The Loudspeaker as Musical Instrument

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ABSTRACT

With the author's own experiences in mind, this paper argues that, when used to amplify musical instruments or to play back other sonic material to an audience, loudspeakers and the technology that drives them, can be considered as a musical instrument. Particularly in situations with acoustic instruments this perspective can provide insight into the often cumbersome relation between the –technology orientated– sound engineer and the –music orientated– performer. Playing a musical instrument (whether acoustic, electric or electronic) involves navigating often complicated but very precise interfaces. The interface for sound amplification technology in a certain environment is not limited to the control surface of a mixing desk but includes the interaction with other stakeholder, i.e. the performers and the choice of loudspeakers and microphones and their positions. As such this interface can be as accurate and intimate but also as complicated as the interfaces of 'normal' musical instruments. By zooming in on differences between acoustic and electronic sources a step is taken towards inclusion in this discussion of the perception of amplified music and the possible influence of that amplification on performance practise.

Keywords

Sound technology (amplification), musical instruments, multi modal perception, performance practice.

1. INTRODUCTION

Considering the loudspeaker a musical instrument is not a very novel idea. It goes back to as early as Luigi Russolo's "Intonarumori", as described in, for instance, Simon Emmerson's *Living Electronic Music* [8] p.151-160. Emmerson is one of the few authors who writes about the amplification of music other than from a technological point of view. This paper regularly references to his work, because of the lack of literature about this subject. A more technological approach can be found in a recent book on Sound System Design. This comprises the design of systems of loudspeakers, microphones and paraphernalia to play back or amplify sounds to audiences in a specified acoustic environment. In *Sound Systems: Design and Optimization* Bob McCarthy [11] writes:

"A central premise of this book is that the loudspeaker is not given any exception for musicality. Its Job is as dry as the wire that feeds it an input signal: track the waveform."

From a technological point of view this premise makes a lot of sense. But from a musical performance point of view there is more to converting electronic waveforms into audibly moving air: the process of translating creative ideas into applied technology make loudspeakers a lot more than just a transducer.

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1.1 Musical Instruments

In this paper I zoom in on how we use the "instrument" Loudspeaker, or rather the whole system of input devices, infrastructure, control surfaces, signal processors and loudspeakers to amplify acoustic instruments or other sources. Just like a musical instrument the loudspeaker instrument comes with its own interface. And like musical instruments a loudspeaker comes with its own relation to an acoustic environment. A big difference is of course the fact that musical instruments like the violin have their sound source attached to the interface. But like earlier examples of instruments with their interfaces detached from the sound source (organ, carillon) the advent of MIDI and other technologies allowed modern instruments to make the separation of interface and sound source a common one (see for instance Bert Bongers [2] p.55 or Chabade [4] p.185). At first sight the interface of the loudspeaker –or amplification– instrument would be the mixing desk as this is where usually all inputs and outputs come together enabling a mixer's or sound projectionist' interaction connected to a performance. But the results of those interactions at the mixing desk are heard through a loudspeaker system that functions in a larger system of input devices and room acoustics. This larger system creates a whole range of different feedback loops that extends beyond sonic feedback. Other feedback comes from (for instance) interactions with performers, audience and other stakeholders such as concert organizers such as a venue's commercial, artistic and production staff.

1.1.1 Ecological approach

In the process of writing this paper I was directed to a comparable holistic approach to amplified performance by Owen Green [9], after Agostino DiScipio [7] stressing that in an "Audible Ecosystem Interface" all components are structurally coupled. In connection to that argument Green makes another important point (quoting amongst others, Simon Waters [16]). Our current (electronic) performance practice is contiguous

with the history of musical performance: new technological developments and possibilities haven't necessary changed the nature or the intricacies, including the importance of social context, of musical performance. However, with the separation of visual (a performer) and aural (sound produced by that performer) sources, from a perception point of view something has changed indeed after the introduction of the loudspeaker. I will discuss this interesting notion further in section 3.

