, and a recording of the soundscape. A second experiment collecting data from inside the cell was made, but not enough data was collected to be used in this part of the analysis.

6.2.1 Narrowing the Scope: Listening Position

With the data gathered in the Engineering Approach, it is now possible to narrow the scope further. As we have seen, the soundscape, vary slightly in acoustic properties. The scope is narrowed to listening position 2, which is a sort of mixture of the 2 other positions.

6.2.2 Mood of the Exhibition

To get some insights into the mood (i.e., the general state of being), of the exhibition the supplied material from the museum D and the interview D.1 is used. It must be stated that this is not in literary science, and the analysis of the supplied material is based on general assumptions, aimed at discovering general themes. The supplied material is in Danish, and is translation for the use in this thesis when needed, but is not made by a professional translator. When referencing the interview, citations include timestamps referring to the transcription D.1.

When describing the background of the exhibition, the museum uses a term "Dragende", which can be translated to compelling. But in Danish it also has the meaning “attract” and “to draw in”. The use of this word indicates an aim of being immersive. The museum describes the cell as “(. . .) et kig ind i et af 2. verdenskrigs mest dystre kapitler”, which can be translated into: "(. . .) a look into one of the gloomiest/sinister/obscure/sombre chapters of World War 2". As understood in the context of Denmark (and not to neglect the terrible history of World War 2). They further mention that the exhibition is in the authentic premises, as they were left by the Germans. They explain the use of an advanced system of film, light and sound, to give life to the shadows of the past. When investigating the mood board I.1 the sombre mood is once again present. The pictures are almost exclusively in black/white, and adds the context of isolation. This is shown in images such as: An empty chair in a spotlight; a person who seems small and almost insignificant before gigantic cathedral-like windows; A plane in smoke; a person with abstract objects that are similar to hands in front of the face. When one of the curators was asked in an email if they had any wanted subjective output from

Figure 6.7: Mood Board for Zelle 2, copied with permission, and credited to Kolding Statsarkiv and others

the exhibition, such as: *"We hope they leave with a feeling of awe and compassion for the prisoners, and an understanding of the terrible emotional experience it must have been, being imprisoned while waiting for possible torture, and the fear of exposing once allies and friends?"* The reply was *"It's pretty much as you describe, it was not something we wrote down while working on the exhibition."* D & D.1. In the interview, it was told that they often use sound specifically to induce feelings to illustrate a story, or to create an atmosphere. Specifically, the curator mentions (08:12) how "Zelle 2" uses sound to create feelings and atmosphere, as this specific exhibition wants the guests to feel something. The exhibition of the cell is an experience design, where the output it should be felt. To further understand the specific mood of the exhibition, the narratives used in the multimedia installation are used.

Mood of the Narrative

For this part, only the manuscript is consulted; the final multimedia installation with sounds and pictures is not analyzed. The narrative can be found in the appendix D).

In the first narrative, the guest is presented as a new prisoner. The second narrative is about the historical context of the war, and the role of the gestapo in general. The third narrative tells the stories of the people of "Zelle 2", both the prisoners and the guards. All the stories are presented in the same way and consist of 3 scenes, beginning at the entrance, moving to the corridor and ending inside the cell.

The first narrative puts the guests in the place of a prisoner. It is emphasising uncertainty, and fright. The guests as prisoners do not know why they are there, how much Gestapo knows, or what will happen next. The manuscripts add that the sound of someone yelling in German is heard, followed by the sound of someone being hit. It mentions rumours of guards using torture. The uncomfortable situation is emphasised with sentences such as *"your body is shaking (...)"*. The guest as prisoners are told that they are forced to sign papers without knowing what they say, and that they do not know what the next moment will bring. Inside the cell in the last scene, they are told they can't remember everything from the interrogation, all they know is uncertainty. The narrative ends with the song "Altid fredig, når du går" [102] ("Always cheerful as you walk"). The song had a special meaning for many freedom fighters, and were regularly quoted in farewell letters sent before they were executed. After the war it was often played at funerals of freedom fighters, and is generally used as a funeral song [102]. The song indicates death, fighting, and the fear. The original melody is in D major [102].

The second Narrative is more historical based, and begins by explaining how Denmark was occupied, of censorship and the death penalty. It then explains how Staldgården was used by the Gestapo and, as with the previous narrative, the sounds of prisoners being hit are heard and yelled at, this time in Danish. It tells the story of the Danes siding with the Nazis, and their brutality. The narrative includes various visuals of historical aspects of the war, such bombings, soldiers marching, the gathering of Jews, etc. Inside the cell, the scratchings on the wall are shown, and highlight names written by people that were later executed. The narrative ends with an instrumental version of a poem "Den blå anemone" [99](The blue Windflower) by Kaj Munk. The text is introduced in the scene as a projection on the wall. Kaj Munk was known to openly criticise the occupations. The Poem is about not giving up, by letting adversity win, and was understood as a statement about keeping up the resistance, to the occupation. The melody of the poem was written by a freedom fighter, that survived being a prisoner in "Zelle 2". The narrative explains that after the poem was published in 1944, Kaj Munk was executed in his home. The narrative ends with an instrumental version of the song, maybe indicating the loss of life, and leaves the visitors with a feeling of something missing [57]. The original melody is in the key of A-major [99].

The third narrative tells the story of both the freedom fighters and the gestapo officers. Some were killed, some were tortured, some did the killing and the torture. It is the story of kill or be killed, get tortured or tell on your friends. When people are mentioned, if they are prisoners, the spotlight shows their name scratched into the walls of the cell. As part of the narrative in the last room, a letter written by one of the prisoners to his family, written on the day of his execution, is read by a young voice. It induces sadness, and despair. Another story is about a prisoner who survived. The stories are thus a mixture of outcomes, but most of them are with a sad ending. By showing the names of walls, it makes the story authentic. The narrative ends with the song "En lærke letted, og tusind fulgte" [107] (a lark took of, and a thousand followed) written by a local of Kolding. The song is about a free Denmark, waking up to a new reality, and that happiness, at some point, will follow sorrow [67]. The original melody is in the key of G minor [107].

While the stories are different, the general feeling is the same as were seen in the mood board. They are designed to induce feelings by making the narratives authentic. The cell is a historical artifact that validates the stories and experiences of the people of these narratives. The mood is one of anxiety and sadness. It is sombre but with a respect for the fallen. With this analysis of the exhibition mood, we can understand what context the sounds are in.

To investigate how the noise of the multimedia installation can be used to enhance this story, an experiment to assess the soundscape was undertaken.

6.2.3 Collecting Subjective Data: Implementing HEARSEPTION - Overall Experiment Design

A few evaluations of the soundscape of the cell, using the HEARSEPTION model, was planned, to supply data on the perceived aspects of the soundscape.

Questionnaires were prepared in both Danish and English, using SurveyExact. They were designed to collect the relevant background information, defined by the setting of the experiment, and ending with an assessment of sound using HEARSEPTION (the results can be found in H.

3 separate experiments were prepared. **Experiment 1: Lab test:** This experiment was conducted by one person at a time. The participants were played a recording of the total soundscape recorded in "Zelle 2", on a pair of Audio-Technica M50xBT2 over-ear headphones at the same level. And were asked to evaluate the sound while hearing it in this manner. **Experiment 2: On-location:** This experiment was conducted on location at the museum, where the museum inspectors asked guests that had participated in a guided tour of the "Zelle 2", to participate in the experiment. **Experiment 3: Virtual:** This experiment was conducted to evaluate the composed, and converted soundscapes online (see more in the evaluation 8.3).

This part of the thesis will be primarily on Experiment 1. While it would have been more valuable to use both experiment 1 and 2, this is not possible, as not enough respondents have participated in the voluntary evaluation at the museum (3 respondents at the date of May 25th 2025).

Questions were added to provide insight into the participants' hearing abilities. To do these, three questions were asked, one in each aspect of listening found in the HEAR Questionnaire [60]. Those being:

- Ability to hear speech in various environments.
- Spatial localisation abilities.
- Emotional wellbeing in connection with hearing. e.g., in social contexts.

6.2.4 Lab Test

The first test was conducted as a lab test, made with the aim of providing insight to use in the development of solutions. It was estimated the listening part of the experiment, and the simultaneous rating of the semantic pairs, would take approximately 5 minutes. A description of how the files were prepared can be found in the appendix J.4.1.

The lab test was conducted April 25th-28th. 20 people participated, 10 males, 10 females. All of them choose the Danish version. All wrote Danish as their nationality, None used hearing aids. The participants were asked to listen to the recording (all at the same volume) and rate what they heard while listening to it. Each of the experiments took between 5–10 minutes, with the listening and rating lasting between 2.5-5.5 minutes.

To enable processing of the data, the averaged data has been inserted into Microsoft Excel, and the document can be found as part of the appendix H.1. For this experiment, the data gathered was sorted to show averages in 4 different ways. A semantic profile of the assessed soundscape was created and can be seen in 6.8. It must be mentioned that some ratings, especially appropriate-inappropriate, do not provide meaningful data, from a lab experiment, as this is highly defined by the context. It was considered to remove the loudness, and the spatial aspects of the model, but it was deemed unnecessary. As it was decided to focus on the aesthetic descriptors, explained in the next section

6.2.5 Results of the Assessment

In general, it can be concluded that the soundscape was assessed as being particularly positive or negative aspect in any of the parameters. When looking at the Annoying-Pleasantness, the soundscape is rated to be fairly annoying (2.9). We know from psychoacoustics that Sharp sound are annoying, but the ratings of sharpness indicate that it is not assessed as sharp, the same is true for roughness. This could indicate that the annoying part of the soundscape is not in the psychoacoustic parameters, but rather has to do with other areas of how feelings are induced. The sound has no noticeable rhythm, but it could be due to evaluative conditions. The sound connects participants to experiences where they have heard such a sound before. 4 of the respondents mentioned that it sounded like a vacuum cleaner. This would bring back episodic memories of cleaning, and visual imagery of the same. These are definitely not memories connected with the narrative of the case. The soundscape was not assessed to stimulate relaxation, potency, or activity. It is clear that even though the sound has tonality, it has no musicality. Where the narrative stimulates emotions, the noise does the opposite. The noise is average, it doesn't stimulate, not even negatively. The assessment found the sound as permanent, without variation, and artificial rather than natural. It can be hypothesised

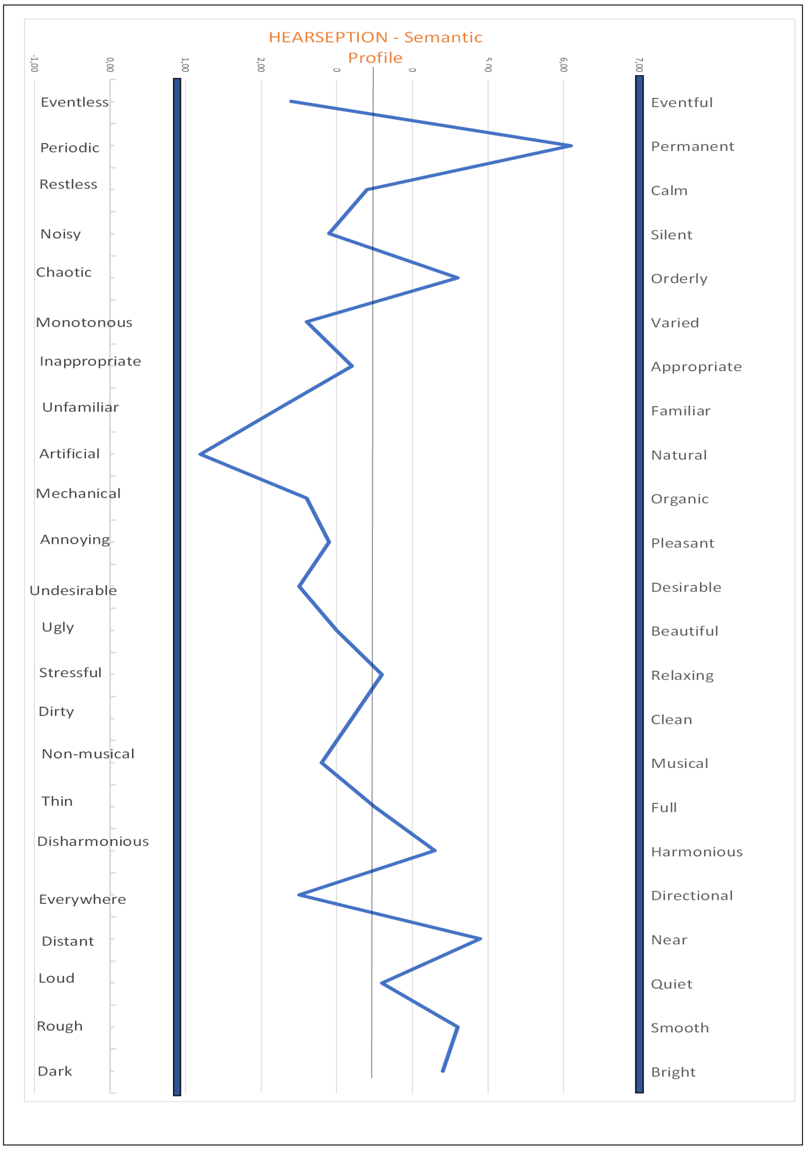

Figure 6.8: Semantic Profile of Zelle 2, from HEARSEPTION, and the Lab Experiment

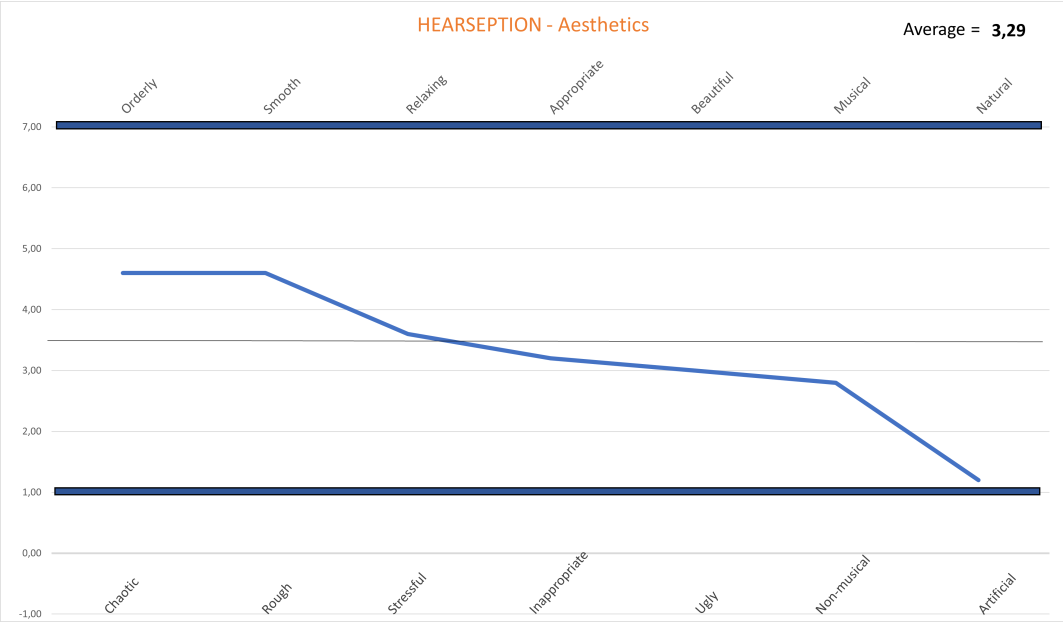

Figure 6.9: The word-pairs indicating aesthetics

from the data that: When the guests of the museum are left in the room, after the end of the narrative, in 2 minutes of permanent noise without meaning or message, this could create an outcome of them leaving instead of experiencing the emotions of the exhibition. There is no stimulation of the brain stem reflex, no stimulation via rhythmic entrainment and no stimulation via musical expectancy. It has evaluative conditions, emotional contagion and visual imagery and bring backs episodic memories of no particularly sought after emotions. Cleaning, ventilation systems, being in a plane, or other places where people have experience noises like this. Aesthetically, it stimulates nothing that brings awe.

HEARSEPTION offers the option of sorting the word into different categories. The descriptors defined in as influencing the aesthetic qualities can be seen as figure 6.9. Aesthetics is just one of the qualities that could be extracted from HEARSEPTION. It would be equally beneficial to, for example, look at the evaluation of EPA, or if wanting to make the soundscape more potent, or to work on changing the Timbre aspect of PFA, these graphs can be seen in appendix I.2.

By consulting the graph aspect for improvements of the aesthetic experience can be evaluated, and solutions can aim of changing ratings of specific aspects of the soundscape. Deciding how and what parameters solutions should aim to change, is done using the Artistic Approach.

6.3 Analysis: The Artistic Approach

The Engineering and the Soundscape approaches have provided insight into the components of the soundscape, both the subjective and the objective ones. These can give some indications on the response, and the outcome 3.1. In the Artistic Approach, the analysis differs from the other approaches. Rather than being an analysis of the soundscape, it is an analysis of the implication found in the analysis, with an aim of creating solutions. In this Master's thesis, this information is used to define the design requirements of the solutions.

With the assessment of the soundscape, it became clear that the soundscape made by the multimedia installation is mediocre, and does not stimulate. An aim is thus to make it stimulating and be an authentic addition to the narrative. Due to the characteristics of the noise as broadband sounds, it seems interesting to mask it using a natural sound, with a similar spectrum. Such as rain and running water. As the purpose of the thesis is to explore how to use ENC as a methodology, finding different solutions with different techniques seems to fit. A second solution could therefore try to mask the sound by making it musical, by abstracting parts of the original soundscape. Lastly, it could be interesting to investigate the aspects of the songs ending the narratives.

As the sounds are made to a particular soundscape, as heard from a specific listening position, making a convolution reverb using the IR, recorded at that position, seem a good way to keep the manipulation of sound in the right context.

These reflections are summed into the design requirements of this thesis as follows:

Functional Requirements

- The soundscape of ENC must use the sounds of the environment, to make the implementation being part of the environment.
- The solutions must explore different aspects of conversion, and not be 3 iterations of the same solution.
- The perception of existing soundscape must be changed by masking.
- At least one solution must be relatable to natural phenomena.
- The solution must be directly related to the measurements of the soundscape and acoustic environment.
- When designing a solution, it should follow the methodological framework of Farnell.

Non-Functional Requirements

- The converted soundscape must aim to enhance the authentication of the exhibition.
- The solution must be made with the aim of enhancing the experience design of the exhibition.
- The solution must be real-time, or be perceived as real time.
- The solution must be made respecting the artifact and narrative of the exhibition.
- The solution must be made to with an aim of changing some aesthetic parameters from the evaluation.

6.3.1 Choosing Tools

With the design requirements and the understanding of both the acoustic environment and how it is perceived, it is now possible to create solutions with well-founded reasoning and goals. To create a solution, it makes sense to first decide which tools should be used to create these. Parts of the solutions will be based on real-time data analysis. To ensure these possibilities, a variation of Miller Puckette's Pure Data [123], called plugdata is used [136]. The plugdata program uses pure data, but is pre-made to include some usable libraries [29], [27], [**enzien_audio_heacylib_2024**], [121] & [59]. Another usable aspect of plugdata is that it works as a VST plugin, and therefore can be used in any DAW. This allows the mix of analytical and specific code to be used with other VST, which gradually increases the possibilities of design. Plugdata will be used inside the DAW Reaper [65], with the SWR/S&M-extension [158].

It is also worth considering what type of device the solutions should be made on. Should it be coded and built on a microprocessor, or with a more traditional computer? As the purpose is to show how ENC can be used to convert soundscapes, the implementation, on site, is not strictly needed. Furthermore, the complications of accessing the multimedia installation, and making an addition to the installation was considered. And while, if the ENC-solutions were to be implemented as an addition to the exhibition, this would be a crucial step. it is not as crucial to the research question of this thesis.

Now we both know what the problem of the environmental noise, is and what tools are used to convert it, we can move to the second implementation step of the ENC methodology: constructing solutions.

Part 7

Implementation Part 2: Solutions

In the previous parts of the thesis, three approaches to the ENC framework, have been explained, framed and used to analyse the unintended soundscape of the exhibition of "Zelle 2". The insights from the analysis will be used in this part of the thesis to enhance the experience of the exhibition, by converting the soundscape. This is the essence of the methodology of Environmental Noise Conversion. Three solutions are created in this part. Each begins by defining individual aims derived from the analytical data. To evaluate and compare the solutions, the spectrogram from MATLAB as described is used 6.1.5.

7.1 Iteration 0: Introducing the Solutions

As the solutions are made for a specific acoustic environment, it wouldn't make sense to create a solution that would sound different when implemented, in that environment. Therefore, a convolution reverb using the impulse response from the second microphone position inside the cell was made. This can be considered creating a virtual representation of the sound of the environment. Convolution is one of the most essential parts of digital audio processing. In the digital realm, it is used to make, e.g., FIR filters. That is, feed-forward filters that always becomes zero after a finite set of samples. Basically, convolution is engineered by combining two signals into a new signal, 7.1. One sound is a variable, such as the sound from a microphone (x), and the other is an IR (impulse response), that is a static set of coefficients (z). By convolving the signals in the time domain, the components of x, are changed by the IR and, and the combined signal is computed.This has many

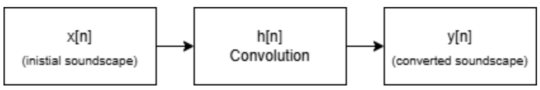

Figure 7.1: Block Diagram of Convolution

useful applications. To make a convolution reverb, the signal of the properties of the room (IR) are combined with a sound source. The new sound now has the properties of the reverberation, of the specific IR. In the case of the museum, the IR of Zelle 2 as recorded from listening position 2. As we saw with the calculation of RT60 F, one impulse is not enough to make a proper representation of a room. The aim of this convolution reverb is to create a representation of how the soundscape is heard from listening position 2, and the foreground sound is the amplifier, it seems logical to use the impulse from the ruptured balloon in the closest proximity to the amplifier. In this case, that would be impulse 5 6.2. A second IR was made by combining all 3 signals, after ensuring that they are edited at the same moment of rupture. The first IR is intended to be used with all the solutions, and the second IR for creative use when making the solutions.

Now, with the possibility of emulating the sound of the room, it seems a good time to formulate the general plan of the solution in accordance with the design requirements. Three possible solutions were thought of and are defined here:

1. Abstracting the soundscape using real-time manipulation of the spectrum using a mixture of energetic masking and sound dressing.
2. Convert the soundscape into one of rain, with control parameters directly from the soundscape, using attention masking, and sound dressing.
3. Using the soundscape, and the data of the soundscape to generate generative music, using attention masking.

7.2 Iteration 1: The Simplest Form

With a general idea of what the conversion of the soundscape should do, the three solutions can be explored, using the approach presented by Farnell 4.4.2. As mentioned in the general guidelines, each iteration will begin with its simplest form, with a maximum of 3 parameters, then be evaluated and compared with the design requirements 4.4. The original sound, and the manipulated sound are implemented as two (or more) tracks in Reaper, where the original sound always is played without manipulation. For the solution, the sound from the HEARSEPTION Lab experiment, normalized to LUFSi -40.7, or peak -30.2, is used as a representation of the soundscape of "Zelle 2". This amplitude is choses to supply some headroom for manipulation and to prevent digital clipping. The convolution reverb added to the signal using the ReaVerb plugin in Reaper. The converted soundscape output is routed though the reverb (see **??**).

7.2.1 Solution 1: Abstraction of Soundscape

What is the Aim of this Implementation?

The general aim of this solution is to change the characteristics of the soundscape, by directly changing the soundscape using manipulation in the spectral-, time-, and frequency domain, using traditional techniques of audio manipulation such as reverberation, equalization, echo, and modulation. Thus changing the spectrum and timbre of the sound, while masking it. From the aesthetic qualities, they aim to make the general ratings less neutral. A second aim is to make the soundscape less static, and more musical.

What Physical Phenomena, and Emotional Response, is Under Investigation?

The complete soundscape as it is in the surrounding is the source of manipulation. By abstracting different aspects of this sound, the emotional response should be changed. The idea is to enhance the qualities of the sound and use this augmentation to stimulate a different Visual Imagery, Evaluative Conditions and Emotional Contagion. Ideally, the sound should be understood as an indication of the general distressing mood of the prisoner, almost like being inside their head. The aim is to give it more character, and thus stimulate aesthetic emotions, by making it abstract and thus more artificial, ugly and chaotic, but without making it annoying. This could be done by removing some tonality from the sound, and changing the roughness and sharpness to be more full. This can be considered trying to draw the guests into the emptiness of the cell, while containing a sombre mood, that is not frightening, but rather mysterious.

What Information Does the Analysis Provide?

