The roles of live-electronics in the chosen electroacoustic solo instrument works

Heidi Hassinen

University of the Arts Helsinki, Sibelius Academy

Submitted for examination for the degree of Master of Music in Composition.
Helsinki, April 8, 2022

Title	**Number of Pages**
The roles of live-electronics in the chosen electroacoustic solo instrument works	40
Author	**Semester**
Heidi Hassinen	Spring 2022
Department	
Composition and Music Theory	

Abstract

In the scope of the research on Western Art Music, the analysis of electroacoustic music is a sparsely crowded subfield. As yet an emerging field, electroacoustic music is not studied with generally agreed methodology. On the contrary, the analytical tools are continuously evolving, and new research attempts to find methodology better suited to the analysis of electroacoustic music as opposed to the Western Art Music analysis tradition. The existing research on electroacoustic music, also, mostly focuses on the music-technological aspects and computing or the experiences of a performer on working with the digital system. The creative usage of electronics and their purpose is rarely studied.

This work studies three electroacoustic pieces with acoustic solo instruments and live-electronics from the aspect of roles. The study attempts to answer to the research questions on the roles live-electronics are given, how the electronics interact with solo instruments, and their relation. In addition, it is speculated whether the pieces could exist without the electronics. By this study, attention is drawn to the electronics as a meaningful and crucial element for defining the characteristics of a piece, not only acting in the background. The study is approached with score and aural analysis, the latter seen particularly important for the analysis of electroacoustic music.

The results of this work highlight the importance of the live-electronics, acting in various roles alongside a solo acoustic instrument. The versatile roles appear in several categories, from perceptional to timbral. Moreover, live-electronics are a crucial element for the characteristic of a piece. The findings indicate that the compositional usage of live-electronics in art music is worth further and more detailed study. The work also demonstrates the value of aural analysis for the research on electroacoustic music.

Keywords

electroacoustic music, live-electronics, digital sound processing, electroacoustic music analysis, aural analysis

This work has been checked in the plagiarism detection program Turnitin

11.5.2022, Johan Tallgren

Abstract

In the scope of the research on Western Art Music, the analysis of electroacoustic music is a sparsely crowded subfield. As yet an emerging field, electroacoustic music is not studied with generally agreed methodology. On the contrary, the analytical tools are continuously evolving, and new research attempts to find methodology better suited to the analysis of electroacoustic music as opposed to the Western Art Music analysis tradition. The existing research on electroacoustic music, also, mostly focuses on the music-technological aspects and computing or the experiences of a performer on working with the digital system. The creative usage of electronics and their purpose is rarely studied.

This work studies three electroacoustic pieces with acoustic solo instruments and live-electronics from the aspect of roles. The study attempts to answer to the research questions on the roles live-electronics are given, how the electronics interact with solo instruments, and their relation. In addition, it is speculated whether the pieces could exist without the electronics. By this study, attention is drawn to the electronics as a meaningful and crucial element for defining the characteristics of a piece, not only acting in the background. The study is approached with score and aural analysis, the latter seen particularly important for the analysis of electroacoustic music.

The results of this work highlight the importance of the live-electronics, acting in various roles alongside a solo acoustic instrument. The versatile roles appear in several categories, from perceptional to timbral. Moreover, live-electronics are a crucial element for the characteristic of a piece. The findings indicate that the compositional usage of live-electronics in art music is worth further and more detailed study. The work also demonstrates the value of aural analysis for the research on electroacoustic music.

Keywords: electroacoustic music, live-electronics, digital sound processing, aural analysis

Contents

1 Introduction

The subgenre of electroacoustic music, live-electronics, has for decades yielded sound processing techniques in the live performance of art music. When combined with acoustic instruments, live-electronics have enabled the real-time expansion of the instrumental sound to directions only possible to achieve by digital means. Thus, the new sonic possibilities offered by the music-technological development have also influenced the music written by the composers working with electronics. However, little research has so far been conducted on the music for acoustic instruments and live-electronics, even less when it comes to the artistic usage of the electronics from the compositional aspects. Too often the electronics have been seen just as a background element, added afterwards on top of the pre-composed instrumental material, or the electronics have only been analysed from the computational viewpoint. The purpose of the sound processing techniques in a piece has not been considered.

To address this issue, in this work, I study the roles that are given to live-electronics in electroacoustic compositions, combining acoustic solo instruments and electronics. My aim is to find an answer to the question of how live-electronics interact with a solo instrument, and what their relation is. I also attempt to speculate whether the pieces could exist without the electronics – stemming from my initial hypothesis of the live-electronics being a crucial part of the piece, as often composed alongside the instrumental material. In order to conduct the research, I chose three pieces falling into my category of interest: *Petals* by Kaija Saariaho, *Sequitur XI* by Karlheinz Essl and *in the universe everyth ng is a circle* by Maija Hynninen. By studying these pieces, I attempt to form a list of the roles that appear to be given to the live-electronics.

To approach the research questions, I base my study on score analysis and aural analysis as the methodologies. Score analysis is a useful tool in this context as the solo instrument part follows the notation tradition of the Western Art Music. However, for the electronics the score-based approach is problematic and in itself not enough, as discussed further in this work. Analytical aural analysis is, thus, needed as well as it seems to better suit for analysing the live-electronics and sonic events generated by digital sound processing in electroacoustic music. In order to conduct the study, I refer both to the scores and audio recordings on the chosen compositions. As only stereo recordings are available, the analysis does not address sound-diffusion.

This work begins with the introduction of the background in the section 2. The concepts of electroacoustic music, live-electronics and timbre are discussed. Also the digital audio processing techniques used in the analysed pieces are defined. The section 3 discusses the applied research methods – score analysis and aural analysis – in the light of the analytical approaches taken for analysing electroacoustic music. In addition, the used materials for conducting the study are addressed. The results of the analysis are presented in the section 4, discussing the pieces in separate subsections. The results are then brought together for further discussion in the section 5. Finally, the work is concluded with a summary in the section 6.

2 Background

This section sets the basis for the on-hand thesis by describing the most important key concepts, used further in the text. The section begins with a definition of *electroacoustic music* and its subgenre *live-electronics*. Also the definition of *timbre* is included, as in many electroacoustic pieces, where acoustic instruments are combined with live-electronics, the timbre of an instrument is expanded digitally. Lastly, the section is concluded by discussing the digital audio editing techniques relevant for the analysis presented in this work.

2.1 Electroacoustic music

The concept of electroacoustic music can be regarded and defined from either a technical or an aesthetic view-point. In terms of technology, electroacoustics are seen as technological attempts to convert acoustic energy into electrical energy, and vice versa (Chambers, n.d.). In physics, this interchange between the energies can be studied for example in the context of microphones and loudspeakers (OED Online, n.d.). Electroacoustic music, in turn, incorporates electroacoustics into creative and artistic use by including electronically produced and modified sounds (OED Online, n.d.; Whittall, n.d.). This can comprise of involving instrumental or vocal sounds with, often computer-assisted, electronic manipulation or by including pre-recorded and edited fixed media, also known as tape, into a musical piece (Whittall, n.d.).

From an aesthetic point of view, electroacoustic music refers to the music genre developed in Europe, Japan and the Americas from the 1950's on (Olarte, 2019, 4). As the experience of listening to music had changed during the 20th century due to the development in sound reproduction and transmission, the new ways to both create and organize sounds inspired also composers in their artistic work (Whittall, n.d.). Thanks to the technological evolution, it was possible to use magnetic tapes for audio recording and later on for further manipulation of the pre-recorded sound as well as to include electronic devices in musical performances (Emmerson & Smalley, 2001). Also the emergence of the first commercial, mass-produced transistorized synthesizer in 1964 and the foundation of the Institut de Recherche et de Coordination Acoustique/Musique (IRCAM), an institution for exploring the possibilities of computer technology in music and both the structure and recreation of sound, in Paris in 1976 became crucial milestones supporting the evolution and popularization of electroacoustic music (Whittall, n.d.).

Already in the early decades of electroacoustic music, the genre began to subdivide into different aesthetics, such as *musique concrète* for manipulating and organizing everyday sounds recorded in the field, or live electronic music. An early example of the latter, Stockhausen's Mikrophonie I (1964) involves real-time transformation and manipulation of the sound of a large tam-tam, setting the standard for the performance of live electronic music in which one individual, often the composer, controls sound-diffusion by the mixing desk. This standard is still the most common way the performance of an electroacoustic piece is organized. On the other hand, the evolution of electroacoustic music brought into artistic use the explorations of the acoustic formation of sound: its reverberations and spectre. (Whittall, n.d.)

More recently, electroacoustic music has typically been divided into two main aesthetic directions: acousmatic music and live-electronics (Olarte, 2019, 4). The term acousmatic music refers to the subgenre consisting of compositions existing only in a recorded format and intended to be performed trough loudspeakers, implying very little performance in a concert playback (Olarte, 2019, 4). On the contrary, live-electronics comprise pieces that are not completely fixed prior to the performance. In live-electronics, technology is for example used for generating, transforming and triggering sounds during a performance (Emmerson & Smalley, 2001). Live-electronics are further discussed in detail in the following section. The distinction between the two aesthetic directions, however, is blurred due to the evolution of the capabilities of portable computing systems and real-time processing. This is demonstrated for example in pieces combining materials prepared in a studio with a performance including improvised techniques (Olarte, 2019, 4).

2.2 Live-electronics

As discussed above, live-electronics is one of the subgrenres of electroacoustic music. Differing from the older tradition in electroacoustic composition of basing a piece on pre-prepared fixed media or tapes, live-electronics provide more freedom for the performance of electroacoustic music through the use of music-technological appliances for manipulating and modifying the sounding material in real-time.

In live-electronics, sound can be generated, processed or triggered in real-time using a set of electronic devices and digital processes, ranging from oscillators and harmonizers to filters and sound-diffusion. In sound generation, both analogue synthesizers, electroacoustic instruments and, more recently, programmed algorithms and machine learning based approaches can be used. To support the nature of freedom in live-electronics, the techniques employed do not need to be fully composed, notated or even basing on presets and configurations defined beforehand (Olarte, 2019, 4–5).

In addition, an electroacoustic piece with live-electronics may build upon processing the sound and timbre of acoustic instruments in real-time. The processing may consist of manipulating the acoustic sound by filters, for example altering the pitch, frequency spectrum or reverberation of the original sound. Some of the techniques used for sound processing with live-electronics are further discussed in the subsection 2.4. The process of manipulating acoustic sound in real-time requires acoustic instruments to be connected to the digital sound processing system through microphones. Once the sound data signal is sent over to the processing system, the signal is altered either by an automatized setup or a person in charge of running the process, and then transmitted to the loudspeakers. In order to work in a meaningful manner, the process should require as little time delay as possible.

