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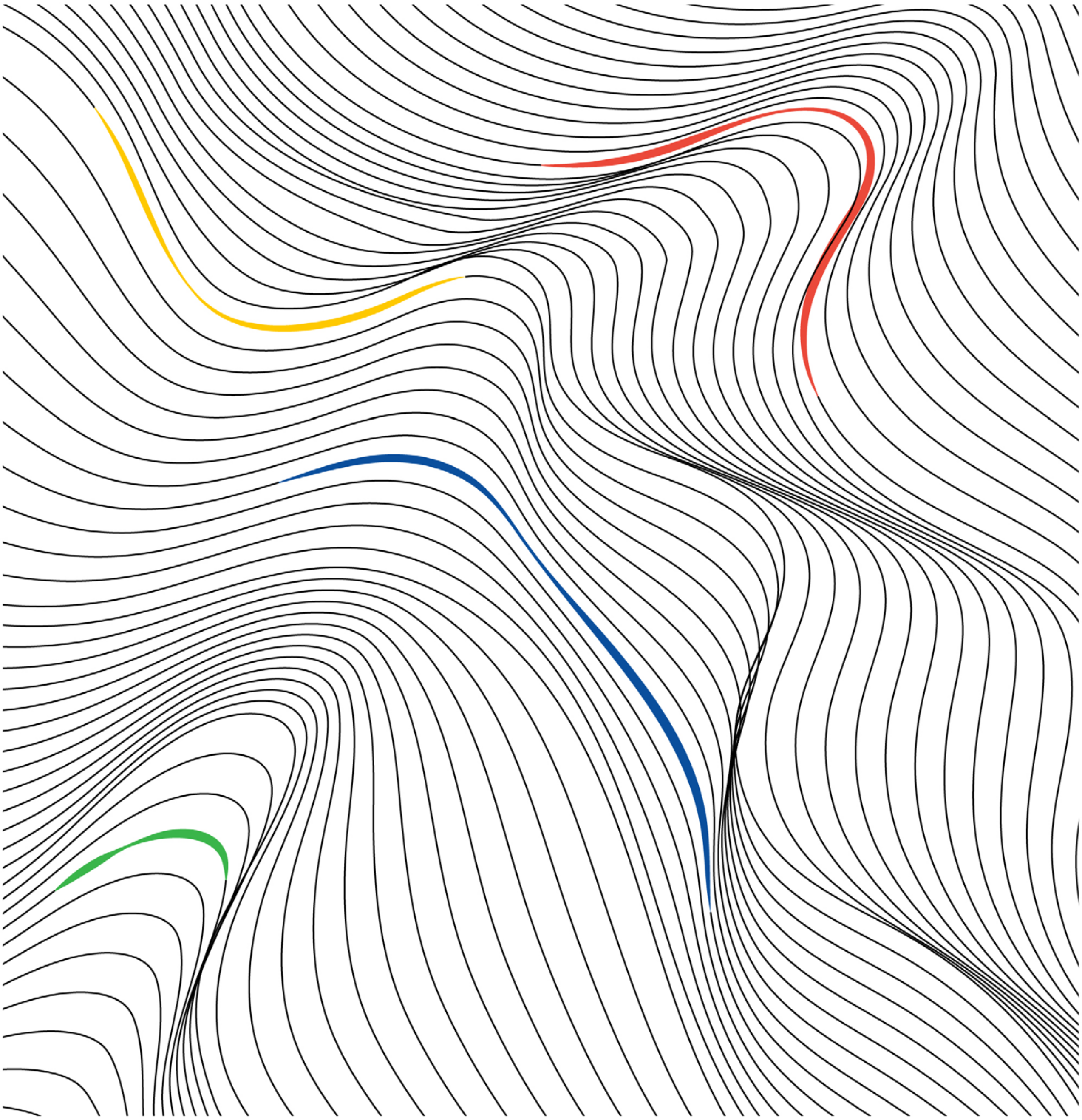

Sound Particles

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State of the art of spatialization in the context of musical composition and sound recording

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1. Introduction

When new instruments will allow me to write music as I conceive it, the movement of sound-masses, of shifting planes, will be clearly perceived in my work, taking the place of the linear counterpoint. When these sound-masses collide, the phenomena of penetration or repulsion will seem to occur. Certain transmutations taking place on certain planes will seem to be projected onto other planes, moving at different speeds and at different angles. There will no longer be the old conception of melody or interplay of melodies. The entire work will be a melodic totality. The entire work will flow as a river flows.

Edgard Varèse[1]

The interaction between sound sources and a given acoustic space is inevitable in all musical performances and the history of music early on tells us of examples of the intentional use of the spatial mise-en-scène of sound. It is, however, in electroacoustic music and sound recording (both musical and for cinema) that this component is emancipated, becoming the object of primary attention since the seminal experiments and a determining factor in the design of its means and spaces of diffusion. If human vision, even if it is three-dimensional, is limited by a field of vision, hearing is always done in all directions simultaneously. In fact, "there is no such thing as 'non-spatial' hearing" (Blauert, 1996). With the visual constraints of acoustic instruments removed, spatialization quickly became a key feature of electroacoustic music and sound recording's impact on novice listeners in these central areas of contemporary musical activity.

This internal report presents a summary of the state of the art of spatialization in the context of musical composition and sound recording. It was prepared within the scope of Corporate R&D Project no. 14339, a partnership between Sound Particles and ESMAE - P.Porto. It was drawn up based on the information contained in the doctoral theses of the two authors:

Penha, R. (2014). Spatialization Models: Integration in Compositional Thinking. PhD thesis, University of Aveiro, Aveiro.

Conceição, M. (2015). Spatiality Control for Sound Field Recording and Reconstruction. PhD thesis, University of Dublin, Dublin.

[1] (Varèse & Wen-chung, 1966, p. 11)

2. Music in Space

Creating spaces with the vocabulary of sound introduces new forms of expression - the potential for a fundamentally new experience. It is above all the intensity, the rhythm, the speed of the moving sound and their interrelated variations that determine the shape of space.

Bernhard Leitner [2]

2.1 Introduction

Like sound, its vehicle, all music exists in an acoustic space and the influence of this is often a relevant factor in the choices that are made both at the time of composition and interpretation. The long reverberation time of the great European cathedrals, for example, is commonly cited as a relevant factor in defining liturgical chant during the Middle Ages (Blesser & Salter, 2007). Even when there are other factors that determine the placement of sound sources in the space, such as the role of the intrinsic limitation of the visual field in the development of the canonical model of concert halls, the acoustic interaction between these elements inevitably informs the decisions made by performers when performing works.

Some experiments stand out for the intentional way in which they explore spatial staging, with antiphonal singing standing out as a seminal example. Of these, the one carried out with the cori spezzati in St. Mark's Basilica in Venice during the Renaissance is particularly interesting for the exploratory way in which Adrian Willaert, Andrea and Giovanni Gabrieli, among others, approach the Byzantine architecture of the Basilica and the availability of various choirs and organs (Blesser & Salter, 2007). Giovanni Gabrieli's polychoral style - evident, for example, in works such as Gloria a 12 [c. 1597], for three choirs, and In Ecclesiis [c. 1615], for a group of soloists, choir, two instrumental groups and continuo - quickly spread throughout Europe and inaugurated techniques of development by "contrast and opposition of sonorities", "a fundamental factor in the concertato style of the Baroque period" that would follow (Grout & Palisca, 1994). Already in the 18th century, Wolfgang Amadeus Mozart made two similar experiments with multiple instrumental groups: the Serenata notturna, K. 239 [1776], for two small string orchestras, and the Notturno für 4 Orchester, K. 286/269a [1776], for four string and horn orchestras. The articulation in space also fulfills a function of alternation, echo and contrast between sections in these works, something not far removed from what happens in the articulation between soloist and orchestra in concertos or in the alternation between orchestral groups in symphonies from this period.

In Portugal, a particularly interesting case is the set of six organs in the Basilica of the National Palace of Mafra, built from scratch to work together and placed in pairs in the main chapel, the north transept and the south transept. The ensemble was inaugurated in 1807, and several composers - such as João José Baldi, Frei José Marques e Silva and Marcos Portugal - wrote works that included the six organs arranged in the Basilica (Câmara, 2010).

Figure 2.1. Organs of the Basilica of the National Palace of Mafra, seen from the north transept. North transept. Photo by the National Secretariat for the Pastoral Care of Culture.

When Ludwig van Beethoven includes an off-stage trumpet in the overtures to Fidelio Op. 72 [1804-1805, r. 1806-1814] - known as Leonore Overture - however, the intention is clearly dramatic, in an effect that takes us back to the ceremonial trumpet call. The same is true of the Grande Messe des morts, or Requiem, Op. 5 [1837], in which Hector Berlioz uses four brass ensembles placed in the four corners of the stage, designated in the score as North, East, West and South, using an absolute spatial referential that is somewhat unusual in that it is external to the perspective of both the performers and the listeners. Perhaps influenced by Berlioz, Giuseppe Verdi and Gustav Mahler also used brass ensembles placed offstage: the former in the Messa da Requiem [1874] and the latter in the Auferstehungssinfonie [1888-1894, revised 1903]. Although Mahler later resorted to placing elements off-stage with some regularity (Licht, 2007), these experiments are isolated examples of the use of spatial composition techniques that would only become established after the Second World War (Roads, 1996).

At the beginning of the 20th century, Charles Ives used an off-stage string ensemble in conjunction with the trumpet soloist in The Unanswered Question [1908]. Despite the fact that he used spatialization mainly for dramatic purposes, this work is identified by Henry Brant as a determining influence on his interest in developing spatial composition techniques. Beginning with Antiphony I [1953], for five orchestras arranged in space, Brant composed mostly works that explored the spatial question, and was responsible for the creation of an appreciable set of spatialization techniques in orchestral music. In 1955 he wrote an article, The Uses of Antiphonal Distribution and Polyphony of Tempi in Composing, the principles of which are paraphrased by Maria Anna Harley in An American in Space: Henry Brant's "Spatial Music":

> 1. Spatial separation clarifies the texture - if the music consists of several layers, "each with its own distinctive sonority scheme, over the same octave range," the presence of casually occurring unisons should be avoided by distributing the performers into widely separated positions in the hall;

[2] (Leitner, 2008, p. 135)

2. Separated groups are difficult to coordinate - exact rhythmic simultaneities are almost impossible because of the distances between the musicians;

3. Spatial separation is equivalent to the separation of textures in pitch space (if performers are together on stage) - separation allows for the differentiation of musical strands, "with no collision or crossing of textures," and it permits a greater complexity in the music;

4. Spatial arrangements must be planned exactly, but allow adjustments of details - there is no single, optimum position for the listeners or the performers in the hall; each situation is different. (M. A. Harley, 1997, pp. 73-74)

These principles thus bring together an antiphonal perspective - used above all as a way of facilitating the segregation of the various elements and allowing for greater musical complexity - and a small set of pragmatic rules for spatialization in acoustic music. It's easy to see the contrast between some of these ideas and those that at the same time, in the context of the musical avant-garde of the emerging Darmstadt School, inaugurated a period of consistent and continuous exploration of the spatial component in orchestral music. Karlheinz Stockhausen, a prominent participant in these meetings in post-war Germany, soon rejected the dramatic function that predominated in the use of space by the composers who preceded him in favor of a serial perspective on the role of space in music (Stockhausen, 1958), using techniques and vocabulary that were developing in electroacoustic music. It was Stockhausen - with Gruppen [1955-1957], for three orchestras, and Carré [1959-1960], for four orchestras and four choirs - who laid the foundations for a practice that would be followed, among others, by Iannis Xenakis - in Terretektorh [1965-1966] and Nomos Gamma [1967-1968] - and Emmanuel Nunes - in Tif'Ereth [1978-1985] and Quodlibet [1990-1991]. Terretektorh is a particularly interesting work because it arranges the instruments of the orchestra inside a circle where the audience is also located (figure 2.2) and because it describes geometric figures through the circulation of sound by the instruments, with an emphasis on spirals that thus include changes in angular position and distance from the center (Santana, 1998).

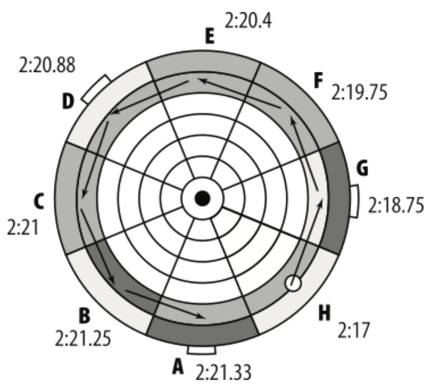

Figure 2.2. Example of the spatial path of Terretektorh [1965-1966], by Iannis Xenakis, between bars 69 and 71. The intensity of the gray indicates the number of instruments responsible for the of instruments responsible for the performance at the time indicated (Miller, 2009).

Although Stockhausen, in Licht [1977-2003], places musicians in movement in the interior and exterior space of the concert hall as a way of spatializing the sounds produced by the acoustic instruments, this type of spatial movement is exceptional, given the technical difficulties it entails. It was thus in electroacoustic music that spatialization became emancipated, taking advantage of the spatialization techniques that were then in full development and quickly becoming a distinctive factor in this unavoidable area of contemporary musical composition. In its period of expansion, at the end of the Second World War, the split between the approaches of French musique concrète[3] - which highlights the potential opened up by the invention of recording and systematizes ways of manipulating recordings of acoustic sources - and German elektronische Musik - which seeks ways of using the precise control capabilities of electronic sound sources to synthesize new sounds - is also reflected in the respective approaches to space and its use as a musical parameter[4].

The placement of moving sound in space, both during composition and in the dissemination of electroacoustic music, can be done in such a way as to convey an intelligible intentionality, forming a spatial gesture. This spatial intentionality can also complement a pre-existing musical intentionality or, on the contrary, diverge from it to the point of becoming disruptive. The relationship between the musical gesture, the traditional vehicle of the composer's intentions, and the spatial gesture with which it is conveyed in space thus becomes particularly relevant in the analysis of the different perspectives on spatialization in electroacoustic music.

2.1.1 The Definition of Musical Gesture and Spatial Gesture

Defining the concept of musical gesture is a singularly difficult task, despite the recurrent use of the expression, e.g. in the appreciation of the musical intentions of a given composer or performer. Definitions of the word gesture - from the Latin gestus[5], perfect participle of gerō: to carry, bear or wear (in the sense of carrying or wearing)[6] - refer both to the idea of non-verbal communication - with varying degrees of awareness ranging, for example, from nodding as a sign of assent to involuntary gesticulation accompanying speech - and to the idea of an intention that is conveyed - as happens, for example, in the appreciation of a gesture as being generous. The idea of transportation, of conveying an expression or intention through gesture, thus seems central from an etymological point of view.

Musical gesture can be analyzed from various perspectives, ranging from interpreting a musical motif by reading the score to observing an instrumentalist's movements during a performance. It is beyond the scope of this paper to review the analysis of musical gesture, which can be found in Gritten & King (2006), in Jensenius, Wanderley, Godøy, & Leman (2010) and, with regard to the particular case of electroacoustic music, in Bachratá (2010). The definition of gesture used in this document is based on the synthesis suggested by Gritten & King in the introduction to Music and Gesture: "a gesture is a movement or change of state that is identified as significant by an agent"[7] (Gritten & King, 2006). Intentionality is

[3] We have chosen to keep the terms musique contrète and elektronische Musik in their original languages, thus highlighting their geographical origin in the context of post-war Europe and avoiding confusion between electronic music as a designation of its production method and electronic music as an aesthetic approach circumscribed in space and time (i.e. elektronische Musik).

[4] For a broad perspective on this period of music history, we recommend consulting Menezes (1996b). This collection of texts includes an in-depth retrospective on the split between the two movements and the translation into Portuguese of various basic texts on electroacoustic music.

5 http://www.infopedia.pt/lingua-portuguesa/gesto

[6] http://en.wiktionary.org/wiki/gero

[7] "Across cultural, aesthetic and terminological differences, however, most scholarship on musical gesture makes a grounding assumption, broadly semiotic in nature: a gesture is a movement or change in state that becomes marked as significant by an agent.", in the original (Gritten & King, 2006 p. xx).

thus transferred from the execution to the perception of the gesture[8] , in a perspective that the authors themselves identify as semiotic and which can include the perception of intentions in gestures produced unconsciously (Hatten, 2006).

In the particular case of purely electronic music, and in the absence of the movements of an instrumentalist, an unavoidable contribution to the definition of musical gesture is the proposal of spectromorphology by Denis Smalley (1986; 1997). This also focuses on the receiver's perception and hearing, drawing direct inspiration from type-morphology (Schaeffer, 1966) and reduced listening (Chion, 1983), proposed by Pierre Schaeffer[9]. Spectromorphology refers to the evolution of the spectral content of a sound over time - as is explicit in the juxtaposition of the words spectrum and morphology[10] - and proposes a comprehensive lexicon that is commonly used in the analysis of electroacoustic music[11] . The separation between content (spectrum) and form (morphology) is, according to Denis Smalley himself, artificial and reflects a conceptual need for discursive and analytical purposes. The definition of musical gesture used in this document is based on the previous generic definition of gesture, incorporating a synthesis of the spectromorphological perspective to define movement as the variation over time (morphology) of the amplitude as a function of the frequency (spectrum) of a sound. Thus: musical gesture is the variation over time of the spectral morphology of a sound that is identified as significant by an agent.

If this definition is inherent in the disconnection between the composer's intention and the listeners' perception of the musical gesture[12] , it doesn't completely close the door on the existence of a relationship between the creator's intention and the receivers' cognition. It assumes, as happens in other fields of communication studies, that factors external to the message are relevant in the perception and interpretation of the information that is conveyed. By focusing the identification of intentionality on the cognition of the receiver, this definition opens the way to analyzing the interference of external factors on the creative intention of the morphology of the musical gesture. From the point of view of spatialization, this issue is particularly important: since morphology depends on amplitude variations in spectral space and spatialization is traditionally achieved by amplitude variations in the placement of sound in physical space, the spatial gesture can have the effect of shaping or articulating the morphology of the musical gesture. It is therefore important to define musical gesture and spatial gesture separately, a necessary condition for analyzing the interaction between the two from the perspective of musical creation. However, it is important to point out that this segregation is also a conceptual necessity, given the simultaneity and interdependence of the arrival of both at the receiver.

Central to the concept of gesture is the idea of movement, i.e. the alteration of a position in space in relation to a referential and over a period of time. So, while the placement of sound in space without movement can be made meaningful by analyzing it from a conceptual point of view[13] , its identification as a spatial gesture implies the existence of movement. It is naturally in the reference to physical space that the most common use of the term movement resides, which makes its application clear: spatial gesture is the variation over time of the position in relation to a referential that is identified as significant by an agent.

2.2 Spatial Gesture in the Diffusion of Musical Gesture

Musique concrète was born at the hands of Pierre Schaeffer, who used the expression as a designation for his work from the late 1940s[14] in the studios of the Office de Radiodiffusion-Télévision Française (ORTF) in Paris (Schaeffer, 1952). The sound material is the manipulation of recorded sounds, with an emphasis on sounds traditionally considered to be non-musical or noises. It is thus possible to identify a conceptual inheritance from futurist experiments such as Luigi Russolo's Intonarumori (1996) or George Antheil's Ballet Mécanique [1923-1924][15]. Nonetheless, it was with Schaeffer that the process of systematizing the use of these sound materials in musical composition began, moving from a reduced listening to sound objects to an experimental approach leading to the creation of a vocabulary for their manipulation (Schaeffer, 1966). This process of discovering the possibilities opened up by new sound material is described by Pierre Schaeffer in his diaries from the years following the Second World War, collected in the book À la Recherche d'une Musique Contrète[16] (Schaeffer, 1952). In this book, musique concrète is presented as a process that moves from concrete sounds to musical abstraction, in contrast to the traditional transition from musical abstraction thought out and notated by composers to sonic concretization by instrumentalists (Dhomont, 1995). In the early 1950s, composer Pierre Henry and engineer Jacques Poullin joined Pierre Schaeffer and the Groupe de Recherche de Musique Concrète (GRMC) was formed.
By the very nature of musique concrète, it cannot be conceived and presented in any other way than through electroacoustic means: recorded sound objects are listened to, classified and manipulated to conceive musical gestures that are finally broadcast through loudspeakers. Although recording and reproduction dominate the process, Schaeffer and Henry included live manipulation in their earliest concerts, in what were certainly the first experiments in what we would now call live electronics (Harrison, 1998). The change in playback medium from turntables to magnetic tape in the early 1950s made it easier to synchronize several tracks, allowing Pierre Schaeffer to imagine a device for spatializing live sounds. This device, which he called pupitre d'espace , was developed by Jacques Poullin (Harrison, 1998).

At the premiere of the 11 movement version of Pierre Schaeffer and Pierre Henry's Symphonie pour un homme seul [1950-1951], five channels of magnetic tape are distributed among four loudspeakers: a stereo pair on stage, a loudspeaker at the back of the room (in the center, behind the audience) and another loudspeaker on the ceiling. Four channels are assigned directly to each of these speakers and the

[8] In the case of music, this refers to a preponderance of listening that is particularly coherent with Pierre Schaeffer's vision of sound objects and the process of composing musique concrète.

[9] Reduced listening is inherent to acousmatic music, which Smalley himself is part of as a composer.

[10] In the original, spectromorpholy, the juxtaposition of spectro and morphology (D. Smalley, 1986).