1.1.2 Remote instruments

The use of MIDI to separate interface and sound source serves as a good example of how sound sources can be controlled remotely. With digital mixing desks, in practice for live amplification since the mid-nineties, something similar happens. For instance all the processing and ADDA[1] is done in one unit on stage (where usually most inputs and outputs come together), the processes are controlled from a networked control surface in the auditorium or any other location. As an analogous example: some, mostly jazz-rock, keyboardist of the seventies would hook their Fender Rhodes or Wurlitzer electronic piano up to outboard gear just like a guitarist hooks up his instrument to many different effect processors. Recently I witnessed keyboardist John Medeski playing his Wurlitzer through, what sounded like a ring modulator. As he was playing the piano he made changes to the ring modulator's settings using a dedicated control surface on top of his piano. The sounds he generated on his Wurlitzer (playing its familiar interface of black and white keys) functioned as one of the sound sources for the ring modulator he controlled with its own interface. I would like to combine this notion of different interfacing controlling instruments that feed into each other with the aforementioned separation of interface and sound source. We can compare a sound system (again, microphones, mixer, loudspeakers and infrastructure) to a controller controlling a remote sound source. The sound system is the interface and the source(s) it controls are the microphones, signal generators, play back devices or other electronic and digital devices that can act as a source to such a system. In other words: we are using the interface of the instrument loudspeaker to control other instruments that are generating sounds controlled by their own interfaces.

1.1.3 An instrument on an instrument

With the example of a keyboardist playing his electronic piano and controlling his external processing at the same time (using one hand on each, limiting his ability to play his keyboard but extending his expressiveness) I hope to underline the interdependency of users of complex systems of sound sources, controllers and transducers. If a guitarist in a band cranks up his amp, for whatever reason, he is adjusting the balance that a mixer at a desk is trying to maintain. Or if a mixer decides to work at a higher, louder level, again, for whatever reason, he may disturb the balance on stage (by creating more or different reflections in the room or simply from leakage of the PA system onto the stage. Rather than suggesting an instrument on an instrument as a metaphor for processes in amplified music it is perhaps better to think of the whole complex system as one big instrument comprising of: a room's acoustics, an (silent, noisy or screaming) audience, a sound system (with loudspeaker, mixing desk, microphones and paraphernalia) a monitoring or fold back system (with its own loudspeakers, mixing desk and paraphernalia) and musical instruments controlled by people, remotely or directly, generating acoustic and or electronic sounds. In other words, this instrument is not just played by a sound engineer! As a premise, all involved should learn how to play that instrument, as an addition to playing their own instruments. Or as part of learning their instruments, amplification being a very regular part of most performance practices.

1.2 Technological interaction is codependent

The complicated interaction between artist and technologists comes to the fore not just in live sound engineering, it is part of many contemporary artistic practices. This complexity is not limited to artist/technologist relations: for a flutist in an orchestra it is not necessary to learn to play the hobo or clarinet, but to be able to play 'in balance' with the other players in the wind section a working understanding of other instruments is essential. Although not as intimate as in an orchestra section, a similar codependent and interconnected relation between performer and technologist could be beneficial.

1.2.1 Good bad and bad good practice

On a different note, music and musicians or compositions and composers function very well without engineers or other learned technicians. Many fantastic musical ideas and developments stem from serendipitous accidents, coincidences or sometimes straightforward 'bad' practice. See for instance in Bert Bongers' *Interactivation* [2] describing the effect of a loose wire in Michel Waisvisz' "The Hands" (p.57). Or on a similar note Nicolas Collins [5] on the topic feedback (p.41): "Feedback became the ur-sound of chance: it erupted whenever composers hooked up sound systems without the benefit of technicians;". Working as a sound engineer for composers and performers of contemporary music I have learned to (when needed) let go of my own practical technology based experiences and (schooled) knowledge but to let counterintuitive notions of how to use sound technology prevail. Some of the performers I have worked with showed highly personal concepts of how to apply sound amplification technology. Concepts that were, or appeared to be, based much more on experience rather than laws of physics, but nevertheless defining for a performance' result or presentation. This led me to believe that there should be room for 'authentic performances' of electronic and electro-acoustic music[2]. Considerations for these authentic performances should deal with questions like type and placement of loudspeakers (not so much period loudspeakers although I would really appreciate such an effort), mixing desks and playback technology. I see this argument as an extension of the question whether, in the digitizing process of analog tapes these should be sterilized to comply with modern standards of noise free and crackle free 'CD-quality' digital sound. See also Simon Emmerson [8] about authenticity (p. 170).