Live-electronics may also include interactivity when sounds and processes are triggered during the performance. Often the players of acoustic instruments involved in the performance of an electroacoustic piece initiate the implementation through control devices, such as pedals. This gives players the power to determine more freely how time is perceived and treated in the performance as the succession of events is in their hands, which in turn may make the performance of an electroacoustic piece with, to some extent, inflexible electronic devices better approachable to the instrumentalists. When it comes to triggering processes through a computer system, Stroppa introduces the distinction of three levels of interaction: immediate reaction, score following and tempo tracking (Stroppa, 1999). In the first, a process is started at will, making the system to react with no perceivable delay. In the second, the system is provided with an event detector and internal information about the piece, usually in the form of a coded score. The system should determine the progress of the performance and when to trigger events with respect to the score. In tempo tracking, also the information on time is added to the event detector. Time can be followed either by an internal metronome or by detecting the speed of a sequence of events and adapting the tempo of the system to the performance.

One of the most commonly used tools in live-electronics is the software Max/MSP by Cycling '74, basing on easily approachable graphic programming. The software can be for example used to sound generation, digital processing or real-time interactivity. A Max/MSP file referred to as *patch* is alongside the score one of the key elements of the underlying documentation of an electroacoustic piece. However, the software has been criticized for not being performer-centric: for novices it can be difficult to use especially as the patches or stand-alone applications created with Max/MSP often have very different user interface in each piece (Bullock, Coccioli, Dooley, & Michailidis, 2013).

One of the critiques on live-electronics is the lack of standardized notation habits. Often the score of a piece including live-electronics does not explain comprehensively the use of the electronic devices, let alone how the electronic processes affect the sounding quality of the piece. Thus, it is very difficult to understand in detail and as a whole how an electroacoustic piece sounds basing the analysis only on the score, as often is common for more traditional Western Art Music analysis. According to Emmerson, another issue raised by the insufficient notation is that for many pieces depending on silent information the performance practice knowledge is fading (Emmerson, 2006). This is even emphasized when, due to technological development, similar instruments to the ones used for the first performances do not exist anymore. As an attempt to address the issue, Emmerson suggests the concept of generic score, generalising the score of a piece in a manner not specific to any particular technology. As generic score would concentrate more on describing how a piece should sound and how it should be performed, exact technological requirements would be left out, making it possible to perform the piece with very different setups.

2.3 Timbre

The concept of timbre is apparent in the context of electroacoustic music, as electronic music is often said to focus on and consist entirely of timbres (Hugill, 2012, 56). According to the Merriam-Webster dictionary, timbre can be defined as the quality that is given to a sound by its overtones (Merriam-Webster, n.d.). This definition implies that timbre is one of the characterizing parameters of sound, and that any sound consists of smaller components, overtones, that have an effect on its sounding qualities. Due to the timbral quality of a sound, different sounds and sound sources can be distinguished one from another (Hugill, 2012, 56).

According to the study on sound, the perception of timbre bases on the harmonic content of a sound, tuning of its components and to some extent temporal aspects (Dodge & Jerse, 1997, 46–58). The physical properties of a sound-producing body affect the spectrum of a sound through concentrations of acoustic energy (Hugill, 2012, 56). By spectrum or spectral envelope one refers to the distribution of a sound into its components, partials or overtones, as well as to the distribution of energy among these components. Both a specific collection of the partials as well as their intensities give rise to sonic qualities and timbre. Spectrum, thus, can be used as a means for studying timbre. In addition, in theory by reproducing the spectrum of a unique sound as a specific combination of sine waves, it is possible to artificially recreate this sound. The most used method for extracting the spectrum of a sound, spectrogram, is the Fourier Transform which has also been widely used in the electronic music field for analysing timbre, for example in order to control the timbral qualities of a piece.

2.4 Digital audio processing techniques

Below, I define the collection of the digital audio processing terms and techniques, referred to further in this thesis. The markings (S), (E) and (H) – as for Saariaho, Essl and Hynninen, respectively – after each term name describe in which of the analysed pieces, discussed in the subsection 3.4, the technique is used.

Bending. (H) Bending is a digital audio processing effect that makes through digital manipulation the inputted sound to slide to another sound.

Comb filtering. (E) Comb filtering bases on adding digitally two similar audio signals together, one of the copies slightly delayed in time (DSPRelated, n.d.). This creates a more colorful resulting sound and timbre, the extent of the change depending on the length of the delay. The longer the delay time gets, the more color is perceived. Eventually, the increase of the delay time crosses the threshold of perceiving the added delayed signal as an echo of the original sound.

Cross-filtering/cross-synthesis. (H) Cross-filtering, also known as cross-synthesis, is a method of, in a way, combining two sound signals. By cross-filtering the shape of a sound signal can be obtained from another signal, affecting the timbral qualities of the sound. The Short-Time Fourier Transform, a variant of the basic Fourier Transform determining the frequency and phase content of a sound signal, is calculated on both of the signals, allowing to analyse the spectral envelope of the first signal, called modulating signal, and to flatten the spectrum of the second signal, called carrier signal (Smith, 2011). When the spectral envelope of the modulating signal is applied on the carrier signal, the resulting sound may for example resemble a "talking wind".

(Spectral) Delay. (H) Delay as a digital audio processing effect bases on modifying the timbral qualities of a sound trough time delay. For a simple delay, the inputted sound can be layered so that each copy of the original sound is played back with a different delay in time. In spectral delay, the received sound signal in turn is divided into frequency bands that are treated with different delays (Välimäki, Abel, & Smith, 2009).

Detuning. (E) As traditionally perceived, the term detuning in digital audio processing refers to the process of slightly moving the frequencies of the original audio signal in the frequency domain to alter the timbre of the heard sound.

Distortion. (H) Distortion refers to the phenomena of a blurry sound signal, the clarity of which is significantly degraded. To achieve a distorted sound by digital means, the curve of a sound signal has to be recognized and to be disrupted from its original, perfect form (Konftel, n.d.).

Flanger. (E) The flanger effect creates the impression of the sound signal surging in the frequency domain. In digital audio processing, this impression is caused by mixing two similar audio signals, the original sound and its delayed copy, using a specified time delay. Mixing the two signals, appearing momentarily in different phases, makes both peaks and cancellations to occur in the resulting sound, altering from the original sound. The narrow cancellations, called notches, move up and down in the frequency domain when the used time delay is changed. (Russ, 1996, 300)

Freeze. (E) The freeze sound effect in digital audio processing refers to sustaining the inputted sound signal for a predetermined duration. When used as a coloring effect for real-time instrument playing, the sustained momentary samples of the instrumental sound are layered, creating the impression of a long sustain pedal or a continuous sound base.

Frequency shift. (E) In frequency shifting, the frequency components of a sound signal are altered by moving them all or in selected frequency bands up or down in the frequency domain. The amount of change is discussed in hertz. Even if all the components of a signal are moved to the same direction by the same amount of hertz, the harmonic relationships between the components are not preserved, as the ratios of the resulting frequencies are not the same as in the original signal (Clark & Hordijk, 2003).

Granular synthesis. (H) Granular synthesis bases on the division of recorded sounds or real-time sound input into short segments called grains, typically 20–30 milliseconds in duration (Russ, 1996, 252). Each of the grains can be manipulated separately, and the order of their playback can be altered by layering or looping the segments, affecting the perceived sound events (Brown, 2019). If the grains are played in their chronological order following the original speed, the perceived sound is similar to the original. In order to avoid series of click sounds between the rearranged grains, each separated grain is enveloped both to begin and to end at zero amplitude (Russ, 1996, 253).

Harmonizer. (S) The purpose of a harmonizer is to layer and to enrich the timbre of a one-voice sound. Harmonizer bases on adding a pitch-shifted copy of the original sound on top of the original signal to create a two-voice harmony (Samplecraze, n.d.).

Resonator. (H) Acoustic instruments are usually considered to consist of drivers and resonators, the first producing the raw sound (such as hammers or reeds) and the latter colouring the raw sound by resonance (Russ, 1996, 244–245). The characteristics of the resonator, for example its size and the way it vibrates, affect the timbral qualities of the raw sound by emphasizing and suppressing certain frequencies. In digital audio processing, the digitally produced resonators by their basic function remind the physical resonators of acoustic instruments.

Reverb. (S) Reverberation in nature is the phenomenon produced by almost any acoustic environment. The effect of repeatedly hearing somewhat repetitions of the original sound is caused by the sound signal reflecting back to the listener from the boundaries of the space: a short pre-delay is followed by a series of echoes called early reflection and the echoes of those echoes, and so on, decaying in volume (Russ, 1996, 298–299). The size of the acoustic environment and the material used in its boundaries determine how long the delays between the echoes are and how the timbral qualities of the reflections alter. In digital sound processing, the effect of reverberation and the perception of a pre-determined virtual acoustic space is created artificially by altering the original signal and its artificial reflections.

Ring modulation. (E) Ring modulation refers to the digital audio processing method of producing the sum and difference frequencies of two different sound signals, basing the process on the frequency contents of these signals. In digital sound processing, one of the signals is produced by an oscillator, electronic device creating artificial sound signals in an electronic circuit. The sounding result of ring modulation is often characterized as metallic or robotic. (Russ, 1996, 300)

Transposing. (E) Similar to detuning, the digital audio processing effect of transposing alters the frequency content of an audio signal so that the sound is shifted according to pitch steps, for example semitones. The shifted frequencies maintain their harmonic relationships.

Tremolo. (E) The impression of tremolo in digital audio processing is created by altering the amplitude of the original sound signal by digital means.

Vocoder. (H) Traditionally designed to manipulate human voice, vocoder uses the characteristics of one sound to process another. The firstly incoming audio signal is split into bands that are analysed and processed separately, allowing to have the control over the timbral contents of the signal (Russ, 1996, 256–258). Due to the separating analysis, the process makes it possible to extract spectral characteristics from the first input. When another signal is fed to the synthesizer part of the vocoder, the spectral characteristics of the first input are applied to the second signal, altering its sounding qualities.

3 Research methods and materials

The following section presents the research methods used in this thesis. Before describing the applied methods, analysis of electroacoustic music in general is shortly discussed, paying special attention to how it differs from the more traditional theoretical analysis of the Western Art Music. As for the approaches applied in this work, both score-based and aural analysis are discussed. Lastly, the materials used in the research are presented.

3.1 Analysing electroacoustic music

It has been said that the analysis of electroacoustic music is yet an emerging field with continuously evolving tools and no generally agreed analytical methodology (Hugill, 2012, 233). At the moment, there are some dissertations, such as (Selle, 2018) and (Mazzoli, 2014), aiming at introducing analysis approaches better suitable for the field of electroacoustic music than the methodologies used in the tradition of the Western Art Music analysis. Namely, referencing the score and basing the analysis on the harmony, melody and rhythm as typical for the traditional analysis is seen ineffective for electroacoustic music (Selle, 2018, vii). Even if these musical parameters are also apparent in electroacoustic music, they may not have the same function or be necessarily the main constituents as in the non-electronic art music (Hugill, 2012, 233). Joanna Demers has said that electronic music sounds and behaves differently from non-electronic music for example in that it distinguishes the meaningfulness of sound (Selle, 2018, 5–6). By this Demers refers to electronic music constantly raising the question of whether sound in itself bears meaning, to an extent incomparable to previous forms of music. The importance of sound and sounding qualities, not apparent in the notation, thus is highlighted for the analysis of electroacoustic music.