The analysis provided the general mood to aim for, and showed that the spectrum of the sound is passive, neutral and non-intrusive or pleasing. The abstraction tries to enhance the aspects of the resonance of the room, to mask the fundamental frequency of the soundscape.

What Methods of Synthesis are Used to Achieve the Aim and Purpose?

In the simplest form, stock plugins will be used for the manipulation, rather than programming the effects from scratch. Reverb and equalization will be the primary tools for manipulation.

Implementation

As the main aspect of the conversion was to use additional reverb to change the spectrum, the first step was to locate a reverb, with a fitting sound. After trying different VSTs, the choice fell on Oxford Reverb by Sonnox [84]. The advantages of using this is that it has a built-in equalizer, that allows adjusting the frequency component of the reverb to the properties of the cell. Additionally, this reverb had the option of adding feedback to the equalized parts if they were augmented. This allowed the recorded sound to build up in different frequency areas, and thus add more variation. The length of the decay was set to be close to 3 times as long as the RT60 of the room (2.34 sec), with a reverberation time of 6.81 seconds. The difference in reverberation was also made to add variation to how the abstracted soundscape behaves in the room of the cell. In general, the reverb was adjusted to add density, and build up. The equalizer setting was set to enhance the 100 frequency components of the reverb, which allows it to be more full in the IR, as this had a peak in the frequency band of 100Hz. The tone at 1.kHz was reduced, and the area surrounding the fundamental frequency it was increased, to add more harmonics to it. The frequencies surrounding 6kH were increased to add some top end of the soundscape, in the same way as more low end were added. This makes the sound much fuller than the original recording. To further change the frequency components, to smoothen and allow the sound to fill more, the Melda Production equalizer, MEqualizer [92], was added before the reverb. It this, the high and low frequencies were augmented slightly. The frequencies half a semitone from the fundamental frequency were augmented, to change the timbre of the tonal component. The audio file was rendered, and had a peak of -20.9. It can be found, together with the other audio files of the thesis, in the appendix A.

Conclusion and Discussion of Implementation in According to the Design Requirements

When comparing the spectrograms of the source recording and the one of Solution 1, iteration 1 7.2, it is clear that it still contains the audible tone. But it can also be seen that the soundscape has activity in the entirety of the spectral plane. Especially in the frequencies below 500Hz. The analysed fundamental frequency of the audio has changed, though, and is now found to be 302.3Hz. The solution uses what is there, and removes a bit of the attack, while adding spectral components. While the converted soundscape is smoother, it is not yet successful in masking the tonal components. The solution would benefit by adding more activity, and by using energetic masking.

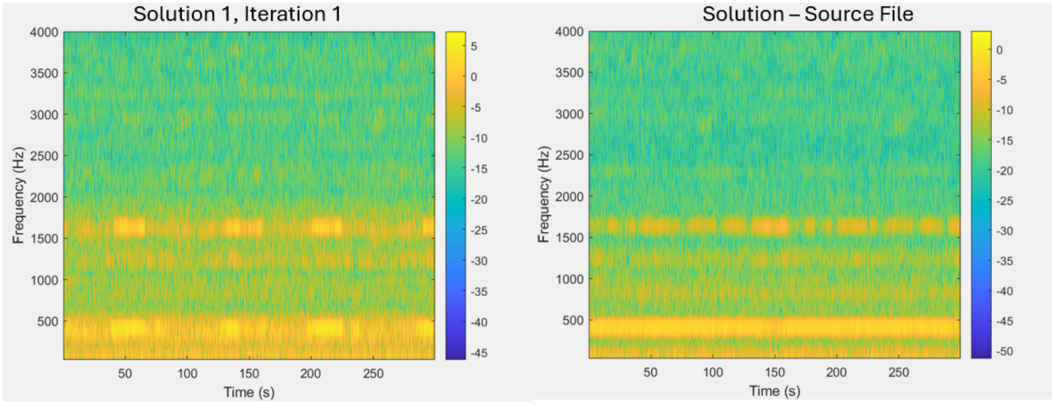

Figure 7.2: Solution 1, Iteration 1, Spectrogram. Compared with Original Soundscape

7.2.2 Solution 2: Rain

What is the Aim of this Implementation?

The aim of the second solution is to change the soundscape into a sound that authentic to the narrative of the exhibition. This will be done using the sound of rain. The aim is this to make the sound more familiar, organic and fit the situation. The rain solution should adapt to the changes that occur in the noise of the cell, due to temperature changes and other atmospheric conditions. When looking at the aesthetic word-pairs of the HEARSEPTION model, the main attributes this solution is made to stimulate is changing the Artificial to Natural, stimulating appropriateness and increasing the feeling of relaxation. While it might not be relaxing being in a prison, making the guest relax, cloud has the outcome of them staying and experiencing the exhibition for a longer period.

What Physical Phenomena, and Emotional Response, is Under Investigation?

As the most present physical phenomena is rain, and how rain interacts with its surroundings, and is perceived by humans. This and how the behaviour of rain, and the behaviour of the sound sources and sound waves, correlates. The second aspect is adjusting the rain sound to be closer in tone and timbre of the soundscape. The rain sound should support the sombre, depressing mood of the exhibition. This solution uses attention masking to change the cognitive and emotional response. Especially by changing the visual imagery that the sound stimulates, as well as episodic memories, emotional contagion, and evaluative conditions. The space, created by the rain, should increase the overall aesthetic judgment.

What Information Does the Analysis Provide?

There are numerous studies showing how natural sounds and especially the sound of rain, are general perceived to be more pleasant than most other types of soundscapes, while also having the ability to stimulate both productivity, restorativeness and relaxation [105], [127] & [63]. While this is true, an interesting aspect of rain in the context of the aim, is its uses in popular culture to describe depression and sadness. e.g., when a lead character in a movie is left by their partner, images of them standing alone in the rain follows. Rain is therefore, both, relaxing, but recalls many memories and associations to loneliness, melancholy, and depression [90] & [**drawing**]. In the context of the narratives of the exhibition, the sound of rain is made to evoke emotions and imagery of a prisoner alone in a cell, isolated, uncertain and anxious. The sound of rain is broadband, much like that of the noise of multimedia devices, but it has no direct tonal components. To ensure masking of the tonal components, filtering in the form of equalization might be required.

What Methods of Synthesis are Used to Achieve the Aim and Purpose?

For the simplest of iterations, the use of a sample or samples is sufficient. That is a natural sounding rain, as could have been heard in the cell. As the rain is a dramatic effect, to support the narrative, there is no need to considered exactly how rain would have been heard in the cell, through the arrow slit. The rain would not be heard as the outside anyway, without adding a speaker to the installation in the arrow window. To control the resonance of the rain, to fit the tonal components of the soundsource, a resonant filter will be used.

Implementation

A creative commons, free for use, sample of heavy rain [172] was found using freesounds.org. It is a stereo WAV file at the sample rate of 44.1 with a bit depth of 24. While it is generous of people from all over the world to upload and share recordings, there are often some drawbacks to these types of audio files. Firstly, while there are many files of rain available online, not all the recordings are more than a minute. Secondly, rain can sound extremely different. The found recording, while good, was not entirely perfect. It was one of the longer ones identified found, but was still only 2:22 minutes. A much longer recording, would have been preferred to add some variation to the sound. Secondly, there were a few artifacts in the recording that sounded like they might be from the recordist. These sounds, which destroyed the illusion of rain, were edited out. The recording did supply a fairly good recording of heavy rain. Light rain was deemed to not have the power to mask the tone in the multimedia installation, without being played in a form that would make it unnatural. The symbolism of the depressive and isolative aspects of the rain, was also deemed to be more related to the heavy rain, than light rain.

To ensure that the spectrum of the rain would mask that of the recorded soundscape, the MEqualizer was used again. A resonance highpass filter (12 dB/oct.) was added, for two reasons. Firstly, there was no need to use the low frequency components of the rain sound. Adding more low-frequency content would not fit the aim of natural sounding rain. . The resonant frequency of the highpass filter, was set to the fundamental frequency of the soundscape, with a Q-value of 2.16. In the MEqualizer a Q-value from 0.05-1.0 is without resonance, and between 1-20 decided the extremity of the resonance. 2.16 is a fairly rounded broad resonant frequency, and it therefore covers both the fundamental frequency and the nearest harmonics. While this setting made the rain sound cover the tonal components as intended, the rain, inside the convolution reverb, sounded unnatural. This makes sense, as heavy rain normally would not be heard inside a room, but as outside the room. To make it more natural sounding, a bandpass-filter was used to add components a 8.5dB boost at 6.9kHz using a broad Q (0.41). This helped make the impact of the raindrops sound natural, but the general rain sound was still a bit artificial. To change this, a second bandpass-filter was added to remove 10dB at 1.28kHz, with a narrow Q-value (0.82), this allowed both to hear the impact of the raindrops, while still masking the tonal components. The rain sound was then turned completely down and attenuated until it was perceived to mask the tonal components of the soundscape. It was exported with a peak of -20.7dB or 33.1LUFSi. As with the other sounds from the thesis, they can be heard using the link found in A.

Conclusion and Discussion of Implementation in According to the Design Requirements

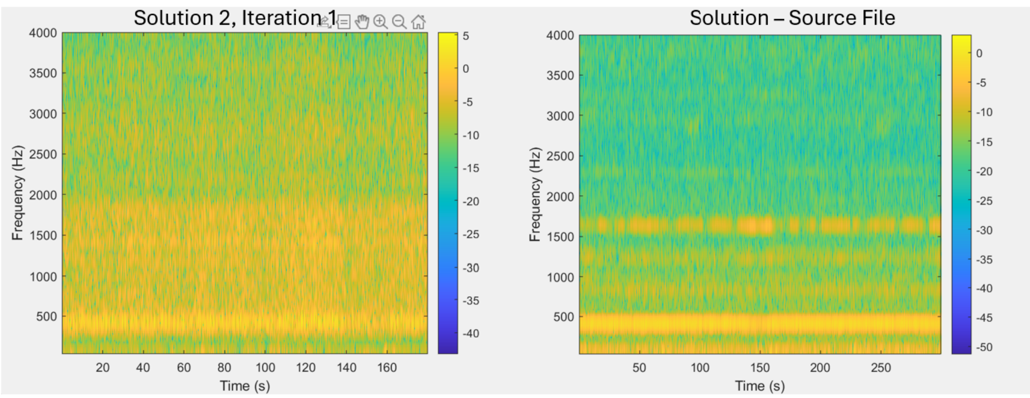

Figure 7.3: Solution 2, Iteration 1, Spectrogram. Compared with Original Soundscape

This solution does a fairly good job of masking the tonal mechanical components of the soundscape, as can be seen in 7.3. The perceived fundamental frequency is still in the same area, 396.8, but the real fundamental frequency is found to be 273Hz. When inspecting the spectrogram, it is much more difficult to locate the tonal components in the 500Hz and 2kHz area. The spectrogram indicates a more mixed frequency spectrum with some variation, with smooth transitions between the different tonal areas. While the frequency component in the 400Hz area is still louder, they are perceived to be part of the spectrum, rather than a foreground sound. The sound could be evaluated to be more rain than noise, and much less artificial. If this is the case, it would be more appropriate, and should evoke a different emotional response.

There are some troubles with the sample, though. It would be preferable if the recorded sound was longer, and thus would allow a bit more interesting sound of rain, as the beauty of natural phenomena is that it is an ever-changing complex system. This can be solved by finding a different, much longer recording, or by using synthesised rain. Furthermore, the resonant frequency chosen for the high pass filter is static, and if the tonal component of the soundscape were to change, the masking effect would not be as successful. Therefore, this resonant frequency should be made to follow changes. This change would also make the solution generative, and connect the solution to the environment. The rain could be integrated to be more part of the environment, rather than just being an addition to it.

7.2.3 Solution 3: Piano

What is the Aim of this Implementation?

The aim of solution 3 is to use music as attention masking. The aim of the perceptual change should be seen in the evaluation using HEARSEPTION, should show the converted soundscape to be higher rated as appropriate, relaxing, beautiful, natural and musical. The solution should be felt as a continuation of the narratives, and create a space a for quiet contemplation. While the sound of music is not authentic to the exhibition room, the instrumentation should still strive towards being authentic to the historical period.

What Physical Phenomena, and Emotional Response, is Under Investigation?

As with the previous solutions, the tonal components of the soundscape of Zelle 2, are the foreground sound that needs to change, and the converted soundscape should be integrated into the acoustics of the exhibition. To make the music connected to changes in the environment, it must be able to be adjusted in accordance to these changes. If the composition of the converted soundscape is successful, it should affect all the aspects of the BRECVEM model. To be relaxing, an investigation on the subject by Tan et al. [157], is followed. They find that the rhythmical components should be less or equal to 60bpm. The most relaxing music also had a high degree of repetitive harmonic components in a diatonic scale (especially, C-major, G-major and D-major). In general, music in the major scale, without lyrics, played by a maximum of small ensemble (4–5 instruments) is preferable. The timbre of the sounds should be smooth rather than rough, and often instruments with a slow attack were preferred, such as a violin played with a bow. While these characteristics were made to define relaxing music, making it beautiful and musical is linked to the performance and composition.

What Information Does the Analysis Provide?

We have observed that the main frequency components are around 400Hz, 750Hz and 1.2kHz. These are not notes in the tempered tuning system with A4, at 440Hz. Therefore, the tuning of the instruments should be adjusted to fit the tuning of the room. The closest note to the fundamental pitch of the room, in standard tuning, is G4 at 392Hz. The closest notes to the other found frequencies are D6 (1174.66Hz), and F5 (739.99Hz), these will be slightly off pitch, but the found tones were also based on approximations. D is the fifth of G, which makes a chord without the colouring 3rd. F is a major 7th. This fits with the diatonic scale of G-major. With the diatonic chords of G, A, B, C and D in major, and B and E, minor.

While this is true for the guided tour, the music could benefit from being adjusted to the songs of the narratives. The first two narratives this would provide no issue, as they are in the key of D major, and A major. The last narrative's end song is in G-minor, and this should be to be modulated into major, before the same composition should be used. The mood of the narrative though indicates that the composition should be in minor, to enhance the sadness and distress of the prisoners. As the natural soundscape consists of the fundamental frequency and the fifth, music in the minor could as easily be created, and still fit. The only change in the diatonic scale, from major to minor, would be to change the B to Bb, and E to Eb. The diatonic natural minor chords, on the other hand, are less straightforward, and would be: G-min, A-dim, Bb, C-min, D-min, Eb-min and F. This would clash a bit with the ending compositions of the narratives, but could be transposed using a bit of musical freedom. In a G-min diatonic harmonic scale, the D-major chord would replace the D minor, and in a G-min Diatonic melodic scale, A-dim would be replaced by Amin. This indicates that there is not a specific diatonic key, that could fit all three narratives, but that modulations of key could be adjusted to fit the three narratives. For this implementation, based on the guided playing in G-min would both tonally fit the soundscape, and enable some relevant connotative associations.

What Methods of Synthesis are Used to Achieve the Aim and Purpose?

For synthesis, the simplest form is to use a VST-instrument with a sufficient sound, that can be changed slightly in pitch to fit the soundscape of "Zelle 2". To enable easy transposition of the musical components, the solution will use MIDI. For the first iteration will be using some improvisational piano. To enhance the musical quality of the piano, and make it more atmospheric, some reverberation should be added.

Implementation

To make the music atmospheric and to further explore the sound of the room, the impulse response of the combined 3 positions was time-stretched to 1:8, that is 8 times as slow as the original impulse. The time-streaked IR was then loaded into a separate convolution reverb, before the 1:1 convolution from listening position 2. This reverb enhances the acoustic properties of the room while simultaneously creating a mysterious atmosphere. To use a sound authentic to the period, the VSTi New York L 1926, from Boz Digital Labs [94] was used. This VST uses samples from a 5′10 (1.78 m)Steinway Model L Grand Piano, that was built in 1926. The piano has been stored in a controlled environment, which should have ensured that it has almost the same sound as when if it was built. The piano was tuned to have A4 as 446.4Hz, which would make it fit the identified close to G4 note of the soundscape. The frequency was found by multiplying the sought for 398Hz G4, with $2^{1/12}$, that is 2 times 1 semitone. The result being that $newA4 = 398 * 1.122462 = 446.4Hz$.

To enhance the emotions of being separated from the music, the VST was, set to use the sample recorded with two room microphones **??**. The sound of the microphones close to the piano, would indicate being right next to it, and the room microphones, while still being close to the piano, add a sense of isolation from the sound source. The time-stretched IR, further brings some lo-fi quality to the overall sound, as the stretched sound has some undefinable faults in the reverb. This combination gives it an unusual, uncanny and slightly disturbed piano sound. While being close, it is still distant, and while allowing the notes to be heard easily, they have some undefinable qualities. The music was played live on a MIDI piano, using long slow notes and chords played to the tempo of 50bpm. Three chords were played in different positions and inversions, in the notes from G1 and A3. The chords were the I-IV-V chords of the G diatonic minor scale, those being G-min, C-min and D-min. When playing the piano, it was done with an effort to enhance a feeling of isolation and sadness. While being played to the standard 4/4 rhythm, there is no completely predictable progression through the chords. They are a slight variation of the same, without being the same. While always returning to the G1 G minor chord, exactly when and how is not predictable, but simultaneously never surprising. The original piano MIDI recording is 3 minutes, and has approximately 30 chords played in different voicings. It is expected that the guests of the exhibition would stay for longer than 3 minutes, or at least that the music should be longer. Therefore, the MIDI take was cut and edited randomly together. Sometimes only one chord from one place, and at other times up to 40 seconds of the original recording was used. This can be considered a sort of pseudo-generative music, where if it were to be real generative, this randomised cutting and editing should be done algorithmic. It was considered playing melodies, and editing them in the same randomized way, but it was deemed unnecessary for this iteration. The final pseudo-generative music piece was made to be 18 minutes, which should be enough to show how the music of solution 3, would work, if completely generative. The file was rendered with a peak of -1.9 and a LUFSi of -19.2. While this is much louder than the original soundscape, this was to be expected, as the dynamic range of music is also much different than one in a static soundscape. As with the other sounds from the thesis, they can be heard using the link found in A.

Conclusion and Discussion of Implementation in According to the Design Requirements

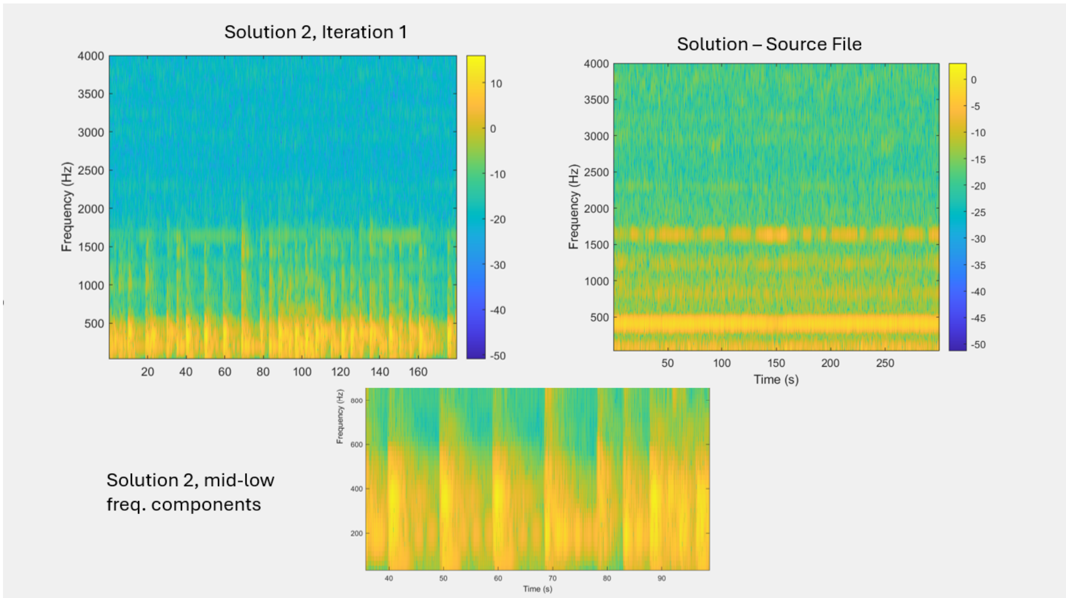

Figure 7.4: Solution 3, and the soundscape before conversion. At the bottom, the low frequency components zoomed in.

Where the other 2 solutions tried to hide the tonal component of the soundscape of "Zelle 2", solution 3 uses it as part of a musical composition. As can be seen in the spectrogram 7.4 this conversion of the soundscape changes almost all aspects shown in the spectrogram. While it is still possible to locate reminiscences of the tonal components of the multimedia installation, they are less dominant in the new soundscape. A few interesting aspects appear. Firstly, the spectral components above 2kHz, appear to be of a much less magnitude than that in the spectrum of the original soundscape (turquoise rather than green). Secondly, as seen in the lowest picture of 7.4, when zooming the frequency components of below 500Hz, then the otherwise rather static fundamental frequency of the soundscape, appears to be periodic rather than permanent. This shows how masking of tonal components, changes the behaviour of other sounds. The tone from the amplifier, is as permanent as it always was, but it is not represented in the same way in the spectrogram because it mixes with the tonal components of the music of solution 3. It can be argued that the converted soundscape is both more appropriate, relaxing, beautiful, natural and musical than the original soundscape. To understand if it is successful in stimulating the wanted emotional response in the museum's guest, a different type of evaluation is needed. It can also be concluded that the solution fulfils the design requirements. Some improvement could be made, though. The solution would benefit from having the adjustment to the tuning of the piano, be closer related to changes in the actual environment, as with the other solutions. Secondly, rather than being pseudo-generative making it properly generative would benefit the longevity of the solution, and it should therefore be made to change between the chords and inversion of the chords algorithmically. It might also be beneficial to add some melodic content to the generative solution in the form of a selection of melodies, that could be played with the chords to give it some variation. Thirdly, if the chords were to be used after the narratives, someways to change the music to fit the key of the different end sounds of the narratives would be beneficial.

7.3 Iteration 2: Real-Time Connection to the Environment

For all 3 solutions, one thing were similar, they could all benefit of adding some changeable control parameters that connect the solution to slow changes to the soundscape of "Zelle 2". The slow changes are primarily connected to the fundamental frequency of the room, that, because of different environmental factors, could change to be a bit higher or lower.

7.3.1 Solution 1, Iteration 2: Modulating Bark Bands

What is the Aim of this Implementation?

The aim of this iteration is to continue to use manipulation of the soundscape of "Zelle 2", to mask itself. While the first iteration changed the spectrum, the converted soundscape was deemed to be too static and permanent. Therefore, some variation, to the converted soundscape should be added. The tonal components of the converted soundscape, were too dominant, and some modulation could be added.

What Physical Phenomena, and Emotional Response, is Under Investigation?

For modulation of the soundscape using the soundscape, it makes sense to approach the sound from the perspective of how it is heard, using the understanding of the critical bands of hearing. That is, instead of manipulating all the sound, then rather manipulate the relevant bark bands. This would be exploring the possibilities of energetic masking. The sought after emotional response is the same as with the previous iteration, while also adding some moving parts that can stimulate rhythmic entrainment and musical expediency.

What Information Does the Analysis Provide?

In addition to the information from the previous iteration, we know from the theoretical and methodological parts of the thesis that sound heard, can be defined into 24 bark bands. This iteration should also address the tonal components of the soundscape in the 400Hz, 750Hz and 1.2Hz area to better mask them.

What Methods of Synthesis are Used to Achieve the Aim and Purpose?

For modulation of the tonal components, the synthesis will use amplitude modulation of specific critical bands, with an addition of some additive synthesis if necessary. Amplitude modulation, is when the amplitude of the signal is used to change the harmonic structure of a sound. In additive synthesis, timbres are changed of waves, by adding sine waves together to create partials and overtones to the signal.

Implementation

The first step, in creating the bark band filter, was adding the 1/3 octave filter and adjusting them to the parameters mentioned in the ISO standard. The 1/3 octave filter was made in plugdata using bandpass-filters centering the 24 critical band frequencies. Each bandpass-filter was set with a Q value of 4.318, which allow it to include all the exact frequency components of the 1/3 octaves [140] & [69]. The patch is the one called *barkBandFilter* patch and can be found in the appendix A. Plugdata was loaded as a the first VST on the converted soundscape channel used in the previous iteration. The equalizer used in iteration 1 was bypassed, and only the reverb from the previous iteration remained.