1.2.2 Acoustic and electronic sources

With the exclusion of some electric and electro-mechanical instruments (see for instance Bert Bongers [2] p. 50) all electronic music relies solemnly on loudspeakers to be heard. This signifies an important difference with electronic amplification of acoustic instruments, as the acoustic source always coexists with the sound from one or more loudspeaker introducing new sources for sounds relating to the same (inter-) actions. The flexibility of the loudspeaker as the actual sound

[1] Analog to digital, and digital to analog conversion.

[2] In November 2009 I presented a paper with that title at a post graduate student conference at City University London: "Outside the Box: practice, participation and method in live electronic music".

source for electronic music allowed for the extension of spatiality as a musical parameter. With flexibility I mean the possibility of placing that loudspeaker in a different spot than a performer, creating different ways of relating to the localization of a sound. Or, in other words, freedom in the diffusion of sounds in a space. Works like Pierre Schaeffer's *Pupitre d'Espace* (1951) or Karlheinz Stockhausens *Gesang der Jünglinge* (1956) are amongst the first to explore this flexibility. However, this flexible separation of source and transducer, of the visible interaction of performer and instrument raises some new questions. In the case of a church organ, the pipes produce the actual sound whereas the very location of the performer is not an important musical parameter. He or she is often hidden from sight! In electronic music, *live* or *support based* this separation is structural and the position of the actual transducers becomes a musical parameter. Obviously this is what makes a big difference between the amplification of acoustic instruments whose mechanical source co-exists with the electro-dynamic source (a loudspeaker), depending of the overall level of amplification.

1.2.3 Mixed Music

In Mixed Music (performances of acoustic instruments with support based or live electronic music) these two different source relations come together. For instance in Bruno Maderna's *Musica su Due Dimensioni* (1952) or Luigi Nono's *La Fabbrica Illuminata* (1964). Or a work like Stockhausens *Kontakte* (1960) where the four-track pre recorded "Elektronische Musik" is projected onto a four channel loudspeaker system to 'make contact' with the acoustic instrumental music. It is common practice (and often prescribed in a score) to electronically amplify the acoustic instruments to allow for better blending with the electronic music. For a thorough discussion of mixed music and the problems around mixing acoustic and electronic sources, see (again) Emmerson [8] p.104-106. In section 3.1 I will describe the importance of the relations between different sources in greater detail.

1.2.4 Loudspeaker orchestras

If the loudspeaker is a musical instrument, multiple loudspeakers can form an ensemble or an orchestra. Mentioned before was Luigi Russolo's *Intonarumori*: the "noise intoners" were part of a "Futurist Orchestra" that performed as an ensemble of noise machines, occasionally combined with acoustic musical instruments. A more literal example is the "Orchestre de Haut-Parleurs" that originated in France. For instance the Gmebaphone invented by Christian Clozier and the Acousmonium (1974) created by François Bayle, both at the Groupe de Recherche Musicale (see Chabade [4] p.68). Different approaches towards the source of such an orchestra are possible. For each of the channels in the orchestra a dedicated tape track could be used. Or sounds from a much smaller number of tracks (or even from only one track) could be divided over the loudspeakers by frequency, spatially, or by other sonic parameters.

2. PERCEIVING AMPLIFICATION

Not unlike singing in the bathroom or playing a pipe organ in a church, amplifying acoustic instruments make the relation of that instrument to a room's acoustic more explicit. Whereas singing in a bathroom is enjoyable because of it's acoustic properties (and it makes you think you can sing), church organs sound good as they were specifically developed for the acoustic conditions of churches. Very few auditoriums are specifically designed for performing amplified music[3], causing problems in the relation the different sound sources to a venue's acoustic. At a concert where amplification is used, that amplification should not be in the way of aesthetic enquiry or musical enjoyment. When it is, due to level, technical faults, or feedback the question that arises is: are these technical faults intentional or are things just going wrong? (See 1.2.1)