The traditional score-based approach for music analysis poses challenges when applied to electroacoustic music due to the utilisation of non-pitched sound, focusing on timbre instead of the organization of pitch and rhythm (Mazzoli, 2014, 1–8). The use of timbre as a driving musical force is seen as the norm in electronic music. According to Mazzoli, timbre serves as an identifiable structural element in electroacoustic music and can be used as a means for segmentation and grouping sonic events. The Gestalt theory for hearing states that there is a natural tendency to group complex and ambiguous information, such as timbral qualities, through pattern recognition (Hugill, 2012, 41–42). The laws of similarity and (spatial or temporal) proximity drive the grouping in the brain (Deutsch, 1999, 299–348).

Timbral events, however, are fundamentally sonic in nature and thus resist the ability to be traditionally notated in a reliable fashion (Selle, 2018, 9). The analysis of timbre may be difficult as similar note-to-note relations as for other musical parameters in the Western Art Music tradition are not available (Hugill, 2012, 233). In addition, electroacoustic music is often organized with regard to sonic objects. While musical objects can be conventionally notated, sonic perception is tied to time and thus cannot be comprehended directly by reading the score (Selle, 2018, 9–10). Score-based analysis is also not very informative for analysing live-electronics nor the interaction between electronics and other instruments (Rossetti, Teixeira, & Manzolli, 2018).

Another critique on applying the traditional analysis approaches in the context of electroacoustic music highlights the assumption that music analysis has only abstract methodologies. In the traditional analysis methods, the perception or effects on a listener are mostly not taken into account – moreover referencing the aural experience may be considered as "impressionistic" and useless for a meaningful analysis. (Hugill, 2012, 233)

Majority of the approaches taken in the literature on electroacoustic music analysis base on listening. The literature covers different ways of listening, motivated by different analytical attempts. Analytical listening can for example be parametric, describing what events happen in specific time points and classifying sounds, or affective, relying on subjective experiences on how music affects the listener and in which way this effect is achieved (Hugill, 2012, 234–235). Delalande, in turn, has defined three listening types (Hugill, 2012, 234–235). The first, taxonomic, aims at the listener getting an overall picture of the piece, identifying contrast and changes. The second, empathic, makes the listener respond only to the feelings produced by music. By the third, figurative, the listener creates images or metaphors to represent something extra-musical. In addition, the concept of *technological listening* by Smalley is a listening approach aiming at aurally perceiving the technology behind a piece and how it is being used (Hugill, 2012, 22). Often the texts on electroacoustic analysis methods start by referring to Schaeffer's notion of *reduced listening*, meaning listening to sound and attempting to understand it for itself without seeking it to represent something (Selle, 2018, 64). Sound is thus considered meaningful and interesting in itself. Also Schaeffer's modes of listening, defining different listening goals and intentions, are seen inspirational. The modes differentiate passive hearing, listening to something and aiming at identifying the source, intentional listening, as well as semantic listening (Hugill, 2012, 21–22).

Besides score-based and aural analysis, currently many applications exist for computer-assisted analysis. For example Rossetti et al. (Rossetti et al., 2018) present a tool for music information retrieval, using tools called Audio Parametric Descriptors for extracting information for example on timbral qualities from audio recordings. The computer-assisted analysis applications base on the usage of spectrograms as the representation of the analysed audio file. Spectrograms, however, may be problematic for elaborated music analysis as they are unable to account for separate musical elements in the audio recording (Selle, 2018, 31–32). Namely, spectrograms function as a time-dependent summary on the underlying piece, so that different musical elements and parameters appearing at the same time cannot be easily distinguished from spectrograms. Wayne Slawson has argued that it can also be hard to make conclusions on timbre or perception out of the representations that are entirely based on acoustic phenomena (Selle, 2018, 32). As this thesis is not concerned about detailed discussion on timbral qualities, computer-assisted tools are not utilized in the further analysis.

3.2 Score analysis

As the main approach for analysis, the score-based method poses challenges for capturing the essential characteristics of interest in an electroacoustic composition. According to Stroppa, the notation of electroacoustic music is always rather approximate compared to the complexity and perfection of the traditional notation of the Western Art Music (Stroppa, 1984). Namely, the notation of electroacoustic music may consist of various schematic representations of the aural result or of operational data on the performance of the piece. The balance of freedom and constraint between notation and interpretation, typical for the traditional notation, is in that form missing (Stroppa, 1984). In addition, I have noticed myself that often the score of an electroacoustic piece does not explain comprehensively the usage of electronic devices nor how the processing affects the sounding quality of the piece. The additional information behind the piece, crucial though for conducting a successful score-based analysis, may only be retrieved from the composer or studied with a technologically well-trained ear from the recordings of the piece.

Despite the limitations of score analysis in the context of electroacoustic music, I partially rely on the score-based approach in this work. The motivation for this choice stems from the fact that in electroacoustic pieces combining electronics with acoustic instruments the instrumental parts are still written following the traditional notation.

In order to better understand how the sound processing methods are connected to an acoustic instrument as well as the role of live-electronics, paying attention to the instrumental writing alongside other analysis methods becomes essential. Also for majority of the electroacoustic pieces it is possible only by reading the score to know precisely which specific electronics are used. Thus in this work I conduct score analysis before approaching the pieces with aural analysis methods. While analysing the score, I do not rely at all on listening. By doing so, I attempt to make sure that the approaches maintain separable and that the score reading does not disrupt the methodology taken for aural analysis.

3.3 Aural analysis

For electroacoustic music, listening is a widely used tool for analysis. On that note, it is not surprising that several approaches and methodologies have been defined for analytical aural analysis. According to Stroppa, it would be limiting to restrict aural analysis only to discovering superficial features without paying attention to cause and effect (Stroppa, 1984). Also Selle has pointed out the difference between intentionally conducted aural analysis and only describing the experience of listening, as a reply to the critique on the credibility of aural analysis (Selle, 2018, 12–13). As for the critique on subjectivity, Selle reminds that in all music analysis own individual judgements and values are brought into the analysis process, and therefore any analysis will always have a certain amount of subjectivity built into it (Selle, 2018, 13).

In this work, I apply analytical aural analysis as a methodology for analysing electroacoustic music. The approach I take bases on the concepts of parametric and reduced listening, introduced above, as well as the aural analysis methodology suggested by Selle. In his dissertation, Selle conducts aural analysis step-wise, starting from a holistic viewpoint and narrowing down to details further on. The first step aims at listening through the piece for its own qualities, without considering any formal or syntactical thoughts or making notes. This way the first impressions on analytical concerns do not enter the first listening nor color the judgements made on the piece later. The second step comprises of a series of self-reflective listenings. During these listenings, one should pay attention to one's own experience of the work and the ways in which it directs listening. Also at this point one should acknowledge the existence of important sound objects, however refraining from speculating about their function. In the third step one identifies the salient sonic parameters that may have guided the listening experience in the previous steps. The following steps aim at conducting a series of listenings, each focusing only on one of the identified parameters, writing down notes on the changes in a parameter as a function of time, and attempting to identify possible recurring trajectories. (Selle, 2018, 69–77)

3.4 Materials

In this thesis, three pieces from the electroacoustic solo instrument literature, combining acoustic instruments with live-electronics, are analysed: *Petals* for violoncello by Kaija Saariaho, *Sequitur XI* for percussions (vibraphone and cymbal) by Karlheinz Essl and *in the universe everyth ng is a circle* for contrabass clarinet by Maija Hynninen. The motivation for choosing these pieces stems firstly from all of the three treating live-electronics and real-time sound processing as a complement to acoustic sound. I specifically chose solo instrument pieces for the analysis to be able to better distinguish the effects of the electronics on acoustic instruments. As my goal was to conduct a descriptive study rather than to compare the analysis results, I decided to choose pieces with different kinds of solo instruments. Also I was motivated by the thought that in these pieces electronics are used as a coloring tool, tightly in correlation with the solo instruments. Namely, from early on it seemed to me that the pieces were composed so that both the instrumental writing and the live-electronics were equally considered, instead of one preceding the other.

In addition, the composers of the three chosen pieces have a link of having either studied or worked at IRCAM during their career, even though they represent different composer generations. Saariaho, Essl and Hynninen all use Max/MSP in their work (in particular all of the chosen pieces in this study base on the usage of Max/MSP). Also I have the impression that each of these three composers has a close personal relation to the electronics in the sense that they have a deep understanding of the possibilities, impacts and limitations of different sound processing techniques, as well as an understanding on how these techniques can be technically carried out.

For conducting the analysis, both the score and a recording of each of the three pieces were accessed. For Saariaho's piece, the score published by Edition Wilhelm Hansen Helsinki AB (Saariaho, 1988) was consulted and the performance by Imke Frank (Frank & Berger, 2011) was used. All the material concerning the piece by Essl was found on the composer's homepage (Essl, 2009a; Essl & Manzanilla, 2014). For Hynninen's piece, the score was received from the composer and the performance by Heather Roche (Hynninen & Roche, 2021) was used.

4 Analysis

In this section, the chosen pieces from the composers Kaija Saariaho, Karlheinz Essl and Maija Hynninen are discussed. Each subsection covers one of the pieces and begins with a short introduction to the piece in question. After this, the piece is analysed both with a score-based and aural approach, discussed separately. Conclusions on the analysis are made in the section 5.