The first part of the patch, was to convert the stereo signal of the soundscape of "Zelle 2" into mono. Secondly, it was sent to an abstract called *barkBandFilter*. This

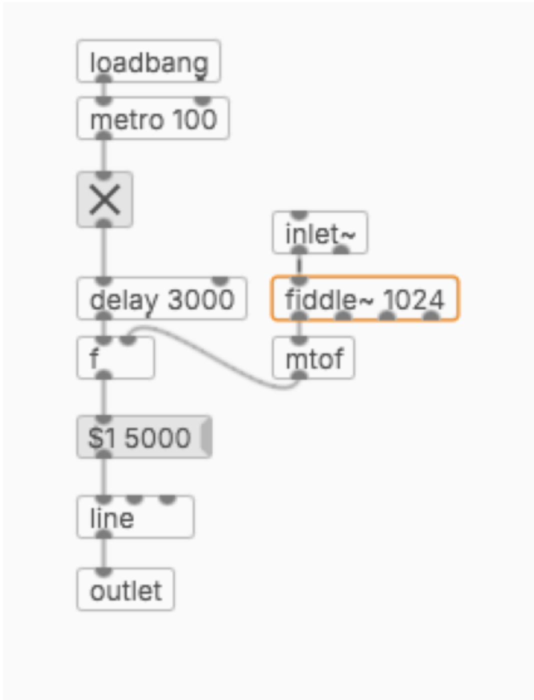

Figure 7.5: findPitch Abstraction for plugdata

abstraction separates the audio into the 24Bark bands, and sends these to the main patch using the *send-object* as b1-b24. the exact centre frequencies of the bands were found using [44] & [143]. As the purpose of the solution was to focus on the dominating tonal components of 398Hz, the 750Hz and the 1.2kHz, only the four relevant Bark bands were used in the conversion process. Those would be Bark 4 and Bark 5 summed, as signal 1. Bark 7 and Bark 10, were used to create signals 2 and 3. Each signal was manipulated separately. The first step of all three masking of the bands begins with the abstraction *findPitch* 7.5. The abstraction used the *fiddle -object* to find the most dominant MIDI-note of the Bark. The MIDI note, e.g., 67.3 is close to the G4 note at 392Hz. The MIDI value is then converted to frequencies using the *mtof-object*. It is then stored as values in a *line-object*, that outputs the current value to the newfound value in 5 seconds in a linear ramp. The process of initializing the *line-object* happens every 3 seconds. This ensures that the found value never jumps to a new value, but always smoothly moves from one found area to the next.

Signal 1 was multiplied with an oscillator, with the Hz decided by the analysis of the *findPitch* abstraction. This could be considered additive synthesis. To keep the signal above 0 it is added 1, and then to give it a higher amplitude it is multiplied by 20. To mask this Bark, with the most dominant frequency, it was thought that it would benefit from the continuous smoothness of the time and frequency

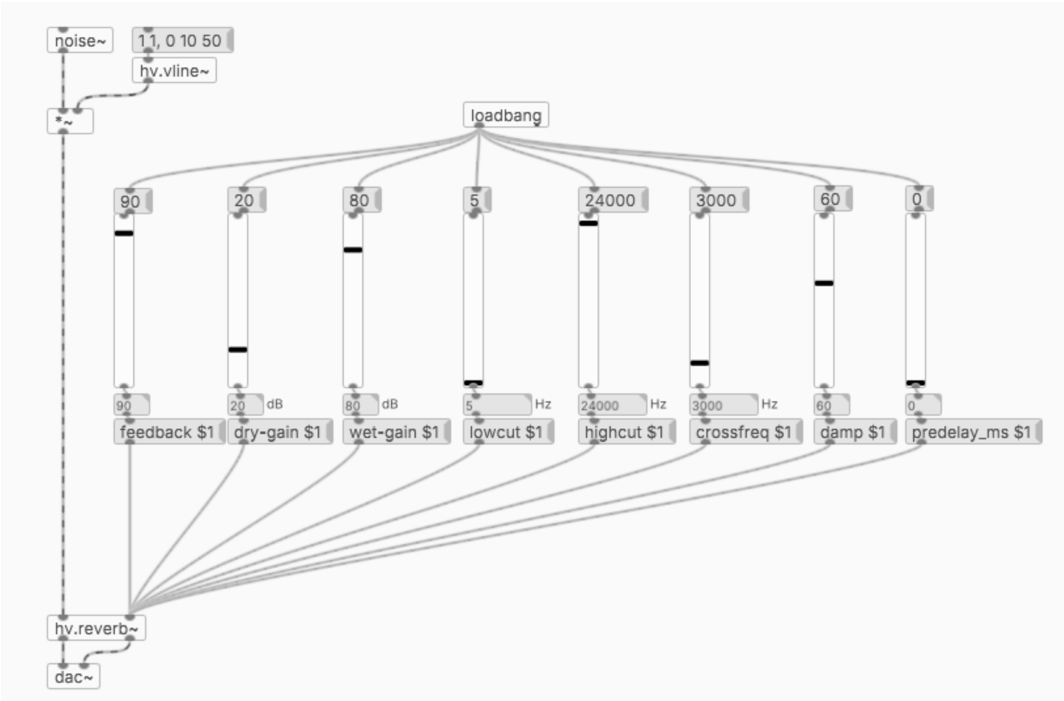

Figure 7.6: heavylib reverb setting

domain, by adding more reverb at exactly this place. To achieve this, the heavylib reverb hv_reverb was used and adjusted to smoothen and dampen the spectrum, as can be seen in 7.6. To add movement, the converted bark was multiplied with the values of an LFO, of 0 to 0.4, with a cycle of approximately 2.5 minutes. This was made the Bark into a slow moving undefinable sound, that seems to moves from non-existence to the edge of feedback, before it disappears again.

The second signal begins in the same way, with the *findPitch* abstraction, that is used to control the frequency of an oscillation that is added to the signal. The main manipulation of signal 2 is made using waveshaping and amplitude modulation. The signal is multiplied with itself and clipped to be within certain values using the *clip -object* . This is all to add harmonics that peak at different frequencies at different times. The peaks change but are generally found around 100Hz, 320Hz and 1160Hz, as can be somewhat seen in 7.7.

Signal 3 begins the with the same analysis of as the previous signals, but instead of using the found pitch to control an oscillator, it is used as the imaginary numbers of the *complex-mod-object* from the heavylib library. The object shifts the frequencies of the signal defined, by a set amount. The amount was controlled by an LFO going from 0Hz to 50Hz in around a minute.

Before reaching the output, signal 2 and 3 are changed in amplitude in a cross-fade. attenuate one of the signals, while augmenting the other signal. When it

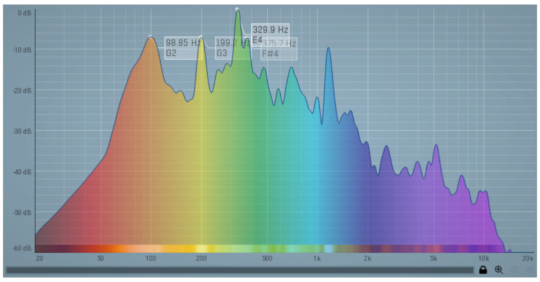

Figure 7.7: MAnalyser view of the output of signal 2, as heard in the master channel

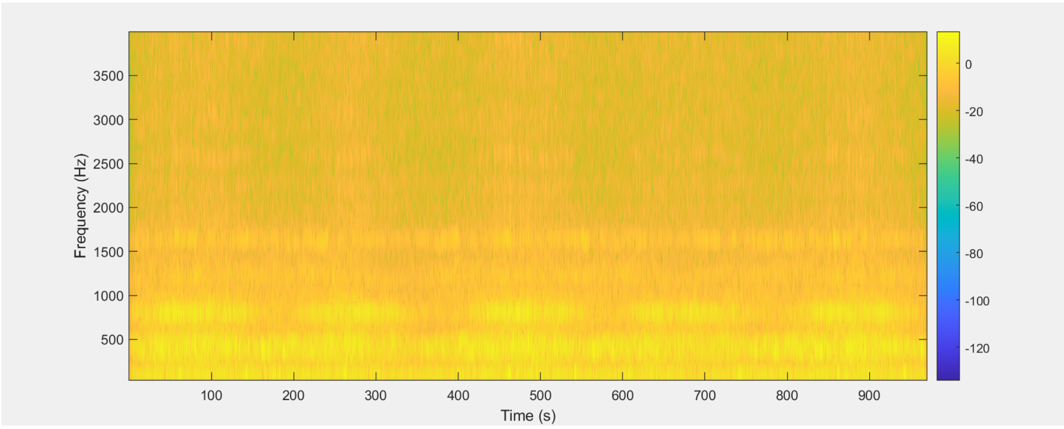

Figure 7.8: Spectrogram of the first 1000 seconds of Solution 1, iteration 2

reaches the point where one signal is 100& and the other is 0&, it has a pause, before fading in the other direction. The complete cycle of the fade is 6 minutes.

The combined signal of the converted Bark band, creates an atmospheric and mysterious converted soundscape. The soundscape was then rendered in a 16-minute version with the peak value of -12.6 and LUFSi of -31.1

Conclusion and Discussion of Implementation in According to the Design Requirements

The overall converted soundscape is mysterious and edgy. It is not natural sounding. It is definitely not an authentic sound to the historical period, but it might be perceived as being inside the head of the prisoners or the gourds. The conversion was successful in using aspects of the soundscape as variables in the implementations. But much of the sound is still based on fixed numbers, that could benefit of being controlled by variables of the soundscape. Adding more movement, and movement connected to more environmental variables, would be a valid aim of a third iteration. When investigating the spectrogram 7.8, it is clear that in this iteration the spectrum has been completely converted. While the problematic frequencies can be detected, they are far from alone. Almost all areas of the spectrum have some sound present. This could be due to the large amount of reverb that scatters the sound, to be in the entirety of the spectrum. On the other hand, this could also be an indication of, that the frequencies might have been to smoothen out, and that too much sound in general is present. In a future iteration, creating some space of more silence, might be beneficial.

7.3.2 Solution 2, Iteration 2: Synthetic Generative Rain

What is the Aim of this Implementation?

While solution 1, iteration 1 was successful in masking the soundscape of "Zelle 2" using sampled rain, it was also concluded that the solution would benefit of being less repetitive. To accomplish this, the sample of the rain could be longer, this, on the other hand, would not solve that it would always sound the same. The soundscape of solution 2, also only had minimal connection to the acoustic environment, the only connecting being that the sample was equalised to resonate in the fundamental frequency of the soundscape of "Zelle 2". The aim of iteration 2 was therefore to make a generative synthetic pseudo-physical model of rain, to be used in combination with the sample.

What Physical Phenomena, and Emotional Response, is Under Investigation?

To understand how to make the noise into the sound of rain, the behaviour of the sound of rain needs to be investigated. Converting the noise into rain, still has the hope of changing the emotional response that fit the sombre mood of the narrative, by stimulating visual imagery and episodic memories as those provided by rain as a symbol for sadness in popular culture.

What Information Does the Analysis Provide?

When rain impacts the ground, it creates a sound that is defined by the density, speed and other variables of the drop, in combination with the material of the ground. Rain impacting grass sounds different from rain impacting a window. As more rain falls, it accumulates and creates puddles of water that thereby becomes part of the material that is impacted, and creates the sound of bubbles [42, pp. 441–449] & [97]. The resonance, and tonal components of a drop is decided by a combination of the density of the water, and the size of the drops. The bigger a drop is, the more low frequency components it contains. A physical model of rain therefore has two main blocks, or components. The first block is the exciter, which is the raindrop. And the second block, or many blocks, are the resonators of the impacted material. The most realistic of models, should have resonators for all the different materials impacted, for example, tree, asphalt, car-roof etc.

What Methods of Synthesis are Used to Achieve the Aim and Purpose?

For this iteration, most of the real-world properties of rain were ignored. The synthesis method focuses on changing the soundscape into impulses, and a resonator was made using a creative approach to convolution reverbs. To create a pseudo-physical model of rain, Andy Farnell's implementation from the Designing Sounds book [42, pp. 441–449], was used and adjusted to fit this aim. Farnell uses waveshaping of Gaussian noise, to create the raindrops, but for this iteration the recorded soundscape will replace the Gaussian noise, and thereby connect the conversion to the environment. Waveshaping is a synthesis technique also known as non-linear-distortion. The basis of it is to change the shape of the waveform without changing the phase and amplitude of the waveform [45] & [128].

A second part of the implementation is to connect the resonant frequency of the equalizer to be adjusted by changes in the environment.

Implementation

Iteration 2 for solution 2 was made with a combination of plugdata programming, and parameter control in Reaper. A channel was created in Reaper that receives the sound of "Zelle 2" as a send. Plugdata was loaded unto the track to be the main component in converting the soundscape. The Reaper session, like all the other reaper sessions, can be found in the appendix A. Some processing from solution 1, iterations 2 were reused for this iteration. Firstly, the soundscape was converted to mono, and then it directed into the *barkBandFilter*. The noise was used as input to an abstraction called *noiseToImpulse*, which can be seen in figure 7.9.

Farnell implementation emulates the sound of raindrops impacting hard ground. e.g., something with little resonating qualities. To achieve this, the input from the Bark, was directed into a bandpass-filter with a fairly wide Q-value surrounding a frequency controlled by a variable. The purpose of this is to concentrate the spikes in the low frequency area. If there is no sound, no impulses are made, if the noise has sudden spikes, more impulses can be heard. The signal following the filtering split into two sections, one is the main processing (left), and the other multiplied back with the processed signal at a later point. The left

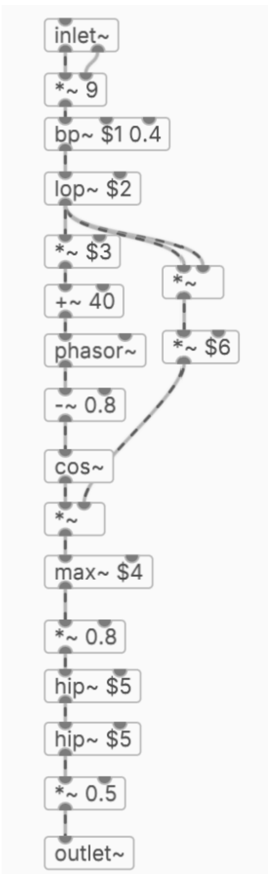

Figure 7.9: NoiseToImpulse Abstraction

signal is multiplied by an integer, that can be said to control the intensity of the impulses, the larger the numbers, the more impulses are heard. The signal is then added 40, to keep it above 0, as the purpose is to work with positive spikes. The signal is then used as input to a *phasor -object*, followed by a *cos -object* . The phasor creates ramps with values from 0 to 1, decided by the input. High number inputs creates faster ramps. The shape of the ramps are then changed by the cosine function into a sort of reversed uneven saw-waveform with sharp attack and linear decay. The signal is then multiplied with an augmented version of the right signal from earlier. When the two signals are multiplied, the shape of the waveform changes into spikes. The larger the integer is, the larger the peaks are, and the more variation of the impulses are heard. The following *max -object* and passes sound that is beneath the threshold, set with a variable. The smaller the variable, the more pulses are created. Lastly, the amplitude of the signal is changed with a multiplayer, and two highpass-filters used to change the overall sound of the impulses.

This was turned into the main patch, "Solution 2, Iteration 2, Rain". The patch was loaded onto two channels in Reaper, that both receive the sound from the soundscape, the reason will be explained momentarily. In one of the patches, 3 instances connected to different Bark bands were used of the *noiseToImpulse-abstraction* were called. Using different Bark bands enables some variation of the rain patch. To further enhance variation, the variables of the abstraction were varied slightly. Two of the Bark Bands were added delays at different lengths, to ensure that they would not create impulses simultaneously (see fig. 7.11. In the second instance, 2 different Bark bands were processed in the same manner. When Farnell wants to change the material of the impact, he creates his own sort of reverb / waveguide abstraction to change the sound to fit this purpose. For this iteration, though, that did not make sense, and this was also the end of using Farrell's guide.

At this point, the sound did create variable impacts, but they were not natural sounding. To make them more natural, it was decided that the impact should be heard in a resonator of a wet surface. To create this, an alternative creative approach to a convolution reverb, was conceived. A sink was filled with water, and drops of water were poured into it at different rates and recorded. This recording of water impacting water at different speeds, and in different shape, was then edited, into two different sounding samples. As the samples were recorded in a metal sink, which has a high pitch resonance, that is fairly sharp, the samples were equalized into a more pleasing rain sound. The two samples were then loaded as

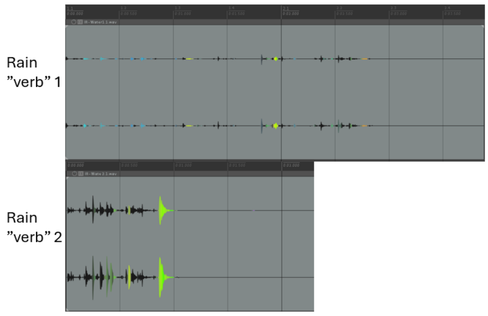

Figure 7.10: Waveforms of the Rain, used to create a rain "reverb"

the IR of convolution reverbs on two tracks with the synthetic rain patches. The purpose of this approach to IR was twofold, firstly using the impulse of water impacting water, makes the synthetic impulses sound like they are water. The second reason was that if a convolution was made of only 1 drop, then all drops would sound the same, which would be very unnatural. The overall soundscape therefore benefits from having more than one sound in the IR (the waveforms can be seen in fig. 7.10).

Connecting an Equaliser to the Soundscape The second part of the iteration was to make the sampled rain more responsive to the real-world sounds, and make it less permanent. To do this, the found pitch of the combined Bark Band 4 and 5 was sending it as control values to the track with the rain sample. The sending part can be seen in the downwards right corner in 7.11. This was done by converting the found pitch into sound using the *line -object*, and sending it as audio out 3 to the channel. In Reaper, audio 3 was then routed to track 3, where the sampled rain sound was. On this track and abstraction called *reciveFreq* was created 7.12. The track receives the data, and output it every 0.5 seconds. To use the audio for control data, a few different methods were tried, but all of them had a few drawbacks. Methods investigated but not used included OSC and audio control data.Both of these could not be made to work in a manner giving sufficient results. The final method outputs the data as MIDI CC, which has some issues. That is connected to the aim of using the information of the found frequency to control the frequency of the resonant highpass filter from the MEqualizer. The first issue was that the equalizer works logarithmic, but receives MIDI data linearly. To change this, the frequency was recalculated logarithmically and converted into MIDI values, using the *expr-object*. The second issue was that it only received the rounded data, i.e., midi note 63 rather than 63.153. This is one of the basic flaws with MIDI CC, but could not be helped. The equaliser therefore changes according to the soundscape, but only in exact midi values, which are not exact replications of the resonance

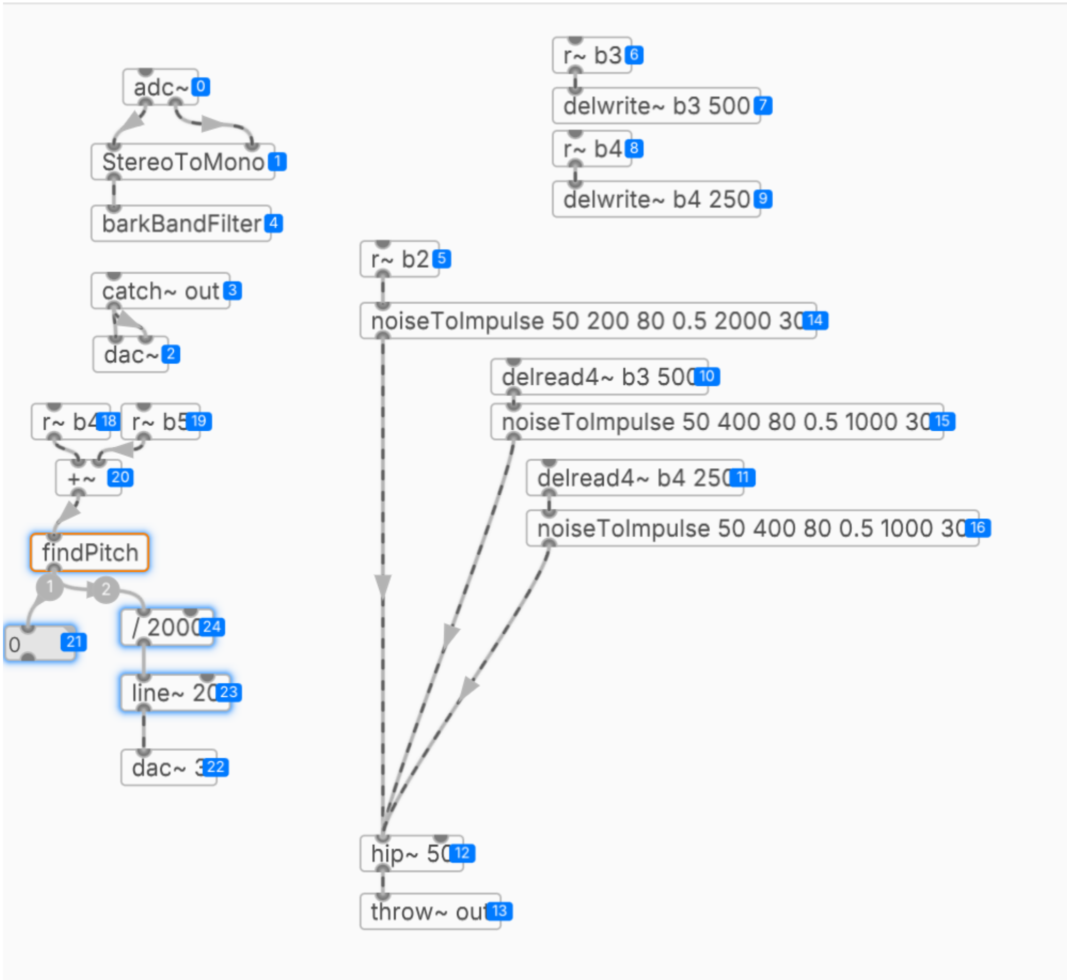

Figure 7.11: Rain abstraction, with a send

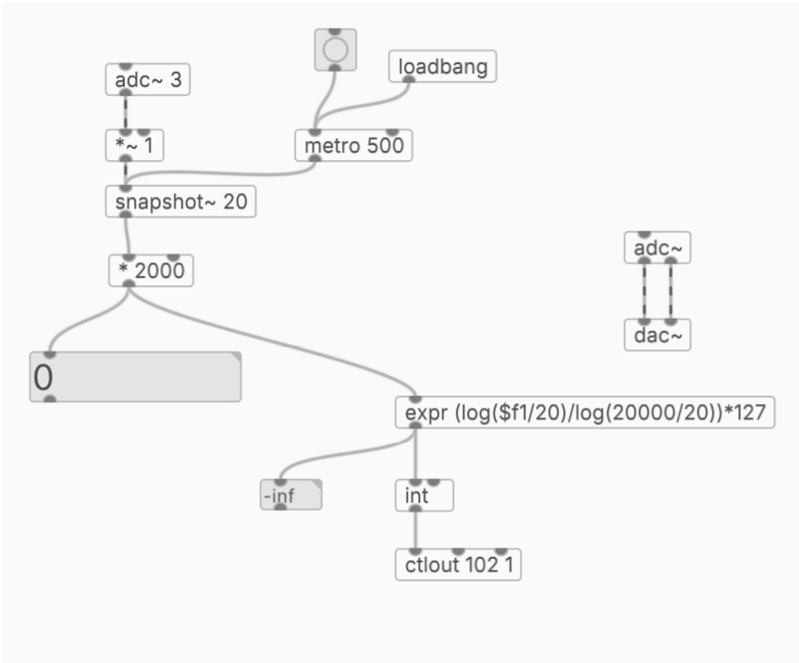

Figure 7.12: ReciveFreq abstraction on the audio track, with the sampled audio

of the rooms. By having a broad Q-value of the resonant equalizer, the difference could be almost inaudible.

The converted soundscape was still deemed to be a bit too static. To change this, LFO's were added to the equalizer of the sample. One to change the dry/wet of the equaliser from 100% wet to approximately 40% slowly, with a sine wave LFO moving at the speed of 0.0071Hz. A second LFO was added with a sine wave if 0.003Hz to control the output volume from 0dB to -10dB. Lastly, a third sine wave LFO was added to control the saturation of the equalizer from 0 to 100% with the speed of 0.0053Hz. The more the sound is saturated, the more harmonics are added to the sound. For the two channels of synthetic raindrops an MEqualizer was added after the convoluted drop reverb, and LFO were added to the output changing them from 0db to approx. -20dB in different speeds. The saturation of both were equally mapped from 0-100% LFO's at slow speed. The idea of the LFO's at different slow speeds, is that they will never be exactly in the same position on all the controlled parameters, and thereby create a generative soundscape where, even though it is similar, small changes will ensure that it is never the same. The audio was then rendered to 15 minutes example (that can be found in A), with a peak value of -14.5dB and LUFSi of -33.0dB.