[11] For an analysis of Schaeffer's type-morphology and Smalley's spectromorphology in the context of the definition of musical gesture in electroacoustic music, see Bachratá (2010, pp. 55-66).

[12] An analysis of this disconnection in the specific case of spatialization is the "Source - Medium - Receiver" model (Begault, 1986), which will be presented in chapter 3.

[13] As, for example, in Aural Architecture, which will be presented in subchapter 2.4.1.

[14] The first musique concrète concert, the Concert des Bruits (literally, Concert of Noises), took place on October 5, 1948, in Paris (Menezes, 1996a).

[15] Score originally written for the film of the same name by Fernand Léger and Dudley Murphy, which ended up being used independently.

[16] Literally, in search of concrete music.

the fifth is distributed live by a performer[17] using the pupitre d'espace (Emmerson, 2007). This control device has four antennas that mimic the position of the loudspeakers around the performer (figure 2.3). The performer, in turn, controls a transmitter coil whose proximity to each of the antennas determines the amplification of the fifth channel in the respective loudspeaker (Poullin, 1999). This duality of approaches to the placement of sound in space is in line with the seminal division proposed by Schaeffer between static relief[18] - fixed sound sources within a reproduction space - and kinematic relief[19] - virtual sound sources set in motion by an interpreter during reproduction - (Harrison, 1998; Poullin, 1999), which will be echoed in a significant part of later thinking on spatialization and diffusion.

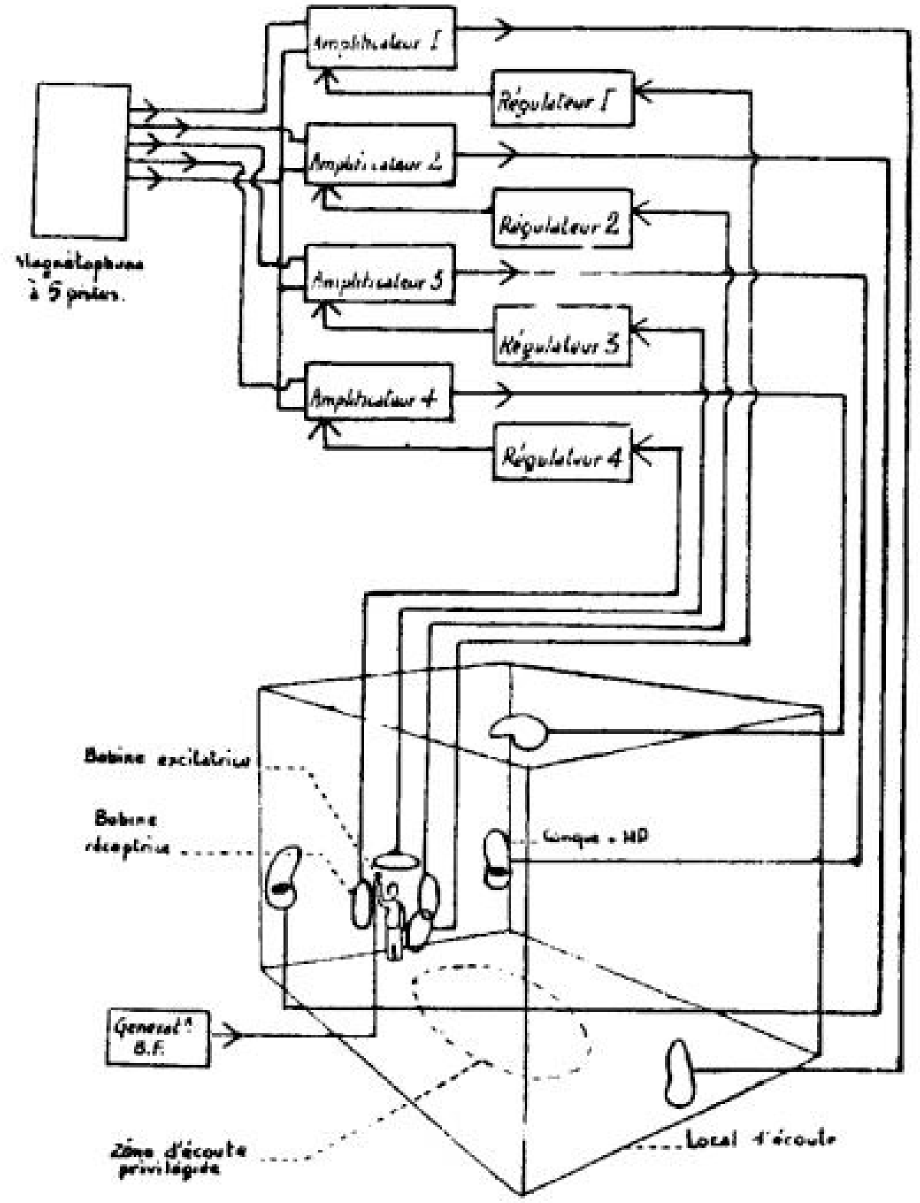

Figure 2.3. Schematic of the pupitre d'espace (Poullin, 1999).

[17] In the first concerts, the role of pupitre d'espace was played either by Pierre Schaeffer or Pierre Henry

[18] "relief statique" in the original (Poullin, 1999, p. 41).

[19] "relief cinématique", in the original (Poullin, 1999, p. 43).

This form of diffusion control makes the movement of the virtual sources correspond to a gesture that is not only visible, but also easily recognizable by the concert-goers. Pierre Schaeffer's aim is to "establish direct contact with the audience and restore a human presence to the performance of the works [...] by printing sound trajectories based on gestures described directly in front of the auditorium"[20] (Poullin, 1999). The treatment given to the "spatial object" - identifiable by its introduction at the time of the performance - thus contrasts with the treatment given to the sound object - a condition achieved by reduced listening in the composition process. Sound diffusion therefore appears from an early stage as an important element in the public presentation of works in the musique concrète tradition.

2.2.1 The Loudspeaker Orchestra

At the end of the 1950s, the GRMC gave way to the Groupe de Recherches Musicales (GRM), whose activity continues to this day[21] . François Bayle, who headed it between 1966 and 1997, abandoned the term musique concrète in favor of musique acousmatique, an expression originally proposed by Pierre Schaeffer and which refers to hearing a sound without seeing its origin[22] (Schaeffer, 1966). It was in this context that Acousmonium premiered in 1974, inaugurating the era of the loudspeaker orchestra, a decisive instrument in the history of the diffusion[23] of electroacoustic music.
The loudspeaker orchestra expands the idea of live performance of acousmatic music, using several dozen loudspeakers to broadcast works reproduced from a medium usually with two channels, a standardization that is due to the fact that stereophony has become dominant in the means of reproduction (Harrison, 1998). The panorama of amplitudes[24] is then used at the time of composition to segregate sounds, to focus or make virtual sound sources diffuse or to articulate the morphology of sounds and musical gestures using movement. As the stereo image only works optimally for listeners in the sweet spot[25] , the use of several pairs of loudspeakers helps to ensure that listeners in different positions in the concert hall can hear the appropriate stereo image (Smalley in Austin, 2000).

In the case of Acousmonium, the loudspeakers also have different acoustic behaviors, which means that a change in position also corresponds to a change in timbre and acoustic relationship with the concert space (Tutschku, 2002). Although this is an important element in approaching the concept of the orchestra, few later loudspeaker orchestras will replicate such a wide range of timbres as can be found in the

[20] "[...] in order to establish direct contact with the public, and to restore a human presence during the performance of his works, P. Schaeffer imagined a device that allows a performer to print sound paths based on the gestures he describes directly to the audience.", in the original (Poullin, 1999, p. 43).

[21] http://www.inagrm.com

[22] It comes from the Greek word akousmatikoi, used to refer to Pythagoras' pupils who listened to him behind a curtain, thus forcing them to concentrate solely on his ideas (Schaeffer, 1966).

[23] The term used by François Bayle is projection, in the sense that sounds are intentionally projected into space like the image in the cinema (Bayle, 1993). Jonty Harrison argues that sound is perceived diffusely in space, so he prefers the term diffusion (Harrison, 1998). As they refer to the same activity, that of live spatialization as an interpretation of electroacoustic music, we have opted for the systematic use of the latter, which is more common in the sources consulted.

[24] Panorama, which will be presented in subchapter 4.5 and which uses the difference in amplitude between two stereophonic channels to place virtual sound sources in space.

[25] Point of convergence of the loudspeakers, a concept that will be presented in subchapter 4.2.

Acousmonium. As in the case of musique concrète, we can identify in this approach a link to the futuristic Intonarumori, since they also projected sounds with different timbres into space in a directional way. Closer is the relationship with the French Ondes Martenot, a musical instrument from the 1920s in which sound is diffused through various loudspeakers (called diffusers) which, due to their characteristics, such as sympathetic vibration strings, give the instrument different timbres.

During the diffusion of the work, the performer manipulates the amplitudes of the sound address with a mixing desk, sending the sound to the different pairs of speakers and simultaneously manipulating the envelopes of the recorded sounds. This practice requires an articulation between movement in space as a compositional parameter - "the internal space of the work"[26] (Gorne, 2002) - and as an element of interpretation - "the external space [...] generated by the interpreter"[27] (Gorne, 2002). The widespread practice of diffusion in electroacoustic music concerts, especially those closer to the acousmatic tradition, ends up influencing the spatial vocabulary that is applied to the internal space, often anticipating its translation into the external space by the interpreter. This interpreter is often the composer himself, who thus finalizes the spatial component of his work live. The ease of disseminating works in stereophonic format, compared to multichannel formats, and the advantage of the performative element are additional incentives for so many composers to adopt the habit of interpreting their works live through broadcasting (Harrison, 1998; Gorne, 2002).

Anette Vande Gorne distinguishes herself not only as a composer, but also as a performer of electroacoustic music, so her thinking on spatialization is informed by both the conception of internal space and the definition of external space through diffusion. He is responsible for identifying and defining an important vocabulary of figures for spatial interpretation: dissolution[28] , unmasking, accentuation, scintillation[29] , oscillation, balance, wave, rotation, spiral, bounce, insertion / rupture, appearance / disappearance, explosion, accumulation and invasion[30] (Gorne, 2002). These figures of space are defined not only by their mode of execution, but also by the musical function they fulfill, with their role always being one of interpretation, i.e. conveying a reading of the musical gesture crystallized in the composition. Vande Gorne also identifies four categories of space in terms of their musical use (Gorne, 2002):

- the surrounding space[31] , in which it is not possible to locate the real sound source - either because of its diffuse nature or because of its role in conveying virtual sound sources whose position does not coincide with that of the loudspeakers, typically arranged in a circle, vault or sphere - which he identifies with the Osaka Pavilion [1970], imagined by Karlheinz Stockhausen, and with the Philips Pavilion [1958], imagined by Iannis Xenakis[32];
- "the source space"[33] , in which it is possible to locate the real sound source - which can exist in more than one channel spread throughout the space, but which cannot be stereophonic (in the sense of virtual sources not coinciding with the real sources, as happens in the case of the surrounding space) -, which he identifies with the historical examples of spatialization in instrumental music and with the work of Pierre Henry;

- "geometry space"[34] , which defines lines, planes and volumes in space, linking it to form and time and turning it into a sound parameter equivalent to pitch, duration, intensity and timbre;

- "illusion space"[35] , which transforms the sound object into a representation of itself as a result of the way it is projected in space - using, for example, loudspeakers with idiomatic spectral characteristics that alter the timbre of the recorded sound - which he identifies with the Acousmonium.

The opposition between the surrounding space and the source space suggests a reflection of the contrast between, respectively, the visions of elektronische Musik and musique concrète, in the sense that, in the first case[36] , the electroacoustic means are used as a way of conveying an abstract approach to movement in space and, in the second, the electroacoustic means are organized in such a way as to allow the geography of the concert space to be explored through the movement of sound. It is also possible to identify a close relationship between the illusion space and the source space, since both highlight the qualities of a given placement of the loudspeakers in the space. The same happens between the geometry space and the surrounding space, since both benefit from the possible autonomy from the idiosyncrasies of the means of diffusion. The contrast between the "ornamental or metaphorical function in the expressive support of the sounds to which [the movement in the source space] offers a spatial support"[37] and the geometry space as a "real and abstract musical object that conducts listening and structures perception through its evolution in time"[38] (Gorne, 2002) is particularly interesting.

Several loudspeaker orchestras dedicated to the interpretation of electroacoustic music emerged in the wake of Acousmonium[39] , with more or less different approaches to the GRM orchestra. In 1970, composers Françoise Barrière and Christian Clozier founded the Groupe de Musique Expérimentale de Bourges (GMEB), later known as the Institut International de Musique Electroacoustique / Bourges (IMEB). This institute, which was abolished in 2011, played a decisive role in the dissemination of electroacoustic music through its Synthèse Festival and the Concours Internationaux de Bourges, one of the most important in the

[26] "l'espace interne de l'œuvre", in the original (Gorne, 2002, p. 13).

[27] "l'espace externe [...] généré par l'interprète", in the original (Gorne, 2002, p. 4).

[28] A smooth transition between sounds, commonly known as a cross-fade.

[29] Establishment of a random texture, close to micro-assembly or granular synthesis, by manipulating amplitude and spectrum.

[30] "Figures d'espace - L'interprétation des œuvres stéréo à la console de spatialisation: le fondu enchainé, le démasquage, l'accentuation, le scintillement, l'oscillation, le balancement, la vague, la rotation, la spirale, le rebond, l'insertion/rupture, l'apparition-/disparition, l'explosion, l'accumulation, l'envahissement", in the original (Gorne, 2002, p. 9-11). 9-11).

[31] Non-literal translation of "L'espace ambiophonique" (Gorne, 2002, p.2).

[32] Examples that will be analyzed, respectively, in subchapters 2.3 and 2.4.

[33] "L'espace source", in the original (Gorne, 2002, p. 3).

[34] "L'espace géométrie", in the original (Gorne, 2002, p. 5).

[35] "L'espace Illusion", in the original (Gorne, 2002, p. 6).

[36] Which will be analyzed in subchapter 2.3.

[37] "Cet espace mouvement, s'il n'est pas gratuit, aurait donc surtout une fonction ornementale ou métaphorique à l'appui expressif des sons eux-mêmes auxquels il offre un support spatial.", in the original (Gorne, 2002, p. 5),

[38] "l'espace géométrie n'est donc pas un support, c'est un objet musical réel et abstractit qui conduit l'écoute et structure la perception par son évolution dans le temps.", in the original (Gorne, 2002, p. 5).

[39] Including, in Portugal, the Miso Music Loudspeaker Orchestra.

field. The works at the Synthèse Festival are broadcast using the Gmebaphone, an instrument consisting of amplification elements and loudspeakers, such as the Acousmonium, to which are added a processing and broadcast control system designed for the performance (figure 2.4) (Clozier, 2001). In Gmebaphone, the loudspeakers are divided into reference loudspeakers, arranged as stereophonic pairs, and loudspeakers with specific frequency responses, allowing for both spatial and spectral diffusion (Wishart, 1996). The need for a control interface arose because, despite its ubiquity, the mixing console made by replicating the channel strip[40] was not designed as an ergonomic interface for broadcasting electroacoustic music with dozens of loudspeakers. The Gmebaphone evolved over two decades in various versions, ending in the early 1990s with the implementation of the sixth version in a digital environment, which came to be known as the Cybernéphone (Clozier, 2001).

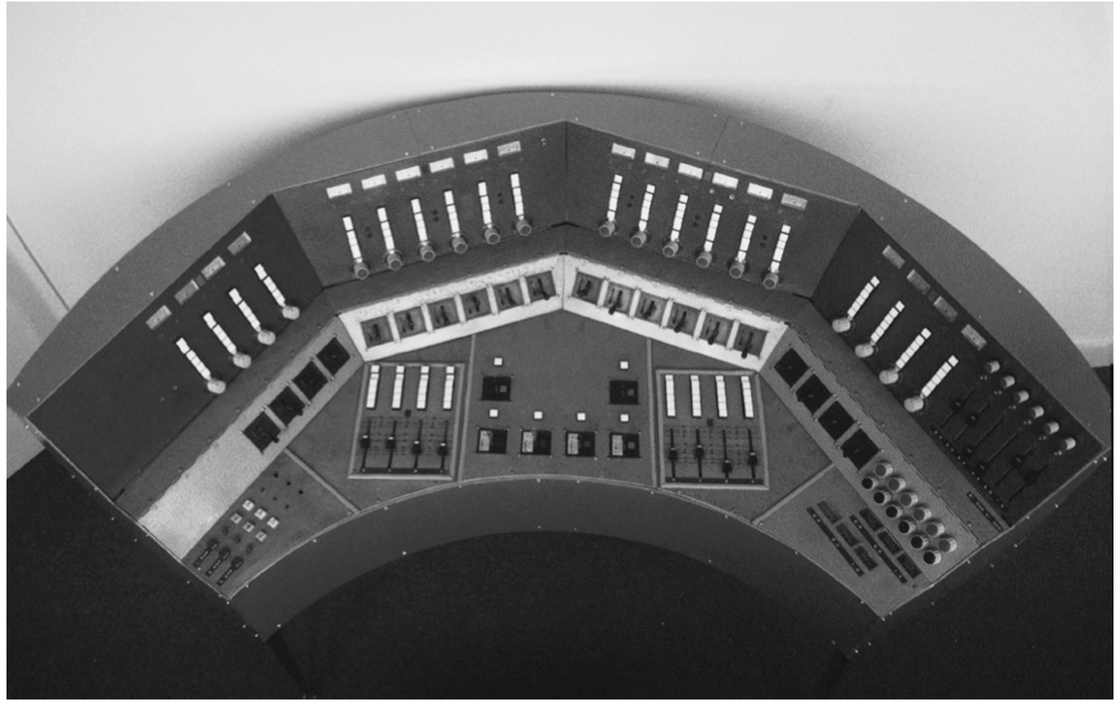

Figure 2.4. Gmebaphone 2 control console (Clozier, 2001).

2.2.2 Space as a Compositional Parameter

One of the new features introduced by Cybernéphone is the possibility of preparing and automating studio broadcasting (Clozier, 2001). This option distorts the vision of diffusion as a performative element of electroacoustic music (Harrison, 1998), as explicitly understood by the IMEB (Clozier, 2001) and central to the path started by Pierre Schaeffer and followed by François Bayle. However, it is easy to see that, since the early 1990s, composers close to this tradition, such as Annette Vande Gorne and Francis Dhomont, have begun to work on works in which spatial movement is defined during composition in more than two channels. In Terre [1989-1991], by Anette Vande Gorne, movement in space becomes an inseparable part of the musical gesture during the composition process (Zelli, 2009). Despite this, and despite its crystallization in eight channels, its diffusion in concert multiplies these channels by several loudspeakers (figure 2.5), in an approach that thus remains closer to the source space than to the surrounding space.

Terre is the last piece in the TAO cycle, which also includes Eau [1984], Feu [1985], Bois [1986] and Métal [1983], four stereophonic pieces that include instructions for interpretation in multi-speaker diffusion (Gorne, 2002).

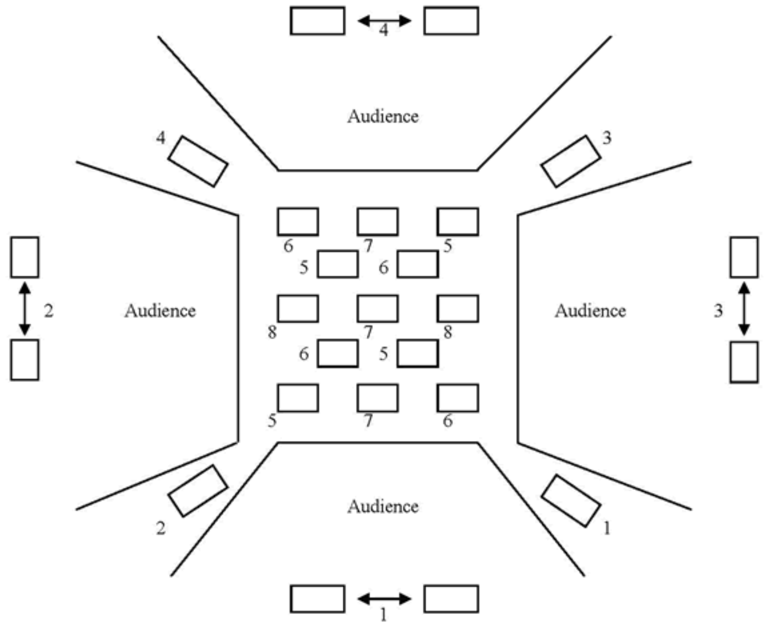

Figure 2.5. Arrangement of the loudspeakers in the work Terre [1989-1991], by Annette Vande Gorne (Zelli, 2009).

In works such as Tangram [1994], by Robert Normandeau, or Vol d'Arondes [1999], by Francis Dhomont, however, the multichannel format chosen for recording the spatialization is equal to the number of loudspeakers used for broadcasting in concert. In the case of Normandeau's piece, the electroacoustic sounds are placed in a source space that is very close to what happens in spatialization with acoustic instruments: each of the 16 channels of the magnetic tape is reproduced by an independent loudspeaker, without any manipulation, in a space that functions as a means of fusing the sound material. "The mix is therefore achieved acoustically and not electronically"[41] . The spatial gestures are inscribed in the articulation of the musical material in the same way as they would be in the case of 16 independent acoustic instruments. The stereophonic version for recording on CD was made by recording the diffusion of the piece with conventional microphones and stereo capture techniques, as if it were an acoustic work.