4.1 Kaija Saariaho: Petals

Petals for cello and live-electronics by the Finnish composer Kaija Saariaho (b. 1952) was written in 1988. According to the composer, Petals brings together the opposite elements of fragile coloristic passages and more energetic events with clear rhythmic and melodic characters, stemming from her piece Nymphéa for string quartet and electronics. Saariaho describes that the more sharper figures pass through different transformations, finally merging back to less dynamic grounds. (Saariaho, n.d.-a)

The live-electronics used in Petals consist of reverberation and harmonizers, marked with R and H, respectively, on the score. According to the instructions for performance, a bright reverberation should be selected, and the reverberation time should start at 2.5 seconds in the beginning of the piece. Reverberation time refers to the time it takes for a sound to fade away. The composer also notes that it is better to have a bit too little than too much reverberation. In addition, two harmonizers are needed for producing microtonal pitch shift. This is carried out by setting the harmonizers so that the transposition is around 50 cents (1/4 tone) on either side of the input signal. The score indicates the desired changes in the degrees of the effects during the piece with approximate crescendos and diminuendos, moving from the previous level of intensity to the next, as seen in Figure 1. Dotted lines, in turn, indicate that the current level should be maintained. The live-electronics can be run either with a Max/MSP patch, provided by the composer on her website, or by using external reverberation and harmonizer processors as in the original version of Petals. In any case, a sound engineer is needed for altering the levels of the effects according to the marks on the score. (Saariaho, n.d.-b)

4.1.1 Score analysis

As first score-based observations on the live-electronics, one can notice the smooth usage of the processing techniques, reverberation and harmonizers, with subtle

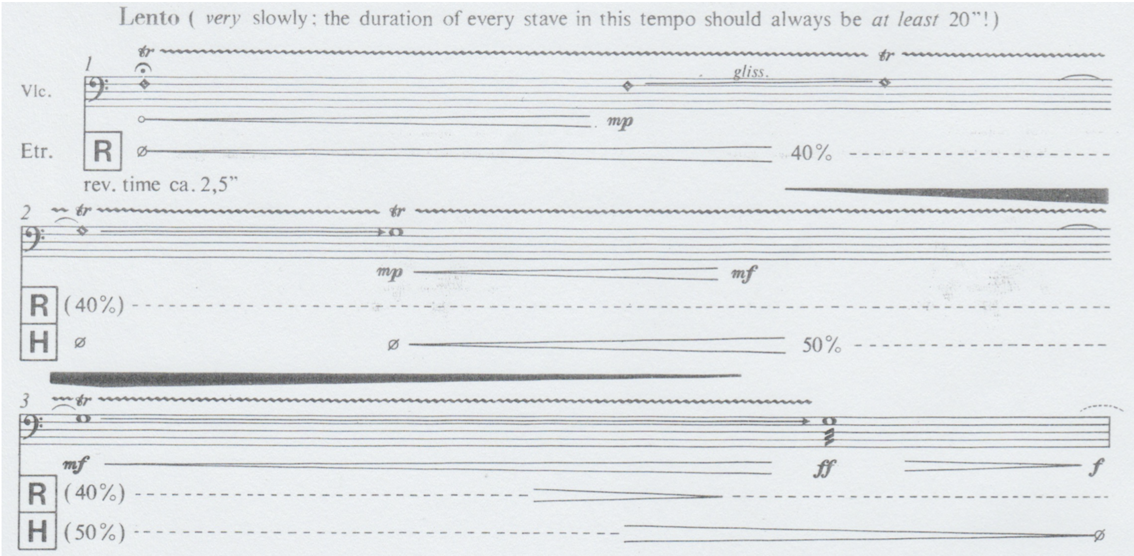

Figure 1: Saariaho: *Petals*, bars 1–3. (Saariaho, 1988).

changes in their intensity. Saariaho uses the crescendo and diminuendo signs for indicating fade-ins and fade-outs, as seen in Figure 1. During the piece, there are no abrupt changes in the intensity of the live-electronics. This creates the impression of the electronics working alongside the instrumental part, however always being subordinated to cello and not aiming at standing out by themselves. Also what seems like a pattern in Petals is the constant appearance of reverberation, while harmonizers are used more sparsely. This indicates at different roles given to the two effects.

Reverberation is used throughout the piece with no bar appearing without the effect. This observation itself indicates to one of the roles of reverberation being to create a general mood or atmosphere for the piece. In the re-appearing places marked with *Lento* (starting at bars 1, 8, 13 and 27) reverberation acts as a static element, supporting the cello passages with long notes, as in Figure 1. The level of reverberation in these places (30–50%) is high enough to influence the sonic characteristic but low enough not to stand out by itself. As a contrast, the intensity of the static reverberation is decreased when the more energetic and rhythmic cello material appears, as for example in the bar 10. During the piece, the level of reverberation is adjusted according to the nature of the cello materials – held long notes and more rhythmical passages – as to differentiate them. From the bar 18 on this adjustment becomes more agile as the crescendo and diminuendo signs written for reverberation become more and more frequent, as can be seen in Figure 2. Also the differentiation between the cello materials with reverberation becomes less sharp towards the bars 20–21 when the reverberation crescendo is already started early during the rhythmic cello climb and the diminuendo long before the end of the phrase.

Figure 2: Saariaho: *Petals*, bars 18–21. (Saariaho, 1988).

Towards the end of the piece, also other roles are given to the reverberation effect. In bars 25–27, reverberation appears in waves, highlighting the low beginning pitches of the rising cello passages, seen in Figure 3. In addition, reverberation is used for blurring. This can best be seen in the very end of the piece when the reverberation time is increased to 30 seconds, adding the layering of delayed cello sounds, and then the level of reverberation is increased to 50%, making the final cello tones drown in the digital sound. The reverberation time is also increased from the initial 2.5 seconds to 15 seconds in the bars 21–22 as to increase the overall intensity and tension of the following section with the exhaustion of the reoccurring cello climbs. In addition, the blurring by increasing reverberation may serve to address the composer's attempt to merge the more energetic material to the mood of the *Lento* sections.

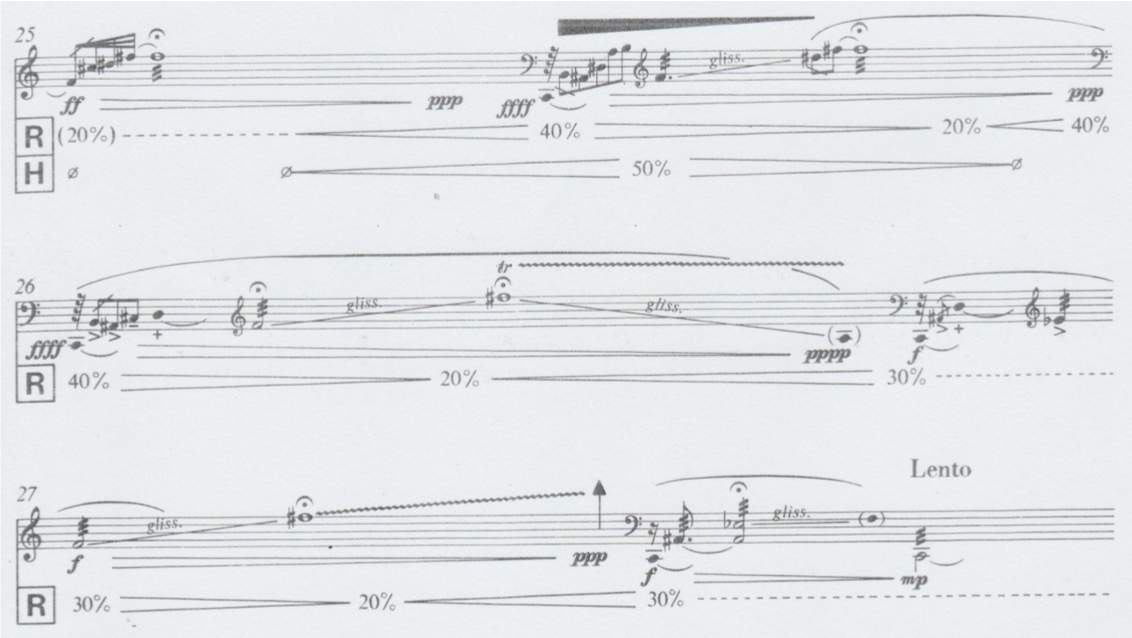

Figure 3: Saariaho: *Petals*, bars 25–27. (Saariaho, 1988).

As a contrast to reverberation, the usage of harmonizers appears in crescendo-diminuendo waves, acting as a temporary coloring effect. Such waves are prominent in the *Lento* sections, appearing during long, static notes on the cello after the characteristics of the passage have already been established by the instrument and reverberation, like in the bar 2. The waves are also coupled with the increase and decrease in the cello bow pressure, as in the bars 14–16, in order to make the intensification stronger. This can be seen in Figure 4. The intensity level of the harmonizers is mostly increased to 50% during the waves, so that the effect is certainly noticeable. The harmonizers are also used alongside the rhythmic cello material, in the bar 11, when the bow pressure is increased during a pitch repetition.

In the bars 18–20, the harmonizer waves are in a new role, acting in a way as an echo of the reverberation. Instead of the processing techniques being separated as before, their intensity levels are altered simultaneously, cross-fading from one effect to the other, as seen in Figure 2. The harmonizers can be seen subordinate to the reverberation as they reach lower intensity level than that of the other effect. One can expect a smooth, multidimensional sonic event where the acoustic cello sound appears in different colors during the same phrase. In the bars 23–25, however, the harmonizers become dominant. A stronger intensity is assigned to the harmonizer than to the reverberation, now statically in the background. Also the harmonizers have a new role in these bars: even though they again appear alongside the changes

Figure 4: Saariaho: *Petals*, bars 14–16. (Saariaho, 1988).

in the cello bow pressure, now the main purpose of the harmonizers is to highlight and intensify the initiating low pitches of the repeated cello ascents. Towards the bar 25, as seen in Figure 3, the harmonizer waves are not anymore in sync with the beginnings of the cello passages, as to make a separation between the sounding qualities created by the increased bow pressure and the harmonizers. This slight separation continues even in the last *Lento* section, making the *Lento* material seem to have been affected by the preceding exhaustion of the cello ascents.

As for the effects working together, one can notice an evolution in their relationship during the piece. In the beginning of the piece, characteristically only one of the effects changes at a time. First the basis of the sonic mood is created with the static reverberation, after which the harmonizers are used on top as momentary colors. However, in bars 18–20 the effects start acting together, as seen in Figure 2. Appearing as layered on top of each other, the effects are not fully in sync time-wise, reverberation changing first. Also the crescendo of reverberation reaches a higher intensity than that of harmonizers. A few bars later, in the bar 25 the proportions of the effects have turned the other way around, as the harmonizers are more intense than reverberation.

4.1.2 Aural analysis

The most surprising finding from aural analysis is the live-electronics being more active and vivid in the piece than what could be expected from the score. Instead of acting statically in the background, the influence of the effects on the cello and the level of how apparent they are alternates as the function of the dynamics of the cello playing. Even if the reverberation intensity is kept in the same percentage, the effect comes through more when the cello plays louder. At times, the sonic result of the effects overcomes dynamically the solistic cello. In addition, the influence of the effects seems more remarkable and longer than what could be interpreted from the crescendo and diminuendo marks assigned to the effects. For example even when the harmonizers are yet faded in, they already create a noticeable layer alongside the cello. Also while and after fading out the harmonizers, their influence expands by being fed back through the reverberation.

One of the roles given to the live-electronics, and only perceivable through aural analysis, is acting as a constructor or carver of phrases. For example from the bar 18 on the phrases are built as a combination of the cello material and the effects, expanding and continuing the cello passages. The sound processing techniques create ghost sounds or shadows, echos to the acoustic instrument, and these echos come to life only by the realization of the music as well as by listening to a performance of the piece. The temporal aspect of the sonic shadows is not visible in the score. In terms of structuring, the effects also sonically highlight the lowest cello pitch used in the piece, the low c, that from the bar 17 on becomes a culmination point for the cello phrases.