Conclusion and Discussion of Implementation in According to the Design Requirements

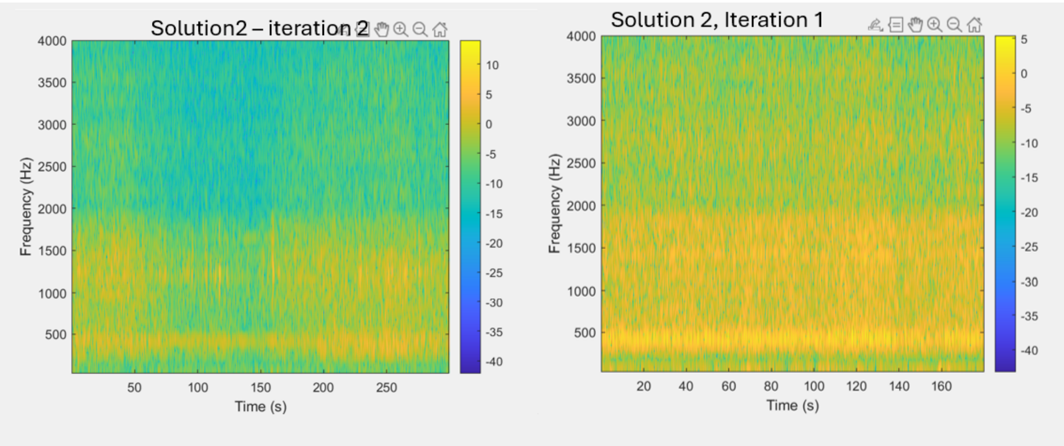

Figure 7.13: The two iterations of Solution 2

When investigating the spectrogram of solution 2, iteration 2 in comparison with iteration 1 7.13, a few things are worth commenting on. Firstly, solution 2 seems to have a lower amplitude. Even though the peak value is 5dB higher, the loudness is the same, which also indicates more variation in the sound. This could indicate that the masking does appear to be more successful in iteration 2. This could be due to using the specific Bark bands, to find and convert problematic frequencies into impulses. As the aim of the iteration was to give variation to the soundscape, this can also be seen in the spectrogram, where especially the frequencies from 500Hz-1.8kHz appear to have much more room in the spectrum. Even the 400Hz fundamental frequency appears to have some variation to it in amplitude.

There are still some areas that could be improved. The synthetic rain is a bit too similar, and a better model could be programmed. The alternative convoluted reverb of the raindrops was an interesting solution but could be refined. e.g., by have more and more varied impulse responses, that change automatically, and could be used to support a narrative of the behaviour of the rain. Likewise, as mentioned, the data from the soundscape to control the frequency of the equalizer, is not exact, and a better implementation would improve the solution.

7.4 Solutions: Closing Remarks

As with all iterative processes, it could continue forever, adding small adjustment. When consulting the research question of the thesis it was deiced that at this point the 3 solutions, in the current iterations, were sufficient to show how ENC can be used to devise different creative solutions to environmental noise problems. The solution converts the soundscape using different methods, to create different moods, with different aims. But they need to be tested on-site, to conclude if they are successful. The next step of this thesis is to test and evaluation the solutions on location.

Part 8

Evaluation

In this thesis, two evaluations of the provided solutions were conducted. Firstly, the solutions are evaluated through self-assessment by triangulating HEARSEPTION with the pleasantness/eventfulness model. The reason for using other models for self-evaluation is to show how HEARSEPTION is connected to other models of soundscape assessment. The second part of the evaluation is made using an online survey collecting subjective data using on-site recording of the converted soundscapes using the HEARSEPTION model.

8.1 Testing Solutions, and Preparing Recordings for Evaluation

To investigate the converted soundscapes, a test inside "Zelle 2" was conducted on May 19th, 2025. During the test, the temperature of the outside rose gradually from 16-20°Celsius. The outside humidity fell from 44% to 22% during the tests [33]. There was no rainfall, or no clouds, and the wind speed was about 3.3m/sec. All doors and windows to the exhibition were closed during the entirety of the experiment, and the inside atmospheric conditions were therefore almost similar to the previous recordings made in the cell. To move the sound from the digital realm inside a laptop, to the acoustic environment of "Zelle 2", a Fostex 6301B 2watt speaker was placed next to the foreground sound source of the amplifier and connected to the computer (see 8.1. The speaker was positioned this way because the main sounds to be masked were the tonal components from the amplifier. This would also replicate the proximity of the IR used for the convolution reverb. The choice of speaker was based on, the need for the speaker to be small, and that way to be easily incorporated into the existing multimedia installation. The speaker allows frequencies from 80Hz to 13Khz [48]. As seen in the analysis, the main components of the noise of "Zelle 2" are below 2kHz, and especially in the

Figure 8.1: Images from the test. Right: in the corridor looking into the cell, The Zoom recorder and the laptop playing the solutions can be seen, Left Top: The recorder. Left down: the position of the speaker next to the amplifier.

100-400Hz range. This is fully covered by the chosen speaker. The speaker was also chosen to test if a small, inexpensive speaker, would be sufficient to mask the soundscape. To prevent the vibration of the speaker transferring into the multimedia platform, it was placed on acoustic foam. A single speaker was used, instead of a stereo pair, as the converted soundscapes were made primarily in mono. Using stereo could have added more spatial aspects, but as the foreground sound source was in mono, it was considered more fitting to work with the converted soundscape in mono in the first iterations. The multimedia installation, was then configured to play the "guided tour mode".

8.1.1 Preparing the Solutions

To prepare the audio to be played inside the cell, some changes needed to be made to it. A microphone was ordered 3 weeks before the test, which could have been used to convert the soundscape in real-time, but on the day of testing it had not arrived. This would require some changes in the code, that are discussed in the future work section 10.3. The preparations were therefore made solely inside Reaper (the projects are attached A.2, and are the ones ending with -Test). All three solutions were prepared in the same way. Firstly, the recording of the soundscape was removed from the main output. This allows the file to play, and supply data, but not be heard. Secondly, the convolution reverb of the sound of the cell was removed.

It was suspected that the solutions would require equalization, but this was not the case. The solutions sounded exactly as intended and indicates that the method of using the convolution reverb to emulate the room, away from the room, was a well-founded method of simulated implementation.

8.1.2 Recording the Solutions

The solutions of the converted soundscapes were then recorded using the Zoom recorder, positioned at listening position 2. The microphone was placed 165cm off the ground, in a 45°angle pointing towards the centre of the room. each solution was adjusted in volume, until it was subjectively decided that masking was a success. A second recording was then made, at a louder volume, to ensure that a recording of successful masking would be made. The Class-1 Sound Level Meter, was no longer borrowed, an inexpensive SPL meter was used to give indications of changes in the overall SPL between the solutions. The sound meter used was the UNI-T UT353, which cost approximately 25EUR. It can supply measurements of SPL in A or C weighting ranging between 30dB and 130dB of the frequencies from 31.5hZ to 8kHz, with an accuracy of +- 1.5dB [159]. The cheap SPL meter works in real-time, which means that it cannot create the same calculations of SPL over a specific period, as the Class-1 meter. Instead, it computes the SPL every 125milli seconds or 1 second, depending on the fast/slow setting. Samples SPL was measured in the beginning and at the end of the individual recording. The measurements were noted for the values it moved between, and as an average of this.

The recordings of the solutions were 9–14 minutes each. An additional recording of the soundscape of the multimedia installation without conversion was recorded in the same way. Table 8.1 contains information on the recordings. When comparing the measurements of the multimedia installation, it became clear that the measurements made with the budget meter, were not exact (as expected). In the measurements from the Class-1 meter found an average SPL from position 2 as 46.7dB 6.2. The inexpensive meter found it to be 48.2dB in these measurements, which fits the + 1.5dB mentioned in the documentation of the budget meter. After the files were edited, RMS and Peak were calculated for the individual files, and added to the table.

8.1.3 Preparing the Files for Evaluation

A few insights were gained when listening to the recorded files, the day after the recording. Firstly, it was decided that the ones recorded with the minimal volume did not mask the sound properly, and these should not be used further in the evaluation. The second realisation was that all the recordings white noise that was not observed in the room when listening. The cause was hypothesised as being from the Zoom recorder. To validate this, an experiment was made. The Zoom recorder was set to record, and then covered with a thick acoustic blanket and

Solution, test	SPL dB-A	Approx. SPL Avg. dB-A	Length in min.	Peak and RM
Solution 1	49.7-52.5	51.1	13:17	-23.47 a
Solution 1, Loud	65.1-76.2	70.65	13:48	-5.59 a
Solution 2	60.0-61.5	60.75	12:45	-16.76
Solution 2, Loud	65.1-69.9	67.5	9:21	-12.43 a
Solution 3	72.2-76.3	74.25	10:10	-6.31 a
Solution 3, with pauses	49.2-76.3	62.75	10:10	-6.31 a
Multimedia Soundscape	47.9-48.5	48.2	8:50	-32.06 a

Table 8.1: Overview of recording made during the test

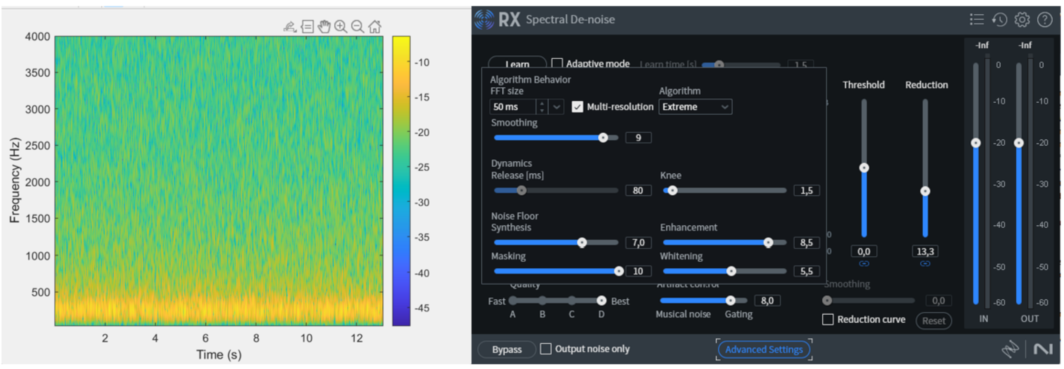

Figure 8.2: Left: Spectrogram of Noise From recorder. Right: Settings of Izotope RX Spectral-Denoise

inserted into a case isolated with foam. When listening to this recording, a low frequency rumble was heard, but was assessed to be caused by a low frequency oscillating ventilator approximately 50 meters from the recorder. As we know from the theory on materials, the lower the frequency, the more difficult it is to absorb it. The recording was therefore filtered using a highpass filter set at 209Hz, with a slope of 36dB/oct. As can be seen in figure 8.2 quite a lot of noise remained in the recording (49.3dB peak, and 62.1dB LUFSi). This noise also sounded very similar to the white noise noticed in the recordings of the solutions. This presents a dilemma. Firstly, this indicates that the previous recording with the Zoom Recorder, used in the analysis could be faulty, and have affected the HEARSEPTION lab evaluation. The second dilemma was how to handle this knowledge of the noise, as it would influence the evaluation of the solutions. One solution would be to rerecord it with better equipment, but this was not an option due to the deadline of the thesis. Two alternatives were conceived. Either to do nothing or to use noise reduction to remove the noise as gentle as possible. The second option would change the audio, and have a chance of removing aspects of the on-site sound of the soundscapes. The second solution was chosen.

To remove the noise as gently as possible, a professional (industry standard), spectral noise reduction tool, RX Spectral De-noise [68] was used. The plugin uses machine learning to learn the spectral profile of the noise, and then reduces the specific spectral components of the noise while adding a psychoacoustic component back to the sound. While it is not perfect and can affect the frequency components of the real sound, if used gently, the change it has to the audio is minimal, especially the more complex algorithm used. The noise profile of recorder noise was found, and adjusted by ear, to the point where most of the noise from the recorder was removed, without affecting the sound of the overall recording (as remembered), of the multimedia installation. The noise reduction plugin, was then set to use the most complex algorithm, and was used to process all the recordings of the solutions.

To prepare the audio for playback online for experiment 3, it is required to play them at a level where the respondents can hear them on their respective devices. The files therefore needed to be normalized. To replicate the difference in SPL of the recordings, this difference was replicated in the normalization process. The integrated LUFS value of the individual files can be seen in table 8.2.

8.2 Self-Assessment

As the first part of the self assessment, four recordings of soundscapes 8.1 were listened to twice and evaluated using the HEARSEPTION model. The reason for doing it twice was that the subjective assessment might change from moment to moment, and thus give better indication in the assessment. The evaluations were

Solution	Normalized LUFS-I value
Solution 1	-21.3
Solution 2	-19.8
Solution 3	-14.1
Zelle 2	-42.4

Table 8.2: LUFS-I of solutions after normalization

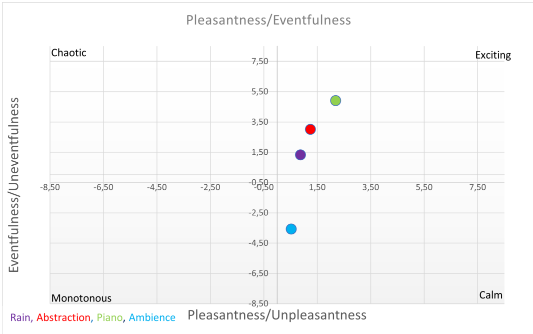

Figure 8.3: Self-Assessment Rating using the Pleasantness/Eventfulness model

then used in triangulation with the Pleasantness/Eventfulness model. Axelsson et al. [8] uses 8 descriptor words for assessment of sound, all of which are represented in the HEARSEPTION model. The words are, and how they are represented, can be seen in 8.3. A difference being that in HEARSEPTION sometimes use two word pairs represent one pair of the Pleasantness/Eventfulness model. In the Pleasantness/Eventfulness model, each of the words are rated separately from 1-100 (e.g., from 1-100 how annoying is the sound, from 1-100 how pleasant is the sound). These unipolar scales are then combined into a bipolar-scale. In HEARSEPTION only a bipolar scale is used. There are pros and cons of each method, that won't be discussed in depth in this thesis, but a reason for HEARSEPTION to use bipolar scales, is to ensure that the context of the words are understood in comparison to each other. Dark means something else, if it is paired with, e.g., light, cheerful, open or sunny. Another difference is in scale. Some research finds that a scale with 7 or 9 steps can supply results of similar and sometimes better value than scales with more steps [125], [82] & [9].

The Pleasantness/Eventfulness model uses Principal Component Analysis (PCA), to recalculate the 8 unipolar ratings into two variables, one for pleasantness and one for eventfulness. PCA is a statistical method used to simplify complex data, by transforming it into fewer dimensions, by prioritizing different aspects of the data [81]. Rather than calculating the PCA coefficients from scratch, ISO 12913-2 [152] supplies an equation based on, and specifically for the use of the Pleasantness/Eventfulness model:

$$Pleasantness = (pleasant - annoying) + 0.707(calm - chaotic) + 0.707(exciting - monotonous)$$

$$Eventfulness = (eventful - uneventful) + 0.707(chaotic - calm) + 0.707(exciting - monotonous)$$

The two variables are then adjusted to context-based factors defined as: "Presence of natural sounds, traffic noise, visual greenness, human activity, sound diversity and wind". Aspects such as traffic, wind, human activity and visual greenness are not relevant for the assessment of the soundscape of "Zelle 2", as they were made in a controlled indoor environment. If the solutions were implemented and analysed while guests were present, the human activity factor, should be included (The context-based factors are further discussed in 9.1.1). The remaining two context-based factors are represented in the HEARSEPTION model, and can be seen in the table 8.3. The context-based factors (rated 1-7) were normalized to values between 0-1 using the formula $Normalized = \frac{x-1}{7-1}$. As the combined context-based factors for each variable should end with a number from 0-1, and only one factor was used in this assessment. The equation was adjusted, with an addition, to accurately reflect the weighing of the factors by the ISO standard: $Pleasantness = Pleasantness * 0.35 * NaturalSounds + 0.65$ and $Eventfulness = Eventfulness + 0.22 * SoundDiversity + 0.78$.

To use the data gathered in HEARSEPTION some recalculation of the results from 1-7 was needed. As the PCA equation determines that, e.g., pleasantness is calculated by subtracting the rating of annoyance from the rating of pleasant, this can result in values from -100 to +100. The bipolar pairs of HEARSEPTION must therefore be recalculated to values from -3.5 to +3.5. Where -3.5 would be the same as $0(pleasantness) - 100(annoyance) = -100$. These recalculations were made using the following equation: $7 * \frac{x-1}{6} - 3.5$. It could be argued that a rating of -3.5-3.5 creates a model that is less nuanced than one made from -100-100. While this is true with only 2 ratings, it could be argued that with 100 of respondents the results would be equally varied. A second recalculation was made to present the pairs in the correct order, e.g., calm-chaotic for pleasantness, but chaotic-calm for eventfulness. After being adjusted to the context-based factors, the two variables were used to create a scatter graph, from -8.45-8.45 (The min/max values of the entire calculation: $(3.5 + 0.707 * 3.5 + 0.707 * 3.5) * 0.35 * 1 = 8.45$). All the results can be found in the Excel Document in the appendix H.1.

When investigating the plotted results of the self-assessment in 8.3. It shows that all the solutions are evaluated as more pleasant and eventful than the ambient soundscape (the multimedia installation). It shows the solution with the piano is the most pleasant and eventful than the other solutions. The two other soundscapes are evaluated as equally eventful, with the abstracted soundscape being slightly more pleasant. It can be concluded that the self-assessment shows that all the solutions succeed in improving the soundscape of "Zelle 2". This evaluation

Axelsson et al. terms	Corresponding HEARSEPTION terms
Pleasant - Annoying	Annoying - Pleasant
Eventful - Uneventful	Eventless - Eventful
Chaotic - Calm	Restless - Calm, Chaotic - Orderly
Monotonous - Exciting	Monotonous - Varied
Natural Sounds	Mechanical-Organic and Artificial-Natural
Sound Diversity	Periodic-Permanent and Eventless-Eventful

Table 8.3: Words from Axelsson, compared to HEARSEPTION

also outlines how HEARSEPTION can be used for methodological and theoretical triangulation.

8.3 HEARSEPTION: Experiment 3

As assessment of soundscape is subjective, an online experiment was conducted to verify if the solutions were successful. This experiment was made as the previous ones, with a few additional questions to provide insights into the listening situation of the participants. The additions were the questions:

- What are you listening on? Headphones, Phone Speaker, Computer Speakers, Studio Monitor, Home audio system or none of the above.
- Do your headphones use ANC (Adaptive Noise Cancelling)?
- What type of headphones are you using? Over-ear, on-ear or in-ear?
- How loud is the environment during the experiment? Rated on a 7-step Likert scale".

This experiment evaluates all four recordings. As a result, the experiment was estimated to last approximately 10–25 minutes, depending on how quick the participant were to assess the audio. SurveyXact does not allow the embedding of audio, and a workaround was therefore needed. A playlist was made on SoundCloud containing the audio, and a link to the audio was added into the survey. Participants were asked to open the audio in a different tab in a browser. This allows the audio to be played during the assessment. Before each assessment, the participants are asked to change to the sound being assessed, and to check a box saying "I am now listening to (NameOfFile)". When the audio files are uploaded to SoundCloud they are compressed into MP3, which will an influence on the spectrum of the audio. This could not be helped if the audio was to be streamed. Some research indicates the MP3 compression affects the emotional response by strengthening negative and neutral emotions, such as mysterious and sad, while reducing the felt positive emotions, such as happy and calm [95]. As all the audio is compressed in the same way, this should not influence how they compare to each other. Ideally, the order of the audio files should be randomized with the survey, but this option was not available. Therefore, the order of audio for all respondents was the same: Rain, abstraction, piano and ending with the soundscape of multimedia installation. Participates were invited via a link, either by email, by direct messaging, or social media posts.

8.3.1 Participants and Results

Some participants experienced an issue, or could not understand, how to use 2 tabs. Instead, they clicked the link in the same tab, and thereby moved away from the survey. When this occurred, they could not return to the survey. Due mainly to these, 16 participants only partially completed the survey. As the design of the experiment, is to get insights into all 4 audio files, the partially completed results were deleted. 19 participants completed the entire questionnaire at the time of data processing (22/05-2025). This is one less than was hoped for, due to the requirements of the ISO, but was still deemed enough to provide insights into the success of the implementations. The complete survey, with all answers, can be found as appendix H.3.

8.3.2 Results of the Online Experiment

The participants conducted the test at all times of day between 06:00-00:00, with majority 0.42 (42%) conducting the experiment between 9:00 and 12:00. The majority were in the age groups 26-45, and male. 17 participants were Danish nationals, conducting the experiment in Danish. One was a native English speaker, and one spoke a different European language. Both finished the experiment in English. The participants' experience with sound was equally distributed in all 7 categories, except at expert level, with only one participant. None of the participants use hearing aids. They rated their hearing ability, with an average of 65.3%. The implication of the general average would be:

- 0-40%: Most likely some hearing problems for the participant.
- 41–69%: An indication that there might be some issue with the hearing ability.
- 70-100%: No problem with hearing.

It can be concluded that as an average, there is a small indication of some hearing problems in the participation pool. A solution to this could be deleting the participants, with a combined hearing ability below 70%. Keeping these participants, on the other hand, supplies the experiment with participants with hearing abilities representing possible guests at the museum. For this reason, they are kept.

When asked about their listening conditions, 84% listened on headphones, 5.5% on a home audio system and 10.5% on phone speakers. 31.25% of the headphone users use ANC. 32% of the headphone users wore closed over-ear headphones. 25% used in-ears. 6.25% uses respectively on-ear and open-headphones. 79% rated their environment as quiet. 15.79% rated it average, and 1 participant, 5.25% was in a noisy environment.

8.3.3 Analysis of Results

When analysing the rating using the SD scale of HEARSEPTION a mistake in the questionnaire was found, as the rating of the piano solution, was missing the thin-full pair. While this is a shame, it is not fatal, as the thin-full rating, is not part of the aesthetic descriptors the solutions aimed at changing.

When investigating the semantic profiles, figure 8.4, of the four recordings together with the rating from the lab experiment some general findings can be derived. Firstly, the semantic profile of the noise from the lab experiment and the recording of the noise of "Zelle 2", have similarities, but also some differences. The main similarity is that the graph behaves in almost the same manner, i.e., what is positive in one, is also positive in the other and opposite. A difference being, that the soundscape from the lab experiment was assessed more negatively in almost all parameters, the exception being monotonous, musical, natural, and harmonious. These could be related to the sound being louder, and thereby allowing increased perception of the small changes in the detected tonal components.

When assessing the three solutions, the first finding is an affirmation of the general conclusion from the self-assessment, rating the piano solution as most pleasing. The self-assessed quality of the abstracted soundscape is not validated in the online experiment. In general, the abstracted soundscape is rated better than the lab recording, but less than the noise of "Zelle 2" used in the online survey. While the conclusions are different, it does not necessarily suggest that the abstracted soundscape was unsuccessful in its goal of inducing emotions better related to the narrative of the exhibition. As mentioned in the analysis, the aim of the solutions was not to stimulate more positive emotions, but to stimulate the aesthetic quality by making it less neutral. A second reason for the different assessment could be related to the time of exposure of the sound. Subjectively, the abstracted solution becomes more interesting when it is experienced over a larger period. This is assuming that the subtle changes, and the slow building and reducing the feedback, is what invokes the emotional response of distress. Prolonged exposure would, of course, have influence in the assessment of all the soundscape, but it is hypothesised that due to the character of the abstracted soundscape, this would change the most. Assessed online, it seems unlikely (due to the experience from the lab experiment) that the participants have heard more than 5 minutes of each soundscape.