In the case of Vol d'Arondes[42] , for eight loudspeakers arranged in an octagon, the evocation of elements from the soundscape of a summer's night in Provence includes the "shrill, constantly changing feeding dance"[43] of the swallows. The technical approach here falls within the surrounding space defined by Vande Gorne, since the aim is to convey a movement that is external to the geography of the broadcast

[40] Literally, channel strips, referring to the traditional arrangement of controls on analog mixing consoles.

[41] "Mixing, therefore, is accomplished acoustically and not electronically.", in the program notes for Tangram [1994].

[42] Literally, Flight of Swallows. It is dedicated to Annette Vande Gorne.

[43] "Through this deep, blemishless blue, the flight of swallows: a strident, constantly changing feeding dance.", in the program notes for Vol d'Arondes [1999].

space. However, this movement is based on the use of connotative sound elements that seek to summon in the listener elements of a memory about the movement of the swallows that will be predominantly visual. The aim is therefore to identify the expressive characteristics of the movement and not to create immersion, such as that sought, for example, in the soundscape composition proposed by R. Murray Schaeffer and Barry Truax (1996tl), in which spatialization is used as a way of mimicking the natural auditory immersion of soundscapes (Truax, 1999). In Vol d'Arondes, the movements that carry the sounds mimic the frenetic dance of the swallows and are directed at the listener's cognition: in the composer's words, "space also belongs to memory"[44] .

The greater spatial definition needed to crystallize the spatial movements of these works leads to the use of the maximum number of channels available in the chosen recording and reproduction medium, which explains the growing affirmation of octophony (Lyon, 2008; Otondo, 2008) as a consequence of the availability of digital recorders on eight-channel magnetic tape (Gorne, 2002) and, later, eight-channel digital audio interfaces for computers. If, in some cases, octophony is understood as an octagon of 8 speakers (e.g., in the case of Vol d'Arondes, by Dhomont), in others it is just a means of reproduction for speakers in other arrangements (e.g., in Terre, by Vande Gorne). In any case, the work is no longer complete in its stereophonic version, awaiting interpretation by the broadcast. Rather, its reproduction in dissemination formats limited to two channels, such as CD, is regularly accompanied by the indication that it is a stereophonic reduction, indicating the loss of a fundamental element of compositional thinking[45] : the spatial gestures that evolve symbiotically with the musical gestures they carry.

D. Smalley identifies this intrinsic relationship between musical gesture - previously defined through its relationship with spectromorphology - and spatial gesture in what he calls "spatialomorphology"[46] (D. Smalley, 1997):

> Spatial perception is inextricably bound up with spectromorphological content, and most listeners cannot easily appreciate space as an experience in itself. Spatial appreciation can be acquired by consciously listening to the spaces in works as distinct from regarding space only as spectromorphological enhancement. I use the term spatiomorphology to highlight this special concentration on exploring spatial properties and spatial change, such that they constitute a different, even separate highlight this special concentration on exploring spatial properties and spatial change, such that they constitute a different, even separate category of sonic experience. In this case spectromorphology becomes the medium through which space can be explored and experienced. Space, heard through spectromorphology, becomes a new type of 'source' bonding[47]. (D. Smalley, 1997, p. 122).

[44] "The space, too, belongs to memory.", in the program notes for Vol d'Arondes [1999].

[45] A reduction that is analogous to the piano reduction of an orchestral score, in which timbral information is lost.

[46] "Spatiomorphology", in the original (D. Smalley, 1997, p. 122).

[47] "I define source bonding as: the natural tendency to relate sounds to supposed sources and causes, and to relate sounds to each other because they appear to have shared or associated origins." (D. Smalley, 1997, p. 110).

João Pedro Oliveira[48] is a paradigmatic example of this growing gestural use of space in electroacoustic music. Already in his works from the 1990s, space began to assert itself as a determining element in the construction of his personal style (Pombo, 2003), including the use of space to articulate electroacoustic media with acoustic instruments[49] in Requiem [1994] (Melo, 2003). It is, however, in the cycle of octophonic pieces inspired by the representations of the four elements in the Old Testament - so far consisting of Et Ignis Involvens [2005], 'Aphâr [2007] and Hydatos [2008] - that the symbiosis between morphology in spectral space (i.e. spectromorphology) and morphology in physical space (i.e. spatial morphology) of musical gestures becomes particularly clear. The use of granular synthesis in Oliveira's electroacoustic works is a far cry from the gas molecules of Xenakis[50] : here, the granules of each musical gesture are subject to a structuring environment that makes the intentionality of their placement explicit. The possibility of meticulous control over an "endless arsenal of subtleties" in this process of agglutinating small sounds thus lends itself to conveying the "gestural energy determined [...] by mutation, transformation and timbral development" characteristic of Oliveira's music[51] (Rudy, 2003, p.84). His desire to compose electroacoustics "in an instrumental way", i.e. in such a way that "the gesture and movement of the sounds" have "a human and natural character" (Oliveira in Salazar, 2003, p. 95), is then enhanced by the creation of musical gestures that encompass a spatial gesture.

2.2.3 The Internal Space and the External Space of Diffusion

The Birmingham ElectroAcoustic Sound Theatre (BEAST), one of the most active loudspeaker orchestras today, was founded by Jonty Harrison in 1982, with an explicit affiliation to the thinking of Pierre Schaeffer[52]. Notwithstanding his resistance, for aesthetic reasons, to the prior automation of diffusion - he argues that diffusion, if it exists, must be "composed in the system and space of performance"[53] (Harrison, 1998), i.e., as deferred interpretation - Harrison admits the need to find a solution that balances the growing work on spatialization in composition and the capacity for diffusion in the performance space. He identifies composing for fixed loudspeaker configurations[54] as a step backwards, since the possibility of interaction with the acoustics of the concert hall space is annihilated. He therefore proposes that a new standardized

[48] Advisor for this work.

[49] The musical gesture in the articulation between acoustic instruments and electroacoustic media is another important feature of his work.

[50] As is the case, for example, in the work Concret Ph [1958], which will be presented in subchapter 2.4, and, instrumentally, in sections of the work Terretektorh [1965-1966].

[51] The text that gave rise to these quotations (Rudy, 2003) is the conclusion of an analysis of the piece Íris [2000], for violin, clarinet, cello, piano and electronics. The stylistic homogeneity of Oliveira's work (Salazar, 2003) nevertheless allows it to be applied in this context.

[52] Jonty Harrison ends his article Sound, space, sculpture: some thoughts on the 'what', 'how' and 'why' of sound diffusion with the sentences "Fifty years ago, Pierre Schaeffer unleashed a new way of musical thinking. Vive la musique concrète - and all that flows from it!" (Harrison, 1998, p. 127).

[53] "Ideally, the automation would be composed on the performance system in the performance space, to which (as already mentioned) there is never sufficient access.", in the original (Harrison, 1998, p. 126).

[54] With some humor, he refers to this solution as "the 'Stonehenge' deployment - an array of eight or sixteen equally spaced, matching loudspeakers at the same height and at equal distances from the central sweet spot." (Harrison, 1998, p. 126).

format be found, with greater spatial definition than stereophony, which would allow for a redistribution of loudspeakers in orchestras such as BEAST (Harrison, 1998). Using Vande Gorne's terminology, he proposes that the increased resolution of the internal space should be reflected in the means used to define the external space, without this implying the crystallization of loudspeaker configurations and the abandonment of live diffusion. As can be seen from the comparison between the typical BEAST loudspeaker distribution of the 1990s and that of the beginning of this century (figure 2.6), the transition from stereophony to octophony in this loudspeaker orchestra has been accomplished.

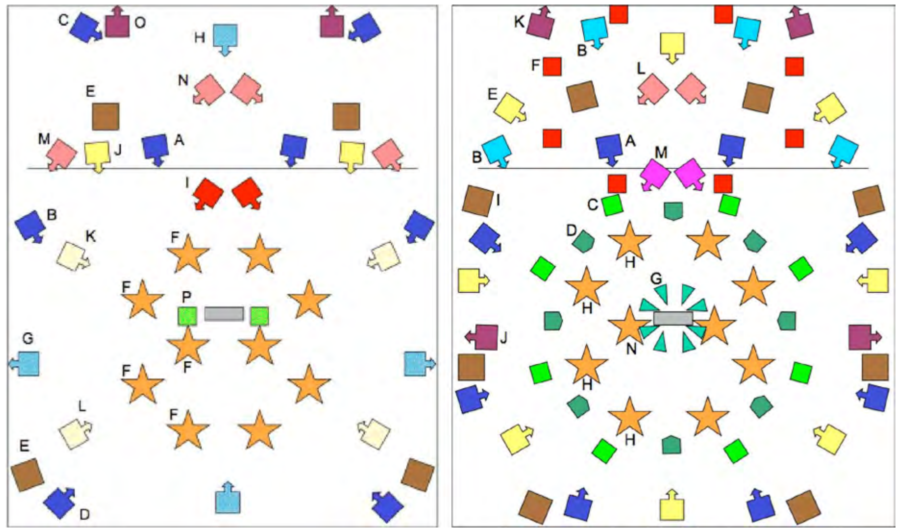

Figure 2.6. The usual layout of the BEAST loudspeaker orchestra in the 1990s (left) and the distribution used in the 20th anniversary concerts in 2003 (right). The transition from a system centered on the diffusion of stereophonic works to a system that encompasses several regular octophonic distributions is notable: A (main), B (distant, only quadriphonic), C (high), D (close), E (elevated gallery), F (stage, with speakers tilted and pointed towards the audience), G (radiating from the mixing desk to the audience), H (treble speakers) and I (bass speakers) (Harrison, 2011).

In works that apply a spatial thinking that is closer to the surrounding space and the geometry space[55] , live performance with a loudspeaker orchestra can break the transmission of spatial thinking. In the case of works that apply spatial thinking closer to source space and illusion space, diffusion with loudspeaker orchestras based on octophonic distributions then allows for an expansion of the composition's internal space without jeopardizing the ability to adapt to the acoustic spaces of the performance by defining the external space in the interpretation. The problem then becomes the complexity that results from the need to manipulate more than two channels in live broadcasting, which leads composers deeply linked to the acousmatic tradition, such as Denis Smalley, to continue restricting their works to a stereo pair at the time of composition, even after overcoming the difficulties of multichannel audio reproduction (Smalley in Austin, 2000). BEASTmulch, developed between 2006 and 2008, is an implementation of the live broadcast concept in software (Harrison, 2011), being based on VBAP[56] and including MotorBEAST, a physical interface based on the mixing console paradigm.

[55] Like those presented in subchapter 2.3.

[56] A spatialization technique that expands the panorama of amplitudes to an unlimited number of channels and which will be presented in subchapter 4.5.1.

2.2.4 The Spatialization of Acoustic Sources

Given its affiliation with the traditional concept of the orchestra, it is to be expected that there will be a reciprocal influence between spatial thinking in the dissemination of electroacoustic music and instrumental music[57] . It is in this context that the works Répons [1981-1984] and Dialogue de l'ombre double [1985] by Pierre Boulez appear, in which the instrumental musical gesture is set in motion in space, in real time, with the aid of electroacoustic means. In Dialogue de l'ombre double, the solo clarinet is confronted with its electroacoustic shadow - i.e. with sounds amplified or pre-recorded by the clarinetist and diffused in a spatialized way. Also included are sounds processed in real time by amplifying the clarinet through a loudspeaker placed under a grand piano. This, which should not be visible to the public, is kept with the pedal depressed so that the free strings can vibrate in sympathy, transforming it into an idiomatic loudspeaker, just like in Acousmonium. The instructions for spatialization are drawn on the score, which, despite its notation based on the paradigm of diffusion with a mixing desk (figure 2.7), allows it to be carried out independently of the technological means available. Perhaps as a result of the common technique and interface, the sound movements made by the spatialization in Dialogue de l'ombre double are part of the vocabulary of electroacoustic music diffusion.

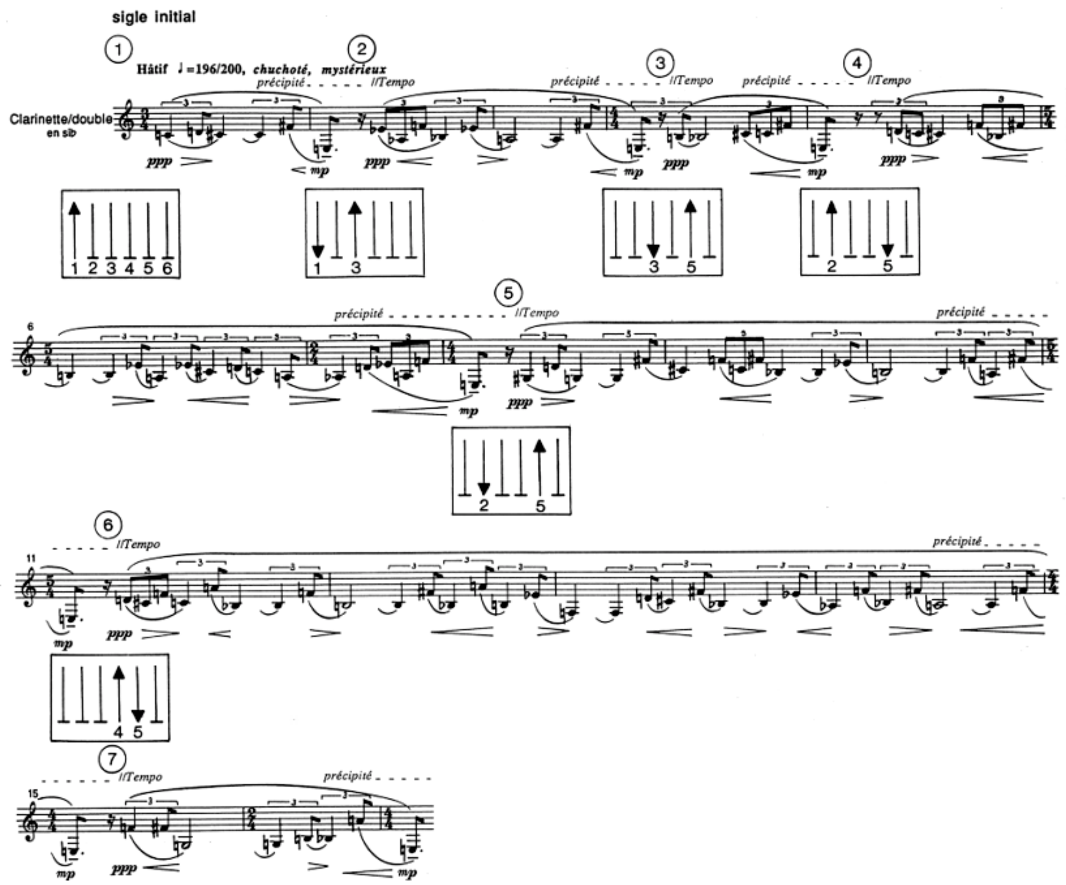

Figure 2.7. Excerpt from the score of Dialogue de l'ombre double [1985], by Pierre Boulez, showing the notation of spatialization using the mixing desk paradigm.

[57] It's not entirely by accident that electroacoustic works such as Terre [1989-1991] (figure 2.5), by Anette Vande Gorne, have a spatial thinking analogous to that of contemporary instrumental works such as Quodlibet [1990-1991], by Emmanuel Nunes.

In Répons [1981-1984], on the other hand, the intention is to spatialize the sound so that "the speed with which the sound moves around the room depends directly on the amplitude of the sound"[58] (Boulez & Gerzso, 1988) produced by each of the six soloists: vibraphone, glockenspiel + xylophone, harp, piano, piano + synthesizer and cimbalon. These, arranged next to the walls of the auditorium, join an instrumental ensemble in the center of the space and six loudspeakers placed in the interstices between the solo instruments (figure 2.8). This arrangement, with the audience surrounding the orchestra and circumscribed by both the solo instruments and the loudspeakers, helps to summon up the idea of antiphonal singing that will be developed by the articulation between the soloists and the instrumental ensemble. Each solo instrument corresponds to a sequence that defines a sound path through the speakers (figure 2.9).

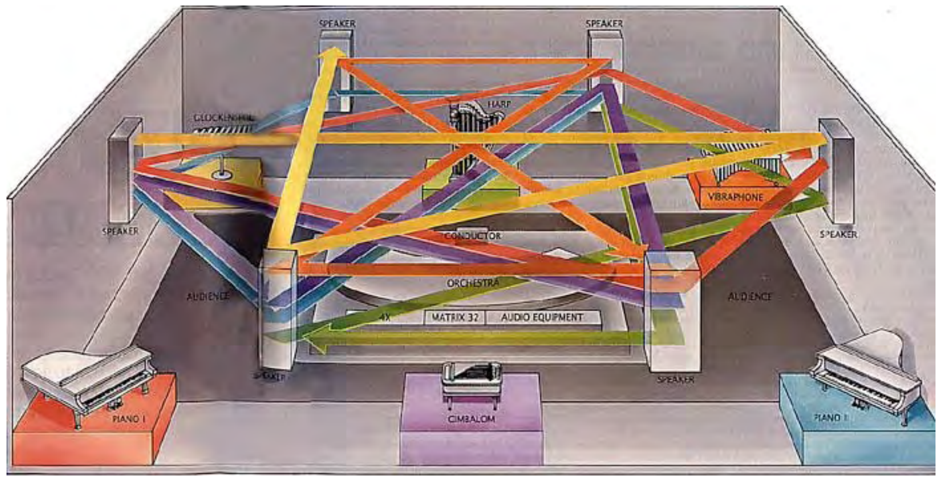

Figure 2.8. Arrangement of instruments, loudspeakers and spatial paths in Répons [1981-1984], by Pierre Boulez (Boulez & Gerzso, 1988).

Real-time spatialization based on tracking the amplitude envelope of the sounds of acoustic instruments is achieved through a digital spatialization system designed at the Institut de Recherche et Coordination Acoustique/Musique (IRCAM), a center founded by Pierre Boulez himself in 1977 and which put into practice his ideas about the benefits of collaboration between scientists and musicians to develop technological solutions for musical composition (Boulez, 1986). The IRCAM technicians use a system consisting of their Sogitec 4X audio processing station and their Matrix 32 audio addressing matrix. The signal picked up by the microphone of each of the solo instruments is analyzed by an envelope tracker, and the amplitude detected defines, at each moment, the iteration frequency between the various loudspeakers in the spatial path defined for the sound of the respective instrument (figure 2.9). Solo instruments have in common that they have a sound envelope characterized by a rapid attack followed by a natural decay. The duration of this decay is different for each instrument, each note and each dynamic, thus affecting the distance traveled and the speed of articulation of each spatial path. Répons is a seminal work of real-time

[58] "The speed with which a sound moves around the performance hall depends directly on the loudness of the sound.", in the original (Boulez & Gerzso, 1988, p. 45).

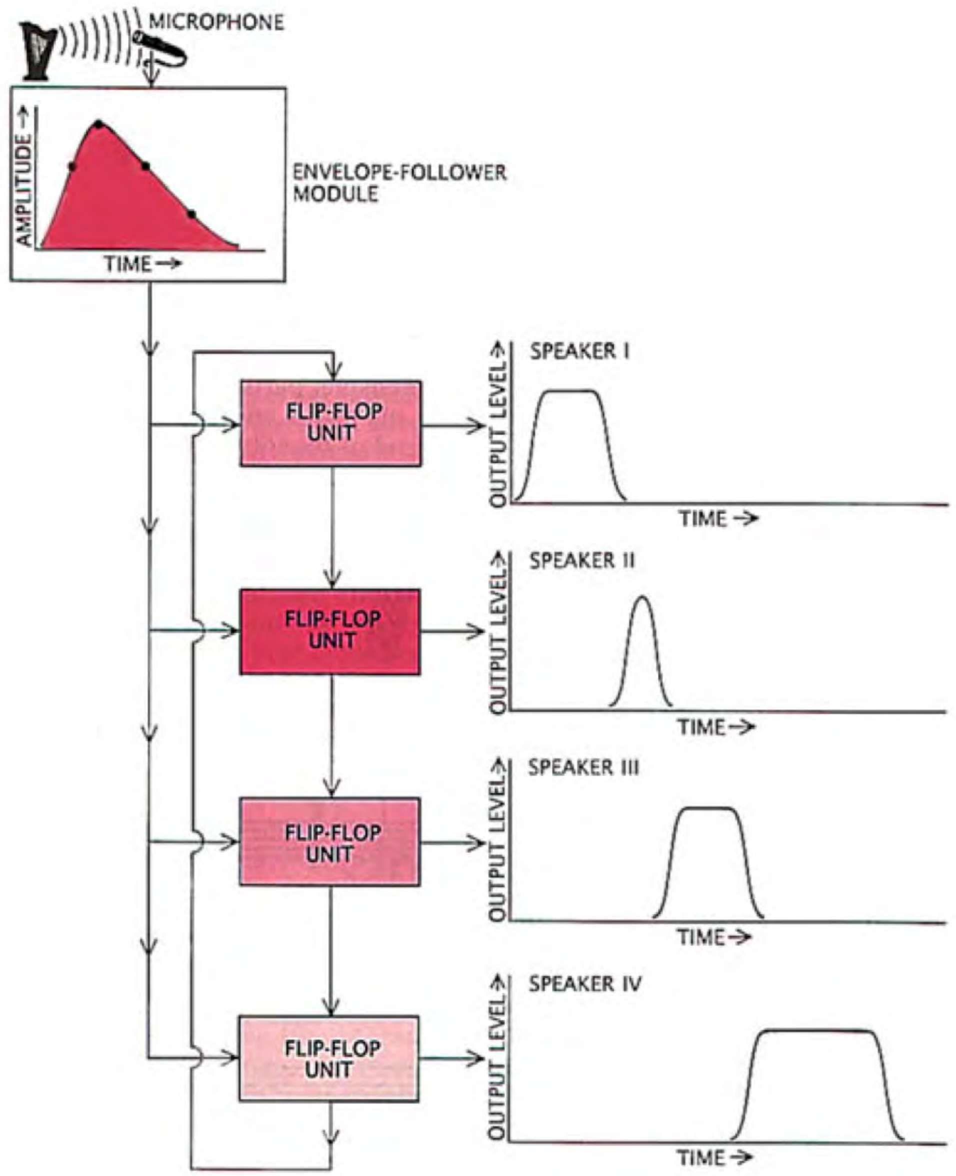

Figure 2.9. Spatialization method used in Répons [1981-1984], by Pierre Boulez (Boulez & Gerzso, 1988).

electronics using reactive digital systems. Its spatial paths, defined geometrically, may suggest an affiliation with Karlheinz Stockhausen's ideas of the serialization of space: Boulez is, in fact, one of the conductors who conducted the premiere of Stockhausen's Gruppen [1955-1957], so he will be familiar with his ideas on spatialization. Nevertheless, the total subjugation of spatialization to the original environment of the spatialized sound unequivocally integrates Répons into the works in which the spatial gesture is used as an expansion and diffusion of the musical gesture.