The live-electronics enrich the acoustic cello sound in the piece. Through changes in the intensity of the effects, the cello sound alternates between dry and wet, noisy and clean, spectrally narrow and rich. The used sound processing techniques, reverberation and harmonizers, deepen the acoustic sound. This is apparent for example in the bars 13–15 where the cello part is subtle and in itself not very loud, but where the effects make a bigger deal out of the cello gestures. What makes sonically the combination of the cello and the sound processing techniques more uniform is both of the used effects being timbrally close to the instrument: reverberation acting on the pitches of the cello and harmonizers transmitting pitches only quarter tone away from the original.

4.2 Karlheinz Essl: Sequitur XI

Sequitur XI for percussions and live-electronics is one of the 14 compositions of the Sequitur series for various solo instruments and live-electronics by the Austrian composer Karlheinz Essl (b. 1960). While the composition of the series began in

2008, the piece Sequitur XI dates back to the year 2010. According to the composer, the series can be seen as a reference to Berio's Sequenze cycle that consists of solo pieces, focusing on specific playing techniques of the respective instrument. (Essl, n.d.)

Sequitur XI, as all of the other parts of the series, uses a software written in Max/MSP for the live-electronics. The software creates an electronic accompaniment from the instrument's live input in the form of a complex 8-part canon. The density of the accompaniment as well as the temporal structure in terms of the rate at which the canonic layers appear, varying between 1 and 8 simultaneously sounding voices, is controlled by random operations. Thus different sounding results occur every time the piece is performed. Essl points out that even though the piece is precisely notated, the fact that the outcome always changes emphasizes the awareness and attentiveness of the performer. Namely, the player is confronted with their own playing, creating the illusion of moving in a house of mirrors where the identities become blurred. Sequitur XI can be performed either by the percussionist alone using a pedal for controlling the live-electronics or by including another musician for performing the electronic part with a MIDI controller. (Essl, n.d., 2019)

For Sequitur XI, live-electronics are described with operational notation. In the score, Essl uses cue numbers for indicating the places where the pedal or a button on the MIDI controller should be pressed in order to trigger a change in the electronics, automatically controlled by a Max/MSP patch. Next to the cue numbers, a textual expression describes the name of the processing technique triggered by the respective cue. By observing the functioning of the Max/MSP patch received from the composer, one can notice that the occurrence of a cue number also silently entails the end of the usage of the effect triggered during the previous cue. Between some of the cue signs in the score, Essl uses the textual expression *flex* followed by *on/off* and a curvy line, seen in Figure 5, to indicate the momentary addition of a user-controlled subtle transposition effect. The composer's notational choices for the live-electronics do not indicate details on each effect, for example the dynamic level or intensity, nor how the effects affect the percussions. This is also highlighted by the fact that the score does not include a preface describing the live-electronics and their notation.

4.2.1 Score analysis

As discussed above, the score of Sequitur XI provides operational notation on the live-electronics. For being able to conduct score-based analysis on the electronics, one needs to have a thorough understanding of the used processing techniques. The

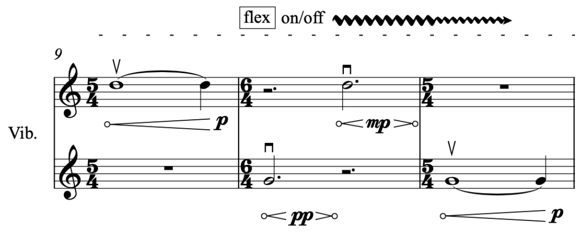

Figure 5: Essl: *Sequitur XI*, bars 9–11. (Essl, 2009b).

notation, namely, only indicates where each processing technique is triggered, which makes it possible to have very approximate assumptions on how the electronics interact with and affect the percussion part. In order to clarify the sparse notation without notes on when and how the effects are turned on and off, as well as the meaning of the marking *flex*, I studied the Max/MSP patch, created for the piece. I observed that all of the cues trigger pre-defined levels for the sound processing techniques, and the effects are both faded in and out following a pre-defined speed. As the curly brackets with multiple effect names in the bars 106 and 155 did not appear to change anything in the patch, I concluded that the brackets may be optional and thus not included in this analysis. The functioning of the patch is not further analysed, yet the previous observations are crucial for the following discussion.

In the piece, a canon with up to 8 parts is created by digital means from the real-time playing of the percussionist. In the score, this canon is described to be either ordinary (ord) or extended with the freeze audio processing technique. The difference between these approaches is that when ordinary, the direct percussion input is digitally layered in canonic parts using delays, and when applied with freeze, a feedback loop is added to this from the output of the delay operation. The ordinary canon is used alongside a variety of musical materials and textures in the percussion part. Typically the ordinary canon appears when other processing effects are used simultaneously. In addition, in places with no percussion playing, such as the bars 58–59 and 91–92, the ordinary canon acts as a purifying element, clearing away the sonic effect of the previously used processing technique. The freeze canon appears less frequently, only in the very beginning and end of the piece. This canon technique is mostly not paired with any other processing technique, however in a few places a subtle transposition is added and in the very end of the piece also reverberation. When the freeze canon is used, the instrumental material seems to base on long repetitive notes or repetitive ascending and descending scale passages.

The other processing techniques are to alter and tone the canonic basis. Transposing, as well as its variant flex, and detuning appear in similar functions: to add color to a passage of same (long) pitch repetition. Typically these effects are triggered when the overall sonic mood of a particular passage is already established, as in the bars 10 and 127, seen in figures 5 and 6 respectively. Repetition is also linked to the effects of tremolo and ring modulation. In the bar 33, the tremolo effect is added on top of long notes on the vibraphone as to introduce increasing activity continued with the vibraphone's repetitive notes a few bars later. Ring modulation that characteristically chops sound in a way similar to pitch repetition appears in the bar 72 alongside the repetitive vibraphone. The vibraphone texture can be estimated to blend in well with the oscillator signal generated by the effect that highlights the metallic characteristic of that passage. While the effects of transposing, flex and detuning alter the percussion material itself, the effects of tremolo and ring modulation are paired with and essentially similar to the percussion texture in their immediate neighborhood.

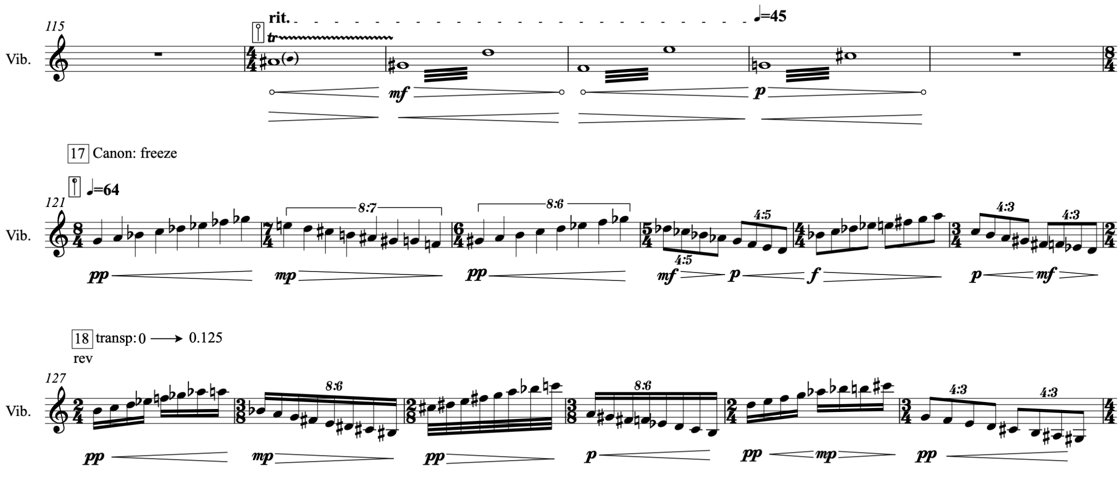

Figure 6: Essl: *Sequitur XI*, bars 115–132. (Essl, 2009b).

The effects of flange, reverberation and frequency shift make the percussion material more richer in sound. Flange is used from the bar 19 on when the percussion material becomes more versatile both pitch-wise and by including the cymbals alongside the vibraphone. By its nature, the effect can be seen to aim at making the changing percussion texture now on two instruments to blend in better. Reverberation is saved to places like the one starting in the bar 52 with tremolo between two pitches on the vibraphone, seen in Figure 7. The usage of the effect seems to serve to make the tremolo sound smoother and denser. From the bar 145 on, seen in Figure 8, reverberation reappears to make the sparse vibraphone pitches sound fuller. The effect of frequency shift only occurs in one place during the piece with a scale-like, hesitatingly rising vibraphone passage. The usage of the effect creates the expectation of the frequency shifting intensifying the vibraphone rise, also highlighted by dynamic increase. As in the vibraphone passage itself the pitches are constantly changing, the addition of frequency shift on it may result in a more pointillistic impression.

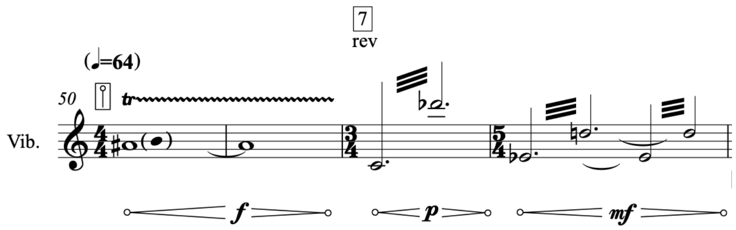

Figure 7: Essl: *Sequitur XI*, bars 50–53. (Essl, 2009b).

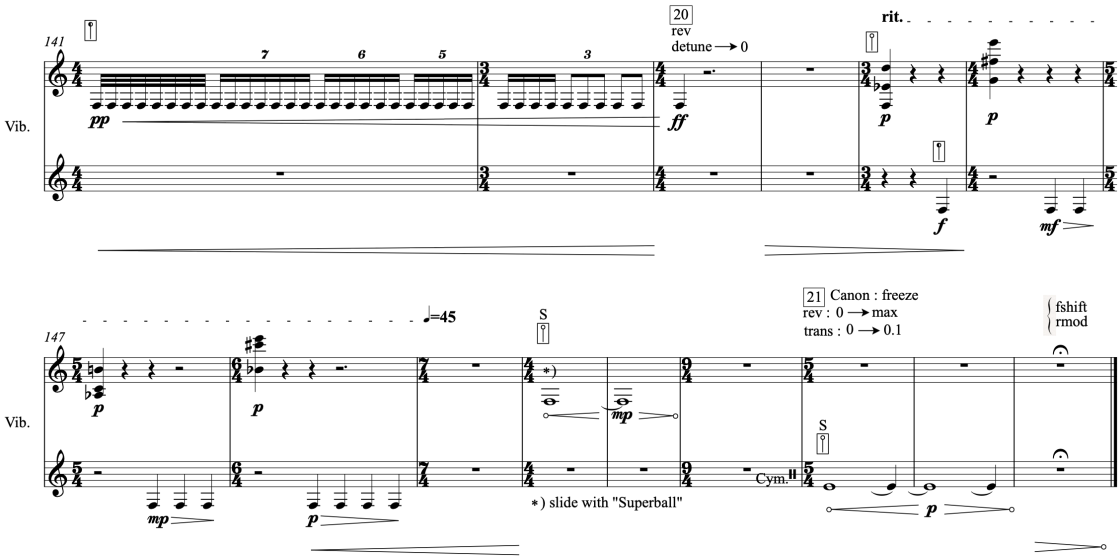

Figure 8: Essl: *Sequitur XI*, bars 141–155. (Essl, 2009b).