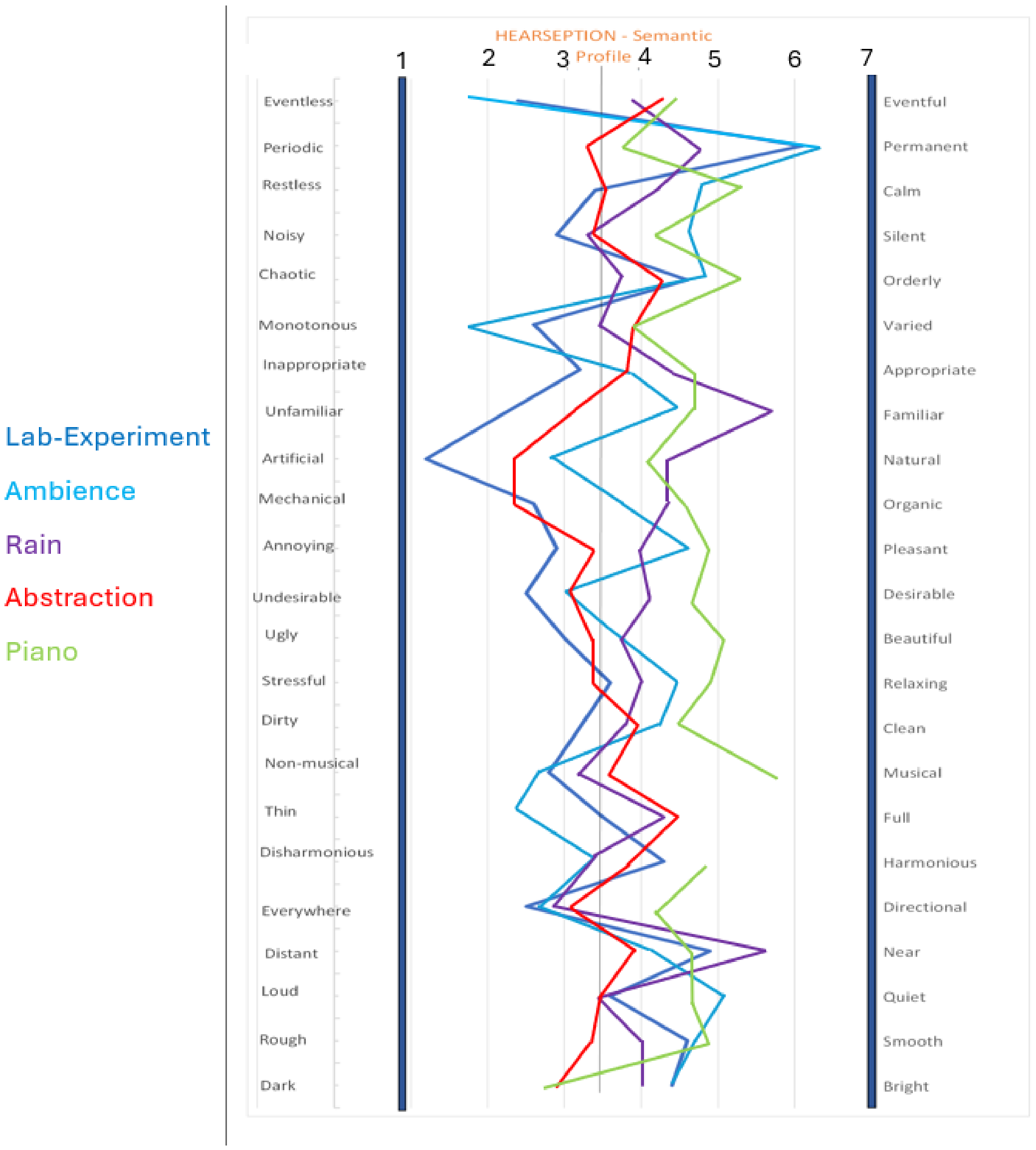

Figure 8.4: Semantic Profiles of All Solutions, as well as rating from the lab experiment

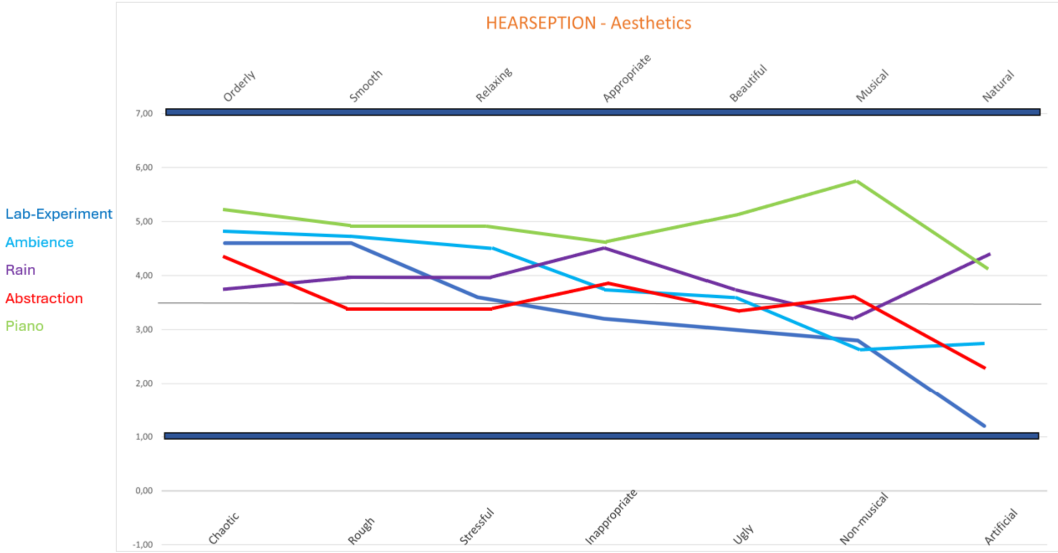

Figure 8.5: Aesthetic word pairs of all solutions

To investigate if the soundscape conversion was successful, the results of the aesthetic qualities should be investigated and connected to the aims of the 3 solutions.

Success of the Solutions

Solution 1: Abstraction The aim of the abstracted soundscape was to stimulate emotions, by making the general aesthetic evaluation less neutral by affecting the negative emotions, without being annoying. A second aim was to make it less static, and more musical. When investigating the aesthetic profile 8.5, this was not completely achieved. In general, all the word pairs were rated very close to average on all parameters in the aesthetic qualities. Except for artificial-natural, where it is rated to be much more artificial than natural. It did succeed in being rated as more musical than the multimedia soundscape, as well as more ugly and stressful. It was also rated to be more periodic, restless, varied and chaotic, which indicates that it was successful being more emotionally evoking. This assumption is based on the sound stimulating, e.g., musical expectancy, that isn't present in the noise of "Zelle 2".

Solution 2: Rain The aim of solution 2, was to change the entirety of the soundscape by converting it into rain, and thereby stimulate associations of sadness and loneliness. The main goal was to change the assessment of the artificial-natural word pair. An addition to this was to increase the assessed relaxation of the soundscape, and make it more appropriate to the narrative of the exhibition. As the assessment is made online, it is not possible to assess whether it is more appropriate or not. When consulting the data, the solution appears to succeed. The soundscape is rated significantly more natural than the original soundscape. The natural aspect, on the other hand, is only rated at 4.3 out of 7, this indicates that something is not as realistic as it could be. This could be due to the looping of the sample, or due to the synthetic rain not being realistic enough. It is also rated as being less relaxing in the noise of the cell, by 0.5 points. Both of these observations indicate that the solution should be improved.

Solution 3: Piano The primary aim of the third solution was to make the soundscape more natural, beautiful, musical, relaxing and appropriate. It also had an aim of creating a mood that was sombre and sad. The musical qualities were designed to affect all aspects of the BRECVEM model, to evoke the sought after mood. When consulting the data in the aesthetic graph 8.5, it appears that the solution was successful on all parameters. The solution was rated marginally higher than all the other solutions and the original soundscape in both musicality, and beauty. It was also assessed as the most relaxing and appropriate. Appropriate is, of course, still not usable due to the context.

Part 9

Discussion

In the previous parts of the thesis, it has been shown how and why to use ENC as a methodology to address noise problems. In this part, some implications found using this investigation must be discussed, in the same manner the pros and cons of ENC must be examined.

9.1 Why ENC, is it new, does it solve anything?

Although the analysis benefited from investigating the problem of the environmental noise in "Zelle 2" from three different angles, each individual apporoach has limitations. While each approach could come with suggestions for solutions, they would not be based on the holistic methodology of using the combined knowledge. From the Engineering Approach we could implement the solution of calculating the exact distance from the speakers, the noise sources and the listening positions and experiment with how to remove the unwanted sound with phase cancellation. We could also investigate how acoustical treatment, and material, could be used to contain the noises of the devices or reflect them from the listening positions. While this solution would change the soundscape, which could be measured in the Acoustic Environment, it is not possible to know how these might change the soundscape. How would these solutions add to the authenticity of the cell, maybe by allowing silence? It is equally likely that such solutions would bring new noises as foreground sounds, and the process could then continue. It seems an expensive solution, both in time and money. While the Soundscape Approach's analysis provides insights into how the soundscape is perceived, and the context of the soundscape, and brings solutions of how we can better connect to the soundscape and our word around us, it does not provide other solutions to the problems, apart from making us understand that they exist, and that some soundscapes are better than others. By understanding it, we know, for example, that the amplifier, or a car driving by, does not stimulate as positive emotions as sounds of life, such as birds and wind. The traditional study of soundscapes indicates that some sounds are better for an environment than others. This knowledge is important if we want to understand how to improve the world's sound, but the Soundscape Approach is mostly analytical. The main solution of the Soundscape Approach, is to listen, and learn how to listen, and in that way, determine which sounds to incorporate. For the exhibition, a solution of soundscape could have conducting listening exercises with the curators as part of planning the exhibition. These exercises could have been Ear-Cleaning from Schaffer [131] or Deep Listening by Pauline Oliveros [109]. This would have provided insights that could be used when considering and designing the exhibition. But listening does not provide solutions to the sounds that are already there. While listening and locating sound sources would identify the issue of the multimedia equipment, it would first happen after they are installed. To change the devices to less noisy ones would be a solution if budget allowed it. When asking the curator if this was sometimes a solution they used, the response was that, as they already bought it, they tend to continue using it, due to budgeting of the exhibition (11:00-11:19 D.1). When researching the multimedial equipment of the exhibition, it became clear that it is by no means inexpensive. This is due to the requirements for the projection during the narratives, that is the visuals. Knowing the importance of how the equipment sounds, is something that needs to be incorporated into the design process to minimize the unintentional sound. Still, it does not solve, that sometimes equipment makes noise, and it is not a sustainable solution to keep changing electronic equipment, if it is found that equipment owned creates unintended noise. An aspect of this is also that the sound noise is masked by the narrative when it is playing. As a designer of sound to an exhibition, using ENC as a framework, would allow the designer to work with both the sound of the room, but also know that they need to address the noise, after installing the multimedia installation. This is done by using the artistic approach. Knowing that the artistic work should include conversion and understanding of the acoustic environment and unwanted noise, after installation of the "normal" work of a sound designer, is part of what makes ENC new. ENC states that it is not enough to design sound for the sake of sound, it must also be designed to continue the aim of the traditional sound design task, when the original sound design is not in use. If the sound designers of the narrative, had been aware of, and used ENC, as a methodology, they could have included aspects of the noise issue, into their work. This is not always possible, and in cases, where something has been made, and it produces unwanted sound, ENC can be used as a methodology to reduce the unwanted sound, and enhance the wanted aspects of the soundscape. The solutions of this thesis used some fairly simple techniques of conversion, to enhance the aesthetical aspects of the exhibition, while considering how the emotional responses of guests could be enhanced. The conversion could easily have been made completely from an artistic perspective, without considering the engineering and soundscape aspects. This would move the solutions into the field of sound art. While artistic works such as those by Østengaard and Kirgegaard 2 uses sound of the environment with the purpose of changing it, their work is much more aesthetic than the solution-driven Engineering Approach. Their work could, and sometimes is, presented in a museum setting, as work in itself. ENC tries to show that sometime the best approach to enhance an artistic experience is by making sound, that is perceived as being part of the exhibition, rather than it's artistic qualities. In cases such as this, the artistic approach is more a design approach. The distinction between what is art, and what is design, and what is code, can sometimes be blurred. This is a discussion for at a different time, though. ENC can be used to create art works, but its strengths are that it approaches sound holistically. Not just as an acoustician. Not just as a soundscape specialist. Not just as an artist, but a combination of all. This is what allows ENC to create new solutions to all kinds of noise problems. Due to this, ENC can address enhancement of soundscape in an artistic setting such as a museum, but likewise in a more complex setting. When analysing the three aspects as suggested by the methodology of ENC, as shown with the noise problem of the exhibition, creative solutions should evolve from the analysis, as they did in this thesis.

While knowing that there is a problem of noise, it still presents the problem of knowing when a soundscape is better than another. Using a model such as HEARSEPTION to understand the soundscape, and to look for areas of improvement, is also one of the aspects of using ENC as a methodology. The same is the general guideline of working from the simplest possible solution, and gradually adding complexity by systematically evaluating, and planning iterations of conversion. It is of course not new, to work in this way, but it is an important aspect in understanding that the problems of noise, do not always require complex solution.

9.1.1 Implications and Realisations After Following ISO 12913

Another aspect that this thesis has tried to show is that if we as society in general should have the opportunity to address the problem of environmental noise, the methods to do it should be simple and affordable. This is the only way to make an assessment of the soundscape manageable for many types of people. This statement might seem improper, considering the analytical and theoretical parts of the thesis, but the purpose of following the ISO standard as a theoretical framework, was to show when it makes sense, and when it does not. The ISO standard is the only, international standard that addresses how to assess and work with soundscapes, and it therefore seemed valuable to understand it, and try to use it, rather than discarding it. While the general idea of the standard makes sense, but many of the requirements do not, if the purpose is to make soundscape assessment a common addition to understanding our society. For that, it has some faults. One is that it overcomplicates measurements and over aims at what is possible. Because would it be possible to collect data on "all auditory sensations, as well as all other context variables" [152]? Instead of writing "shall", should it not ask that researchers "strive towards"? By making the demands impossible to follow, they ensure that no one, will be able to collect the data, and therefore won't. Simultaneously, as discussed when implementing the Pleasantness/Eventfulness model, it seems to have some biases of what context-based factors are given value, and which ones are not. The 6 factors mentioned indicate the soundscape analysis, of both ISO and the Pleasantness/eventfulness model have a confounder factor of focusing on outside sounds, or noise analysis in an apartment. That is, the traditional work of acoustical engineers, rather than the "new" field of soundscape assessment. The models do not represent all the potential sounds of a soundscape, which again could be a result of the taxonomy used to categorize the sound sources. An example of this is how, when following the models, we should consider the soundscape created by a multimedia installation in the setting of a museum exhibition. While visual greenness is important, and has an influence, other visual aspects also have an influence (as is shown by the BRECVEM model). Does the visuals of the multimedia setting, or the gloominess of an empty prison cell, not likewise influence the overall emotions evoked by the soundscape of the cell? Or would the visuals of a multimedia installation not induce different emotions related to the interpretation of the auditory sensations of the soundscape if they showed someone sitting alone inside a prison cell shaking or someone doing pushups. Furthermore, a confounder factor can be found in the outside world. E.g., it could be imagined that hearing a playground induces different emotions, than hearing a playground, while also seeing children having fun playing in the playground. This observation indicates that parts of especially the ISO 12913 does require some revisiting if it is to by used to analyse all types of soundscapes, and to comply with its statement of "all auditory sensation, as well as all other context variables". One improvement suggested by this thesis is to use the HEARSEPTION model, for analysing the subjective data, as this supplies data that is more open for analysis and theoretical triangulation.

It could be argued that the ISO addresses objective measurement like they were objective, and that all data can be collected. This is impossible, as we already saw when describing the physical aspects of soundwaves, and general acoustics. The idea of the ISO standard might thus be to require more than needed, and then let people decide how to interpret what is possible in the context. As we saw, even the fairly straightforward "hard science", is full of subjective choices that define the outcome, and calculations. With soundscape assessment, this issue of subjectivity, is even bigger, as it is in its most basic form, is completely subjective assessments. And as described in the section on phenomenology, is it not possible to collect objective data, as long as people are involved. What therefore makes it impossible to conduct assessments of soundscape complying with the ISO standard, is that the requirement of including all aspects of something subjective cannot be done.

It appears that the working group behind the ISO 12913-2 tried to make a framework for the ideal soundscape assessment for all the right reasons, but without considering the implications on implementation. If soundscape assessment is something that should be widely used, it should also be accessible. This accessibility is one of the aspects addressed by this thesis, and in the creation of the methodology of ENC. Another example of the neglected consideration for implication is to require that all assessments are made using class-1 binaural head microphones. These are costly. These types of Sound Level Meters, would thus only be owned by a handful of companies, and those would be ones with considerable economic backing, or that the companies use these regularly. These specific Sound Level Meters are not required in general acoustical measurements. Therefore , only specialized companies would have them, and would be able to conduct these assessments according to the requirements. This is not a sustainable solution if the aim is to include soundscape assessment as a common practice. To further complicate the physical measurements, after mentioning that they are secondary, is to require an array of complex physical measurements of the soundscape. Including SPL in 2 weightings, two types of Loudness (but without directly supplying a reason for why it is necessary), and two types of LAF. But as became apparent when trying to comply with these requirements in the Engineering Approach part of the analysis 6.1, even with professional Class-1 equipment, these measurements are not always possible. As discussed in the section, LAF is normally not a requirement in the work of professional acoustical engineers. The borrowed Class-1 devices, and dedicated software, could not calculate loudness. The general suggestion of ISO 12913, especially ISO 12913-2, would be that the measurements should be conducted by professional acousticians, as these would be the only ones with the correct equipment and knowhow of using it correctly. While this appears to be logical, as they are the professionals working with environmental sound and noise problems, but at a second glance, this is another indication of the problem of implementation. This becomes especially clear in the section on data collection of subjective data. ISO 12913-2 thus suggests the use of interviews, that is then required to be analysed using the methodology of Grounded Theory [152]. This requires the acousticians to attain skills that normally are not a part of their day-to-day, the solution would be either to use a considerable amount of time to gain these skills, or to ignore this part of the standard (Personal communication with both employees at “FORCE Technology”, and at “103aps Rådgivende Ingenører”, Nov, 2024). It is more likely that soundscape assessments should be conducted by cross-disciplinary groups, and that such teams will be common in the future. But for now, the standard sets to many cross-field specific requirements to allow wide-scale implementation of soundscape assessment. This could be an indication of the ISO standard aiming for soundscape assessment to be made by cross-disciplinary teams working at universities, as these seem to be the institutions that both have the finance for the equipment, and the cross-disciplinary employees with the required expert level of skills in all fields. This thesis argues that this is paradoxical, as the essence of a standard, is to allow wide scale implementation, following certain rules to ensure consistency. Even when striving to fulfil the requirements of the standard, as this project does, it is impossible not to cut corners, and skip certain aspects due to either problems with time, economical backing or too wide a requirement of cross-subject expertise in close to all scientific fields.

A more general critique of the standard is that while the definitions of sounds from ISO 12913 are simple and easy to understand (sound source, acoustical environment and soundscape), it could be argued that they fail to be sustainable and ecological. The definitions neglect that organisms as a whole live in the soundscape, and by focusing on humans it indicates a bias of anthropocentrism. And as the field of bio-acoustics is evolving with more and more complex algorithms, interspecies communications, and the perspective of these other organisms will at one point have to be considered [10]. Also, as we move into a future where machines will build machines, can these be defined as a sub-category of human activity, or is it a new category? Even though this might be slightly philosophical, when the aim of the standard is to ensure a future practice, it could have ensured that such views cannot be used to discard the standards.

The positive aspect of using the ISO standard, as this thesis has hopefully shown, is that it supplies a systematical way of knowing what to look for in a meaningful way, that tries to make the assessments holistic. This thesis though claims that the standard needs to be changed if it is to be followed.

Changing models

By changing the models provided by the ISO, it is obvious that this thesis is not exactly following the requirements of the standard. Specifically, that it requires the use of Brown et al. taxonomy [21]. But as hopefully was made clear when the taxonomy was presented, the models were not changed despite the models, but rather to improve the models and adjust them to the specific setting of the exhibition. While this might suggest that the models should always be changed to fit certain settings, this was not the purpose. Rather, the purpose is to emphasise that the model from the ISO is useful, but could benefit from being adjusted, as pointed out in the arguments in the theory section. It could be argued that changing the models is bad scientific practice, but the argument could as easily be turned around to claim, that changing the models were precisely what was needed to evolve and further iterate the scientific field, which would be good scientific practise. ISO standards have been updated before, and as is hopefully shown in this master's thesis, the ISO 12913 could use a revision to ensure easier and more fitting implementation of soundscape assessment and analysis. It could also be argued that by changing the taxonomy it is easier to use in triangulation, due to the categories being more flexible. Why is for example laughter in the category of voice instrument, while they have a category of "Other human" which includes "coughing" as an example? Why is laughter similar to singing and speech, but crying or screaming, must according to the taxonomy be "Other" and closer related to coughing. Even though they argue that a sound can be in different places in the taxonomy at the same time, this does not explain this distinction. Especially if the setting is an exhibition, and inherently art, where one could imagine experimentation with the perception of sound, could be the aim of the artwork. If the taxonomy should be holistic, it should allow these artistic interpretations and soundscape transformations to be in the taxonomy without too much argumentation and interpretation. The taxonomy, presented in this paper 4.2.2, could be argued to be an improvement in that direction. Including the distinction of other sounds as "soundmarks" or "non-soundmarks" also seems to be a valuable addition in understanding the soundscape. This is due as the purpose of the taxonomy is to investigate and classify the sound source, it does not need categories such as, foreground or background sounds, as well as distinctions if the sound is a soundmark or not. It could be argued that a taxonomy of soundscapes would benefit of including these aspects in the definition of the soundsource, and thus connect the context more directly to the soundsource. This would be helpful in archival and retrieval work of soundscape. All of these changes are to try to make the requirements of the ISO standard more holistic, and thus better fit within the methodology of ENC.

9.1.2 ENC as an Alternative to ISO 12913

Rather than ignoring the implications of ISO 12913, this thesis suggests using ENC as a much more accessible way of working with soundscape assessment, while also having the benefit of creating solutions as already mentioned. Being accessible and simple does not mean, that what is found of less quality than assessments made following the ISO standard. It instead suggests e.g., that rather than hard-coding and calculating everything from scratch, to find and use available software, that fits the skills of the user, or at least allows the user to learn it without much hassle. The thesis should thus be considered a framework showing how, and why, these measurements and analysis can be made. It does so by explaining the theory behind the measurements, and showing how this theory can be implemented by using easily accessible software. The users conducting assessment of soundscape using this framework, do not need to know the theory, they just need to know what to do, and what not to do. By following the methodology of ENC, they can assess soundscapes and get acceptable and usable results. If people are mathematicians, they might want to focus their creative power, on the calculations, and manipulation of the sound using mathematics. Programmers might want to create their own algorithms, or improve upon existing ones from the programming community. Artists might want to focus on specific aspects of the sound, that fit their artistic practice. Curators might want to focus on the context of the exhibition and how understanding the soundscape and manipulation of the soundscape can be used to enhance the experience of their guests. How thorough the ENC investigation of the soundscape needs to be, is defined by the context of the investigation. In a museum, the need for exact Class-1 measurements are not strictly needed, rather the same aspects of RV60, SPL, LAF and loudness, can be found using an inexpensive measurement microphone and REW. If the case, on the other hand, is the soundscape of an open office, the context changes, and the laws that are relevant for this type must be complied with. In the office case, Class-1 measurements of RV60 as an example. ENC can thus be used accordingly with the project, using the framework of implementation that this thesis presents. For sound designers working with specific manipulation of the sound, proper spectrograms, and other relevant data could be made and coded to fit the context of their design task. What this thesis tries to state with the methodology of ENC is that: Sometimes there is a need to create something from scratch, but only when it must be made from scratch (it might be required by the context or by the users wishes for the sound manipulation), if not, there are many available tools that can be used. In this time, we live in (as of 2025), finding these tools, and getting to know them, has never been easier. Both search engines, and language-based AI models, are freely available, and if used correctly can locate what the user is looking for. The general rule is, "that if you think about something, someone else has probably already made it", and what they have made is often free, like REW. If not completely free, then it is often free to use for non-commercial use, and for a small fee, can be used commercial (e.g., amroc, costs 25USD a month, for business use). For people who have the skill, many libraries can be found on, for example, GitHub. When needing to be completely exact, and have full control of the data, libraries such as "Reverberation Time Calculator" by Zechmann [176], for MATLAB supply this for RV60 calculations. But in most cases, there is no reason to understand the thousands of lines of complex code, that it supplies. For many cases, such as this thesis, REW supplied the same initial data, that could be used to make the same calculation, but reduced the time. With AI, search engine and YouTube, almost anyone can be guided to make the necessary calculations required by ENC.

In the thesis, the solutions were made in a combination of using standard functions in a DAW and different VST's. When the solutions required direct manipulation of Bark Bands, and specific goals for analysis, this was made in code using plugdata. The specific codes, such as the Bark Band filter, could easily be made available on GitHub or used by all. There, of course, are some aspects of using different gear, as the thesis also showed. For example, how the data from a inexpensive Sound Level Meter, is much less precise than that of a Class-1 meter. But that does not mean that the data from the inexpensive meter is useless. In the thesis, it was used, to indicate the different levels of the solutions compared to each other. It is also possible to create a fairly inexpensive device that others could use to make the measurements (more of this in 10.2.