The use of musical gesture articulated by acoustic instruments as a source of movement in real-time spatialization is explored in in many, many ears [2011]. In this work, the recorder is amplified by placing a pair of binaural microphones inside the instrumentalist's auditory pavilions, thus using his head as an acoustic obstacle between the two microphones. The signals picked up by the capsules of these microphones are then amplified by a pair of loudspeakers placed at the ends of the stage. Because of the way they were designed, the musical gestures that the performer interprets have the effect of spatializing the sound captured, amplifying his movements up to the width defined by the loudspeakers. In this way, the aim is to return to spatialization as a performance, just as it was in the GRMC's pupitre d'espace concerts.

2.3 The Spatial Gesture in the Articulation of the Musical Gesture

Elektronische Musik emerged in the post-war period at the Westdeutscher Rundfunk (WDR)[59]. It was founded by Werner Meyer-Eppler, who coined the term in 1949 (Menezes, 1996a), referring to the possibility of creating music using only synthesis from electronic sources. Meyer-Eppler was joined in the early 1950s by Robert Beyer, Herbert Eimert (who would become the first director of the WDR's Electronic Music Studio), Gottfried Michael Koenig and, fresh from a short stint in the studios led by Pierre Schaeffer, Karlheinz Stockhausen. This group of composers formed the nucleus of what became known as the Cologne School, which explored the possibility, opened up by electronic tools, of working sound from its fundamental acoustic elements, namely through the use of additive synthesis from the sum of pure sounds (i.e. sine waves). Expressly inserted in the context of post-Webernian thinking (Menezes, 1996a), which was expanding across Europe at the time, these composers' approach involves applying serial thinking to the conception of musical material. Electronic media were then seen as allowing for a more precise and virtually unlimited realization of the composers' ideas. These are subject to detailed notation even before the execution phase[60] , as in the case of Stockhausen's Elektronische Studie I [1953] and II [1954], maintaining a process that starts from abstraction to concretization, in direct opposition, therefore, to contemporary musique concrète.

Among the composers of the Cologne School, Karlheinz Stockhausen is undoubtedly the most prominent. His conceptions of spatialization in electroacoustic music, as well as in instrumental music, are no exception and definitively mark the establishment of space as a relevant element in musical composition. Sara Ann Overholt, in her thesis dedicated to Stockhausen's theories on space (Overholt, 2006), with emphasis on the analyses of Gruppen [1955-1957] and Oktophonie [1990-1991], proposes dividing Stockhausen's work on spatialization into three distinct phases[61] : the initial period (from 1951 to c. 1965), the intermediate period (from c. 1966 to c. 1976) and the mature period (from c. 1977 to 2007[62]).

In the initial period, which includes the aforementioned instrumental works Gruppen and Carré, Stockhausen approaches space as a musical element integrated into serial thinking, which is made explicit in his 1958 article, Musik im Raum[63] (Stockhausen, 1958), which stems from a paper given that same year in Darmstadt. In this article, written when he had already finished Gesang der Jünglinge [1955-1956] and was about to start Kontakte [1958-1960], Stockhausen briefly analyses the history of spatialization

[59] Until 1955, it was still part of the Nordwestdeutscher Rundfunk (NWDR).

[60] This allows, for example, the recreation of works with current technical means, as is the case with the recreation of Karlheinz Stockhausen's Elektronische Studie II [1954], which accompanies the installation of Max software.

[61] This division is not only reflected in the spatialization, although this is the focus of Overholt (2006), but is transversal to Stockhausen's compositional process in each of the three periods.

[62] In the thesis in question (Overholt, 2006), this period appears to be from 1977 to the present, as it was defended in 2006, before Stockhausen's death in December 2007.

[63] Literally, music in space.

in Western music as a prologue to the description of spatial thinking in his works, presenting Gesang der Jünglinge as a work in which he "tried to make the direction of sound and its movement in space open up a new dimension of musical experience"[64] (Stockhausen, 1958). In fact, the placement of the sound in the speakers is a determining parameter in the articulation of the other elements: in the performance score of Gesang der Jünglinge we find the notation of a musical discourse distributed over five layers, with each line corresponding to a speaker, in a similar way to the arrangement in one line per instrument in conventional notation for acoustic instruments.

The work was originally conceived for five channels, using a 4-channel magnetic tape player for the loudspeakers around the audience and a second monophonic player with the fifth channel, intended to be reproduced by a loudspeaker suspended from the center of the concert hall ceiling. However, technical limitations meant that, at its premiere in May 1956, the fifth channel was broadcast by a loudspeaker in the center of the stage. The synchronization of the two magnetic tape players, done manually, was also unsatisfactory, so the composer decided to mix the fifth channel with the others and turn Gesang der Jünglinge into a quadraphonic work (J. Smalley, 2000). Despite these changes, spatialization always remains an intrinsic element of the work: "from where, through how many loudspeakers simultaneously, rotating left or right, moving or stationary, the sounds and groups of sounds are projected into space: all this is decisive for understanding this work."[65] (Stockhausen, 1958). The loudspeakers are, however, still used in what Vande Gorne would call the source space, just as they were with the instrumental groups in Gruppen and Carré.

In Musik im Raum, Stockhausen shows that he has a profound understanding of the phenomenon of sound perception in space[66] , on which he bases a proposal for its use as a serializable element, just as he had done with the other musical parameters in the Elektronische Studie. He identifies direction in the

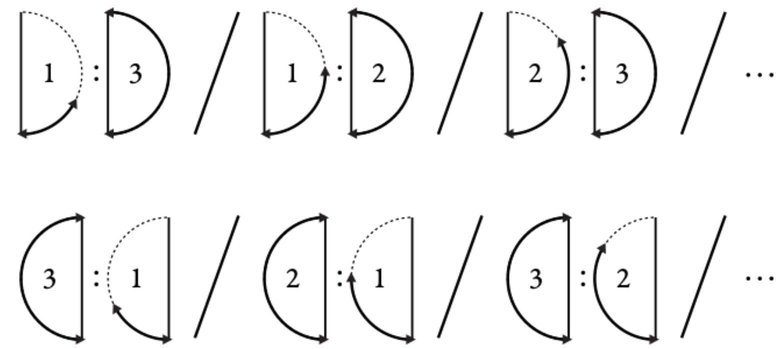

Figure 2.10. Examples of spatial proportions proposed by Karlheinz Stockhausen in Musik im Raum (Stockhausen, 1958).

[64] "In der Komposition habe ich versucht, die Schallrichtung und die Bewegung der Klänge im Raum zu gestalten und als eine neue Dimension für das musikalische Erlebnis zu erschließen.", in the original (Stockhausen, 1958, p. 153).

[65] "Von welcher Seite, mit wie vielen Lautsprechern zugleich, ob mit Links- oder Rechtsdrehung, teilweise starr und teilweise beweglich die Klänge und Klanggruppen in den Raum gestrahlt werden: das alles ist für das Verständnis diese Werkes maßgeblich.", in the original (Stockhausen, 1958, p. 153).

[66] His description of distance perception - which he makes dependent on recognizing the sound source, which is why he downplays the potential for its use in elektronische Musik - is surprisingly close to that resulting from more recent research.

transverse plane (i.e. azimuth) as the main serializable spatial parameter and proposes dividing space into proportions similar to those used in time division and tuning (figure 2.10).
He then states that the distribution of sounds in space can be used to clarify the relationships between different musical layers[67] or as an additional way of articulating long phrases and structuring musical material. The latter will turn out to be his most influential and original contribution to thinking about space in electroacoustic music: the idea that spatialization can be a way of articulating and shaping musical material. This geometric approach to defining forms and paths in space thus differs from the tradition of musical gesture diffusion in the sense that spatial gestures tend to become independent of the musical gestures they carry.

If Gesang der Jünglinge is the first work in which Stockhausen mixes electronic sounds with recorded sounds[68] , Kontakte [1958-1960] is the first work in which he mixes electronic sounds and real instruments. Written for piano, percussion and four loudspeakers around the audience[69], in Kontakte Stockhausen uses "six forms of spatial movement, with different speeds and directions, [which] contact each other [...]: rotations, cyclical movements, alternations, fixed disparate sources (different sounds from each of the four loudspeakers), fixed identical sources (the same sounds in all the loudspeakers) and isolated spatial points."[70] (Stockhausen quoted by Miller, 2009). These indications are present in the performance score

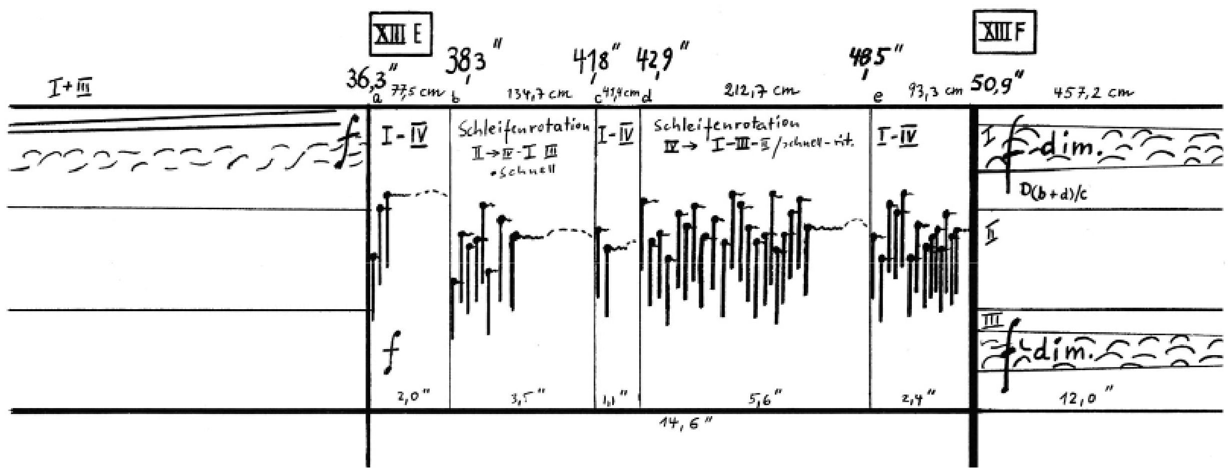

Figure 2.11 - Excerpt from the score of Karlheinz Stockhausen's Kontakte [1958-1960]. Spatial indications are visible below the top horizontal line: the Roman numerals indicate the speaker (I - left, II - front, III - right, IV - rear), Schleifenrotation indicates a cyclical rotation, sometimes fast (schnell), sometimes slowing down (rit.).

[67] A rare point of contact with the ideas of Henry Brant (M. A. Harley, 1997).

[68] The voice of the adolescent quoting the text of biblical origin, among other recorded sounds, leading some supporters of musique concrète, including Pierre Schaeffer, to try to classify it as such (Menezes, 1996a).

[69] Although it also exists in a version for electroacoustic media only.

[70] "Six forms of spatial movement, with differentiated velocities and directions, contact each other in ever changing ways: rotations, looping movements, alternations, disparate fixed sources (different sounds from each of the 4 loudspeakers), connected fixed sources (the same sounds in all the loudspeakers), isolated spatial points.", in the original (Stockhausen cited by Miller, 2009).

(figure 2.11) and reveal the materialization of the proposed experimental exploration of the movement's characteristics (Stockhausen, 1958).
To realize the rotational movements of Kontakte, Stockhausen developed a peculiar technical solution: a loudspeaker is placed on a rotating platform, with a cone serving as a guide for the sound waves reproduced by the loudspeaker (figure 2.12). Four microphones, connected to a four-channel magnetic recorder, are mounted around the platform and the sound to be spatialized is reproduced by the loudspeaker while the interpreter of the spatial indications (in this case the composer himself) rotates the platform.

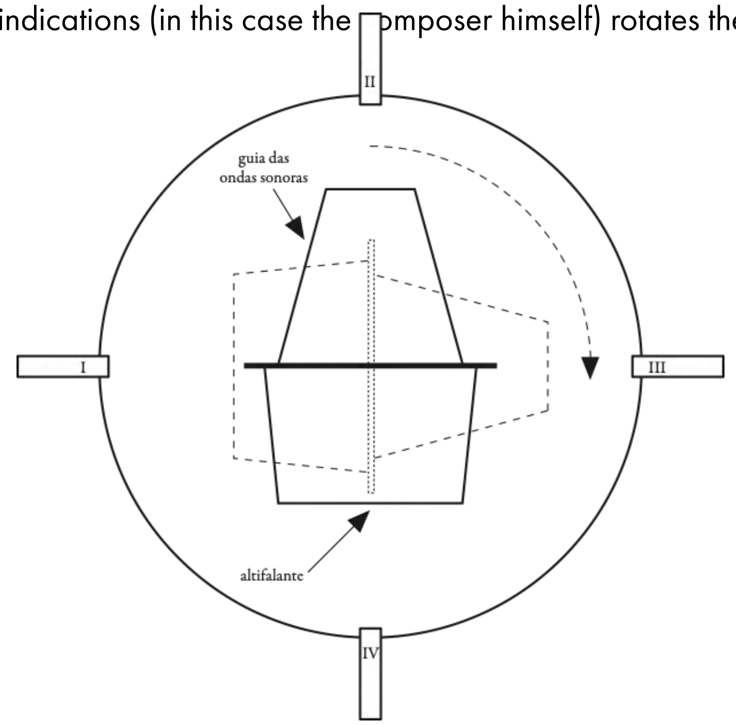

Figure 2.12 Schematic of the spatialization table used for the conception of Karlheinz Stockhausen's Kontakte [1958-1960].

This turntable allows the recording of signals that include both differences in intensity and differences in the time of arrival at the various microphones. Given that the turntable can reach angular velocities of around seven revolutions per second[71] , these differences in arrival times cause lags and Doppler effects[72] (Maconie, 1990). These effects, which appear at high angular velocities, are impossible to replicate with traditional spatialization based on the manipulation of amplitudes. The physical rotation of a loudspeaker had previously been used in the development of the Leslie loudspeaker for Hammond organs[73], and was later implemented on a larger scale by Edwin van der Heide and Marnix de Nijs in the interactive installation Spatial Sounds (100 dB at 100km/h) [2001]. Stockhausen's solution differs, however, in that it is a spatialization tool intended not for dissemination but for the process of composing the work. The

[71] Above the limit of perceived location in this type of movement, as a result of the effect of persistence of location, which will be described in subchapter 3.7.3.

[72] Variation in the frequency of sounds emitted by moving sound sources in relation to the listener, an effect that will be presented in subchapter 3.6.1.

[73] http://hammondorgan.co.uk/page5/page5.html

rotating loudspeaker, which will be reused in Sirius [1975-1977], is therefore one of Stockhausen's most important original marks in the approach to spatialization in this first period of his production (Miller, 2009), and only recently has its complete implementation been achieved in a digital environment[74] (Peters, Braasch, & McAdams, 2011a).

The movement of sound masses in space - which, in this case, is independent of the performance aspect in concert, despite its mode of execution in the studio - thus becomes a musical parameter of the same importance as harmonic, melodic, timbral and rhythmic movements, and its perception is interdependent on theirs. Going beyond the articulations between static sources - as happens, for example, in Antiphony I [1953], by Henry Brant or Gruppen [1955-1957], by Stockhausen himself - in Kontakte, it is the movement's interference with the other musical parameters that articulate and shape them. In the composer's own words:

> Our perspective of musical space is utterly frozen and has led to a music in which the movement and direction of sound in space has no function. But the moment we have the means to move sound with any given speed in a given auditorium, [...] movement in space of music becomes as important as the composition of its melodic lines and its rhythmic characteristics. (Stockhausen, 1989, pp. 102-103)

The middle period of Stockhausen's production (from c. 1966 to c. 1976) is characterized by a simplification of compositional processes and is centred on the Osaka World Expo in 1970. West Germany's participation in this event centered on the construction of a spherical auditorium, in the form of a geodesic dome[75], used during the six months of the exhibition to broadcast works by various composers from the German musical heritage. Built under his direction (Stockhausen, 1989), the program includes five and a half hours a day of Stockhausen's music. Fifty loudspeakers are installed, distributed over seven different elevations, in circles of five in the upper and lower pair and circles of ten in the three middle elevations (figure 2.13). Between the third and fourth elevation, from bottom to top, an acoustically transparent platform supports

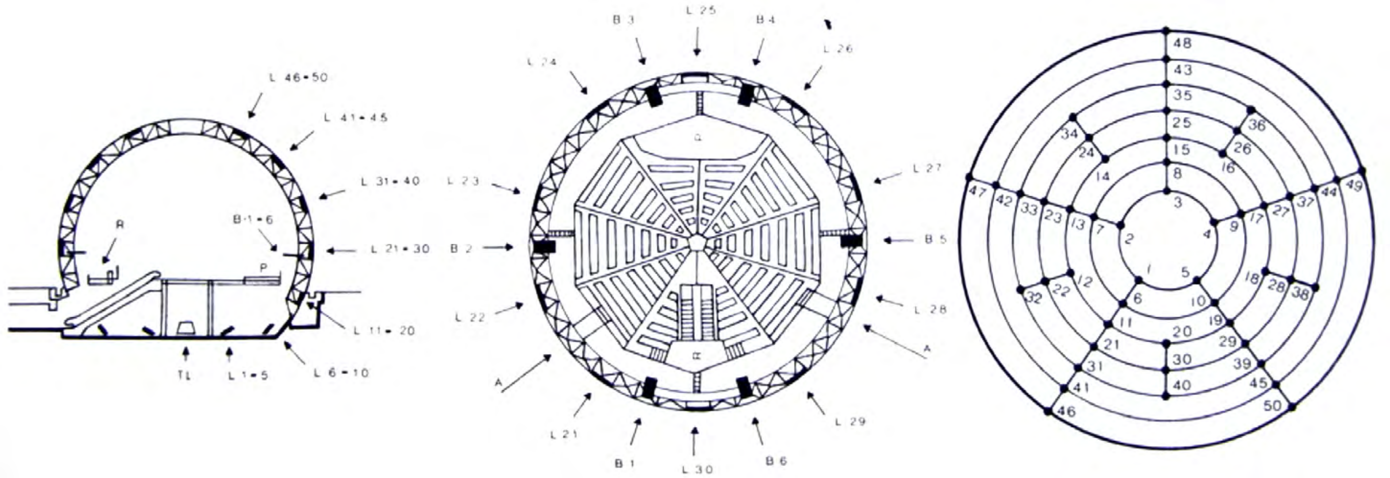

Figure 2.13. Schematic of the West German Pavilion in Osaka'70. Legend: A - exit; L - loudspeaker; B - soloist's desk; P - musicians' podium; R - control desk; TL - low-frequency loudspeaker. In the score of Spiral [1968], by Karlheinz Stockhausen.

[74] Using ViMiC, a spatialization technique based on placing virtual microphones in a virtual space. It will be presented in section 4.6.4.

[75] The geodesic dome is a hallmark of the architecture of the time, especially after the construction by architect Buckminster Fuller of the American pavilion at the Montrèal World Expo in 1967, now known as the Montrèal Biosphère.

the audience (Stockhausen, 1971). This pavilion thus makes possible the materialization of some of the ideas that Stockhausen had launched a decade earlier (Stockhausen, 1958).
To control the movement of sounds in the hall, Siemens[76] developed a sound direction controller known as a sound mill. This is used to distribute a monophonic signal through a circle of ten loudspeakers by rotating a small wheel similar to that of a coffee grinder, which makes it possible to achieve angular speeds of up to five revolutions per second[77]. In conjunction with the mixing desk, this device makes it possible, for example, to have a voice picked up by a microphone describe "an upward spiral movement for two or three minutes [...], while the sound of another performer is set in circular motion by another sound mill and a third sound crosses the space in a straight line, using only two potentiometers"[78] (Stockhausen, 1989).

Hinab-Hinauf [1968], a large multimedia work for ensemble, electroacoustic media, film and light projection, was deliberately conceived for the Osaka pavilion (Stockhausen, 1971). It never came to fruition, however, as it was passed over by the committee organizing the German participation in favour of other works with less complex means (Maconie, 1990). However, its title - literally, downwards-upwards - illustrates the importance of the new auditorium opening up the vertical dimension that had been frustrated in Gesang der Jünglinge. This dimension greatly expands the geometric vocabulary in the approach to space, allowing, for example, the transformation of circular rotations into ascending or descending spirals.