As general observations, the percussions appear only by themselves in a very few places during the piece. It seems like the border between acoustic instruments and digitally reproduced sounds with processing techniques is constantly blurred. The acoustic sound is chopped, enriched and colored by live-electronics. Also the processing techniques act as mediators between different percussion textures, or the sounding result of a processing technique is imitated on the percussions, as for the ring modulation effect. The live-electronics add instability to the piece in terms of frequency, pitch content and vibration in many forms. The usage of sound processing seems to make the rather simple percussion material sound more intriguing.

4.2.2 Aural analysis

On a general note, aural analysis reveals important characteristics of the live-electronics used in Sequitur XI that are not apparent in the score analysed above. The usage of live-electronics takes on a new level by the way the sonic material with canon interacts with itself. As the score does not indicate how long the influence of a specific sound processing technique can be heard, the way the effects mix together cannot be directly seen from the score. Only through aural analysis one can notice how the digitally repeated and altered percussion material acts at times as melody or accompaniment alongside the real-time playing of the instrumentalist. Also the sonic results of the mixture between the timbres of different materials fed back through the live-electronics comes across as surprising during aural analysis.

The listenings conducted during aural analysis raise the main sonic motif of the piece: development of activity. In a big perspective, Sequitur XI contrasts long sustained sonic masses with activity based on repetitions or internally chopped sounds, such as colored by ring modulation. The boundaries between the two are constantly questioned as blurring occurs for example in places like between the bars 116–136, seen in Figure 6. In this passage, the more prominent vibraphone material starting from the bar 121 is made less melodic using the freeze technique, and through this is sonically even brought closer to the preceding sustained tremolo. As a strong contrast, also sonic clearings occur for example starting from the bars 58 and 107, where momentarily no sound alternating processing technique is in use.

When focusing on the sonic qualities, the organization for the subtle development of sound can be tracked from the beginning of the piece. The sustained sound carpet created in the very beginning with the freeze canon is dissolved to moderate action in the bar 21 where the flange processing technique supports the addition of the cymbal and pitch jumps between different registers. Action is taken further by the addition of repetition, tremolo which at the same time creates the sonic impression of being sustained in one pitch while increasing instability. Repetition is also internally altered through detuning and transposing. Changing the sound processing technique from freeze, flange and detuning to tremolo makes the vibration of sound evolve from internal to external. Later on tremolo is expanded between pitches in different registers while blurred with the usage of reverberation. The development of sound and sonic qualities go on further in the piece, also by making the at first faded usage of electronics more apparent.

Sonically, live-electronics are given multiple roles during the piece. As discussed above, the sound effects create a sustained base or accompaniment for example through freeze and reverberation. The same effects are also used for blurring the material written for the percussion instruments. A good example of this is the usage of the freeze canon starting from the bar 121, as seen in Figure 6. Here the almost melodic vibraphone is blurred and multiplied so that the composer's metaphor of a house of mirrors seems sonically to be achieved. In addition, the live-electronics bring variation and color to the percussion material that at times in itself may seem almost as a crude continuum. Only through listening, one can hear the true organization of the piece: how the instrumental material, at times sparse and repetitive, creates melodies, harmonies, accompaniment and sonic layers through the structure of the digitally generated canon as well as the usage of the sound processing methods. The addition of layers adds a pointillistic impression to places where percussion passages with a strong rhythmic nature are repeated with different timings.

Live-electronics also act as a link between percussion materials with very different characteristics. For example, the materials of the bars 116 and 121, seen in Figure 6, are bound together by the freeze canon turned on in the latter bar, creating a long sustained background of the same pitches that were previously used in a tremolo. In addition, the bars that seem empty in the score, such as the bars 19–20, act as bridges between the alternating sound processing techniques instead of being used as pauses or sonic clearings. This is due to the influence of the live-electronics continuing also in those bars, against the expectation of silence stemming from the score-based analysis.

4.3 Maija Hynninen: in the universe everyth ng is a circle

The piece in the universe everyth ng is a circle for contrabass clarinet and electronics by the Finnish composer Maija Hynninen (b. 1977) was composed during the years 2020–2021. According to the composer, the piece draws inspiration from the novel Settle Her by Sawako Nakayasu. The novel consists of writings from the Thanksgiving 2017 when, as a protest against meaningless festivities, the author decided to ride a bus throughout the whole day, circling the same route. Also the book itself forms a circle where the ending leads seamlessly to the beginning. This is reflect in Hynninen's piece, which according to the composer is a journey in circles towards the stillness of the center. The name of the piece comes from a fragment of the novel: "Cecilia Vicuna says th according to Am ric n Indians 'in the universe everyth ng is a circle'". Some other fragments of the novel have also been transcribed and intertwined in the delicate airy textures of the contrabass clarinet. (Hynninen & Roche, 2021)

The score of the piece utilizes a mixture of operational and descriptive graphical notation for the electronics. The preface on the electronics mentions only the requirement of a computer, an audio/midi-interface, a microphone for live-processing the clarinet sound and a pedal for launching events in the electronics, but does not describe how the electronics are produced. From the need of a triggering pedal and the operational notation of the live-electronics one can deduce that the electronics are controlled automatically by a Max/MSP patch. However, the supposed patch was not available for the analysis in this work. As for Essl's piece, also the piece by Hynninen requires a good understanding of the sound processing techniques as the various techniques are not defined in the score.

Hynninen writes the three different elements of the electronics – pedal, live-electronics and fixed media – on separate staves on the score. As this thesis is not focusing on fixed media, the fixed media of the piece is not further discussed. On the pedal staff, boxed cue numbers indicate the places where the pedal should be pressed by the contrabass clarinetist. Triggering changes in the electronics is, besides the cue numbers, indicated by notes with specified duration as to instruct how the pedal should be pressed. On the live-electronics staff, events in the live-electronics are marked with text boxes describing the used effects, triggered by the pedal, as well as a line continuing from the box to show how long the respective effects are in use. Based on these lines alongside the pedal cue numbers, one can see that the effects are never cut off straight at cues but rather have pre-timed fade-outs. Also it can be seen from the score that some of the cues do not seem to have a self-explanatory function. For example the cues in the end of the bars 8 and 15, the latter seen in Figure 9, do not seem to change anything: the on-going live-electronics line does not end or change in any way. In addition, the cue in the bar 30 is not paired with any events in the electronics.

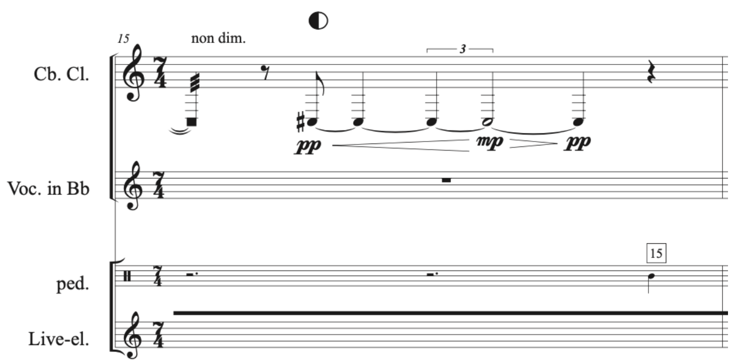

Figure 9: Hynninen: *in the universe everyth ng is a circle*, bar 15. (Hynninen, 2020).

4.3.1 Score analysis

Hynninen's piece is organized in five parts: (anonymous), Bass – Persistently, Glissandi – Accumulating, Speakings – Scattered, and The Center – Record Shop. In addition to differing in the material written for the contrabass clarinet, sound processing techniques are used differently in each part, apart from a few similarities between the parts called (anonymous) and Glissandi – Accumulating. In general, the frequency and the density of the used sound processing techniques increases along the piece. In the beginning, the contrabass clarinet appears at times alone and the sound processing techniques are introduced one by one, while towards the center of the piece many effects are layered. The fourth part is evidently different from the other parts of the piece in that it strongly focuses on the interaction between the contrabass clarinet and fixed media, leaving live-electronics with less attention.

One of the most used processing techniques is the resonators paired with granulation. The effect extends and colors long static notes on the clarinet, as well as appears during key clicks and air sounds as to deepen the soft and quiet sounds. The resonators, coupled with granulation, also accompany the harmonically rich clarinet effect called *jazzy scream* and overtone slides, for example seen in the bar 68 in Figure 10. Mostly the resonators are used in the first and third part of the piece, also combined with delay.

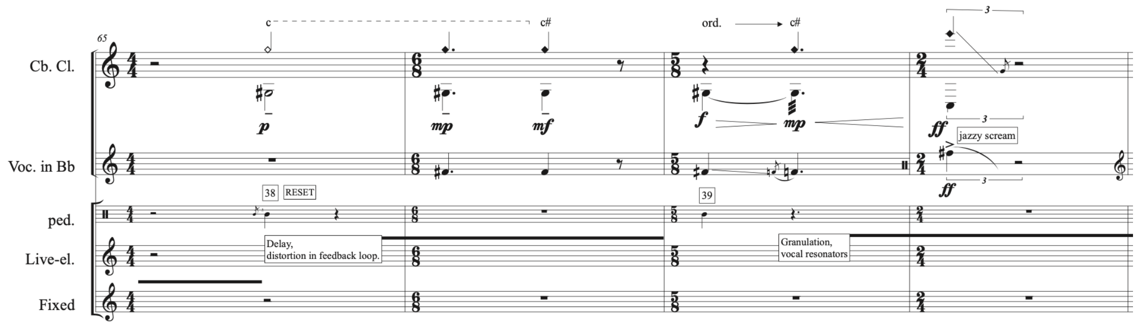

Figure 10: Hynninen: *in the universe everyth ng is a circle*, bars 65–68. (Hynninen, 2020).

The usage of delay is apparent almost throughout the piece. Especially in the second part of the piece, one of the delays used by Hynninen is constantly on. Two types of delays appear in the piece: normal delay and spectral delay. In addition, normal delay is at times coupled with slight distortion, multilayered or following the amplitude of the contrabass clarinet for controlling the intensity of the processing technique. Delay accompanies long or statically repeating pitches on the clarinet, key clicks and air sounds. The second part of Hynninen's piece with the clarinet overtones and harmonics seems the most important for delay as the processing technique dominate the part. On one hand, the normal delay is coupled with the spectral delay for the first time in this part. On another hand, the usage of the amplitude following delay is the most versatile by changing whether the softest of the loudest clarinet sounds are assigned the most delay.