2.1.1 The amplified singer's dilemma

A problem that occurs very often in many different practices of contemporary music is that the musicians are on stage during the concert (and usually during a sound check or rehearsal). Normally they are not in a position to hear what the audience is hearing. For instrumentalists this problem can be overcome (to some extend) by having someone else play for you and listen in the hall. But this only gives a suggestion of what you sound like during a concert, as conditions with or without audience can vary enormously, not in the least if you consider the difference in atmosphere feeding back to the performers. For singers this problem is a bit harder to overcome, as you can't ask someone else to 'play' your instrument for a while. Walking out in the room while singing (with a wireless mike for instance) is hardly representative, as singers still perceive a lot of their voice through their own body. In older music traditions such as orchestras there is usually an assistant conductor or someone of the 'artistic' staff in the audience (and in the hall during rehearsals) to give feedback to a conductor. With most sorts of amplified music these strategies are rare and musicians have to rely on the person at the mixing desk. Often bands and groups perform with their own trusted sound person. Friends or relatives in the audience, reporting back on the sound person's "mix", occasionally monitor such a person's work. Remarks from related people are then fed back to the sound person: (for instance) "my brother told me he thought my voice sounded thin/fat/big/small/bad". At occasions the faith performers have in their dedicated engineer exceeds the engineer's capability, leading to interesting situations (and often less interesting results). Some bands choose to travel without a dedicated engineer (or simply can't afford one). They are relying on the abilities of a venue's own sound crew. A sound check and often a (annotated) set-list informs the engineer at the mixing desk about how a band 'wants to sound' for each song.

2.2 Functions

Emmerson is one of the first authors to create a systematic overview of when and how we amplify music. In *Living Electronic Music* [8] he lists a number of common (musical) applications of amplification technology, identifying six functions of amplification that he considers vital to discussing "live music requiring electronic technology for its presentation". As I have mentioned before, systematic research into this area is very scarce making Emmerson's overview very important and an excellent basis for further research.

[3] The *Radio City Music Hall* in New York (1936) comes to mind and the *Heineken Music Hall* in Amsterdam (2001), the latter was constructed to have a minimal acoustic of its own, leaving it for the user to create acoustics (or the suggestion of acoustics) electronically.

Table 1 Six functions of amplification (Emmerson)

1	Balance	Correcting acoustic imbalances
2	Blend	Integrating timbres
3	Projection/ Spatialisation	Zooming in perceptually/intentional (ac ousmatic) dislocation.
4	Perspective	Suggesting different acoustics (dislocation of space and time)
5	Coloration	Intentional distortion
6	Resonance	Use of feedback

For the argument presented in this paper, I would like to add a very common function that for now I would like to describe as *reinforcement*. At a pop or rock concert (or even an opera or André Rieu's Wiener Waltz circus) in a stadium, the scale of amplification goes beyond the subtle functions in Emmerson's list. Beginning sporadically in the 1950's with certain jazz concerts[4] getting out of hand, but certainly with the Beatle-mania in the early sixties, loud amplification became necessarily to allow for the music to be heard over the singing/clapping/screaming audience[5]. In the Oxford concise dictionary we find for amplify: increase the amplitude of (an electrical signal or other oscillation). For reinforce we find: extra personnel sent to increase the strength of an army or similar force. For reinforcement we find: the action or process of reinforcing or strengthening. Increasing the amplitude of an electrical system is what we usually do when we make music louder; this is no different if we call it reinforcement. But I like the notion of strengthening and supporting in the definition for reinforcement. Strengthening the sound to make it available for many. Strengthening also suggests an addition, causing a change to the original. Festivals with unprecedented numbers of visitors required larger sound systems. A recent book by David Collison [6] is one of the most concise overviews of the use of sound in the theatre (mostly in England), including amplification. He describes how in England in 1967 the first sound system in excess of 1000 watts was installed for the annual jazz festival at Windsor. All of a sudden the balance problem of pop bands was reversed: the acoustic instruments and vocals had microphones and were amplified but now the guitars and drums had problems coming through using just their own dedicated amplifiers.

2.2.1 Functions of amplification depending on level

A more overall idea I would like to add to Emmerson's overview is that the working of these functions is dependant of the level of amplification. Acoustic imbalances cannot be corrected with very loud amplification nor is reinforcement in a stadium at a very low level very useful. In projection and spatialization, amplification is not so much used to make things louder, but to bring details to the surface (zooming in) or change the perceived location of a sounding event. The same goes for perspective, although a certain level of loudness must be reached before effects (such as reverb) can be heard in balance with the acoustic sound of an instrument (see Mulder [12]).