In the solutions, the thesis used an impulse response of the room to create a convolution reverb from an exact listening position. This method is easy to replicate, and supplies the designer with an emulation of the acoustic environment that makes implementation of solutions much easier. For most cases, it is not necessary to understand the RV60 of the room, as the IR will supply the general sound. Measuring RV60 is only necessary if the found information is to be used as values for manipulation. For most people, creating a spectrogram using free software should also be sufficient to give indications of what frequency areas are most present, and should be the main aim for the masking. If the case is to use energetic masking, a more general analysis using bark bands should be used. It has not been possible to find such a tool, but one could be coded and supplied by, e.g., GitHub. In general, and in the most simple form, people using ENC should as a minimum investigate the spectrum of the soundscape, and use a measure of SPL, to know how loud the solution should be when designing it. Then an investigation of how the soundscape is assessed using HEARSEPTION should be conducted, as well as an analysis of the specific context. This information should then be used to inspire creative solutions to the noise problem based on the experience and skills of the person trying to solve it.

It is important to know that the cheaper the equipment is, especially preamps and microphones, these will influence the recorded soundscape. However this does not mean that inexpensive equipment cannot be used, rather it means that the user should know that the equipment has limitations and changes the sound. It is not catastrophic to have much noise from a microphone if the converted soundscape is made to use this added noise to create solutions. In analysis, it should be noted that cheaper equipment will always create less precise results, and this should always be considered in comparison to the context and aim of the ENC implementation.

9.2 Evaluation and Solutions

Using the "prototype" of HEARSEPTION to investigate the data, worked as intended. It was easy to implement, and the participants had no problem in rating the words. It was also possible to use the data in triangulation. In general, the evaluation would benefit from many more respondents. Using specific aspects of the HEARSEPTION model as aims of improvement, for example, making it more beautiful, was an easy way of evaluation if the aims of the solutions were successful. In general though, as many of the aims were to change the assessment using BRECVEM, this could have been investigated better. Participants could have been asked what inner imagery they saw, or some other questions that elaborate the association, would have been a valuable addition. On the other hand, in the analysis, if the semantic profiles were analysed more in depth, BRECVEM could have been used to hypothesise why, for example, the piano was perceived as more beautiful than the rain. While this would have been valuable, it was not strictly necessary to evaluate if the solutions were successful or not. Other theoretical models of emotions, could also have been explored, and used to investigate how theoretical triangulation could happen. In general, the evaluation neglected the psychoacoustic parameter and indicators slightly. The theory showed how important in perception they were, but that aspects were not further investigated. The analysis of both the solutions and the soundscape calculation psychoacoustic indications, could have supplied some valuable insights into the possible emotional invoked by the soundscapes.

A major flaw in the solutions, and the thesis in general, is that the solutions are made using a recording of the soundscape rather than being directly related to the soundscape. Due to this is it not completely possible to conclude that the ENC solutions would work as intended in the context, or if they would create a total unpredictable and controlled soundscape. While there is a possibility of this, a hypothesis is that this would not be the case, if it is programmed intelligently knowing that these factors exist. One approach is explained in the future work section 10.3.

It is also a shame that the experiment in the museum did not attract participants, as this would have been valuable data in understanding the difference of perception in the different types of experiments. As the lab and online experiment showed, the soundscape was assessed similar, but not the same due to the setting.

While the evaluation showed that all the converted soundscapes succeeded in changing aspects of the soundscape according to their aims. The abstracted soundscape, did not entirely deliver on the general aims, but it did succeed in making a more varied version of the static soundscape of "Zelle 2". The rain solution uses attention masking to change the entirety of the soundscape, but can be improved and made more natural. The solution with the piano was rated most successful both in the self-assessment and in the online survey. Further iterations of this might further improve it's rating, especially over long periods of exposure. Both the sounds that used attention masking, rather than sound dressing and energetic masking were more successfully evaluated, this, on the other hand, does not mean that they were unsuccessful in masking the sound, as can be seen in the spectrograms in the conclusions of every iteration. Interestingly, the abstracted soundscape was the one that masked the sound with the lowest measurement of SPL, which in the context of the exhibition might influence the successful implementation of the ENC solutions in the exhibition. It is easier to mask a sound by adding more sound, but this might not always be the best solution. If ENC was to be implemented to solve general noise problems in society, the less sound produced by these solutions could be a valid design requirement.

Part 10

Future Work

10.1 ENC as a Methodology

Environmental Noise Conversion, as presented in this thesis, could be considered an iteration of developing the methodology. In this iteration, the most thorough aspects as related to previous work were in the Engineering Approach, by using and interpreting the requirements of ISO 12913. While this has given useful insights, developing a general, easily understandable, step-to-step guide on how to implement ENC should also be made. This would make it much more accessible, and simpler to understand. This step is vital, if ENC is to be a general model of soundscape assessment. It would be a shame to present ENC in the same way as the ISO 12913, that is difficult to read, and overcomplicates matters. By using the standard it allows, as mentioned in the discussion, ENC to be used as an analytical methodology, that can be used to find solutions to differently complex problems of noise on various scales. It became apparent, as also found in the related works, that future work on how to address and use the variety of context-based factors should be further developed and defined, if the purpose is to develop a holistic model.

The same rigour given to the physical characteristics of sound, and investigation on how to use them in different contexts, could be made for the other two approaches, each building on the previous one. A second iteration of developing the methodology would be to validate and further develop the HEARSEPTION model of collecting subjective data. A response from participants in the lab test was that they thought it was fun to listen to sounds in this way. This indicates that the chosen words are varied enough to make people think. During the controlled experiment, almost all the participants laughed at one point during the test, and asked about it, they couldn't recall exactly what word pair it was, but that it was because it made them think. As the order of the words was random, it is likely that it is not the same word, but the combination of a thought process at one point during the test. This indicates that HEARSEPTION might also be used as a way of enhancing listening experiences, in the same way as Ear-Cleaning and Deep-Listening does. Further investigating this aspect of the model, would be interesting. During the experiments, and especially when using HEARSEPTION for triangulation, it did appear that the model would improve with adding a word pair to represent Exciting of the Pleasantness/eventfulness mode. This could be represented in a word pair such as: Exciting-Unexciting, Stimulating-Boring or Arousing-Suppressive. Furthermore, the term periodic-permanent, could be reversed to permanent-periodic, as permanent could be considered as being more negative than periodic. But this is inconclusive, and would depend on the sound. As intermittent and impulsive noises are understood as being more annoying than permanent noises, if they are at a certain SPL [101]. In general, while the HEARSEPTION model supplied valid data in the evaluation of subjective data, it would improve through more thorough testing. A proper systematic literature review, defining where the words are found, and where, would be needed. Furthermore, a test of the words is understood as intended. The categorization of words to create averages and graphs, such as Aesthetic, is a very useful feature, but the exact definitions of which words belong to what description would also benefit a more thorough explanation and testing. HEARSEPTION is thus still an early iteration of a final holistic model, but it does work as intended, even though it can be improved. An especially useful addition to the model relates to how it can address the problems of the language barriers as defined by other research 2.2. A solution to this could be to make a dedicated website for the HEARSEPTION model, where all the words, and descriptors are available, and users or experts could translate the model into an array of different languages, all with explicit definitions of the words, to ensure that people can use it in their native language. A website like this would further improve, if it could do the recalculations of the model into other models, and into specific theoretical frameworks. The frameworks used in the original creation, are by no means the only ones that could relate to the theory.

A second addition to developing the Soundscape Approach, would be to research, how to analyse the context, to find some methods that could simplify and standardize these aspects. In the thesis, the narrative, and the scores of the music in the narratives, were generally analysed and somewhat superficial. While there are many methods of e.g., media studies, and literature science, many of these might not be easily implementable, and they should be investigated. Especially if the analysis of context is less straightforward than a museum exhibition, this research would be valuable. How, e.g., do we analyse the context of a city square, next to a hotel, where a noisy tram passes by every 10 minutes? Indications of this could possibly be found in urban planning. A general guide to the complexity of different locations should be investigated. Possibly different methodologies could be added to the taxonomy used to define the acoustic environment. Moreover, the aspect of how to ensure that the solutions of ENC are sustainable, could be researched and defined.

The Artistic Approach could also be researched in the same way. In the thesis it was mainly used in the analytical aspect, combining the findings from the other two approaches to, get insights into what aspects would be interesting to convert. This analysis was used to create design requirements to help to ensure the solutions were connected to different aims. It could be argued that this an approach more in the field of engineering and design, than that of art. There is therefore a lot of potential in exploring different methodologies and artistic practices, that could be used to inspire, frame and create solutions within.

10.2 Making ENC more Accessible

In addition to providing an easy-to-understand implementation guide for the ENC methodology of soundscape assessment and solutions, could be to make algorithms and devices that can conduct the measurements and calculations. This would be in the same way, as a website that can help organising and using the HEARSEPTION mode. A future project in this sense could be to create a small computer, for example on a Raspberry Pi, that is programmed to make the necessary calculations, that only requires the user to follow some directions, such as: Decide where the sound is heard, place the microphone at that spot at the same height as your head, press calculate. The measurements could be done with using the MiniDSP UMIK-1, or UMIK-2 and MiniDSP EARS (they cost between 79-299USD), to make measurements accessible and easy using REW or Dirac. Most of the calculation could be done using REW or Dirac, and directed by some code in, for example, Python or ArduinoIDE. While they are not Class-1 SPL devices, they can supply most of the information needed. They can find SPL, RV60 and much more that could provide data, that could be used in both the analysis and in the conversion process. Sensors could be added to the device to add some variables that more closely relate the device to the room. This could be sensors to measure temperature, humidity, or light. These could be used to change the sound if it is day or night, or winter or summer. An array of alternatives could be preinstalled on the device, and an easy interface could be made that allows users to change between algorithms. Such a device could be made in a nice-looking 3D-printed case, and sold to, for example, museums.

Future work with creating algorithms and different codes that could be reused in different context could also be the aim of future iteration. It was not possible to find an easily usable algorithm or pd-patch that could calculate loudness, and it should not be impossible to create one. The same was true for an algorithm to recalculate RMS to SPL, and this should likewise not be impossible, especially if a measurement of SPL could be used as reference. Such basic calculations should be made, to allow easier and better analysis for future ENC solutions. All of this could also be made accessible via e.g., the same website as the HEARSEPTION model.

10.3 Future Iterations of Solutions

The iterations made of the solutions, in the specific case of "Zelle 2", have many areas where they can be improved. An example could be by adding spatial elements, and incorporating the solution into the multimedia installation. By adjusting the converted soundscape to the spatial aspects of the speakers of the multimedia installation, a more immersive experience would have been created. Investigating the spatial aspects would also allow adjusting the converted soundscape to fit the other exhibition rooms, and different listening positions. This could be done by sending a signal of the solution to the projector in the entrance, and use the built-in speaker of the projector to play a version of the converted soundscape, that was adjusted to fit the spectral components of the noise from the projector.

To prepare the audio to the real-time soundscape from the room, some aspects would also have been needed to be incorporated into the code of the solutions. For solution 2 and 3, the plan was to take a snapshot of the data in intervals of 1 minute, and convert the values of the solutions using a ramp. To ensure that unintentional sounds would not disturb the intended conversion, a noise gate would have been placed before the snapshot, that would close if the amplitude recorded would exceed a certain level, that would have been found in the room. To prevent unintended feedback, the microphone would have been placed close to the foreground sound of the amplifier. While this would prevent some feedback, it is not certain, that it would work entirely as expected, and would have needed adjustment as part of the test. For solution 1, that uses the sound of the environment as the source of the audio it generates, a different method would have been used. Firstly, it could be tested without interference, but it was expected that this would create some uncontrollable feedback. A second solution planned was to record the soundscape, for example 5 minutes, and playback a recording as the input to the solution. This would have to be programmed in plugdata, to allow recording from the microphone, and playback the previous recording of (5 minutes), simultaneously inside the conversion algorithm. A gate would, in the same way, be used to ensure that sounds of guests talking would not be recorded. If the solutions were implemented as part of the existing multimedia installation, some data from the installation indicating when the video is on or off, would be needed as well. This would be an iteration of the solution design.

Part 11

Conclusion

11.1 Recapitulation of the Work of the thesis

This thesis has now explained and demonstrated how to use ENC as a methodology to understand and create solutions. This was following the ISO standard for soundscape assessment. This understanding and different approaches to measuring sound were then used to investigate the acoustic environment of the soundscape of the exhibition "Zelle 2". The first step of the methodology was to analyse the objective aspects of the soundscape and acoustic environment as the Engineering Approach. Subjective and context-based data was then gathered and analysed, and presented as the Soundscape Approach. This was done by introducing the evaluation model of HEARSEPTION, as an efficient alternative to subjective assessments of soundscape. To understand the context of the soundscape, the narrative of the exhibition was investigated, and combined with an interview with a curator of the exhibition. The last aspect of the analytical aspect of the methodology of ENC was to analyse the findings for interesting aspects that could be used in converting the soundscape. This was introduced as the Artistic Approach.

Three different solutions of sound conversion, with different aims and techniques, were then used to transform the soundscape to enhance the experience of the exhibition. The solutions were evaluated, firstly by self-assessment, by triangulating HEARSEPTION with the Pleasantness/Eventfulness model. Secondly, the solutions were evaluated by conducting an online survey using HEARSEPTION. The evaluation indicated that the implementations of solutions were successful in most parameters.

Subsequently, the general methodology and theoretical aspects of the thesis were discussed. The discussion both presents a critique of the ISO standard, and suggests improvements to it. Likewise, it discussed the complications and benefits of using the ISO standard. Suggestions for future projects using the methodology as presented in this thesis were discussed, as well as aspects to further develop

ENC as a methodology. It was stated that the methodology, at this state, is mostly based on a systematic approach to the engineering aspects, and that future developments should aim at the same systematic development of the two other approaches. It was discussed how the evaluation model of HEARSEPTION would be improved and made more accessible.

It was discussed that the methodology of ENC could be used to solve large-scale problems of environmental noise, using the same methodological approach presented in the thesis. The implementation in the thesis had some limitations, as some requirements of the ISO 12913 were not followed, such as measuring loudness. This important aspect is a major limitation in the thesis analysis of the acoustic environment. Secondly, the on-site assessment of the soundscape was not successful in attracting a sufficient number of participants. In general, the assessments of the soundscape were made using a minimum number of respondents, but were successful in demonstrating the potential of HEARSEPTION.

11.2 Conclusion

This thesis has thus shown how Environmental Noise Conversion can be used as a methodology to enhance and understand site-specific experiences of soundscape. This was done in compliance with requirements of international standards, to show how these can be validated through a holistic investigation. The introduced methodology of ENC as presented in this thesis, can be used to solve many types of problems of environmental noise. Some of them would require a more thorough analysis, and the use of the best equipment. Assessments using inexpensive equipment should acknowledge and comment on their limitations, such as added noise, or imprecise measurements. Other problems can be addressed with the same rigour required by the standards, but be adjusted to fit the aim and budget of the soundscape investigation. The thesis suggests that while ISO 12913 is a valuable addition to soundscape assessment, it does not make soundscape assessment accessible for wide-scale implementation. The requirements of the standard emphasize the engineering aspects, and while this is a valuable guideline, it does complicate who will be able to conduct assessment of soundscapes. This Master's thesis has shown how using Environmental Noise Conversion can be used both to analyse environmental noise problems and to create practical, cost-effective, solutions to the problem of noise. It furthermore shows how the model of HEARSEPTION can be used to collect subjective data in a highly efficient and accessible way, that does not require any expensive equipment, or large budgets. ENC is presented as an alternative context-based methodology, that adds the aspects of creating solutions, rather than having an emphasis on problems.

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Appendix A

Audio files, Reaper Sessions, Video, MATLAB and Plugdata Patches

A.1 Audio Files

The Audio files , has been handed in as an appendix on digitaleksamen. They can be found in the folder called "Audiofile". The files are organised in folders, after the type and stage of the file. The measurements made using Svatntec are in the folder called "Svantec".

A.2 Reaper Sessions

The Reaper sessions, has been handed in as an appendix on digitaleksamen. They can be found in the folder "ReaperSessions".

A.3 Plugdata Patches

The plugdata patches have been handed in as an appendix on digitaleksamen. They can be found in the folder "PD - Patches".

A.4 Video

The presentation video of the project and solution has been handed in as part of the appendix on digitaleksamen. It can be found as the file "PresentationVideo.mp4". The video uses video recorded inside the exhibition at Museum Kolding, made during the guided tour mode.

it can also be found using this link:

```
[y, fs] = audioread("RecorderNoise.wav");
nfft = 2^11;
l = 2^9;
w = hann(l);

low_bar = 30;
high_bar= 4000;

y = bandpass(y,[(low_bar*0.8) (high_bar*1.25)],fs);

y_db = 20*log10(abs(y))

fundamentalFreq  = pitch(y,fs);
fundamentalFreq  = mean(fundamentalFreq)

fundamentalFreq_db  = pitch(y_db,fs);
fundamentalFreq_db = mean(fundamentalFreq_db)

[mag, freq, time] = spectrogram(y,w,[],nfft,fs,"yaxis");

freqSpec = find(freq >= low_bar & freq <= high_bar);
freq - freq(freqSpec);
mag = 10*log10(abs(mag(freqSpec, :)));


imagesc(time, freq, mag);
axis xy;
xlabel('Time (s)');
ylabel('Frequency (Hz)');
colorbar;
ylim([low_bar high_bar]);
```

Figure A.1: MATLAB Spectrogram Code

A.5 Matlab Code Used in Project

The MATLAB code, as an M-file, can also be found in the appendix files handed in on digitaleksamen. It is the file called "spect.m".

Appendix B

Use of AI in the thesis

AI has become, and probably will continue to be a tool, that will be used in many parts of society and in the day-to-day work of many people. Aalborg University, CREATE, allows the use of AI, as the knowledge and experience of using AI should be part of the most valuable education [170]. Using AI demands that the user approach it critically, as AIs are far from perfect. AI has been used as a helping tool, and not to generate theme, ideas, experiments, code, or others contend of the thesis. All part of the thesis are the responsibility of the author and the author alone, and no part of the thesis is generated by AI.

B.1 The use of Artificial Intelligence (AI), in the thesis

As grammar checker, LanguageTool and Claude, was used to spot mistakes in language use and syntax, that could have been missed, due to the cognitive bias, of not noticing ones own mistakes.

Secondly, Perplexity and Primo Research Assistant was used as a helping tool to localising some literature, when a subject or an angel to a subject. The validation of the literature was afterwards investigated, both to investigate the review process and how often it has been cited using Google Scholar and Scopus.

Claude was used to check if some formulation of ideas and concepts, written in the thesis, are explained as intended. The answers from the AI were often biased, simplification and (sometimes) wrongful of a complex subject. The point being that AI has been used to explore knowledge, but never to be the source of knowledge.

Whisper, supplied by Aalborg University licence, was used to transcript an interview. The transcript was full of mistakes, and was afterwards manually adjusted. There were mistakes in words, and in the time code, Sometimes whisper added sentences, that were not from the interview.

Claude has further more been used to provide feedback on the planning of the project, the structure of the report, and the flow in presentation of ideas and iterations. Claude was chosen specifically for this because of Anthropic behind Claude, promises not to train or use the data inserted into Claude, unless specifically stated in the prompts, or by using the like/dislike buttons. The prompt for the project was as follows:

Supply feedback on my master's thesis, in Sound and Music Computing, from Aalborg university, Denmark. The thesis concerns soundscape, conversion of soundscapes, and general I want to get feedback in these areas:

- 1. The readability, and if there are mistakes in spelling, syntax or word use.
- 2. Mention if the interpretation of theory, calculations, or methodology is used wrongfully.
- 3. If improvements are needed in the overall building of arguments.
- 4. I do not want AI to change anything, but solely to provide feedback.

Appendix C

Full list of Word pairs with EPA Definitions

Pair number	Word	Word 2	Definition word 1 Eng	Definition word 2 Eng
1	Eventless	Eventful	no activity or non-noticeable events.	with a multitude of simultaneous or sequential instances of activity.
2	Periodic	Permanent	repeating cycles; recurring in intervals; some time is, sometime is not;	always; will not change
3	Calm	Restless	without disturbing or disorderly activity: resting; relaxing	unable to relax; not keeping still; always in motion
4	Silent	Noisy	absence or disaperance of sound	abundance of loud turbulent and sound; something making it difficult or imposible to pinpoint elements within
5	Chaotic	Orderly	completely random and unpredictable	following a predictible pattern; being organised; well defined rules
6	Monotonous	Varied	having no or very little variation; something repeated to the state of inducing restlessness and/or boredom	containing aspects of many aspects that differ over time; something divers; changes over time
7	Appropriate	Inappropriate	fits or appear to be correct in a context or in comparison to requirements	Something that stands out as wrong in a context
8	Unfamiliar	Familiar	not experienced before; something new; having no acquaitance with	recognisabel; incountered before; beeing acquainted with

Figure C.1: Word Pair 1-8

Pair number	Word	Word 2	Definition word 1 Eng	Definition word 2 Eng
9	Natural	Artificial	not natural; made by humans;	as made by nature; Occurring in nature without human intervention; Something that seam to be as it is supposed to be
10	Mechanical	Organic	something like a machine; without counsiousness; automatic	natural; like a living organism;
11	Pleasant	Annoying	something that gives or stimulate pleasure or satisfaction. e.g., stimulating positive emotions.	not giving pleasure, something that irritate, something that is stimulating negative emotions.
12	Undesirable	Desirable	to not strive for; unwanted; does not appealing ; giving no pleasure	giving pleasure; appealling; something to furfill a wish
13	Ugly	Beautiful	without aestheticly pleasing qualities; inducing negaitve emotions; something that is unapealing to senses	asthetically pleasing; inducing positive emotions; something that is appealing to senses
14	Relaxing	Stressful	releved from tension; loose in stucture; something not tense; incucing calmness and peace	creating tension; something that induces/cause stress

Figure C.2: Word Pair 9-14

Pair number	Word	Word 2	Definition word 1 Eng	Definition word 2 Eng
15	Clean	Dirty	free from dirt, smudge or smear; a thing without interference	something that has something attached to if that adds impurity; contaminated;
16	Non-musical	Musical	not percieved as having any elements relating to music	percieved aesthetically as being or being like music; something than includes musical aspects such as melody, harmony and rhythm
17	Thin	Full	consiting of little material without much power; with minimal substance and debth	uses all avalible space; maxinum substance and debth
18	Harmonious	Disharmonious	elements suplement each other; something in agreement; something consitant	elements that do not suplement each other; something in diagreement; something where parts are clashing notisably
19	Everywhere	Directional	in all places; has no pinpointable placement	in a particular/specific/notisible direction
20	Near	Distant	in close proximity to the point of interest;	war away from the point of interest
21	Quiet	Loud	little or no sound; sound with a low dB/volume	sound with a high dB/volume; sound that is difficult to ignore
22	Smooth	Rough	something caursing no resistance / friction; something causing no difficulty	something with resistance/ friction; something difficult
23	Dark	Bright	without light; emotions that are negative; not reflecting light; completely immersive;	with high intensity of light; something clear; emotions or thoughts that are hopeful; reflecting light

Figure C.3: Word Pair 15-23

Appendix D

Exhibition Narrative and Inspiration, supplied by the museum

The museum has shared the two documents that they have used as part of planning the exhibition. The first document I.1, is the background information with some illustrations to capture the mood of the exhibition overall, and the 3 narratives of the exhibition. The second document D.3 is the manuscript they supplied to the production company behind the installation, this includes both the text that should be narrated, and also some comments of what sounds and images they wish for, and at what time, in the different scenes of the narratives. As the exhibition is in Danish, made by Danish people, both materials are in Danish, and will not be translated.

D.1 Interview with Curator

The transcription of the interview has been handed in as an appendix on digitaleksamen. It can be found in the folder "Exhibition material + Interview". The signed consent form, allowing the use of the data from the interview, can likewise be found in the same folder.

D.2 Mood board, inspiration, and milestones

The Mood board and background information on the exhibition is part of the material supplied by the museum and has been handed in as an appendix on digitaleksamen. It can be found in the folder "Exhibition material + Interview", as the PDF "Zelle 2 - baggrund og inspiration - Milestone". The images from the Mood Board are borrowed from the Museum, and they are allowed to be used if they are credited to "Kolding Stadsarkiv and Others".

Hej [redacted]

Email sent 18th of April

Her er en kort update. Jeg er stadig i gang med min analyse af Zelle 2, som tager lidt længere tid end forventet.
Det er primært det teoretiske og en triangulerbar metodisk tilgang som trækker arbejdet ud.
Jeg skriver blot for at sige, at det går frem af, men at jeg ikke regner med at skulle teste noget de næste par uger. Som det er nu regner jeg dog med at komme forbi den 28, for at undersøge hvordan min løsning kan implementeres i de korrekte rammer.