Spectral delay is introduced in the beginning of the piece after the normal delay. The processing technique is used similarly as the other delay: with long notes and airy sounds on the contrabass clarinet. The reappearing clarinet passage starting for example in the bar 14 is characteristically paired with spectral delay, recalled in the bar 99 in the third part, seen in Figure 11. Also the *jazzy screams* and overtone slides on the clarinet, singing while playing the instrument, and the passages of harmonic painting called *liberamente – freely* are fruitful places for the usage of spectral delay.

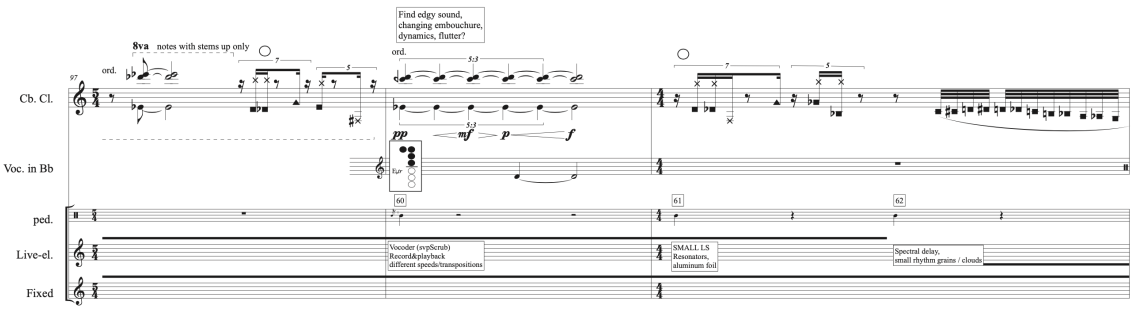

Figure 11: Hynninen: *in the universe everyth ng is a circle*, bars 97–99. (Hynninen, 2020).

In addition to the majorly used resonators and delays, Hynninen momentarily flashes a few other sound processing techniques. While first being subordinate to the delay effect, distortion breaks free in the bar 117 with the thicker chords on multiphonics, as seen in Figure 12. This role given to the distortion returns in the bar 207 and acts as the closing processing technique in the whole piece. Bending and transposition appear both only once on long clarinet pitches. The vocoder is used in the third part of the piece alongside rhythmic passages with key click in the high register of the clarinet as well as in the bars 96–98 with airy sounds and multiphonics. The effect is used so that the clarinet material is recorded and then played back with different speeds and transpositions. The cross filtering technique appears only in the closing part of the piece in the function of changing the loudness of the events in fixed media based on the dynamics of the contrabass clarinet, thus not changing the sound of the instrument itself.

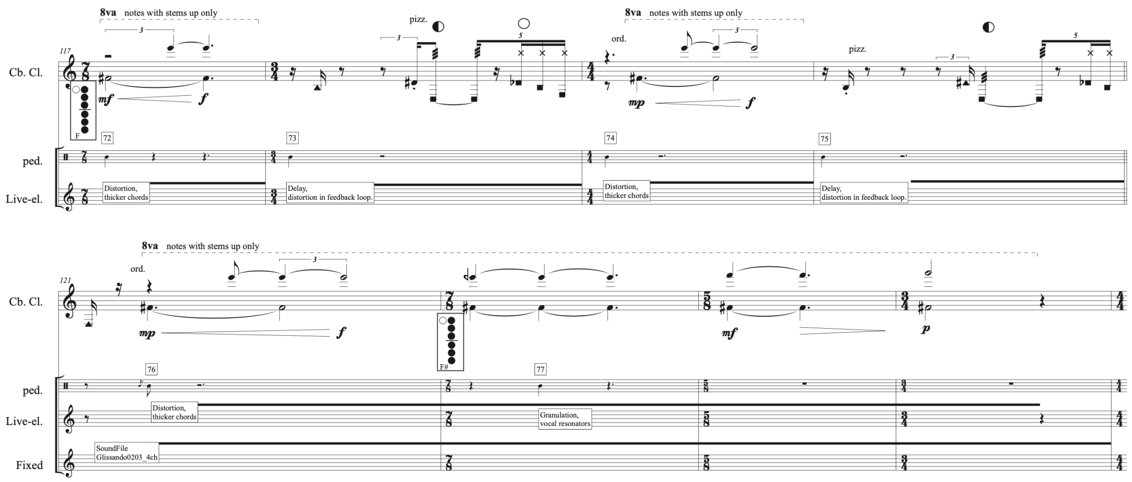

Figure 12: Hynninen: *in the universe everyth ng is a circle*, bars 117–124. (Hynninen, 2020).

For Hynninen's piece, due to the rich and layered usage of both sound processing and contrabass clarinet playing techniques, it seems challenging to fully imagine the final sonic outcome. For example, in the third part of the piece, the graphical notation on the duration of each sound processing technique becomes unclear when multiple effects are turned on and off simultaneously. This can be seen in Figure 13. Score analysis, thus, does not seem enough for understanding the usage of the electronics nor for conducting the analysis on the roles given to the electronics, as the true nature of the piece does not seem to be easily perceivable from the notation. In particular, it seems that for analysing Hynninen's piece the approach basing on aural analysis is necessary.

4.3.2 Aural analysis

Aural analysis on Hynninen's piece demonstrates that against the impression given by score analysis, highlighting the rich and abundant usage of sound processing, for most parts live-electronics have a less prominent role in the piece. Live-electronics act in subtle ways, adding to the contrabass clarinet sound but not remarkably standing out by themselves. During the first listenings, in fact, more attention is drawn to the clearly apparent clarinet sound and the material on the fixed media. One can only speculate if this could be due to the mixing of the audio recording, lacking the 3D space for hearing the live-electronics' sound-diffusion or due to assigning compositionally more importance to the fixed media than to sound processing. In addition, the sounding quality and timbre of the sound processing results are at

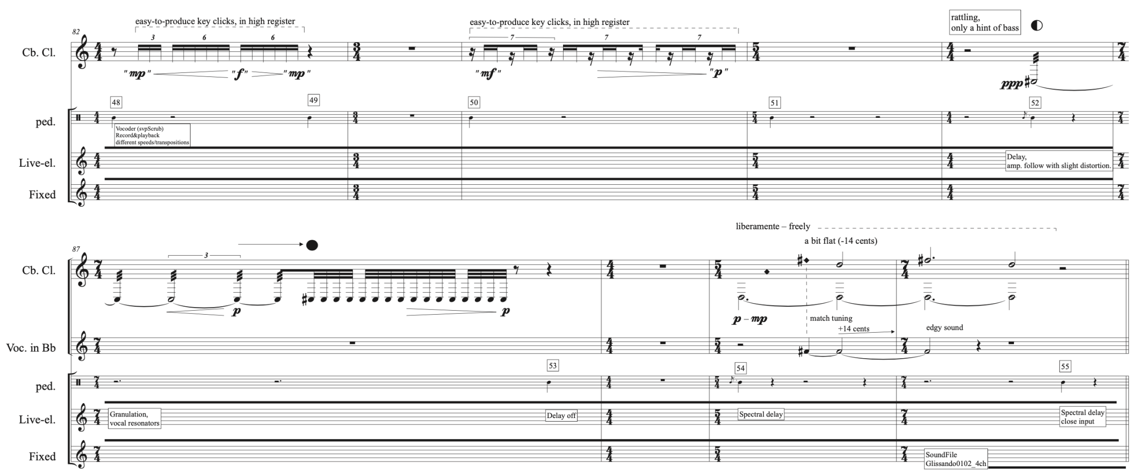

Figure 13: Hynninen: *in the universe everyth ng is a circle*, bars 82–90. (Hynninen, 2020).

times very similar to the contrabass clarinet as well as to what is heard on the fixed media. For example, in the beginning of the piece the rattle of the clarinet prepared with laminated paper, amplified by the tremolo playing technique, reminds of the granulation used with the vocal resonators. Extended slides and fuzzy hums on the fixed media, in turn, seem similar to the different delays used in live-electronics. Due to the sonic similarities, at times during aural analysis it is challenging to distinguish which sonic events stem from the live-electronics and not from the fixed media.

By the ear, the development in the usage of sound processing goes from chopping and splitting effects to the effects deepening and layering the sound. The sonic build-up seems to be placed between the pages 11–13, with the climax of alternating thick chords and airy points, distortion and delay in the bars 117–124, seen in Figure 12. After the climax, the combination of clarinet multiphonics and distortion is assigned a greater purpose, as the sound processing technique dominates in the very end of the piece. The sonic quality of distortion is particularly designated to the multiphonics.

During each listening, it becomes more and more evident that the live-electronics have two major roles: to work as extension and to build mass. The idea of extension is initialized in the beginning of the piece when sound processing techniques are added on top of the clarinet material in the middle of the instrumental phrase. The effect expands the clarinet sound even when the instrument has stopped playing and prolongs the closing of the phrase. Different levels of extension appear in terms of granulation, pitch bending, transposition and spectral movements. Especially during the overtone slides in the clarinet, the spectral qualities of the instrument sound are layered and widened by spectral delay. In addition, the resonators with aluminium foil make the clarinet key clicks and air sounds remind of a snare drum.

The sound processing techniques such as resonators, delays and distortion add hums and noise to the acoustic clarinet sound, making the sound thicker. The most remarkable of such places is when distortion is used during the clarinet multiphonics, adding up the sonic mass. In addition, the usage of resonators and delay alongside the quiet key clicks and air sounds on the clarinet bring the subtle sounds more apparent, even so that in the fourth part of the piece the clarinet material sounds as much in the front as the speech recordings on the fixed media.

5 Discussion

The results of the analysis, presented above, demonstrate that the usage of live-electronics in the three chosen pieces is essential, significant and meaningful. Both score and aural analysis revealed several roles given to the sound processing techniques, ranging from highlighting and emphasizing instrumental materials to creating multidimensionality and adding sonic instability. To summarize the most important findings, Table 1 gathers from the piece-specific analyses the most remarkable roles in which live-electronics act in the analysed pieces. The roles are categorized in five groups: perceptional, structural, atmospheric, sonic and timbral roles.

While the perceptional roles in the table determine how live-electronics affect the perception of a piece, structural roles influence the way the organization of a piece can be understood. The atmospheric roles affect the broader sonic impression on a piece, and the sonic roles are more centered on specific sonic events. Even though timbral qualities of the pieces were not analysed in detail in this work, some apparently timbral roles could also be detected through aural analysis. Noteworthily, the collected roles stemming from score analysis are almost without exception located in the perceptional roles' category, while the clearly sonic by nature categories of atmospheric, sonic and timbral roles consist of findings during aural analysis. Even though in the Western Art Music analysis structural observations are traditionally made from the score, the structural roles in Table 1 were detected mostly aurally. The reason for this is time-dependency: as structural hierarchy bases on time and many of the sonic influences of live-electronics can only be understood in the time domain during a performance, also structural perception is related to aural perception.