Several of Stockhausen's works are broadcast in the Osaka auditorium during the exhibition. Among them is Telemusik [1966], composed in the studios of Japan's radio station (NHK), in which Stockhausen uses electronic means for the first time to control spatialization, another hallmark of this intermediate period (Overholt, 2006). This period also includes Mantra [1970], for two pianos and ring modulation, and a series of procedural works on sounds broadcast by short-wave radios[79] . Of this series, Spiral [1968] is the most notable and the one whose title most strongly refers to the spatial question and, specifically, to the introduction of its vertical component. The spiral is, in fact, a figure that will profoundly mark his later compositional thinking (Overholt, 2006). Spiral is performed more than 1,300 times during the course of the exhibition by various interpreters, including the composer himself (Stockhausen, 1971). There is, however, no precise documentation on how the diffusion of this and other works is thought out, since it is improvised by Stockhausen himself and a group of performers who surround him at this time (Stockhausen, 1971). This comparative lack of documentation contrasts with the profuse crystallization of thought on spatialization in earlier works, such as Kontakte [1958-1960], or later ones, such as Oktophonie [1990-1991]. It is possible to see, however, through an analysis of the evolution of his later spatial thinking, that the use of spatialization as an articulation of musical material remains a central element of his production. Rolf Gehlhaar, the composer who accompanied Stockhausen during his period of residence in Osaka,

[76] A major German manufacturer of electronic equipment, among other things.

[77] As such, they are close to the limit of location perception in this type of movement, as a result of the location persistence effect, which will be described in subchapter 3.7.3.

[78] "For example, I could decide to make a voice go in an upward spiral movement for two or three minutes, either clockwise or anti clockwise, while at the same time another player's sound moved in a circle using the other soundmill, and a third crossed in a straight line, using just two potentiometers.", in the original (Stockhausen, 1989).

[79] A source of sound unpredictability previously used by John Cage in Imaginary Landscape No. 4 [1951], for twelve radio sets.

confirms the geometric nature of the improvisation of spatial movement in this pavilion: the articulation of the spatial component live allows a morphology to be imposed on sources of unpredictable sound material, such as that generated by the performer in Spiral[80].

Few experiences will have had such a significant impact on Stockhausen's career as the one in Osaka, as a result of the unique opportunity to have an auditorium built, according to his specifications, to perform his works for a total of around 1,000 hours[81] concentrated in a short period of six months. The building was destroyed after the exhibition, despite Stockhausen's attempts to bring it back to Europe (Stockhausen, 1989). Despite this, some of the ideas inherent in its construction are present today in auditoriums built for the dissemination of electroacoustic music, such as the Sonic Lab at the Sonic Arts Research Centre (SARC) in Belfast. This auditorium, inaugurated by Stockhausen himself in 2004, includes an acoustically transparent platform and circles of loudspeakers arranged on various levels, both above and below the audience area.

Karlheinz Stockhausen's mature period (from c. 1977 to 2007) is marked by the composition of Licht [1977-2003], a cycle of seven operas totaling 29 hours of music. Significant parts of Licht can be interpreted as independent works. Of these, Sara Ann Overholt identifies Oktophonie [1990-1991] and Helikopter-Streichquartett [1992-1993][82] , as paradigmatic examples of the spatial thinking of this period (Overholt, 2006). As the name suggests, in Oktophonie Stockhausen uses eight loudspeakers, which are, however,

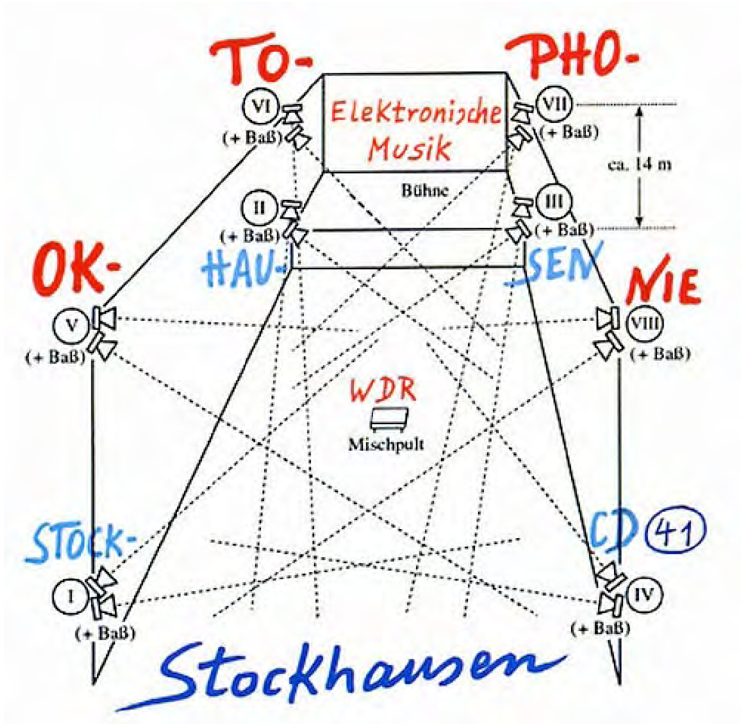

Figure 2.14. Spatial trajectories of Oktophonie [1990-1991], by Karlheinz Stockhausen.
On the CD cover with the stereophonic reduction of the same work.

[80] This testimony by Rolf Gehlhaar was collected in person, in the course of several personal conversations about music, composition and the figure of Karlheinz Stockhausen.

[81] 5.5 hours a day, for 183 days (Wörner, 1973).

[82] Respectively, parts of Dienstag and Freitag.

arranged in a cube (figure 2.14) and not in the common octagonal arrangement that he had used in previous sections of Licht, such as Sirius [1975-1977] (Stockhausen, 1993).
This arrangement allows for the composition of "vertical and diagonal movements" which, according to the composer, are here "composed for the first time in conjunction with the horizontal movements of the earlier electronic music for 4 and 8 channels"[83] (Stockhausen, 1993). Used to portray the cosmic battle between the archangel Michael and Lucifer, this type of movement had in fact already been used in works by other composers, such as Roger Reynolds' Archipelago [1982-1983][84] . However, in Oktophonie, the spatial gestures take on the importance of a primary element, according to which all the others are articulated (Overholt, 2006). "By superimposing several layers" of spatial gestures, "each with its own complex spatial movement [85], Stockhausen creates a rich polyphony of spatial movement" (Clarke & Manning, 2008). Almost the whole of his article on the conception of the work (Stockhausen, 1993) is dedicated to spatialization. This element is, however, the last to be realized in the process of composing the work, taking place only after the conception of all the sound material. In his own words:

> The simultaneous motions [...] make it clear that with Octophony a new dimension of musical-spatial composition has opened. In order to be able to hear such motions - above all, simultaneous ones - the musical rhythms must be drastically slowed down; the pitches must change only very occasionally, and only in small steps or with glissandos; amplitude composition is completely bound up with the audibility of the individual layers - and therefore is dependent on the tone colors of the layers and on the tempo of their motions; tone-color composition primarily serves the clarification of these motions. (Stockhausen, 1993, p. 163)

This perspective expands Stockhausen's previous spatial thinking and, in fact, inaugurates what seems to be a new way of seeing spatialization as a musical parameter: no longer confined either to the role of a vehicle for musical intentions that are alien to it, or to that of an articulating (or even disruptive) element of the other musical parameters, spatialization emancipates itself and becomes the structuring element of the musical discourse, around which the traditional parameters circulate - or converge. Nevertheless, his spatial works are available in stereo versions, reflecting the limitations of the ubiquitous CD, in which case the potential for dissemination is privileged over the intelligibility of the spatial component.

In Cosmic Pulses [2006-2007], part of his latest cycle Klang [2004-2007], a process similar to that of Oktophonie is applied to the spatialization for an octophony, this time horizontal[86]. It was only after the sound material of the 24 overlapping layers of this electroacoustic piece had been realized that Stockhausen developed 241 trajectories in space (figure 2.15) to spatialize them. These trajectories are

[83] "In this music there have been composed for the first time vertical and diagonal movements, alongside the horizontal movements of previous four- or eight-channel electronic music.", in the original (Stockhausen, 1993, p. 151).

[84] Work that will be presented in subchapter 2.3.1.

[85] "By superposing several layers each with their own complex spatial movement, Stockhausen creates a rich polyphony of spatial movement.", in the original (Clarke & Manning, 2008, p. 186).

[86] I.e., eight columns arranged in an octagon.

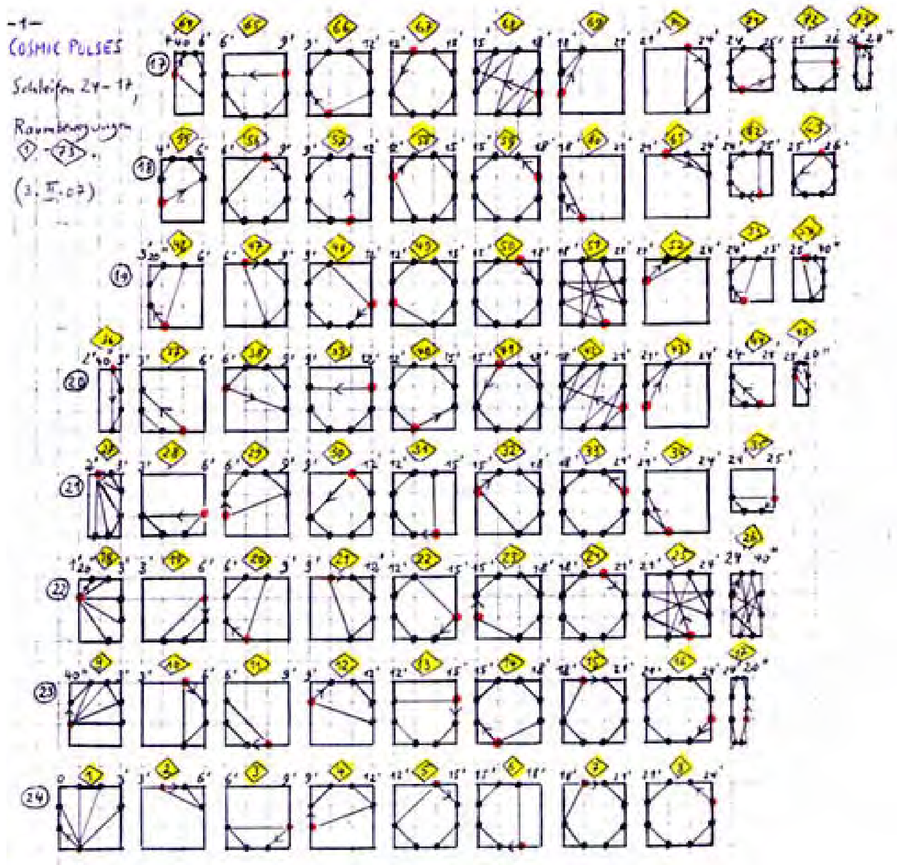

Figure 2.15. First page of the 241 trajectories in space defined by Karlheinz Stockhausen for Cosmic Pulses [2006-2007]. On the CD with the stereophonic reduction of the same work

defined as chains of straight line segments, with the links at points defined by the loudspeakers, and are traversed in cycles, mimicking the orbit of celestial bodies.

This spatialization - carried out by Joachim Haas and Gregorio Karman, from the Experimental Studio for Acoustic Art in Freiburg - is thus done between pairs of loudspeakers for each segment of the chain, highlighting their position. A customized spatialization tool has been developed, named Okteg and reflecting the history of Karlheinz Stockhausen's contributions to spatialization in electroacoustic music, almost fifty years after Musik im Raum (Stockhausen, 1958):

> The OKTEG [...] merges different ideas present in former devices such as the QUEG, the Rotationsmühle[87] , or the Rotationstisch[88] , all related to previous works composed by Stockhausen. The QUEG (Quadraphonic Effects Generator), a four-channel spatialization unit - designed by Tim Orr and manufactured by EMS in 1975 - was used by Stockhausen in OKTOPHONIE (1990/1991). The OKTEG resembles the QUEG for being a spatial step sequencer, as well as in its LED-based visual feedback system. [...] Like in the Rotationsmühle [...] the OKTEG provides the performer with manual control of rotation velocity, and different routings are accomplished by means of matrix programs. The Rotationstisch, first used as a spatialization instrument in KONTAKTE, was later further developed for exploring the artifacts, which appeared at very high rotation speeds. Following this idea, the OKTEG provides with sample accurate trajectories and arbitrary high rotation speeds, assisting the exploration of a continuum linking space and timbre. (García-Karman, 2007, pp. 2-3)

[87] Referred to in this document as a sound mill.

[88] The spatialization table used for the conception of Kontakte [1958-1960] and later adapted as a rotating loudspeaker for Sirius [1975-1977].

2.3.1 Programming in the Composition Process

Many composers have been interested in the potential of computer music since its pioneering developments in the 1950s[89] . This fertile ground of opportunities for creating new sounds and new approaches to composition, however, requires composers to devote a substantial amount of their time not only to deepening their knowledge of subjects already familiar to composition - such as acoustics and mathematics - but also to exploring new territories - such as digital signal processing and computer programming. This new knowledge has led many composers to integrate the creation of their own digital tools as part of their compositional process .[90]

Recognized for the invention of frequency modulation (FM) synthesis (Chowning, 1973), John Chowning belongs to this group of composers who profoundly combine their aesthetic demands with the research and development of new techniques. His work, which pioneered the spatialization of sound through the manipulation of digital audio on a computer, paved the way for a generalization of the approach to spatialization, materialized in the design of software capable of manipulating the perception of direction, distance and speed of a sound source[91] (Chowning, 1971). In fact, Chowning identifies the spatialization of sound as one of the primary elements of his interest in musical computing, the origin of "a number of perspectives on perception that led not only to [his] discovery of FM synthesis", but also "enriched [his] way of thinking about music ever since"[92] (Chowning, 2011). A reflection of this is Sabelithe [1971], his first work made with computer means and, simultaneously, both the debut in music of FM synthesis and the first use of computer spatialization.

The work that Chowning identifies as the one in which the two lines of research converge decisively is, however, Turenas [1972] (Chowning, 2011). This is also the work in which he introduces the Doppler effect as a compositional element. This is an important element not only in the perception of the speed of sound sources, but also in the perception of their distance, since the variation in frequency helps to highlight reverberation (Chowning in Zelli, 2010), which is also simulated by the software. The possibility of simulating the distance and speed of the sound sources makes it possible to explore complex movements that move towards and away from the listeners, describing Lissajous curves (figure 2.16). Despite the fact that the Doppler effect was an inevitable consequence of the spatialization technique used by Stockhausen in Kontakte [1958-1960], Turenas is still today the main reference in the use of this effect in the spatialization

[89] Among them is the series of programming languages for digital audio synthesis MUSIC-N (now known as Csound), started by Max Mathews at Bell Laboratories in 1957 and decisive in the dissemination of computer music. His seminal article The Digital Computer as a Musical Instrument (Mathews, 1963) is a milestone responsible for attracting various composers to computer music, such as Jean-Claude Risset and John Chowning.

[90] This is why it is now common to include subjects related to music programming in composition courses.

[91] This software will be presented in subchapter 4.6.1.

[92] "Illusory motion of sound in space was a musical goal from the very beginning of my work with computers, a goal that led to a num- ber of perceptual insights that not only set up my discovery of FM synthesis but insights that have enriched my thinking about music ever since.", in the original (Chowning, 2011, p. 1).

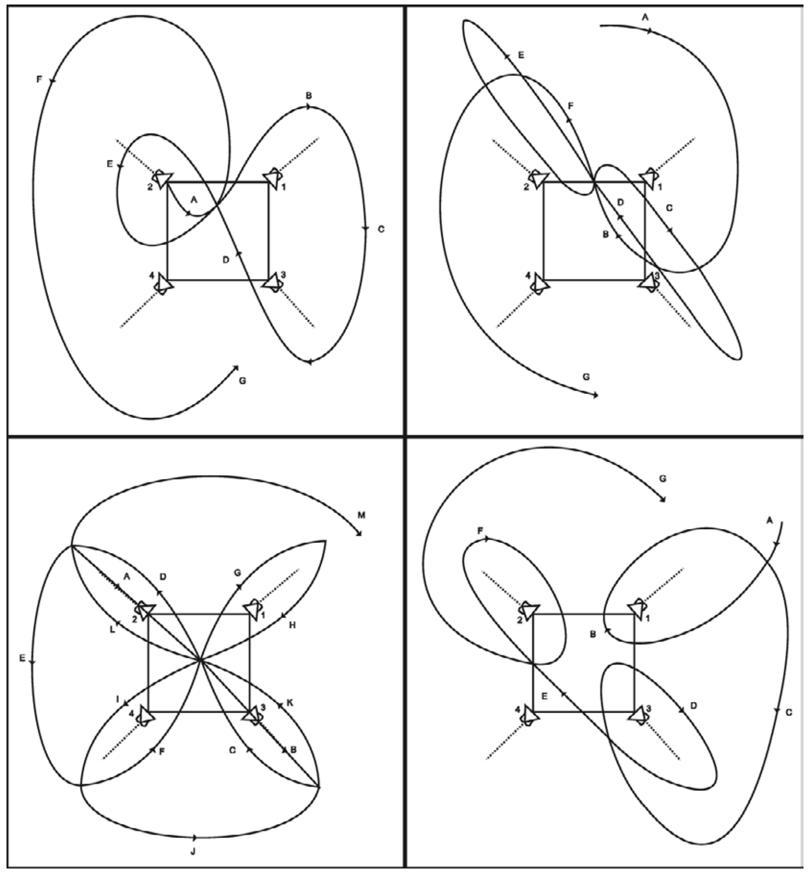

Figure 2.16. Lissajous curves used in the spatial movement of the first minute of John Chowning's Turenas [1972] (Zelli, 2009).

of electroacoustic music. Although it remains his main study on spatialization, Chowning will continue to use elements of this software and spatialization using quadraphony in subsequent works such as Stria [1977] and Phoné [1980-1981].
For few composers will spatialization be such a defining element of their work as for Roger Reynolds, in whose biographical notes the issues of space and multichannel audio generally feature prominently. While early on he worked with spatialization in instrumental music (Gabel, 1985) - as, for example, in the work Threshold [1968] - it was in the 1970s that he began to work with spatialization in electroacoustic music, composing his series of works known as Voicespace [1975-1986][93] . These works use the voice as a primary element, since, given our deep knowledge of "the behavior of the voice - intimate whispers, anger at a distance -", it becomes "an ideal vehicle for auditory spatial illusions"[94].

The first two works in the cycle - Still [1975] and A Merciful Coincidence [1976] - were made using analog means in the studios of the University of Californa, San Diego (UCSD). It was only after visiting John Chowning at Stanford in the late 1970s that Reynolds began to investigate the potential of digital signal processing and computer control in spatialization (Zvonar, 2004). This line of research gave rise not only to the other works in the cycle and other works with spatialization, but also later, in the 1990s,

[93] Still (Voicespace I) [1975], A Merciful Coincidence (Voicespace II) [1976], Eclipse (Voicespace III) [1979], The Palace (Voicespace IV) [1980] and The Vanity of Words (Voicespace V) [1986].

[94] "Since each of us knows so much about the behavior of the voice - intimate endearments, rage at a distance - it is an ideal vehicle for auditory spatial illusions (all the more when in the service of language and its powers of invocation).", in the program notes of the CD Voicespace (1993).

[95] http://cycling74.com/products/max/

to the Toward Real-time Audio Spatialization Tools (TRAnSiT) project, in which other UCSD researchers collaborated (Licata, 2009), such as Miller Puckette, known as the creator of programming environments such as Max[95] and Pure Data[96].
From the tool developed by John Chowning, Reynolds retains the importance of elements relevant to the psychoacoustics of spatial hearing, such as reverberation, atmospheric absorption and the directionality of sound sources. Perhaps more importantly for his own compositional thinking, he also retains a geometric vision of movement in space, achieved by simultaneously manipulating the parameters mentioned according to a path drawn in a space that transcends that circumscribed by the loudspeakers (figure 2.17).

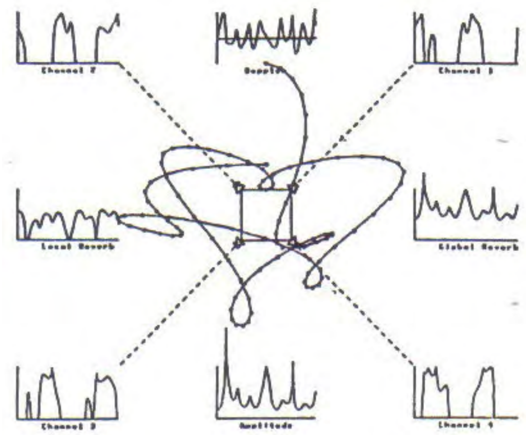

Figure 2.17 - Example of the spatial movement of The Palace (Voicespace IV) [1980], by Roger Reynolds (Gabel, 1985)

It is this geometric vision that informs his urgency to create tools that can serve as models for the exploration of spatialization (R. Reynolds, 1978). While at the end of the 1970s there was already "the equipment and much of the perceptual information" needed to explore the "geometry of sound", there was a lack of an "informed strategy", since there was still no "grammar [...] for the movement of sounds in spaces"[97] (R. Reynolds, 1978). The articulation between the development of a vocabulary for the geometric treatment of space and the development of tools for its realization is therefore a hallmark of Roger Reynolds' work in the following decades.