Jeg har et par spørgsmål inden, som jeg håber i kan svare på.

1. Har en en form for "behind the scene" af udstillingen, hvor visionen med den er klar, og gerne en jeg må citere? Det kunne være en specifik teoretisk eller metodisk tilgang, eller bare en plan for udstillingsdesignet.
2. Har i et ønsket output, som i håber at publikum tager med sig fra udstillingen? selvfølgelig er der noget viden, men jeg tænkere mere på om i har et mere subjektivt response, så som: "Vi håber de går der fra med ærefrygt og medfølelse for fangerne, og en forståelse for det følelsesmæssige forfærdelige ved at være indespærret i Zellen imens man venter på mulig tortur, og frygten for at man kommer til at afsløre sine venner."?
3. Ift. Filmen, har i et brief til den, eller evt et manuskribt, som jeg må citere?

Mvh og endnu en gang tak for at lave mig eksperimentere i jeres celle.
Nikolaj

Hej Nikolaj

Reply received April 23rd

Vi har nok ikke helt det du efterspørger, men forhåbentlig kan du få noget ud af det alligevel. Det, du beskriver i punkt to, er ret meget det vi håber på gæsten oplever, men vi har bare ikke rigtig skrevet det ned undervejs i arbejdet. Inden næste uge får jeg lige set efter om vi har noget fondsansøgningsmateriale liggende hos museumsdirektøren.

Figure D.1: Email correspondence with curator (cited with permission

D.3 Narrative of the Exhibition Videos

The manuscript for the narrative of the exhibition has been handed in as part of the appendix on digitaleksamen. The PDF is called "Manus for Narrative of Exhibition video", and can be found in the folder "Exhibition material + Interview".

D.4 Scores

The Scores from thee ending songs of the narrative, used to find the key of the music, have been handed in as part of the appendix on digitaleksamen. They can be found by name of the score in the folder "Scores" inside the "Exhibition material + Interview" folder. The scores are identical to the scores as they are shown in Højskolesangbogen [64].

Appendix E

List of Sound Sources

and been giving codes, based on the room they are located in. When the narration is playing, all the sounds are background sound, but this changes the moment the sound from the multimedia presentation ends, some of them change into foreground sounds. new definition that is mentioned in the table. In the taxonomy, the sound sources are positioned as "Indoor Acoustic Environment" ↓ "Exhibition" ↓ "Sounds Created by Human Activity" ↓ "Electro Mechanical Device" ↓ Device description in table. There are a few exceptions, and in these the description of the taxonomy begins with x-"earlier position in the taxonomy" ↓ New position.

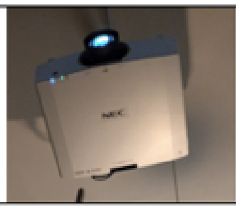
Code	**Sound Source**	**Taxonomy**	**Foreground / Background**	**Where**	**Image** *(if not overhear from wall, or door)*
COR-01	Sound from 1943 exhibition	Speakers / Sound Installation	Background	Door, walls	
COR-02	Sound from 1943 exhibition	x-Sounds Created by Humans Activity– Social Sounds	Background	Door walls	
COR-03	Speakers x4 – Audac VEX011A	Low amplitude white noise from speaker	Background	Between ventilation pipes, in ceiling	
COR-04	Ventilation pipes	Ventilation	Background	Ceiling next to entrance	
ENT-01	Projector – NEC PA803U	Projector	Foreground	Ceilling	
ENT-02	Sound from outside the museum	x-Sounds Created by Human Activity – Social Sounds	Background	Door, walls	
ENT-03	Sound from outside the museum	x-Sounds Created by Human Activity – Traffic - Cars	Background	Door, walls	
ZEL-01	PA Amplifier – Monacor PA-9125	Amplifier for speakers	Foreground	Multimedia platform	
ZEL-02	Projector x2 – Epson EB-L530U	Projector	Background	Wall above and next to Multimedia Platform	

Figure E.1: Sound Sources 1st part of list

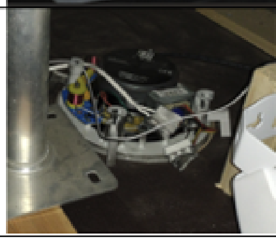
Code	**Sound Source**	**Taxonomy**	**Foreground / Background**	**Where**	**Image** *(if not overhear from wall, or door)*
ZEL-03	Spotlights x5 (Probably EUROLITE LED-PFE-20	Spotlights	Background	Multimedia platform	
ZEL-04	Arrow-slit /"window"	(Nothing in the recording but) - All types of nature sounds, such as birds, rain etc. – As well as possible traffic.	Background	Wall in Zelle 2	
ZEL-05	Speakers – Audac VEX011A	Low amplitude white noise from speaker	Background	Multimedia platform	
ZEL-06	Speaker - DIY	Low amplitude white noise from speaker	Background	Below multimedia platform	

Figure E.2: Sound Sources 2st part of list

Appendix F

Calculating RV 60

In this appendix the data used to calculate the reverberation time can be seen.

From Room EQ Wizard

Data from Microsoft Excel

ISO 3382 parameters

	50	63	80	100	125	160	200	250	315	400	500	630
EDT (s)	*1.420*	*0.862*	*1.075*	*0.762*	*0.820*	*0.934*	*1.450*	*1.294*	1.267	*1.050*	1.088	1.431
T20 (s)	1.071	*1.162*	*0.740*	*1.201*	*1.061*	1.618	1.417	1.307	1.172	1.062	1.182	1.284
T30 (s)	1.292	1.189	0.736	1.176	*1.142*	1.441	1.231	1.225	1.200	1.182	1.145	1.189
Topt (s)	1.081	1.166	0.703	1.181	1.284	1.467	1.238	1.386	1.243	1.246	1.249	1.190
T60M (s)												
C50 (dB)	0.24	1.73	2.29	2.89	2.42	-0.82	-7.03	-5.30	0.42	-0.65	-0.73	-0.23
C80 (dB)	4.00	5.77	4.53	5.98	4.49	2.36	-3.32	0.25	1.96	3.56	2.28	1.99
D50 (%)	51.4	59.8	62.9	66.0	63.6	45.3	16.5	22.8	52.4	46.3	45.8	48.7
TS (s)	0.137	0.107	0.102	0.088	0.086	0.094	0.135	0.117	0.094	0.085	0.091	0.100

	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	6,300	8,000	10,000
EDT (s)	1.420	1.146	1.152	1.227	1.186	0.869	0.820	0.888	0.807	0.676	0.570	0.480
T20 (s)	1.222	1.192	1.183	1.147	1.006	0.946	0.862	0.828	0.738	0.649	0.514	0.433
T30 (s)	1.160	1.252	1.190	1.151	1.068	1.005	0.888	0.820	0.740	0.642	0.535	0.446
Topt (s)	1.149	1.287	1.194	1.155	1.077	0.966	0.864	0.837	0.742	0.647	0.556	0.447
T60M (s)												
C50 (dB)	-1.07	-1.42	-0.37	0.77	1.65	2.00	1.34	2.88	2.51	2.70	4.73	6.74
C80 (dB)	0.85	1.02	2.25	3.30	3.92	4.72	4.17	5.87	5.76	6.59	8.66	11.03
D50 (%)	43.9	41.9	47.9	54.4	59.4	61.3	57.7	66.0	64.1	65.1	74.8	82.5
TS (s)	0.101	0.089	0.086	0.071	0.062	0.056	0.059	0.048	0.047	0.044	0.034	0.026

Figure F.1: Data example from REW, of position 1, balloon 1

RV30	p1b1	p1b2	p1b3	p2b4	p2b5	p2b6
50,00	1,48	1,16	*1,22*	1,32	1,21	1,48
63,00	1,19	*1,06*	1,20	1,17	1,18	1,19
80,00	*1,46*	0,68	1,10	*1,18*	*1,34*	*1,46*
100,00	1,98	1,12	1,37	1,83	1,74	1,98
125,00	1,79	*1,49*	*1,12*	1,30	1,10	1,79
160,00	1,25	1,40	1,45	1,26	1,22	1,25
200,00	1,13	*1,32*	1,40	1,34	1,40	1,13
250,00	1,26	1,28	1,29	1,45	1,21	1,26
315,00	1,34	1,25	1,19	1,18	1,39	1,34
400,00	1,22	1,28	1,26	1,12	1,27	1,22
500,00	1,16	1,07	1,17	1,27	1,19	1,16
630,00	1,13	1,22	1,19	1,12	1,12	1,13
800,00	1,16	1,14	1,19	1,22	1,19	1,15
1000,00	1,25	1,18	1,22	1,13	1,18	1,19
1250,00	1,19	1,13	1,20	1,07	1,15	1,12
1600,00	1,15	1,13	1,15	1,15	1,10	1,17
2000,00	1,07	1,11	1,06	1,04	1,06	1,09
2500,00	1,01	1,02	0,69	0,68	0,63	0,68
3150,00	0,62	0,63	0,60	0,60	0,58	0,59
4000,00	0,57	0,58	0,57	0,55	0,56	0,57
5000,00	0,51	0,54	0,52	0,50	0,50	0,51
6300,00	0,45	0,45	0,44	0,43	0,43	0,43
8000,00	0,37	0,37	0,37	0,37	0,36	0,36
10000,00	0,31	0,30	0,31	0,30	0,30	0,30

Figure F.2: RV30 Measurement 1/3 octave bands

RV60	p1b1	p1b2	p1b3	p2b4	p2b5	p2b6
50	2,96	2,31	2,44	2,63	2,42	2,96
63	2,38	2,11	2,40	2,35	2,36	2,38
80	2,92	1,36	2,20	2,36	2,68	2,92
100	3,96	2,24	2,73	3,66	3,48	3,96
125	3,58	2,97	2,24	2,60	2,20	3,58
160	2,49	2,80	2,91	2,52	2,45	2,49
200	2,27	2,64	2,80	2,67	2,79	2,27
250	2,52	2,55	2,58	2,91	2,41	2,52
315	2,68	2,50	2,38	2,36	2,79	2,68
400	2,45	2,56	2,51	2,23	2,55	2,45
500	2,32	2,14	2,35	2,55	2,38	2,32
630	2,26	2,44	2,37	2,25	2,24	2,26
800	2,32	2,27	2,39	2,44	2,38	2,29
1000	2,50	2,36	2,43	2,25	2,36	2,38
1250	2,38	2,27	2,40	2,15	2,29	2,24
1600	2,30	2,27	2,30	2,30	2,19	2,34
2000	2,14	2,22	2,13	2,08	2,12	2,17
2500	2,01	2,04	1,37	1,36	1,27	1,36
3150	1,23	1,25	1,20	1,19	1,16	1,19
4000	1,14	1,16	1,14	1,10	1,11	1,14
5000	1,03	1,07	1,05	0,99	0,99	1,03
6300	0,89	0,91	0,89	0,87	0,85	0,85
8000	0,74	0,74	0,75	0,75	0,72	0,73
10000	0,62	0,60	0,63	0,59	0,60	0,61

Figure F.3: RV60 Measurement 1/3 octave bands

Appendix G

SPL-Measurements from All Positions

In this appendix, the different measurements of the positions can be seen as figures.

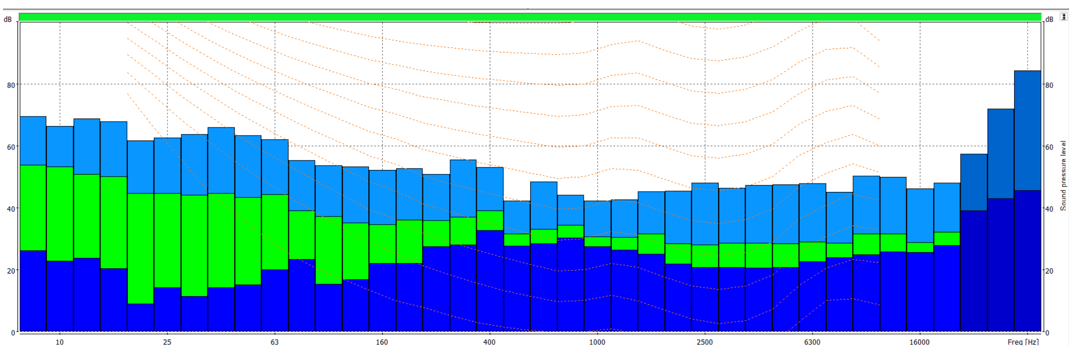


Figure G.1: Zelle 2, position 1

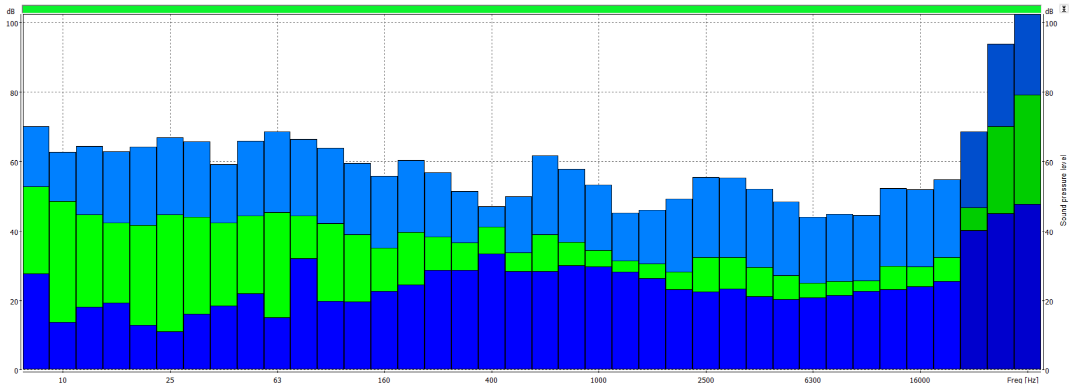


Figure G.2: Zelle 2, position 2

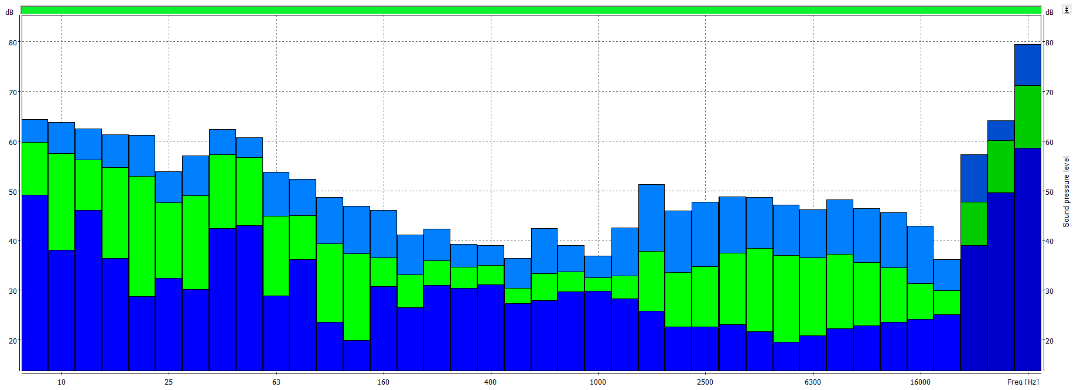


Figure G.3: Zelle 2, position 3

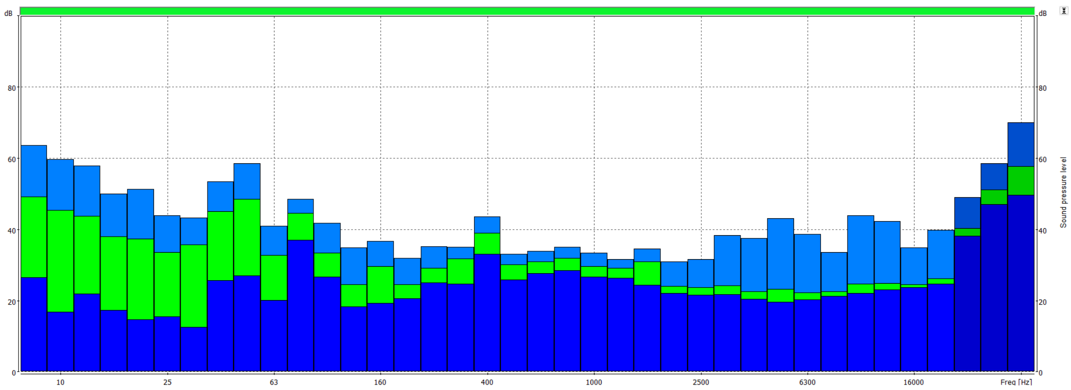


Figure G.4: Corridor, position 2

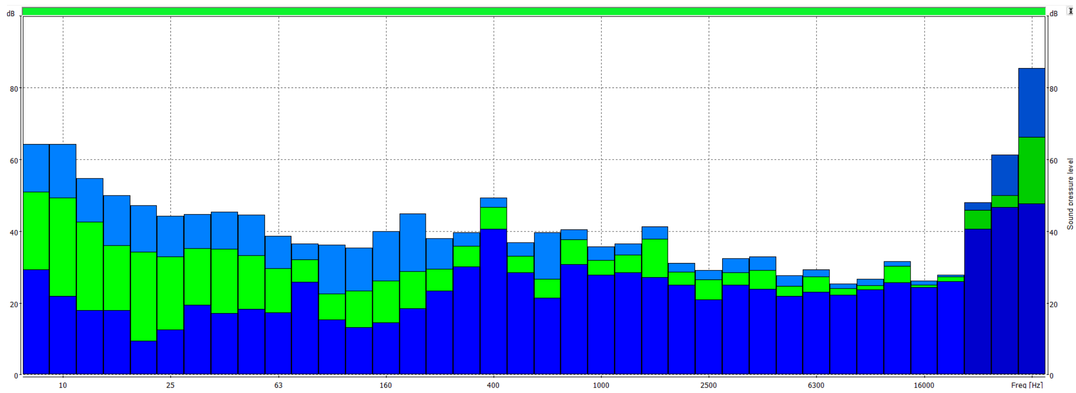


Figure G.5: Entrance, position 1

Appendix H

Evaluation

H.1 Excel Document

The Excel document is not part of this appendix, and can instead be found in the files of the hand in made on digitaleksamen. The document is called HEARSEPTION-Answers. In sheet 1 the formulas for creating graphs. In sheet 1 (Graphs and Averages), the categorisation of the terms in accordance with different theoretical frameworks for descriptor categories can also be found, in addition to the formulas of calculating averages of those. Sheet 2 (Results) contains all the results of the average rating of the individual word pairs, from the results from SurveyXact. Sheet 3 (Axelsson) contains the recalculated values to fit the -3.5 to 3.5 scale of the 2-axis Pleasantness/Eventfulness model, as well as the values and normalized versions of the context-based factors. The sheet also contains the graph of the Pleasantness/Eventfulness model.

H.2 HEARSEPTION

link to soundcloud, and the evaluation files. `https://soundcloud.com/nikolajgerlach/sets/soundscape-experiment-evaluation/s-iWBymGVNbuU?si=328884659e5a44bf88fd6e182cc9e5a6&utm_source=clipboard&utm_medium=text&utm_campaign=social_sharing`

Link to cloud: `https://ln5.sync.com/dl/673f32c30#x26nsg28-4wedrkje-pgichmef-br7q77z9`

H.3 Results from Evaluation

The Survey can be found in the appendix files from digital eksamen. The PDF is called OnlineReport.

Appendix I

HEARSEPTION - Experiment 1: Lab Test

I.1 Overview Report, From the Survey, from SurveyXact

The entire overview report can be found in the appendix files, handed at digitaleksamen. The PDF is called "LabTestOverview", and can be found in the folder "EvaluationData".

I.2 Experiment 1, Additional Sorted Graphs

In addition, the aesthetic graph shown in the analytical implementation section 6.2.4, 4 additional one was made.