2.2.2 Role of sound engineer depending on level

Apart from (to some extent) the functions, the amplification level also changes the role of the sound engineer, sound diffuser or projectionist at the mixing desk. When electronically adjusting acoustic balances or blending acoustic and electronic timbres the person at the desk functions as a conductor in a conductor's role of balancing an ensemble or orchestra. Same as for a conductor, the control over a balance is limited to physical acoustic possibilities of the involved instruments (unless players are asked to not play or leave the stage). This is different in situations where the acoustic source plays no audible role: when the amplification becomes so loud that it drowns out the sources being amplified the mixer's job becomes much more like that of a producer in a recording studio. He is solemnly responsible for what the audience hears of the intentions of the musicians on stage. Much like in a recording studio there are many options (filtering, compression, reverbs, delays or even muting parts) to adjust a performance, with the obvious difference that a concert this will have to be done in real time. The use of click-track (sometimes combined with whole pre-recorded orchestra sections) suggest that these big, what Dennis Smalley [15] (after Auslander [1]) calls "mediatized" concerts become more like an instantaneous play back of a recording rather than a live performance[6].

3. Sound sources for amplification

3.1 Acoustic sound sources

Microphones pick up acoustic sound sources such as instruments, the human voice or a guitar amplifier and transfer the acoustic energy into an electronic sound source, existing independently of the "original" acoustic source. If we zoom into the microphone as a sound source we find that its membrane is moving with the sound waves it comes across at its particular position. We can consider the membrane in a microphone as a resonating body that is set in motion by the sound waves it comes across. The membrane traces the acoustic waves, not unlike a stylus following the grooves on a record.

3.1.1 The microphone as musical instrument

A microphone, when handled by a skilled performer, can be an excellent musical instrument with several very direct sensitivities. Probably the most famous example of such application would be Stockhausen's *Mikrophonie I* (1964) (see Emmerson [8] p. 128-9 or Chabade [4] p.83-4). A less famous but equally expressive example is Dick Raaimakers' *Twelve ways to silence a microphone* (1992). Amplified microphones are destroyed in twelve different ways, while "reporting their own doom through loudspeakers" [3]. Some of these destructive ways include the use of acid or straightforward 'drowning' in water.

3.1.2 Electronic sound sources

Examples of electronic sound sources are numerous. Bongers [2] (p. 61) describes the work of Wart Wamsteker a Sonology student at the Royal Conservatory in The Hague in the nineties. He used a glove with sensors to control a set of filters, using feedback to turn the filters into signal generators. Before this Wamsteker used to play "no-input mixer" by connecting outputs to input, feeding channels back into itself and thus

[4] For instance the concerts of Lionel Hampton in Europe in the fifties that would occasionally have crowds going wild and end in rows. See for instance Hamptons biography [5] p.108.

[5] Or if we want to stay in the realm of electronic music: a performance of Schaeffer's and Henry's *Orphée 53* at Donaueschingen with an offended audience making more noise than the loudspeakers. As recalled by Henry quoted in Chabade [2].

[6] Latency in the signal chain, introduced by using digital equipment, strengthens this idea, in my opinion.

generating sound. Electronic sound sources come in an endless variety, especially if we include playback devices such as record players, tape decks, CD-players or hard disks. These last two may use digital storage, but after DA conversion their output is as electronic as any other electronic source.

3.1.3 Spatial displacement

One very important difference between amplifying acoustic instruments, and amplifying or playing back electronic sources is the change in perception of the acoustic source. Not only will it sound like appear to be coming from a different direction[7], the "detached" electronic sound will have a different relation to the acoustics of the same space. This detachment of the sound, not at all unlike Pierre Schaeffer's [13] "Acousmatic" condition[8] or R. Murray Schafer's [13] "Schizophonia", appears as a function of the level of amplification. In the case of reinforcement this displacement is complete as the acoustic source drowns in the sound of the loudspeakers. At lower levels the displacement can become an interesting parameter, as both acoustic and electronic sources are audible.

3.1.4 Hearing and seeing

The connection between seeing and hearing in the perception of visible sound sources is very well established. For instance, in room acoustics optimal sightlines help understanding of speech. Dennis Smalley [15] takes this idea a bit further when he writes about seeing proprioception at work. Not only do we see and hear a musician at work, according to Smalley we recognize how the musicians utilizes proprioception in playing an instrument. To support his claim and to show how powerful 'just the movements' possibly can be, we can think of the popularity of "Air Guitar" contests, or the successful *Guitar Hero* computer games. The detachment of visible and audible stimuli from the one source when amplifying sound makes this connection between aural and visual perception more apparent, and as such a musical parameter.