Part of this work was carried out at IRCAM, where Reynolds arrived in the early 1980s and had the opportunity to accompany the technical developments for Pierre Boulez's Répons [1981-1984]. In Archipelago [1982-1983], Reynolds uses the same spatialization system developed for Répons, but without real-time spatialization and with a three-dimensional loudspeaker configuration: a quadriphonic

[96] http://puredata.info

[97] "The equipment and much of the perceptual information that would allow an orderly examination of the geometry of sound already exists; what is lacking is informed strategy. Moreover, no grammar is on hand, however rudimentary, for the movement of sounds in spaces.", in the original (R. Reynolds, 1978, p. 183).

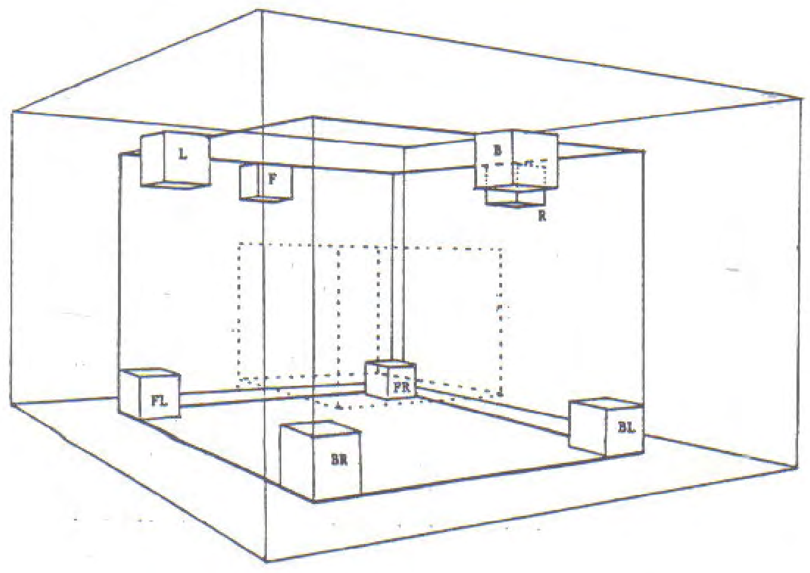

Figure 2.18. Arrangement of the loudspeakers in Archipelago [1982-1983], by Reynolds.
The three boxes represent three distances: near, normal or far (Gabel, 1985).

arrangement on the ceiling and another on the floor, with a rotation of 45° between the two (figure 2.18). This system is joined by a 32-piece chamber orchestra.
The spatialization in Archipelago is centred on sounds that cross space from and to a distant point. The spatialization system is expanded to include real-time control of reverberation, thus allowing the manipulation of the perception of the distance of sounds between three categories: near, normal or far. Figure 2.19 illustrates the movement of a sound that translates into the arrival of a distant sound from above, its fall on the floor in front and its exit through the middle of the back wall. In the composer's words, "the liquid metaphor I have adopted allows the vision of sound as a fluid medium that emanates from a

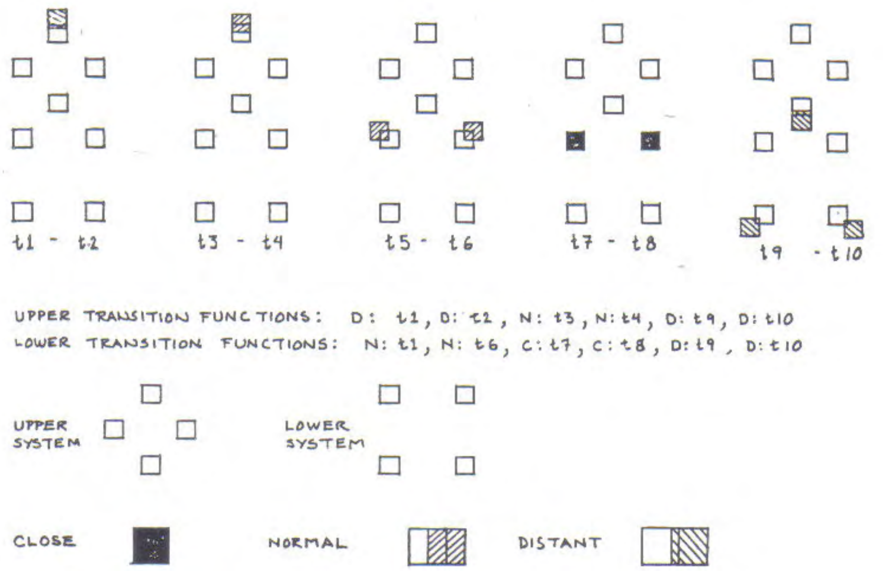

Figure 2.19. Notation of a sound path from Archipelago [1982-1983], by Roger Reynolds. From left to right: the sound appears in distant F; it approaches F; it approaches FL and FR; it is close in FL and FR; it is distant in B, BR and BL (Gabel, 1985).

[98] "The liquid metaphor I adopted allows one to view sound as a fluid medium that can emanate from one point in space, spread out - perhaps surrounding the listener - and then contract again into a different final position.", in the original (Gabel, 1985, p. 13). Indirect quotation since it is a quotation from an unpublished manuscript.

point in space, spreads out - perhaps enveloping the listener - and then contracts again to a different final position."[98] (Reynolds cited by Gabel, 1985).
This method of creating spatial paths allows for the development of a vast vocabulary of spatial gestures which, in turn, can be used to create a counterpoint of intersections in space (Gabel, 1985). Thus, while Archipelago's starting point is close to that of Répons, due to the use of the same system and the common development team, the thinking about movement in space has a clear origin in the geometry of the latter, in contrast to the articulation of space by the surroundings of acoustic sounds in Boulez's work.

Watershed IV [1995], for percussion and real-time spatialization, is a paradigmatic work as it is the first use of real-time spatialization with TRAnSiT. This project was born out of the desire to provide software similar to that developed by John Chowning with the possibility of real-time control introduced by the IRCAM system. At the time, TRAnSiT consisted of a computer capable of controlling an audio address matrix in real time (Zvonar, 2004), mimicking the system developed at IRCAM. In Watershed IV, the various families of percussion instruments are arranged not in the traditional sense (i.e. to make it easier to play) but, on the contrary, to force the instrumentalist to describe movements in space that serve, through their geometry, as a generating and binding element for musical gestures (Licata, 2009). Returning to a form that had already inspired both Stockhausen, in the Osaka pavilion, and Xenakis, in Terretektorh [1965-1966], the spiral is here a central element to the whole work, including the formal division into two large sections, one describing an upward spiral and the other describing a downward spiral, in a relationship defined by the golden ratio[99] (Licata, 2009).

During the performance of Watershed IV, the percussion instruments are picked up by various microphones, whose signals are addressed to loudspeakers around the audience (figure 2.20). This approach allows for a projection of sound into space as an amplification of the instrumentalist's gesture, in an approach that is only not identical to Pierre Schaeffer's pupitre d'espace because it is the very definition of spatial movement that informs the creation of sound morphology and because the mapping of position is not a direct expansion of the performer's gesture. Nevertheless, the benefit for listeners' spatial hearing, achieved by simultaneity with the visualization of the instrumentalist's gesture, is also one of the aims of this approach (Licata, 2009). Real-time spatialization is used on top of this diffusion to create one or more

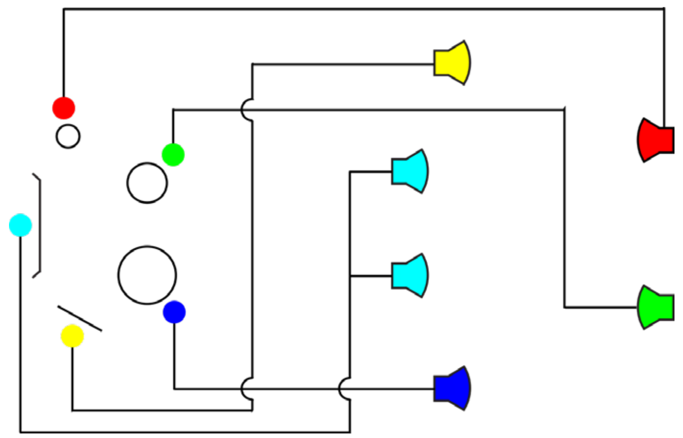

Figure 2.20. Microphone addressing scheme (colored circles) around the circles) around the percussion instruments to the loudspeakers around the audience in Watershed IV [1995], by Roger Reynolds.

[99] Proportion used in art since antiquity, designated by the letter ø, which dictates that the size of two parts a and b should be related in such a way that (a + b) / a = a / b.

layers of spatial counterpoint, using not only the rotation and permutation of address channels, but also the creation of paths that connect the loudspeakers (Licata, 2009).
One of the starting points of auditorium [2012], for an improviser with small percussion instruments and electronics in real time, is also the creation of layers of spatial counterpoint using the rotation and trajectories that connect the loudspeakers, superimposing an external space onto the internal space of the musical gestures recorded live by the performer. In this piece, the performer uses a pair of binaural microphones placed inside his auditory pavilion to, as in in many, many ears [2011], capture musical gestures that are then amplified by a multichannel system arranged around the audience. However, this diffusion happens here in a deferred way: the faint sounds of the instruments are first recorded - while the audience can practically only see the performance - and then diffused through the loudspeakers - at which point the audience only hears the result of the performance. This process, which changes over the course of the piece, reflects the deferred construction of musical gestures and spatial gestures that takes place in many of the works in which space is approached in a geometric way, such as in Karlheinz Stockhausen's Oktophonie [1990-1991] and Cosmic Pulses [2006-2007]. As in these Stockhausen pieces, the final result of the auditorium consists of the simultaneous diffusion of several layers of sound that are articulated and segregated by their different movements in space.

2.3.2 The Vocabulary of Spatial Movement

Trevor Wishart stands out among composers who use the geometry of space for the fact that he "not only includes movement as a primary element in his compositional work, but also attempts to categorize it theoretically"[100] (Zelli, 2009), thus responding to the challenge launched by Roger Reynolds (R. Reynolds, 1978). The beginning of this construction of a musical language for the articulation of space took place, as had happened before with Reynolds and his Voicespace [1975-1986], with the composition of his cycle of six pieces about the human voice: Vox 1 [1980-1982], Vox 2 [1982-1984], Vox 3 [1985-1986], Vox 4 [1987], Vox 5 [1979-1986] and Vox 6 [1988]. Of these, Vox 1 and Vox 5 have an important spatialization component, the former focusing on the use of spatialization as an additional element of articulation and segregation of the musical material. Vox 1 "begins with an indistinct stream of vocal sounds [...] which divides into 2, and then 4, both sonically and [...] spatially, evolving into a counterpoint of detailed articulations of these sounds and the gradual emergence of speech." [101] .

It is to this movement in space as a way of creating variation on the musical material that Wishart devotes the most significant part of the chapter on spatial movement in his book On Sonic Art (Wishart, 1996, pp. 191-235). Assuming a grid of nine positions that a listener in the center of space can distinguish (figure

[100] "Trevor Wishart is perhaps the only composer who not only includes movement as a main element in his compositional work, but also tries to categorize it theoretically.", in the original (Zelli, 2009, p. 7).

[101] "It begins with a seamless stream of vocal sounds, emerging from the tape sounds. This divides into 2, then 4, both sonically and (in the live version) spatially, leading to the counterpointing of detailed articulations of these sounds, and the gradual emergence of speech.", in the program notes for the CD The Vox Cycle (1990).

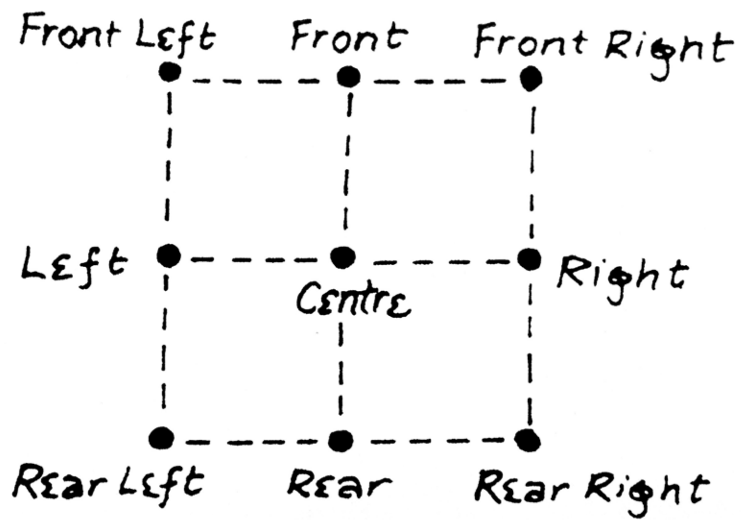

Figure 2.21. Grid with nine distinguishable spatial positions (Wishart, 1996).

2.21), Wishart then begins a thorough qualitative analysis of the types of movements that, because they are easily perceived by listeners, can be used by composers as a way of articulating sound material.
The simplest movements are the direct ones, connecting any of the nine positions to any of the others in a straight line and in a finite period of time. When they pass through the center without stopping and without maintaining the same direction[102], they are, according to Wishart, perceived as arcs. Circular movements are "the first type of movement that is (potentially) cyclical"[103] (Wishart, 1996) and which can be combined with other movements to create different classes of movement. Wishart also distinguishes circular movements from oscillatory movements - i.e. movements that describe a cyclical movement between two points in alternating directions - spiral movements and figure-8 movements. When two types

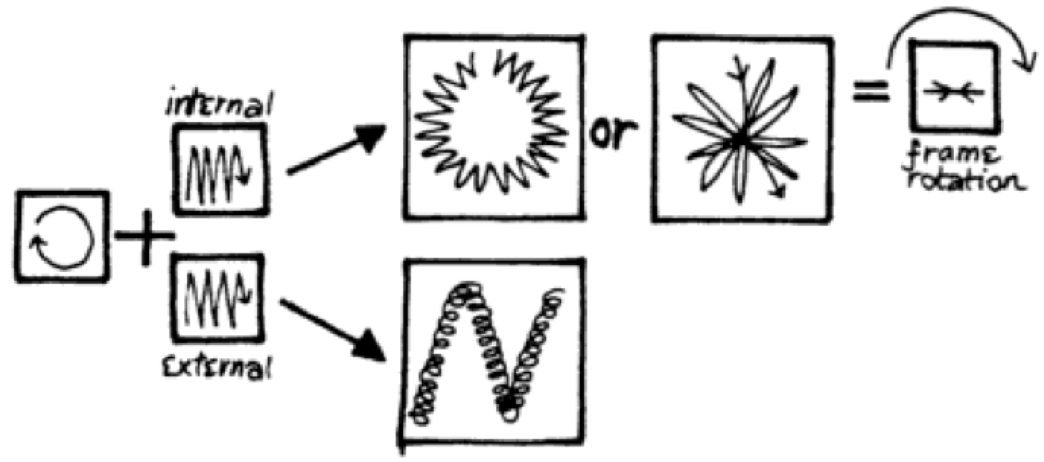

Figure 2.22. Double movements: adding internal or external internal or external to an initial movement (Wishart, 1996).

[102] Linking, e.g., the front left position to the rear left position passing through the center.

[103] "Next we must consider circular motion. This is the first example of a motion type which is (potentially) cyclic.", in the original (Wishart, 1996, p. 206).

of movement are combined, a double movement is generated whose morphology depends on whether the second element is internal or external to the first (figure 2.22).

The perceived quality of the movement depends on its speed: from slow movements that are perceived as mere displacements to fast movements that suggest urgency. Since a movement is a displacement in both space and time, Wishart then turns to the question of time, identifying three types of properties: first-order properties - which concern the different speeds of the movement - second-order properties - which concern the acceleration of the movement - and third-order properties - which concern the changes in acceleration over time. His view of acceleration is particularly interesting, in that he identifies it as responsible for a greater sense of intentionality in movement - in the case of acceleration - or of spatial resolution[104] - in the case of deceleration. The six classes of movement he identifies are: constant (i.e. no acceleration), accelerating, decelerating, accelerating-decelerating, decelerating-accelerating and irregular. These temporal contours allow for the realization of elastic movements (figure 2.23), which Wishart curiously describes dynamically (i.e., taking into account the forces causing the movement), rather than kinematically: "as if the sound object were thrown from its point of origin attached to a rubber band whose tension slows down the movement and then accelerates it back towards the source."[105] (Wishart, 1996). Uniqueness is conferred on the spatial gesture by the temporal contour (i.e. acceleration), since the

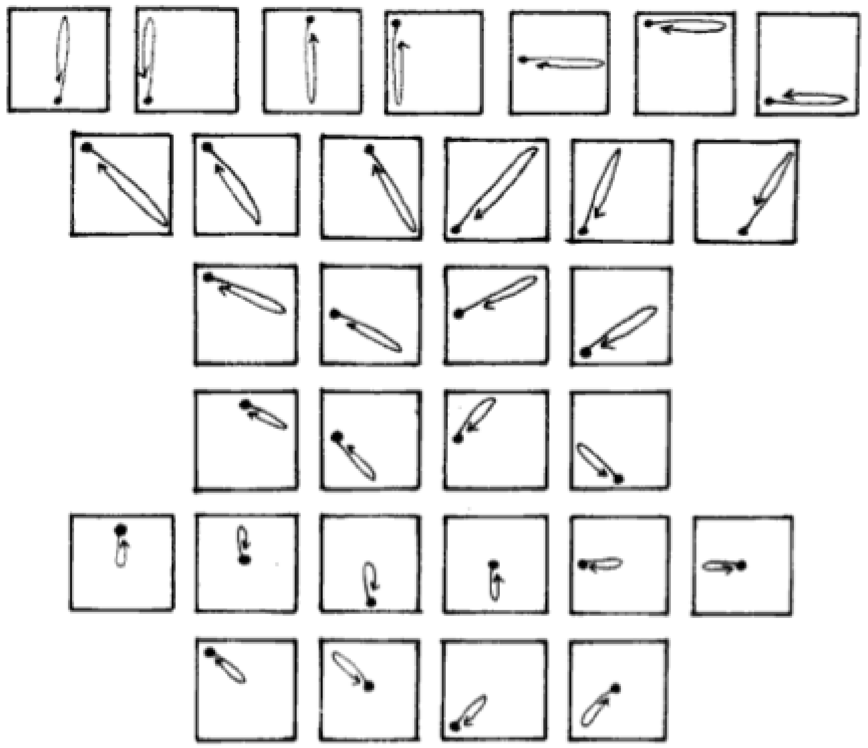

Figure 2.23. Movements with a time contour: elastic (Wishart, 1996).

[104] In the same sense of harmonic resolution, i.e. concluding the previous movement.

[105] "It i as if the sound-object is thrown out from its point of origin on an elastic thread whose tension slows down its motion and then causes it to accelerate back towards the source.", in the original (Wishart, 1996, p. 223).

[106] "Simple constant speed motion along any of these paths would usually break down in our perception into two separate motions, one in the outward and the other in the inward direction.", in the original (Wishart, 1996, p.223).

"simple movement with constant velocity along these paths would be segregated by our perception into two separate movements"[106] (Wishart, 1996), one in each direction.

Finally, the spatial counterpoint arises, as in the work of Roger Reynolds, through the simultaneous articulation of several layers of spatial gestures[107].

2.4 The Definition of Architectural Space

In the context of the relationship between music and architecture, an analysis of the work of Iannis Xenakis is inevitable. A composer, architect by training and Le Corbusier's assistant after World War II, it was in Xenakis' hands that the Parisian architectural firm entrusted the design of the pavilion commissioned by Philips[108] for the Brussels World Exhibition in 1958. In this building, Xenakis explored the geometric function known as the hyperbolic paraboloid, which a few years earlier had inspired him to write the glissandi of Metastaseis [1953-54]. The pavilion is intended to house the Poème Électronique, a vision of a total work of art proposed by Le Corbusier, which starts from the peculiar architecture for the conception of synchronized audiovisual components.

The longest-lasting element of this pioneering multimedia installation is the homonymous musical work commissioned from Edgard Varèse. This Poème Électronique [1958] uses the manipulation of recordings of various percussion instruments, machines, voices and synthesized glissandi as its musical material. It is broadcast through a spatialization system that leads the sounds recorded on a three-channel tape along predefined paths, using around 400 loudspeakers[109] placed in space. These spatialization paths guide

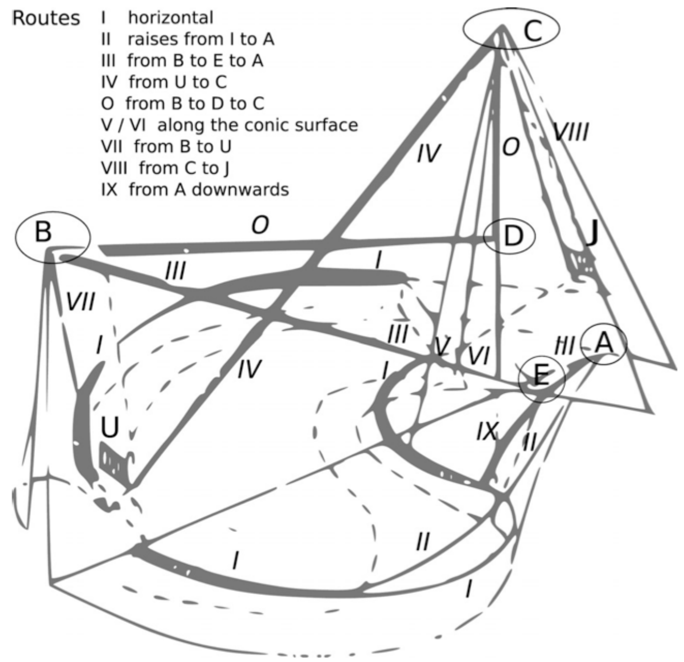

Figure 2.24. Spatialization paths defined by Xenakis for the Philips Pavilion (Valle et al., 2010).