During the analysis, I noticed that for all of the pieces I formed initial interpretations on the roles given to live-electronics during score analysis and then either confirmed or refuted them based on the results of aural analysis. This was highlighted by the findings that often the sound processing techniques affected longer in time the solo instrument than was expected from the score. Also for example for Saariaho's piece it seemed during score analysis that the electronics are subordinate to the instrument, even though during aural analysis they turned out to be much more active and varying than expected. On the contrary, the expectation formed during the analysis on Hynninen's score of many simultaneously used sound processing techniques being sonically very apparent turned out to be false during aural analysis. Thus, this notion stresses the importance of aural analysis in the context of electroacoustic music analysis.

Perceptional	**Structural**	**Atmospheric**	**Sonic**	**Timbral**
differentiating instrument materials	indicating different sections	setting general mood and characteristic	deepening instrumental sound	creating timbral multidimensionality
highlighting instrument materials	bridging different instrumental materials	creating sustained base	chopping and splitting instrumental sound	adding color to long notes
blurring, making instrumental sound less apparent	layering instrumental materials into harmonies, melodies etc.	building mass	creating echos, shadows and continuations of instrumental sound	altering sounding quality on different scales (for example dry–wet)
emphasizing soft, quiet instrumental sounds	extending instrumental phrases	adding instability and noisiness	layering instrumental material, making denser	
making instrumental materials more interesting			adding vibration (either internal or external)	

Table 1: Roles given to live-electronics in the studied pieces.

The notational choices used in the score affect how well the roles of live-electronics can be perceived directly from the score. Especially when the description of the sound processing techniques is not comprehensive and only operational notation is used, the interpretation of the effects of live-electronics is the better and the easier to form, the better one knows the used techniques and their sonic functioning in practice. However, even for a more educated analyst estimating the influence of live-electronics may be challenging when multiple effects are in use simultaneously, as in Hynninen's piece. In this study, I felt that it was the easiest to interpret the influence of live-electronics on the solo instrument from Saariaho's score, as the crescendo–diminuendo signs and intensity percentage numbers act both operationally and descriptively. The relation between the instrumental writing and the usage of electronics can be estimated from the score only. Also the duration of the sound processing techniques, marked in Hynninen's piece, help in score analysis. The most difficult score to analyse in terms of the usage of live-electronics was the one by Essl. Due to sparse operational markings, the Max/MSP patch of the piece had to be consulted during score analysis for better understanding the notation.

To speculate on whether the analysed pieces could function without the live-electronics, I would say 'no'. Even though in the score of Petals the electronics are marked as optional, it is through the evolving usage of reverberation and harmonizers during the piece that the two opposite cello elements – fragile passages and rhythmic characters – are merged together through transformations, as Saariaho states to be the leading idea behind the piece (Saariaho, n.d.-a). Similarly, in Sequitur XI the canons and sound processing techniques create the illusion of the percussionist being "in a house full of mirrors" (Essl, n.d.). Without live-electronics, the pieces would not reach these essential characteristics or metaphors crucial for the meaning and existence of the whole composition. Petals would lack the sounding quality and atmosphere characteristic to Saariaho's music. The percussion material of Sequitur XI would seem fractured and monotonous. And the clarinet passages in Hynninen's piece would not merge so seamlessly to the fixed media without the live-electronics.

6 Summary

This work attempted to study the electroacoustic compositions by Saariaho, Essl and Hynninen in terms of the roles assigned to live-electronics when working alongside a solo acoustic instrument. Through both score and aural analysis, several functions were detected for the sound processing techniques, ranging from perceptional roles to sonic roles. The roles were discussed, categorized and listed in order to highlight the versatile usage of live-electronics in these pieces. In addition, referring to these roles, live-electronics were concluded to be a crucial part of the compositions.

The analysis conducted and the results discussed demonstrate the importance of aural analysis in the field of electroacoustic music analysis. Even though some notes on the live-electronics and their usage could be made directly from the score, it was seen how score analysis did not always lead to correct interpretations on the sonic effects of the sound processing techniques nor comprehensively indicated all of the roles live-electronics have in the analysed pieces. Moreover, it was seen that the quality of the results of score analysis highly depends on the notational choices used for live-electronics.

As for suggestions for future work, this study shows that the analysis on the purpose and compositional value of the electronics in electroacoustic music deserves to be more researched. Seen from the results, live-electronics are used in various important roles, as opposed to just acting as background for the solo instrument. I believe that studying more in detail the usage of live-electronics in electroacoustic music also concretizes why the sound processing techniques are used in art music as well as can act as self-reflection for composers using the sound processing techniques. In addition, future work could be conducted in collaboration with the composers working with live-electronics, hearing from the composers directly how they see the roles of live-electronics already during the composition process.

References

Brown, G. (2019). *The Basics of Granular Synthesis.* iZotope, https://www.izotope.com/en/learn/the-basics-of-granular-synthesis.html. (Accessed 10.8.2021)

Bullock, J., Coccioli, L., Dooley, J., & Michailidis, T. (2013). Live electronics in practice: Approaches to training professional performers. *Organised Sound*, *18*(2), 170–177. doi: 10.1017/S1355771813000083

Chambers. (n.d.). *Electroacoustics.* In The Chambers Dictionary: Chambers (online). (Retrieved 9.6.2021)

Clark, J., & Hordijk, R. (2003). Advanced programming techniques for modular synthesizers. Online book, 2003 edition, https://www.cim.mcgill.ca/~clark/nordmodularbook/nm_spectrum_shift.html. (Accessed 7.6.2021)

Deutsch, D. (1999). The psychology of music, 2nd edition. In D. Deutsch (Ed.), (chap. Grouping mechanisms in music). Academic Press.

Dodge, C., & Jerse, T. A. (1997). Computer music: Sythesis, composition, and performance (2nd ed.). Schirmer Books.

DSPRelated. (n.d.). *Comb Filters.* DSPRelated, https://www.dsprelated.com/freebooks/pasp/Comb_Filters.html. (Accessed 7.6.2021)

Emmerson, S. (2006). In what form can 'live electronic music' live on? *Organised Sound*, *11*(3), 209–219. doi: 10.1017/S1355771806001427

Emmerson, S., & Smalley, D. (2001). *Electro-acoustic music.* Grove Music Online, Oxford University Press. (Retrieved 10.6.2021)

Essl, K. (n.d.). *Sequitur.* https://www.essl.at/works/sequitur.html. (Accessed 15.2.2022)

Essl, K. (2009a). *Material for Sequitur XI.* https://www.essl.at/works/sequitur/sequitur-11.html. (Accessed 15.2.2022)

Essl, K. (2009b). *Sequitur XI, for vibraphone, large cymbal and live-electronics.* (Score). https://www.essl.at/div/scores/sequitur-XI.pdf. (Accessed 28.6.2021)

Essl, K. (2019). *Sequitur Generator.* https://www.essl.at/works/sequitur-generator.html. (Accessed 15.2.2022)

Essl, K., & Manzanilla, I. (2014). *Performance of Karlheinz Essl's Sequitur XI.* YouTube, https://www.youtube.com/watch?v=3uY3B4JKodQ&t=773s. (Accessed 18.2.2022)

Frank, I., & Berger, G. (2011). *Performance of Kaija Saariaho's Petals.* YouTube, https://www.youtube.com/watch?v=wkmzXHTrixI. (Accessed 14.2.2022)

Hugill, A. (2012). The digital musician. New York: Routledge.

Hynninen, M. (2020). *in the universe everyth ng is a circle, for contrabass clarinet and electronics.* (Score).

Hynninen, M., & Roche, H. (2021). *Performance of Maija Hynninen's in the universe everyth ng is a circle.* YouTube, https://www.youtube.com/watch?v=dTleJxHQisc&t=464s. (Accessed 18.2.2022)

Konftel. (n.d.). *Dr Sound explains distortion.* Konftel, https://www.konftel.com/en/academy/dr-sound-explains-distorsion. (Accessed 8.6.2021)

Mazzoli, M. (2014). *Emerging musical structures: A method for the transcription and analysis of electroacoustic music* (Unpublished doctoral dissertation). City University of New York.

Olarte, L. A. (2019). *Elements of electroacoustic music improvisation and performance* (PhD dissertation). Sibelius Academy, University of the Arts Helsinki.

Merriam-Webster. (n.d.). *Timbre.* In Merriam-Webster.com dictionary. (Retrieved 22.2.2022)

OED Online. (n.d.). *Electroacoustics, N.* In OED Library: Oxford University Press. (Retrieved 9.6.2021)

Rossetti, D., Teixeira, W., & Manzolli, J. (2018). Emergent timbre and extended techniques in live-electronic music: An analysis of desdobramentos do contínuo performed by audio descriptors. *Música hodie*, *18*(1), 16–30. doi: 10.5216/mh.v18i1.53568

Russ, M. (1996). Sound synthesis and sampling. Oxford: Focal Press.

Saariaho, K. (n.d.-a). *Petals.* https://saariaho.org/works/petals/. (Accessed 14.2.2022)

Saariaho, K. (n.d.-b). *Petals (electronics).* http://www.petals.org/Saariaho/Petals-electronics.html. (Accessed 2.2.2022)

Saariaho, K. (1988). *Petals: For cello solo with optional electronics.* Helsinki: Hansen.

Samplecraze. (n.d.). *Harmonizer Effect – what it is and how to use it.* Samplecraze, https://samplecraze.com/tutorials/harmonizer-effect-what-it-is-and-how-to-use-it/. (Accessed 8.6.2021)

Selle, A. (2018). *Experiencing sound: A hybrid approach to electronic music analysis* (Unpublished doctoral dissertation). Florida State University.

Smith, J. O. (2011). Spectral audio signal processing. Online book, 2011 edition, https://ccrma.stanford.edu/~jos/sasp/Cross_Synthesis.html.

(Accessed 7.6.2021)

Stroppa, M. (1984). The analysis of electronic music. *Contemporary Music Review*, *1*(1), 175–180. doi: 10.1080/07494468400640161

Stroppa, M. (1999). Live electronics or... live music? towards a critique of interaction. *Contemporary Music Review*, *18*(3), 41–77. doi: 10.1080/07494469900640341

Välimäki, V., Abel, J. S., & Smith, J. O. (2009). Spectral delay filters. *Journal of the audio engineering society*, *57*(7/8), 521–531.

Whittall, A. (n.d.). *Electroacoustic music.* In The Oxford Companion to Music: Oxford Univesity Press (online). (Retrieved 9.6.2021)