3.2 The loudspeaker as a multiplayer musical instrument

By zooming in from the general complexities of amplified sound into the minute details of different sources I hope to demonstrate the complex relation between acoustic sources and microphones, electronic sources, and loudspeakers sounding in an acoustic space. The microphone becomes an expressive tool with an interface that stretches beyond its placement in the proximity of an instrument. A musician interfaces with it (although some choose not to), while a person at a mixing desk interacts with the source(s), relating it to a space through projections on a sound system. In a less temporary sense interactions with audiences (complaining or complimenting during or after a performance), production and artistic staff at venues, friends or relatives of the performer, generate complicated feedback loops that extend beyond the stage and the timeframe of a performance.

[7] Delaying a sound to invoke the famous Haas or precedence effect, as is common practice, only works within relatively small margins.

[8] For a discussion of a possible relation between the amplification of acoustic sound and the Acousmatic condition see Jos Mulder: *Sound amplification technology and the Acousmatic experience* [12].

4. CONCLUSION

In the above paragraphs I have tried to provide insight in a systematic approach to amplifying sound in the context of musical performance. To clarify the complicated interrelation between stakeholders, technology I propose using the idea of a musical instrument, subdivided into a sound source and an interface. When broken down as such the sensitivities of technological and artistic interaction can be addressed. Although not a novel idea, I have tried to operationalize this metaphor to stress the interdependency of performers, technologists and other stakeholders. Again this interdependency is nothing new in musical performance, but by focusing on the differences between electronic and acoustic sources when amplifying music I have suggested that there is a break with the history of musical performance since the introduction of amplification. Awareness of this changing relationship, although going on since the thirties, is important and calls for new strategies in musical performance and collaboration between stakeholders, on different levels. From policy makers and architects, music critics, programmers and production managers at venue's to performers and technologists.

5. RESEARCH

My own research will continue in the direction of trans-modal perception, trying to establish how the source displacement, when amplifying an acoustic sound source, influences our aural and visual perception of that sound source. Other research that is needed in this area is a broad history of sound amplification both from a technological and a musical perspective.

6. REFERENCES

[1] Auslander, P. *Liveness : performance in a mediatized culture*. 2nd edition, Routledge, London ; New York 2008.

[2] Bongers, Bert. *Interactivation*. Ph.D thesis Vrije Universiteit Amsterdam 2006.

[3] Brouwer, Joke and Mulder, Arjen (eds.). *Dick Raaymakers, A Monograph*.V2, Rotterdam, 2008.

[4] Chabade, Joel. *Electric Sound*. Prentice Hall, New Jersey 1997. P32.

[5] Collins, Nicholas. Live electronic music. In Nick Collins and Julio d'Escriván (eds) *Electronic Music*. Cambridge University Press 2007.

[6] Collison, David. *The Sound of Theatre*. Professional Lighting and Sound Association, London 2008.

[7] DiScipio, Agostino. Sound is the Interface: From interactive to ecosystemic signal processing. In *Organized Sound* 8/3/ (2003) pp 269-77.

[8] Emmerson, Simon. *Living Electronic Music*. Ashgate Publishing Limited, Aldershot, 2007.

[9] Green, Owen. Pondering Value in the Performance Ecosystem. In *eContact* 10 (4), 2008.

[10] Hampton, Lionel en Haskins, James. *Hamp*. New York: Warner Books, 1989.

[11] McCarthy, Bob. *Sound Systems: Design and Optimization*. Focal Press, Burlington, 2007.

[12] Mulder, Johannes. Sound Amplification Technology and the Acousmatic Experience. In: *Proceedings of the second international conference of students of systematic musicology 2009*. IPEM, Ghent 2009.

[13] Schaeffer, Pierre. *Treaté des Objets Musicaux*. Éditions du Seuil, Paris 1966.

[14] Schafer, Raymond Murray. *The Tuning of the World*. Random House, New York, 1977.

[15] Smalley, Dennis. Space-form and the acousmatic image. in *Organized Sound* vol. 12, no.1, 2007, pp. 35-58.

[16] Waters, Simon. Performance ecosystems: Ecological approaches to musical interaction. In: *Proceedings of Electroacoustic Music Studies Network Conference 2007*, 2007.