[107] Mario Mary's spatial polyphony is related to this spatial counterpoint and will be presented in subchapter 2.6.1.

[108] A major Dutch manufacturer of lighting and sound equipment, among others.

[109] There are contradictory references in the bibliography, from 350 (Valle et al., 2010) to 425 (Zvonar, 2004).

the path, also pre-defined, taken by visitors inside the pavilion, helping to highlight the space defined by the architecture (figure 2.24).
At the beginning and end of each visit, the work Interlude, by Xenakis himself, known today as Concret PH [1958], is played. Xenakis, in a text published about the Philips Pavilion (Xenakis, 1996), describes the sound points (i.e., loudspeakers as point sources) as being able to define spaces in a geometry of acoustic space, through two different approaches: the one that defines areas in space through the simultaneous diffusion of a sound through several loudspeakers[110] - which he calls static stereophony -, and the one that defines lines in space through the movement of sound between loudspeakers, introducing acoustic velocity and acceleration - which he calls kinematic stereophony. These concepts are a reformulation of the concepts of static and kinematic relief proposed by Pierre Schaeffer. Their relationship with loudspeakers is close to the concept of source space, later defined by Vande Gorne, in the sense that the relationship with the space defined by the loudspeaker is established by the correct location of the real sound source in relation to the listener's referential.

Concret PH is a study of a sound manipulation technique that anticipates what is now known as granular synthesis. It thus uses relatively undifferentiated particles of sound, a sonic matter whose frenetic microscopic level of activity contrasts with the comparative textural staticity of the short work of less than 3 minutes. This technique is a practical application of Dennis Gabor's original ideas (Roads, 2001) and allows the composer to stochastically distribute micro sound elements in both time and space. The relationship between granular synthesis and the occupation of space is as if the sound grains were gas molecules whose movement is circumscribed by the volume of space and, by taking its shape, ends up defining it (Valle, Tazelaar, & Lombardo, 2010). The behavior of gas molecules is something that had already interested Xenakis as a stochastic system used, for example, in the composition Pithoprakta [1955-1956] (Xenakis, 1992).

Xenakis, who would abandon architecture in favour of composition, would continue to explore the creation of works with spatialization: at the same Osaka World Expo where Stockhausen built his pavilion, Xenakis presented Hibiki-Hana-Ma [1969-1970], a work for 12 channels composed at NHK and broadcast through a system of 800 loudspeakers arranged in 250 positions around the audience (J. Harley, 2002). A significant part of his work in the 1970s revolved around the Unité Polyagogique Informatique de CEMAMu (UPIC), a pioneering example of a graphic interface for digital synthesis that he used in composition and music education (J. Harley, 2002). Xenakis will not see the profusion of techniques for spatialization with granular synthesis made possible by the digital implementation of this technique, driven by Curtis Roads (Roads, 2001). Nevertheless, some of these techniques unequivocally reflect the legacy of Xenakis' compositional thinking, such as controlling the position of each sound granule through stochastic systems

[110] Xenakis gives the example of defining a "droite acoustique" (literally, acoustic right) by the diffusion of a sound through all the loudspeakers (emitting points) to the right of a reference.

that mimic the behavior of flocks or swarms (Kim-Boyle, 2005; Davis & Karamanlis, 2007; Wilson, 2008; Mariette, 2009; Schacher, Bisig, & Neukom, 2011).

2.4.1 Aural Architecture

At the end of the 1960s, composer Alvin Lucier highlighted the ways in which a space resonates as a transforming element of musical material in one of his best-known works: I am sitting in a room [1969]. This work consists of a recording of a spoken text inside a room, which is then played back by a loudspeaker inside the same room in several iterations. This process of feedback[111] mediated by time lag is repeated until only the resonances imposed by the modes of the room and articulated by the recorded text remain from the original phrase (Lucier, 2012). Despite the explicit statement, in the text recited in the work, that the composer sees "this activity not so much as a demonstration of a physical fact, but as a way of smoothing out the irregularities that his speech may present"[112], this work ends up becoming a paradigmatic example of the exploration of the timbral particularities of a space through electroacoustic means. Exploratory approaches, either to the phenomenology of auditory perception, or to a given timbral peculiarity, or even to an acoustic phenomenon highlighted through electronic means, will, in fact, be the dominant features of Alvin Lucier's subsequent work.

The use of feedback is also a recurring element in the work of Nicolas Collins, a pupil of Alvin Lucier. It was during his studies with Lucier that he composed Pea Soup [1974, r. 2002-2011], a piece that explores the different feedback frequencies of a system placed in a given space. A circuit - analog in the original version (figure 2.25) and digital in the revised version - alters the delay introduced into the signal depending on the amplitude envelope of the captured signal. This effect is analogous to changing the distance of the microphone from the loudspeaker and stimulates the stabilization of the feedback at a new frequency. A limiter and an equalizer help, respectively, to prevent the signal amplitude from rising too much and to control the system's frequency response. In this way, three feedback channels create "unstable patterns of raw sounds, a space-specific raga that reflects the acoustic personality of the room"[113]. The development

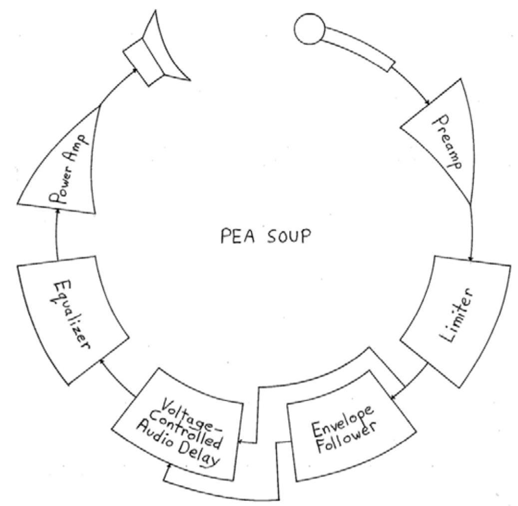

Figure 2.25. Instructions for Pea Soup [1974, r. 2002-2011], by Nicolas Collins.

[111] More commonly referred to as feedback.

[112] "I regard this activity not so much as a demonstration of a physical fact, but more as a way to smooth out any irregularities my speech might have", text recited by Alvin Lucien in I am sitting in a room [1969].

[113] "The familiar shriek is replaced with unstable patterns of hollow tones, a site-specific raga reflecting the acoustical personality of the room.", in the program notes for Pea Soup [1974, r. 2002-2011].

of the piece, presented both in installation mode and in concert format, is influenced by the movement of people in the room or by the use of musical instruments and other sounds to stimulate responses at certain frequencies. The feedback proposed by Lucier is thus transformed into a performative element.
This performative element of feedback is also explored in Bird and Person Dyning [1975], again by Alvin Lucier. For the performance of this piece, Lucier places an electronic generator that imitates the chirping of a bird in a given acoustic space. He then walks slowly through the space with a pair of binaural microphones placed in his ears, which are in turn amplified by two loudspeakers, creating feedback. As it moves through the space, the stabilization frequency of the feedback is altered and interacts with the sounds of the electronic chirping, producing beats, in a process analogous to that of a heterodyne[114], which is why the title of the piece is spelled dyning[115]. Since it is up to the composer, in this case also as a performer, to choose between immobility and different types of movement, and since the resulting sound is directly dependent on the way he or she directs his or her hearing, Bird and Person Dyning is a work in which the audience hears the result from the performer's point of view. This perspective is identical to the one created, also by placing binaural microphones in the performer's ears, in many, many ears [2011] and, above all, in auditorium [2012]. A section of the latter piece is even filled with the real-time creation of morphologies on feedback, directly inspired by Bird and Person Dyning.

Aural architecture, as defined by Blesser & Salter (2007), refers to the recognition of the morphology of space through its acoustic response, including elements relevant to the ability to navigate within it. Although it has a strong relationship with acoustics, aural architecture does not refer to the acoustic properties of the space per se, but to the potential they present to the listeners' perception of the space. It thus encompasses cultural, social and cognitive elements: psychoacoustics and "cultural acoustics"[116] (Blesser & Salter, 2007). The aural architect is therefore the one who identifies, designs or highlights certain acoustic characteristics of the space with a specific objective of perception by a listener. In this sense, I am sitting in a Room and Bird and Person Dyning are just two of several works by Alvin Lucier that can be analyzed as seminal examples of aural architecture. These range from works composed in the 1960s - such as Vespers [1968], in which the performer-listeners are invited to navigate the space[117] using echolocation devices - to more recent works - such as Ever Present [2002], in which two oscillators produce sine waves in constant slow glissandi while three instrumentalists (flute, alto saxophone and piano) sustain sounds that interact with the previous ones.

The impact of the publication of Spaces Speak, Are You Listening? (Blesser & Salter, 2007) and the transdisciplinary concept it proposes can be measured by the growing number of works that inform his approach to space from the perspective of aural architecture[118] . The installation Liquid Sonorities [2007], contemporary with the first edition of the book, is part of the same type of approach and can be analyzed as an example of aural architecture. As in I am sitting in a Room and Pea Soup, the modes of the space in which it was installed (the East Foyer of Casa da Música, in Porto) define the entire harmonic field of the installation. However, unlike in these works, the acoustics of the space are not treated here as an objet trouvé which - either as a filter or revealed by feedback phenomena - alters the harmonic field of the work at each performance. Rather, the acoustic response of the space to a stimulus diffused by the electroacoustic system set up was studied in the initial phase of the composition process, and a harmonic progression was then conceived within its resonances as a starting point for the composition. This installation is then specific to this space and its particular harmony, rather than being revealed by the compositional process, is at the origin of the compositional thinking.

2.4.2 Dynamics in Spatialization

Around the same time that Lucier composed I am sitting in a room [1969], Austrian architect Bernhard Leitner began a series of exploratory approaches to defining space through sound. "Sound architecture", as he defines it, consists of "creating spaces through the movement of sound"[119] (Leitner, 1998). Feeling that the relationship between sound and space had hitherto been neglected in architecture, his approach is voluntarily distinct from music and the approach to musical space. Rather, he explores sound as a building material, treating the "intensity of sound like the intensity of light"[120] (Leitner, 1998). The body of installations born from his initial work is thus based on defining spaces through lines created by the reproduction of sound in movement by a series of loudspeaker points. These sound lines define an architectural space that takes on the characteristics of sound itself: speed, intensity, rhythm or repetition. Leitner also explores the creation of situations in which space momentarily disappears and reappears, with both similar and different geometries. While in Lucier's work, the presence of sound in space highlights the acoustic properties of the latter and uses them to build a form on the former, in Leitner's work space is neutral or non-existent until the placement of sound gives it a form. Reminiscences of Xenakis' kinematic stereophony can be identified in the paths designed by Leitner, creating, for example, curvilinear paths traversed by virtual sound sources within rectangular prisms defined by the configuration of the real sound sources (i.e. the loudspeakers) (figure 2.26).
Leitner's work also explores acoustic phenomena and, above all, their effects on the perception of space, balance and orientation. In some works, such as the long series of Ton-Liege sound chairs [1975-1991][121]

[114] "adjustable high-frequency oscillator which, incorporated into a receiver, makes it possible to obtain an oscillation of audible frequency beats", at http://www.infopedia.pt/lingua-portuguesa/heteródino.

[115] From the English heterodyning.

[116] "[...] cultural acoustics [...]", in the original (Blesser & Salter, 2007, p. 5).

[117] Navigating "the" space, since the aim is to understand space through navigation and not movement per se.

[118] Such as, for example, the proposals by David Letellier - e.g., Tessel [2010] and Versus [2011] - and Filipe Lopes - e.g., Numa Sala com Cortiça e Som [2012] and Vexations [2012], about Erik Satie's homonymous work.

[119] "Sound Architecture: Space created through traveling sound", in the original (Leitner, 1998, p. 38).

[120] "Sound intensity like light intensity", in the original (Leitner, 1998, p. 23).

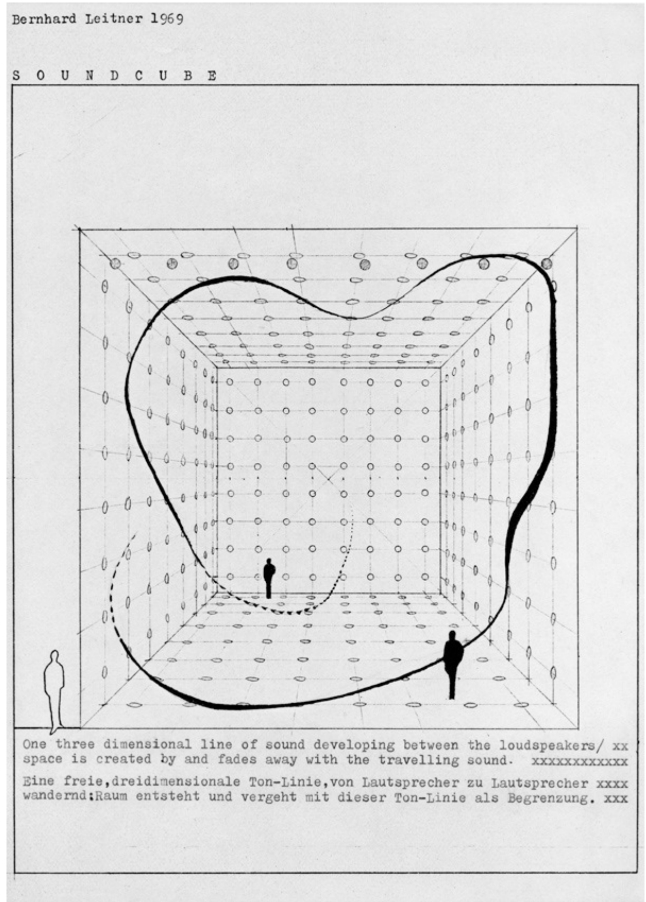

Figure 2.26. One of the sound paths in Soundcube [1969], by Bernhard Leitner (2008).

, the physiological reactions of users are even the subject of research at the Department of Clinical Neurophysiology at the University of Bonn in West Germany (Leitner, 1998), revealing the ability to induce relaxation close to that of the first two stages of sleep. Despite the voluntary distance from the world of musical composition, the sound material used in the installations largely comes from traditional musical instruments, such as the trombone sounds in Kneten I [1980], cello and horn sounds in Ton-Liege II [1976] or the martellato cello in Pendel-Liege II [1995]. Sometimes he also uses relationships described through their musical meaning, such as the one he establishes between anacruse and forte tempo in the articulation between different points in space in various works from the 1970s (Leitner, 1998).

One of the ideas that Leitner explores over a number of years is the definition of space by the movement of pendulums, which begins with a series he calls Raum-Wiege [1975-1980][122] (figure 2.27) and which is continued in the Pendel-Liege series [1992-1995][123]. The manipulation of the amplitude of the sounds is pre-programmed manually in order to impose an external morphology on the pre-recorded sound material (figure 2.28). The visitor's familiarity with the type of movement allows for a sense of continuity and balance, despite the cyclical suspension of sound on either side of the pendulum movement (Leitner, 1998). The spatial gesture - simultaneously defining the sound gesture and defined by its filling with sound

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[121] Literally, Sound-Divan.

[122] Literally, Space-Berth.

[123] Literally, Pendulum-Divan.

- together with its sculptural placement, thus summon up the representation of gravity and pendulum movement present in the listener's cognition, enveloping them within the spaceberth.

Figure 2.27. Grosse Raum-Wiege [1980], by Bernhard Leitner (1998).

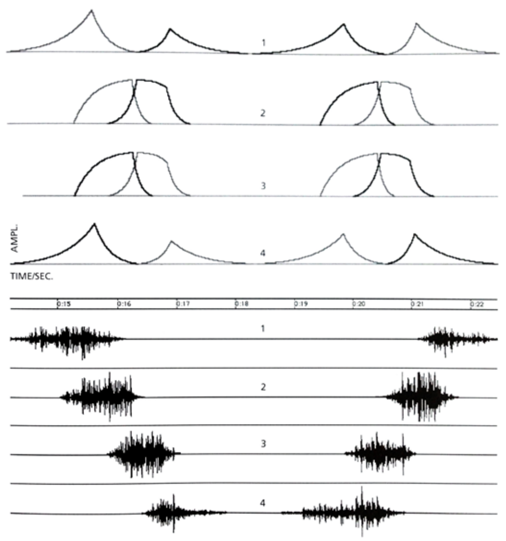

Figure 2.28. Audio envelopes from Pendel-Liege II [1995], by Bernhard Leitner (1998).

A year before I am sitting in a room [1969], by Alvin Lucier, and Soundcube [1969], by Berhnard Leitner, Steve Reich composed Pendulum Music [1968], a procedural piece in which some microphones are suspended over loudspeakers and dropped some distance away in order to describe pendulum movements over them. When they get close to the speakers, the microphones engage in feedback, which is attenuated when they move away. Over time, and as a result of friction, the pendulum movement of the microphones tends to stop. The feedback then becomes constant and the piece ends with the amplifiers unplugging. In this piece, which shares the use of feedback with I am sitting in a room and the pendulum movement with Raum-Wiege, the morphology of the sound gesture is defined by a dynamic process and, although there is no movement of sound in space, it is the visible spatial gesture that shapes the sound gesture. If the loudspeakers were oscillating over the microphones, the visual spatial gesture would correspond to a sonic spatial gesture, as in Speaker Swinging [1982], by Canadian composer Gordon Monahan. In this work, three performers rotate a pair consisting of a loudspeaker and a light bulb around their heads (figure 2.29), causing a projection in space that transforms the concept of the rotating loudspeaker, previously used by Stockhausen, into a performative element.

Figure 2.29. Performance of Speaker Swinging [1982], by Gordan Monahan. Photo by Dwight Siegner.

In the piece Pendulum [2012], by Rui Penha (co-author of this report), for flute, bass clarinet, piano, violin, cello, video and real-time electronics, the co-generation of spatial gesture, both visual and auditory, and the morphology of musical gesture are explored through dynamic movements. Physical models, in a digital environment, of simple pendulums, wave pendulums, gravitational systems with many bodies and elastic systems are used to generate a video that is projected during the performance. This video is controlled in real time by the pianist and the movements it conveys in turn control both the spatialization and morphology of the musical gestures.

2.5 Resonance in Space

David Tudor is known above all for his role as a pianist, having, in the post-World War II period, premiered and promoted works by composers such as Karlheinz Stockhausen, Pierre Boulez, Morton Feldman and John Cage. The collaboration with the latter was especially fruitful, being recognized by Cage as fundamental (Cage, 1991) and identifiable as an influence on Tudor's subsequent work as a composer. The series of works entitled Rainforest, from the first Rainforest I [1968] to the more widespread Rainforest IV [1973], is certainly the most recognized of his compositions and reveals the influence of works such as Cartridge Music [1960], by Cage[124]. It is the result of various experiments on an idea that he himself describes as the "dream-vision of an orchestra of loudspeakers, in which each loudspeaker is as unique as a musical instrument"[125] (Tudor quoted by Driscoll & Rogalsky, 2004). Tudor put this idea into practice using contact transducers[126] attached to various objects which, by vibrating, imprint their sonic signature on the sound being broadcast. Several versions were made, with Rainforest IV being the name chosen by Tudor for a version that took the form of a sound installation, made in conjunction with the group Composers Inside Electronics[127], formed for the occasion by John Driscoll, Phil Edelstein, Linda Fisher, Martin Kalve, Greg Kramer, Susan Palmer, Bill Viola and David Tudor himself (Driscoll & Rogalsky, 2004). In this fourth version, synthesized sounds and magnetic tape recordings are broadcast through 16 to 40 sound sculptures, built by the members of the group following Tudor's instructions (figure 2.30). Each of these sculptures is based on an object - a resonant element - to which a contact transducer is attached to reproduce the sounds and a contact microphone to amplify their resonant frequencies (Collins, 2006). They are then suspended in the space where visitors are invited to circulate and can touch the sculptures to feel their vibration, thus interfering with their acoustic behavior.