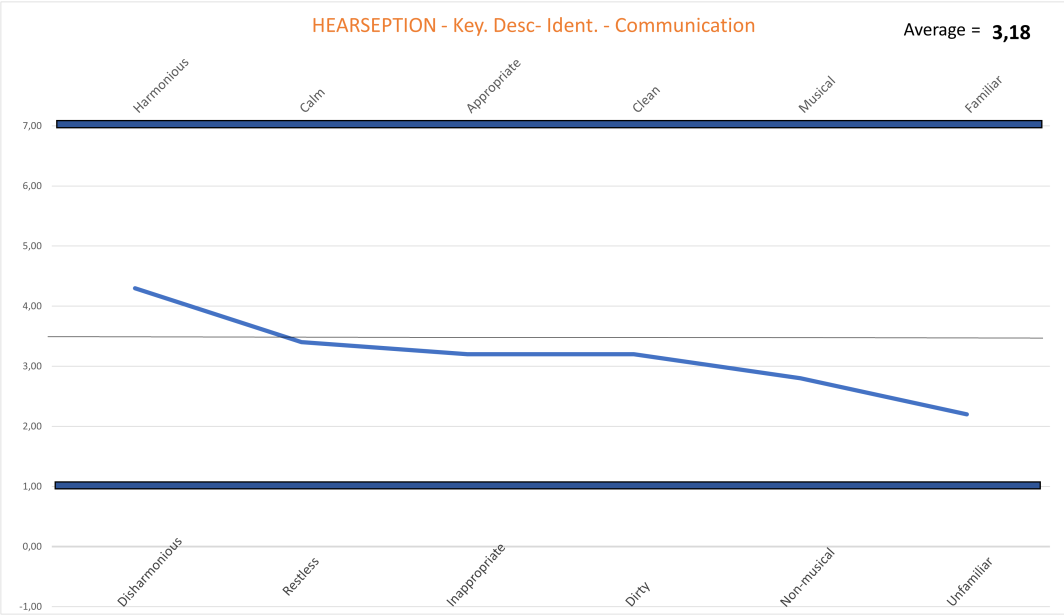


Figure I.1: Communication aspect, from the Zhang and Kang key identifies

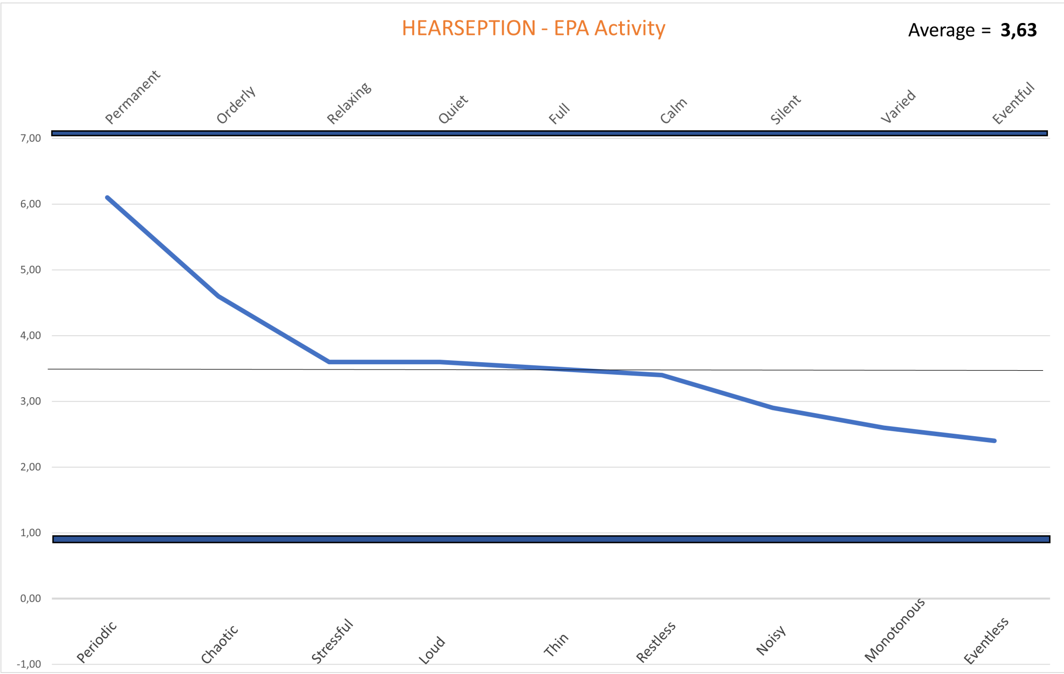


Figure I.2: EPA - Activity

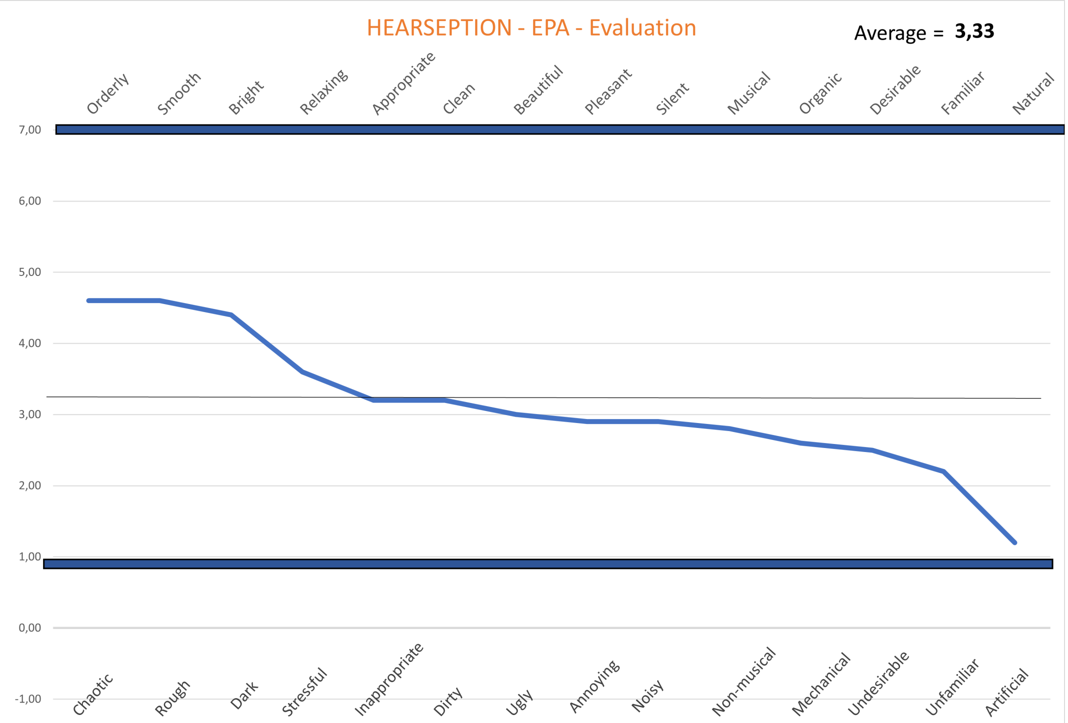


Figure I.3: EPA - Evaluation

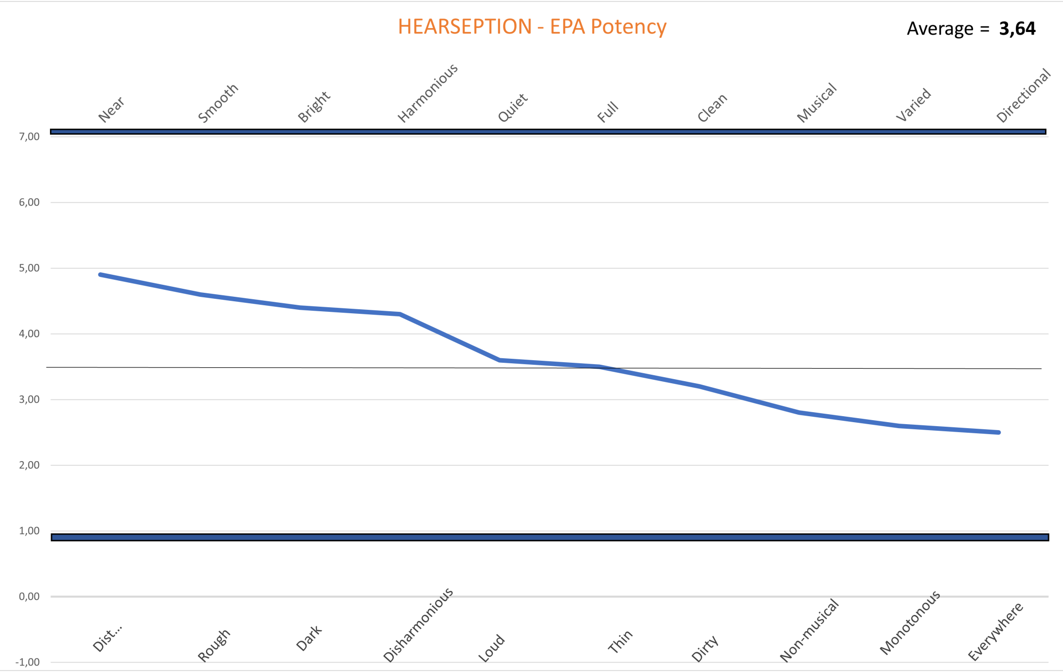


Figure I.4: EPA - Potency

Appendix J

Additional Sections

This appendix includes different parts of the thesis, that ended up not being used. Some of them were removed, as they were irrelevant, and others because the final thesis was deemed too long, and needed some heavy editing.

These sections have not been edited properly, and they will include many mistakes in grammar and syntax. For this, I apologise in advance.

J.0.1 Soundscape Studies

The work of the thesis thus builds on the general theories of soundscape which must be understood both as an evolution in the understanding of noise as music, as just mentioned, but also as a general field of research. The term was first coined by Murray Shaffer in [132] and refined during the World Soundscape Project [168] & [133]. This latter book is sometimes defined as the founding text of the field of Sound Studies [75]. The general idea presented by Schafer was that we neglect the aesthetic and natural aspect of sound because humans of modern society are bad listeners, and if we clean our ears, (Ear-Cleaning [131]). To create a better sounding, more natural sonic environment, we must thus be better listeners [171] & [167]. Since Shafer's time, the term has broken from the original context and into everyday language [75]. Truax [**truax_music_2016**] has defined three broad subcategories of soundscape studies:

- Soundscape: How environments are heard.
- Acoustic Communication: How sound conveys meaning.
- Eco-Acoustics: How sound and all organisms are connected.

Soundscapes studies aim to understand sounds of the environment as natural and unnatural sounds in a holistic framework, and research how we want society to sound like, rather than only focusing on what it sounds like. Schafer emphasises that we must strive to live in dynamic soundscapes, which allow nature and humans to coexist, where the ability to hear nuances is essential for the survival of many specie' chance of survival. While soundscapes are based on the listening capacities of humans, bio-acoustics primarily works with the sounds of all organisms, often by focusing on the sound of a single organism, such as coral reefs or whales, and how this is influenced by other sounds [10]. That being said, soundscape studies do not claim that we as society should ignore or neglect the sounds of animals, rather it claims the opposite. Soundscape studies are investigations of the collected sound of an environment as it is heard. The aim of soundscape studies as Eco-Acoustics can therefore be considered the important aspect of understanding sound, and its influence on a sustainable world for all organisms. Schafer coined numerous terms used to describe different aspects of sounds ([166] & [166]), instead of listing them here, they will be explained when and if they are used. The research of this paper build on this understanding of the sonic environment, but emphasises that soundscape are present when we are inside as well as when we are outside, and what is unnatural outside isn't necessarily unnatural when it is used as part as, for example, and exhibition to create a authentic view of a specific historical period.

J.1 Definitions of Common Terms on Sound

The general definitions were made by consulting how they are used by [41] & [103], and presented in a common language dictionary [**noauthor_merriam-webster_2024**]:

- Frequency: The oscillation or vibration of the sound, measured in Hz.
- Amplitude: The magnitude or strength of sound, typically measured in decibels (dB).
- Phase: The relative position of the sound in time, related to a fixed point, influencing how sounds are combined.
- Fundamental Frequency: The lowest, and frequently with the highest amplitude, frequency that defines the perceived pitch of the sound.
- Harmonics: Frequencies that in combination with the fundamental frequency define a sound, typically directly related as an integer multiplication (100hz fundamental with a 200Hz and 300Hz harmonic).
- Transient: A high amplitude sound, of a short duration, that appears in the beginning when a sound is produced.
- Spectrum: The combined distribution of frequency content and amplitude.

- Temporal Envelope: Change in amplitude over time without interference, described as the attack, decay, sustain and release of the sound.
- Temporal Fine Structure: The rapid oscillation close to the fundamental frequency and temporal envelope, that influences perception, being closely linked to pitch [96].
- Modulation: When one aspect of a sound changes the characteristic of another, most commonly as modulation of amplitude (AM), or of frequency (FM).
- Timbre: A combination of the above, and what makes a sound unique, the "colour" of the sound (e.g., cowbell, church bell or Fender Telecaster 1967).

J.2 Additional Theory

J.2.1 Sound as Properties of Vibration

To understand sounds as properties of vibration [56], [119], we acknowledge that sound is more than what we experience through the ear. Sound is also moving through objects, sound is tactile and can be felt. Sounds are the embodiment of objects oscillating, and in that way affecting their surroundings by, for example, compressing particles of air, that expand, and in turn affect other particles, and are thus converted into a wave [119, pp. 173–174]. The vibration is affected by all the dynamic complex systems as mentioned previously when explaining materials. Knowing that sound is properties of vibration opens up some interesting possibilities when working with sound and soundscapes, and it explains why sound sometimes are present even if the source sound is difficult to locate. Another interesting aspect is the Electro-Mechano-Acoustical analogies (or EMA-Analogies) [15], [16]. The basic principle of EMA analogies are that the basic physical properties and behaviour of the acoustic properties of soundwaves, the behaviour of electrons in electronic equipment and the force of thermodynamic and mechanical law, all share the same equations. This means that if we know how a machine vibrates due to the mechanical components, such as mass, elasticity and spring, we can use the "same" calculations made to build the machine, to calculate how it sounds because sound is a property of vibrations. This could be used as a valuable method of understanding and changing the soundscape of an everyday object, or using properties of EMA-analogies, to build modify or in other ways change aspects of the sound source.

J.2.2 Calculating Reverberation

The basic theory of reverberation is based on Sabines' discovery that the average energy of the sound, as we hear it in a room, is almost nearly the same across the whole room. This, as stated in the introduction to this section, a simplification of the matter, but with that in mind, we can dive further into the usage of this knowledge. When measuring the reverberation of a room, in this general statistical manner, we must do it in frequency bands. This is either done in octave-bands or in 1/3 octave-bands. This provides an insight into how frequency content of the sound is scattered, but to make it usable we need to understand the time of scattering. This is usually found by investigating the decay of the measured bands as T_{60}, i.e., when the sound's energy density is decreased by a factor of 60dB. Sabine made a simple equation that, still these more than 130 years later, is the backbone of understanding reverberation. The equation says that T_{60} of any given room is the volume (V), in cubic meters, of an empty room multiplied by a factor connected to the speed of sound. The multiplied volume is then divided by the sum of the surfaces and elements (A) in the room multiplied by the absorption coefficient (α) of the material [119, pp. 28.7–288], [41, pp. 127–133].

$$T_{60} = \frac{0.161V}{\Sigma_i \alpha_i A_i}$$

While the equation is simple, it is only possible to solve, by calculating the absorption coefficient of all present materials, which is time-consuming and complex. Luckily, for acousticians, a standardized representation of the absorption coefficient of specific material and material components is available both in online databases, catalogues and scientific papers [162, pp. 45–48].

J.2.3 Digital Sound Theory

In its basic form, digital music is the representation of sounds as numbers between -1 and 1 in a system, that can be used to generate soundwaves by using the numbers to create vibration and movement in the membrane of a speaker. With 1 the speaker moved to the complete forward position, with -1, to the complete backwards position (when the speaker is standby it is in 0). The Fourier Transform showed that all sounds can be represented as a combination of sine and cosine functions, of different amplitude, frequency, and phase. An increase in sample rate and bit-depth increases resolution and thus the quality of the representation of real-world sounds. The sample rate is the number of instances the data is recorded/generated each second, and controls both what possible frequencies and how close in time the numbers are computed. The sample rate also directly represents the possible frequencies of the sound. As a frequency of 100Hz physically moves 100 times in one second, digital it must likewise be computed to oscillate in the same manner. As the human hearing goes from 20hZ-20kHz, the Nyquist theorem defines that the sample rate must be at least twice that of the highest frequency to be accurately represented, by preventing the phenomena commonly known as aliasing (unintentional sidebands, and this change in frequency). Bit-depth defines the possible positions of the numbers for each sample, in the power of 2. Commonly $16^2 = 65536$ amplitude positions, is understood to be needed to make a somewhat realistic representation of sounds, according to human hearing.Sound signals are characterises in real-time, or non-real-time systems either part of linear or non-linear Continuous or a discreet-system. [87], [13], [61] & [114].

- Discrete Systems: Change over specific intervals of time. Computed signal are discrete time, as they must be computed, and this is done with a every defined power of 2 milliseconds, often described as buffer-size. e.g., every 128 sample.
- Continuous Systems: Change constantly. Continuous system, are analogue, e.g., electronics, with no "loading time".
- Real-Time Processing: The digital signal is processed as quickly as the discrete system allows, and is commuted simultaneous with the signal. E.g., adding an equalizer to a signal, where the effect of changing a parameter is immediately heard.
- Non-Real-Time Processing: The digital signal is computed, and the results are then displayed. For example, converting a sound into a spectrogram (a specific visual representation of time, amplitude, and frequency of a signal).
- Linear Systems: Can be scaled linearly if one part is added to one, a different part of the system is equally changed, so the relationship between the parts remains the same.
- Non-Linear Systems: A complex system, where change in one part results in change in another part, that results in the relationship between the parts being different (sometimes marginally) to each other. E.g., changing the amplitude results in filtering of specific frequencies.

Digital sounds are traditionally worked with in two 2dimensional domains (X and Y axis):

1. Time-Domain: Used to compute the change in signal over time.
2. Frequency-Domain: Represents frequencies and magnitude (power) of the signal component

Other domain than frequency and time are [13], [61] & [114]:

- Spatial-Domain, the sound is considered pixels in a picture and can thus be analysed 3-dimensionally (time, freq, magnitude), this method is particularly useful when using machine-learning and neural-networks.
- Transform-Domain is used when applying mathematical transformations to the signal, when for example designing filters.
- Z-Domain is used to analyse stability of discrete systems to ensure that the computed sound, for example, does not exponentially rise and thus destroy speakers, and electronic components.
- The Wavelet-Domain is the result of a mathematical model used for multi-resolution analysis of parts of the sound, that finds both time and frequency, used instead of the Fourier Transformation. It is especially useful to localise transients and noise reduction. It is also used in biomedicine as wavelets are more precise when working with complex, non-stationary systems, compared to Fourier analysis, but does require higher computation power.

There are, of course, many other aspects of digital sound, and some descriptions are somewhat simplified, but they should be sufficient to supply a foundation for discussion, analysis, and implementation. If the conversion of a soundscape should be perceived as changing aspects of the acoustic environment, this must be done using real-time processing in both frequency and time domain, as well as using different methods of filtering and otherwise manipulating the sounds. While the analysis of the sound sources, and the general environment will benefit from using thorough and precise methods in non-real-time, with an understanding of the non-linear, continuous aspect of the dynamic system of sound that represents the real-world acoustic environment.

J.2.4 Annoyance

Another important term, when working with the concept of positive and negative felt emotions evoked by environmental sounds, is annoyance. Annoyance is the main way that negative aspects of the environment are understood, and the main term in prevention. Decreasing annoyance is the main goal of noise prevention suggested by for example, the World Health Organization [40] & [78, pp. 604–714]. Annoyance has been shown to increase when people have no control of the sound. Control could be such as closing a window or going to a separate room [104] & [50]. In general, with an increase in annoyance, is followed with an increase in negative consequences caused by the sound. Annoyance is caused by the subjective experience of the sounds, in a combination with the physical and physiological characteristics of the said sound, that courses emotions such as irritation, frustration, sleep disturbance and desperation. Annoyance is subjective and while some people might enjoy the sound of a motorcycle starting, other people's reaction could be the opposite. When there is an opportunity to control a sound, but that the control does not have the wanted result, on the other hand, increase annoyance [117]. Namba et al. [104] e.g., showed that people that frequency complain to their neighbours are more annoyed, than people that ignore them, even if they live in same exposure of sound. Annoyance is therefore not just related to sound, even though the sound might cause it. Annoyance should be understood in as being social, aesthetic and generally subjective. All context of soundscape assessment, would, for these reasons, benefit with an assessment of soundscapes.

With this solid foundation of understanding how sound affects humans, and we can interact with sound, it is almost time to decide on the methodological approach and begin implementation. But one last aspect needs to be illumination to complete the conceptual framework from the ISO requirement, and that is the context of the acoustic environment, that will heavily influence the individuals' experience of the sounds.

J.2.5 Sonic Affordances

When interacting with sound both physically, perceptually or algorithmically, sound can be understood as a material with affordances. Affordances are inherent possibilities of interaction of the material theorised by Gibson [54]. While affordances are defined by both the physical qualities of the material, such as a sound wave, they are likewise defined by the background of the person or animal interacting with the material. Affordances are therefore created by the relationship between the material and to perceive of the material. An example is that when a human interacts with a rock, the size, and shape of the rock, combined with the experience, social and cultural background of the human defines the possibilities of interaction. If it is a large, big rock, an affordance could be that it can be used to sit on. A small rock could be thrown. A rock of gold could have an affordance of being traded for food or a smartphone in some societies, while in others the affordance of trade would not be understood. Sounds have affordances of physical soundwaves, and the possibilities of interaction they present, but sounds to have the affordance of communication [163]. When discussing, sonic affordances can be considered how we perceive embodied interaction as linked to cultural practices and understanding of sound. For example, if a person makes gestures to explain the amplitude of a sound, by moving their hands from the ground to above their head, this could be considered moving from low to high amplitude [5]. Another example would be how sonic affordances of a specific acoustic environment, influence the interactive actions of people. This could be a setting of a classic library or museum could with a sonic affordance that stimulating quiet conversation [137].

J.3 Additional Methodology

J.3.1 Type of triangulation

It identifies 4 general types of triangulation.

1. Data Triangulation: Collectings multiple datasets using various context and settings.
2. Methodological triangulation: Using the same methodology to collect data on multiple but slightly different occasions (within-method). Or by using a combination of methods in the same research design (across-method).
3. Investigator triangulation: Different researchers use the same data to draw their own conclusions, using the same framework, but approaching the data from different disciplinary backgrounds.
4. Theory triangulation: examining the data from different theoretical backgrounds.

Using the ISO as a method of research therefore suggests that the data should be approached from different angles, and understood as a complex entity, that can be analysed with a diversity of approaches, perspectives, and statistical methods.

J.3.2 Steps of Loudness Calculations

- Step 1: Frequencies below 300Hz are weighted in accordance with a specific table supplied in the standard [150, pp. 22–23].
- Step 2: To better comply with the critical bands of the listening experience the low frequency components are converted from dB to linear power $dBtoPower = 10^{\frac{dB}{10}}$ and added together in this following order, before being recalculated in dB: The 1/3 octave-bands between 20Hz and 90Hz are summed, likewise the bands between 90Hz and 180Hz and the two bands between 180Hz and 280Hz.
- Step 3A: Each band, in dB, is corrected using a table defining what to add or subtract that band (A.4), and if the measurements are made in a diffuse field (inside), they are likewise corrected using a separate table (A.5) [150, pp. 23–24].
- Step 3B: The bands are summed within each critical band, and adjusted to the numerical value of the table (table A.7). This step gives the SPL of each critical band.

- Step 3C: Compare the bands with "The threshold of quiet" (table A.6), if the critical band has a lower or equal dB value than the threshold, it is ignored, in the following.

After finding the SPL of all the critical bands, and their relationship with the threshold of hearing, they are converted into sones, by calculating the loudness using a formula that converts each band by adjusting aspects according to masking, the physiological aspects of the ear, and the non-linear connection between SPL and perceived sound level. But as the objects of the assessment in this paper is primarily low amplitude, broadband noises it seems that breaking this equation down, would be moving the project slightly off-topic. Instead, to complete this requirement a function from MatLab, that is made in accordance with the ISO is used instead. This also ensures that the basis of the calculation is correct as the function, is made to specifically be used to correctly calculate loudness according to the requirements of the standard.

ISO 12913-2 wrote that both Loudness and Root Mean Cubed Loudness should be calculated according to ISO 532-1. While investigating ISO 532-1 "Root Mean Cubed Loudness" is only mentioned once [149, p. 16], and that is in a note concerning time-varying sounds, and a guidance to calculation is made as a casual remark, in comparison to the otherwise thoroughness of the ISO standard. This alternative calculation of loudness, has, according to the ISO, been argued to be somewhat more precise when analysing this type of sound. The basic difference is that the averages are calculated differently.

J.4 Additional Analysis

J.4.1 Preparing Files for the Experiment

To ensure that the sound could be heard throughout the experiment, it was decided that the file of the experiment should be at least twice as long. As mentioned earlier, the scope was narrowed to position 2, and a file from the Zoom recorder. While it is a recording from the same position as the previous spectrogram 6.1.5, it is not the same recording. The previously used was 25 seconds, and would be required to be looped at least 40 times. It was decided that a better practice would be to use as long a recording as possible, and thus make it less manipulated. As mentioned before, most of the recordings were to long, but it was possible to find one that was 2 minutes 41.5 seconds. This recording wasedited together to an approx. 18 minute file. But as the notable pitch of the soundscape changed slightly throughout the recording, it was therefore not possible to edit it together without taking a few liberties. At the end of the file at approx. 2:38, a sub sound (100Hz) is heard for a second or so, before it disappears again. This could be an environmental sound from outside the cell. As this sound drew attention to itself, it was used in marker to begin a cross-fade that lasts approx. 4 seconds. In the fade, the end of the recording reduced was faded into the beginning of the same file. This creates an almost smooth transition from the end of the file to the start of the file, that does not make it noticeable that there is a loop. There is one drawback, and that is that in the cross-fade some beating is introduced, as the pitch of the two files are heard simultaneously. This could be perceived as some fluctuation, that is not present in the real soundscape. On the other hand, it was decided that it was better to introduce this small effect rather than a quick jump in pitch, or to introduce silence before repeating the file.

An obvious drawback within the headphone experiment is the volume of the audio, in comparison with the loudness of the room. While it would be ideal to play back the sound at the exactly same loudness as was measured in the room (these measurements were not conducted as mentioned in 6.1.4), it would still not be an exact replication of the real-world soundscape, due to a few factors. Firstly, the headphones frequency response changes the playback of the sound, and thereby also the loudness because it changes some octave bands. Secondly, when audio is played back on headphones, the volume setting of the headphones, as well as the volume setting of the audio player, influences the loudness of the audio. This can be somewhat controlled in a lab setting, by ensuring the all playback is at the same level, the loudness of the headphones would need to be measured with a binaural-head microphone, or a specific headphone test microphone. Thirdly, as the sound is played in headphones, loses some spatial aspects of the soundscape. As the sounds are played as two channels, one in each ear, it looses the spatial aspects of soundwaves interacting and reflecting, once again changing the loudness. The spatial loss, is the second flaw of the experiment, as the spatial aspects of the soundscape can be essential. Using headphones has some benefits, though. The main being they remove other environmental noises (these have an approx. 30dB dampening effect), and thereby allowing uses to focus solely on the sound of the recording. Therefore, this first experiment is ideal to identify different subjective aspects of the perceived soundscape by using the HEARSEPTION semantic profile for the assessment.

The soundscape recording of the room was normalized to -21LUFS-I. this turned the sound up by 27.4dB. It was done using the "Normalize items(peak,RMS,LUFS)" feature in the Reaper SWR extension. The choice of this normalization level was completely subjective, and was made as it at this level was deemed to contain the soundscape without distorting it, but also not making the soundscape too quiet when they were played back in the headphones. The normalization as previously mentioned, introduces some confounder factors, as it changes the noise-floor of the file as a whole, while also possible allowing some sound to cross the threshold of hearing, that they were below before. But this confounder factor is equally true

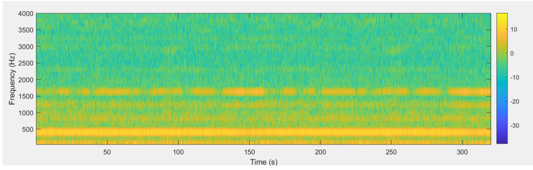


Figure J.1: Spectrogram of the first 2 loops of the file from experiment 1, as a downsampled mono file.

for the original gain setting of the recorder, which once again is an argument of a class-1 device, that records wave files that can be extracted and used in other software, than the dedicated software of that device. As the recording was of two microphones, they were not summed, to contain some spatial qualities, that would be lost by summing them to a mono file. The edited recording was exported at 44.1kHz, 24bit. The first 2 loops of the recording of the experiment can be considered a spectrogram in J.1. As the spectrogram is in mono, the recording was made into mono, as with the previous spectrograms. The fundamental frequency and the logarithmic fundamental frequency were 399.99 Hz, which does correspond quite well with the previous measurement from the same position. Interestingly the spectrogram shows that the tone at around 1600Hz, changes a bit in amplitude during the recording, and when the edit occurs at 158-162 seconds in the magnitude is a bit higher, and the a a bit broader in the frequency axis, which corresponds with the fluctuation, and possible some added harmonics at that point. The peak of the sub sound can be seen at 160 seconds.