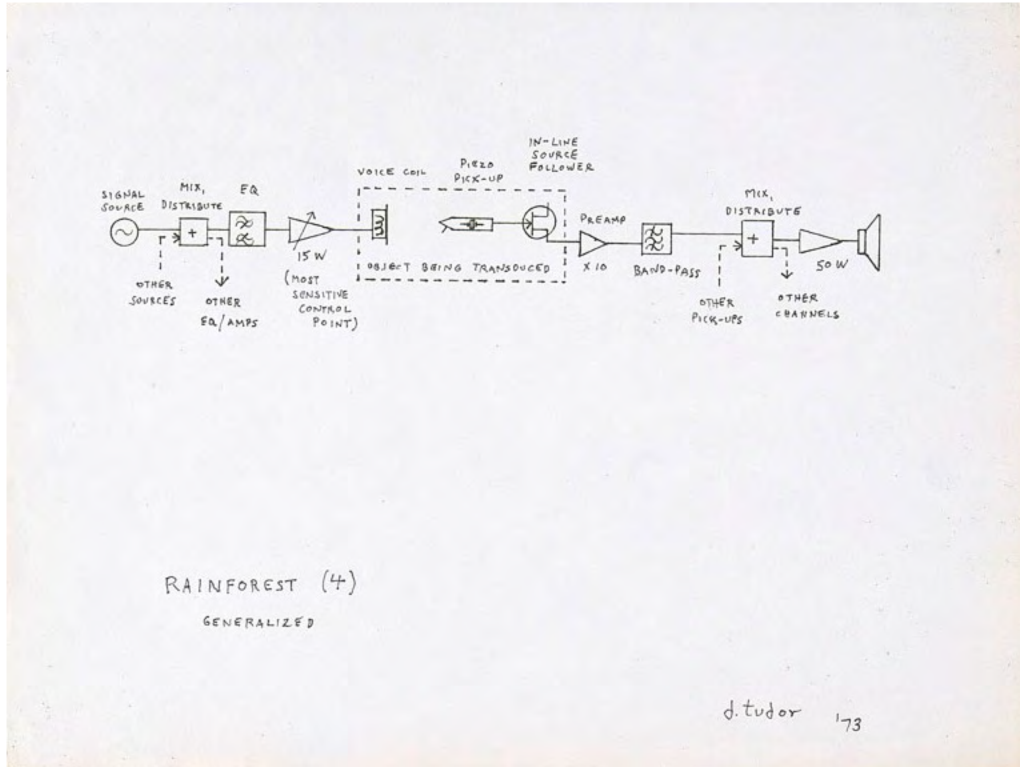

Figure 2.30. Instructions for Rainforest IV [1973], by David Tudor.

If the idea of an orchestra of idiomatic loudspeakers is similar to the concept of the contemporary Acousmonium, the exploration of the resonances of objects by feeding external sounds and feedback brings Rainforest IV closer to the work, also contemporary, of Alvin Lucier and Nicolas Collins. In the case of Lucier and Collins' works, the dominant element is the response of the idiomatic acoustics of each room to the electroacoustic system set up. In the case of Tudor's work, it is the way the sound is placed in the space that is highlighted. Unlike timbral diversity as an interpretative element of acousmatic diffusion, in Rainforest IV the timbral differences between the loudspeakers are themselves the genesis of musical thought. New versions of Rainforest IV are currently being put into practice by the Composers Inside

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[124] A pioneering work in live electronics, which used as a sound source a series of objects (e.g. sticks and feathers) introduced into the needle hole of a record player head, together with other elements amplified using contact microphones. In this way, an unusual perspective on acoustic sounds was revealed through amplification.

[125] "dream-vision of an orchestra of loudspeakers, each speaker being as unique as any musical instrument", in the original (Tudor quoted by Driscoll & Rogalsky, 2004). Indirect quotation, as the online reference of the interview is not available.

[126] I.e., loudspeakers without a cone, capable of vibrating the objects to which they are attached, like those used to vibrate the percussion instruments in Music for Solo Performer [1965], by Alvin Lucier. For an example of this type of loudspeaker, see Collins (2006, pp. 41-46).

[127] http://composers-inside-electronics.net/cie/cie/cie_home.html

Electronics group (Driscoll & Rogalsky, 2004), making it a rare case of longevity in the world of sound installations. The members of the group themselves, with an emphasis on John Driscoll, continue the line of work launched by Tudor, developing, for example, loudspeakers designed to focus the sound diffused at a specific point in space and robotic loudspeakers capable of altering their directional diffusion.[128]

The concept of a prosthetic instrument[129] , developed by Portuguese composer Pedro Rebelo, is based on the ideas behind the conception of Rainforest IV, applying them to traditional acoustic instruments. This type of instrument uses human prostheses as "metaphors for the relationship between natural and artificial parts of an organism"[130] (Vriezenga & Rebelo, 2011), applying them to the installation of electroacoustic means capable of intervening in the behavior of acoustic instruments such as a conga (Walstijn & Rebelo, 2005) or a mbira (Vriezenga & Rebelo, 2011). The intervention on the prosthetic conga used in Music for Prosthetic Congas [2004] consists of placing a loudspeaker in the lower opening and a contact microphone on the underside of the membrane, both connected to a computer capable of processing and synthesizing audio signals (figure 2.31). The circuit thus obtained is used not as an idiomatic loudspeaker, as was the case in Rainforest IV, but as a way of making it possible to manipulate the acoustic properties of the conga, which is played by the performer in the traditional way (Walstijn & Rebelo, 2005). The performer is forced to continually adjust the way they play, adapting to an interactive instrument that can react in an expanded way - e.g. by extending the instrument's natural resonance - or even with a different behavior than normal - e.g. by suppressing natural resonances. The careful integration of the electronic components and the design of the processing contribute to the ambiguity in the perception of what is natural and what is prosthetic, a central element of the metaphor explored.
In Shadow Quartet [2007], for string quartet and electronics, Pedro Rebelo once again explores the concept of a prosthetic instrument, but this time without the instrument played by the performers coinciding

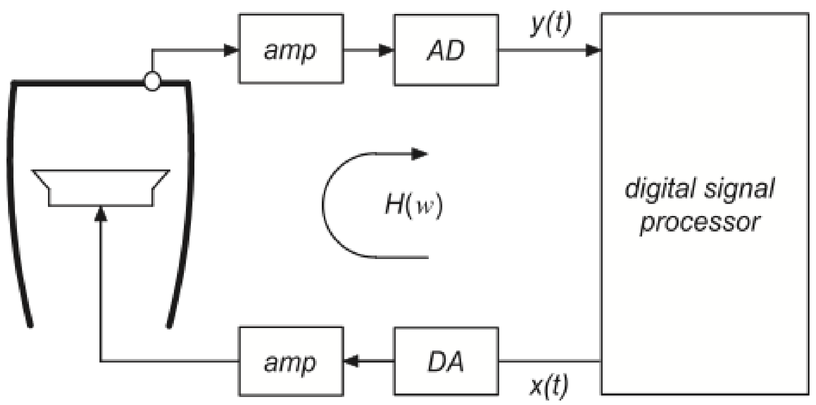

Figure 2.31. Model and signal flow of the prosthetic conga used in Music for Prosthetic Congas [2004], by Pedro Rebelo (Walstijn & Rebelo, 2005)

[128] http://composers-inside-electronics.net/jdriscoll/home/BIO.html

[129] "prosthetic instrument", in the original.

[130] "The use of prosthesis in the human body provides us with potent metaphors for the relationship between natural and artificial parts of an organism.", in the original (Vriezenga & Rebelo, 2011, p. 697).

with the one used as a prosthesis. In Shadow Quartet, the resonant behavior of four violins is analyzed and serves as the basis for the tuning of the quartet's instruments and for the harmonic structures explored in the piece. In concert, the four violins are suspended above the musicians (figure 2.32) and used, through the placement of contact transducers, as idiomatic loudspeakers for the diffusion of the electroacoustic component of the piece. The prosthetic relationship between the quartet's instruments and the suspended violins goes, in this case, from "ambiguity to contradiction, both extending and reacting against the material played by the quartet"[131].

Figure 2.32. Smith Quartet at the premiere of Shadow Quartet [2007], by Pedro Rebelo. The resonant violins, used to diffuse the electroacoustic sounds, are visible suspended above the musicians. suspended above the musicians.
Photo by Miso Music Portugal.

The omnidirectional diffusion of most traditional acoustic instruments contrasts with the unidirectional diffusion of common loudspeakers[132] . Due to the characteristics of their construction, which are often intentional, acoustic instruments such as the violin or piano emanate sound in multiple directions, each with its own specific spectral behavior (Henrique, 2002), which becomes particularly relevant when capturing them for recording. Similarly, the interaction of Rainforest IV and Shadow Quartet's idiomatic loudspeakers with space is substantially different from that of loudspeaker diffusion, being closer to that of traditional instruments.

The piece eCaro [2011], by Rui Penha (co-author of this Report), for two improvisers, explores the fusion between the acoustic sounds of a piano (including expanded techniques) and various sources of electronic sounds by superimposing their means of placement in space. In this piece, the electronic media are amplified by contact transducers coupled to a traditional acoustic instrument, as in Shadow Quartet. However, unlike in Pedro Rebelo's work, these transducers are placed in the body of the same instrument that is used as a source of acoustic sounds thanks to the size of the piano and the possibility of placing the contact transducers in a hidden and innocuous way on the soundboard by the action of gravity

[131] "The relation between the quartet and the four prosthetic violins ranges from ambiguity to contradiction by both extending and reacting against the material played by the quartet.", in the program notes for Shadow Quartet [2007].

[132] Instruments such as the trumpet are exceptions, as they have a comparatively unidirectional behavior presented by the loudspeakers.

alone. All the means necessary for the performance are also placed inside the piano, seeking to maximize its perception as a prosthetic instrument and eliminate the need for an off-stage sound technician. An interdependence is thus created between the various sound production techniques, using, for example, traditional acoustic means such as mufflers to manipulate the surroundings of electronic sounds.

2.5.1 Multidirectional speakers

The different ways in which acoustic and electroacoustic sources interact with space contribute to the recurrence of fusion problems between these two types of sound sources in mixed works[133] . A common way of solving these problems is to amplify the acoustic instruments through the same loudspeakers used to broadcast the electroacoustic part. This solution can, however, contradict "the acoustic qualities of the performance spaces and make it difficult to locate the acoustic sources"[134] (Trueman, Bahn, & Cook, 2000), without contributing positively to the performers' perspective on the balance between the different sound sources, as naturally happens in chamber groups made up exclusively of acoustic instruments.

In 1997, Dan Trueman, dissatisfied with the solutions for amplifying his electric violin, and Perry Cook began building spherical and hemispherical[135] speakers and using them to broadcast electroacoustic sounds (Smallwood, Cook, Trueman, & McIntyre, 2009). In parallel, they developed the NBody project (Cook & Trueman, 1998), with the aim of studying the radiation patterns of string instruments for application, e.g., in synthesis by physical modeling. After building a series of speakers and instruments such as the Bowed-Sensor-Speaker-Array (BoSSA) (Trueman & Cook, 1999), these experiments culminated in 2005 with the construction of the set of hemispherical speakers for the Princeton Laptop Orchestra (PLOrk) (Trueman, Cook, Smallwood, & Wang, 2006).

In this laptop orchestra, each participant has their own meta-instrument, consisting of a laptop, audio interface, amplifiers and a hemispherical speaker with six autonomously addressable loudspeakers, as well as any interfaces for musical expression. PLOrk is responsible for establishing the laptop orchestra paradigm as a research laboratory (Trueman, 2007), a model for composing chamber repertoire in electroacoustic music (Smallwood, Trueman, Cook, & Wang, 2008) and a medium for teaching (G. Wang, Trueman, Smallwood, & Cook, 2008). Its implementation is quickly replicated, notably by the Stanford Laptop Orchestra (SLOrk) (G.Wang, Bryan, Oh, & Hamilton, 2009), founded in 2008 by Ge Wang, himself one of the founding members of PLOrk. Unlike PLOrk, whose passive hemispherical speaker model is the subject of commercial distribution, SLOrk's initial emphasis is on building an active (i.e. self-amplified) hemispherical speaker from materials that are easy to find in various locations around the world (figure 2.33). The outer structure, for example, is a wooden salad bowl from the almost ubiquitous IKEA furniture store[136] . Its construction process is documented in detail on the website[137] and in the presentation article (G. Wang et al., 2009), which helps turn these speakers - which eventually become the hallmark of SLOrk - into tools that are easy to replicate by other musicians and research and teaching institutions.

Figure 2.33. Replica, built for a work with the long title*[2009], of the hemispherical column developed for SLOrk.

Diffusion from hemispherical speakers raises a series of new questions for spatialization in electroacoustic music. If there is a micro-spatialization in the distribution of sounds across the six individually addressable loudspeakers that make it up, this is not perceived by the audience in the traditional way. A rotating movement through the lower coplanar loudspeakers, for example, has, from the point of view of the distant listener, implications only for the way in which the diffusion relates to space and not for the perception of spatial movement. The relationship with acoustic instruments, one of the main motivations for designing these speakers, is also strengthened by replicating their natural mode of diffusion. These are the issues explored in a work with the long title* [2009], by Rui Penha (co-author of this Report), which uses a replica of SLOrk's multidirectional hemispherical column. In this work for alto flute, clarinet, vibraphone, piano and pre-recorded electroacoustic part, the harmony and metric parameters are designed to create a continuous, tight and homogeneous counterpoint. The various voices of this counterpoint circulate through the instruments arranged around the hemispherical column, thus making it the agglutinating axis around which the voices move continuously. The micro-spatialization of the hemispherical column is further translated into the instruments around it, which articulate the attack transients of the sound morphology it spreads, expanding it to the scale corresponding to the area occupied by the instruments on stage.

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[133] I.e., for acoustic instruments and electroacoustic media.

[134] "While good for many applications, this approach usually has the effect of negating the natural acoustic qualities of performance spaces and can make it difficult to localize the acoustic sources", in the original (Trueman, Bahn, & Cook, 2000, p. 1).

[135] The word column is used here instead of loudspeaker, as these multidirectional speakers have several individually addressable loudspeakers.

[136] http://www.ikea.com/pt/pt/

[137] http://slork.stanford.edu

2.6 Conclusion

The various approaches to spatialization in electroacoustic music have different implications for the way in which spatial gestures are interconnected with musical gestures. The preponderance can be given to the musical gesture - as in the tradition that emerges from the diffusion of acousmatic music - or to the spatial gesture - as in Stockhausen and Reynolds' geometry of space. However, the perception of the intention - i.e. the meaning of the gesture - depends in either case on the analysis of the whole.

The term spatialization is used very broadly to designate various musical approaches to space and, if we exclude the term diffusion[138], there is no clear and consistently used nomenclature to designate the different approaches to spatialization in electroacoustic music. The numerous proposals for terminology associated with space in music are often the result of the idiosyncratic approaches of their proponents and, as such, difficult to generalize to other applications[139]. The reflection informed by reading the examples described above is the basis for proposing a taxonomy of spatialization, taking spatialization to mean the placement of sound in space in an intentional and meaningful way, which does not imply the existence of movement.

Although soundscapes[140] already existed before they were named by R. Murray Schafer (1994), it is clear to see the impact that this conceptualization has had on subsequent work in both acoustic ecology and musical composition. His concern, however, was not to detail small boundaries: in fact, he states that "we can speak of musical composition as a soundscape, or of a radio program as a soundscape, or of an acoustic environment as a soundscape"[141] (Schafer, 1994). A soundscape, then, is more than just a pre-existing landscape: it is a perspective, an attitude towards sound which, firmly based on active listening, establishes a point of view for its analysis. Similarly, this taxonomy of spatialization is not intended to be an exhaustive cataloguing of spaces per se, whether those imagined by composers (Dhomont, 1988; 1991; D. Smalley, 1997; Gorne, 2011), those revealed by interpretation (Gorne, 2002) or those perceived by the listener (D. Smalley, 1997; Merlier, 2006; D. Smalley, 2007). Rather, it seeks to distinguish the different perspectives of composers in their approaches to spatialization, starting from the existence or non-existence of a spatial gesture and, in the first case, its relationship with the musical gesture. Although it is naturally the result of an individual perspective - its primary function is to serve as the basis for the creation of the tools for spatialization and the composition of the works that accompany this document - it seeks to be generalizable because it is based on the analysis of a wide range of perspectives from more than half a century of spatialization in electroacoustic music.

2.6.1 Taxonomy of Spatialization in Electroacoustic Music

Taking as a starting point the designations of static stereophony and kinematic stereophony proposed by Iannis Xenakis[142] , we can begin by defining static spatialization and kinematic spatialization. Static spatialization refers to the meaningful placement of sounds in space without spatial gesture (i.e. without movement), which can be achieved by manipulating the characteristics of real or virtual sound sources. If works like I am sitting in a room [1969], by Alvin Lucier, or Rainforest IV [1973], by David Tudor, don't have spatialization in the sense of movement of sound in space, their conception depends largely on their mode of diffusion and the placement of sound in space. The use of electroacoustic means of placing sound in space as a fundamental element in the construction of musical thought is explicit in both, as in other works previously presented. The multidirectional speakers of the PLOrk and SLOrk groups are also designed with the aim of making possible a particular mode of interaction between the loudspeaker and the broadcasting space and not to benefit the reproduction of spatial gestures external to the space they define.

There are three works which, in the context of this work, explore static spatialization: Sonoridades Líquidas [2007] starts from the resonance modes of a space to generate the harmonic material on which the composition is based; obra com título longo* [2009] explores the mode of diffusion and micro-spatialization with a hemispherical column in interaction with acoustic instruments; eCaro [2011] explores the concept of a prosthetic instrument as a way of promoting both the acoustic fusion of different materials and the integration of the roles of composer, instrument builder and sound technician in the figure of the performer.

We can find a common element in Stockhausen's Musik im Raum, Xenakis' spatialization paths, Chowning's Lissajous figures, Reynolds' spatial movement vocabularies and Wishart's cataloguing of movements: these are geometric approaches to space that make the spatial gesture autonomous from the musical gesture. Kinematic spatialization thus refers to the placement of sounds in space by generating spatial gestures from the geometry of their movement. The spatial gestures generated through kinematic spatialization can

[138] And its associated term projection.

[139] In his thesis Space in Musical Semiosis, Juha Ojala (2009) presents, with inevitable humor, a survey of the numerous terminologies for musical space: "In addition to the complexity of the term 'musical space' alone, we are faced with an abundance of terms such as acoustic space (e.g. Schafer 1991; Tohyama, Suzuki and Ando 1995), auditory space (Blauert 1983/1974), composed space (Smalley 1991), compositional space (Morris 1995), conceptual musical space (McDermott 1972), diffused space (Smalley 1991), external space (Smalley 1997), feature space (Toiviainen, Kaipainen and Louhivuori 1995), headspace (Smalley 1991), implied space (Emmerson 1998), informational space (Drew 1968), information-sound space (Barrass 1996), instrumental space (Emmerson 1998), internal space (Smalley 1997), listening space (Smalley 1991), literal space (Emmerson 1998), logical space (Morgan 1980), metaphorical space (Emmerson 1998), methodological space (Morton 2005), multidimensional music space (Juhász 2000), notational space (Morgan 1980), parameter space (Feiten and Behles 1994), personal space (Smalley 1991), real space (Emmerson 1998), solution-space (Di Scipio 1995a), sound space (Barrass 1996), sonic space (Wishart 1996; Emmerson 1998), spectral space (Smalley 1986), state space (Goguen 2004), superimposed space (Smalley 1991), virtual acoustic space (Wishart 1996) and so on. The confusion is augmented when many terms refer to the same concept (e.g. natural, physical, empirical, external, extrinsic, acoustic, and sound space all referring to the actual space). On other occasions a single term may be used for altogether different concepts (musical space). Furthermore, the list could be continued with space terms pertaining to musical parameters such as pitch space (Lerdahl 1988, 2001), timbre space (Wessel 1979; Grey 1977), melody space (Todd 1992), rhythm space (Desain and Honing 2003), and with other space-related terms such as dimension, axis or distance. Finally, the terms of musical spatiality do not necessarily translate directly from one language to another. It seems that, in so far as words express thoughts, music as a thought process is saturated with spatiality." (Ojala, 2009, pp. 345-346).

[140] A term commonly used in English and which can be translated as soundscapes.

[141] "We may speak of a musical composition as a soundscape, or a radio program as a soundscape or an acoustic environment as a soundscape.", in the original (Schafer, 1994, p. 7), a text originally published in 1977.

[142] Which, as mentioned above, are related to the concepts of static relief and kinematic relief proposed by Pierre Schaeffer.

be imposed on musical gestures - in a parallel, competing or disruptive way - or themselves articulators of musical gestures, when their temporal morphology becomes dominant.

There is a clear distinction between this kinematic spatialization and the use of spatialization as a way of emphasizing, ornamenting or highlighting musical gestures. In the case of diffusion, this action on movement is itself the result of an intentional and expressive manipulation of an interface for spatialization with the aim of interpreting pre-existing musical gestures in space.
The very concept of interpretation summons up the idea of decoding and conveying a preexisting message, which, in the absence of a score for diffusion, means decoding the musical gesture in order to convey it through the spatial gesture. Even in the works of this tradition that progressively distance themselves from diffusion as interpretation in favour of spatialization in the studio, thinking about movement is focused on the articulation of a morphology that develops in parallel in spectral space (i.e. spectromorphology) and physical space (i.e. spatial morphology). Gestural spatialization thus refers to the placement of sounds in space using spatial gestures designed to emphasize, embellish or highlight the morphology of musical gestures.

The dominant approach in the interfaces of software tools for spatialization is kinematic, even when this kinematics results from the automation of static positions[143] . Thus, some works with gestural spatialization are inevitably conceived by defining kinematic instructions, which implies a process of abstracting the composer's gestural imagination and translating it into geometric notation[144] . Nevertheless, an analysis of the process and the composer's intentions can reveal whether the origin of the spatialization lies in an intention to define space geometrically or whether, on the contrary, it starts from a translation into space of the morphology of the musical intention.

The clear distinction between these two approaches is also established by Jonty Harrison, who, however, bluntly assumes his aesthetic bias in favour of what is defined here as gestural spatialization. In his address to the 1999 Australasian Computer Music Conference (ACMC) (Harrison, 2000), he opposes what he calls the quantitative and architectural view of space - here referred to as kinematic spatialization - to the qualitative and organic view of space - here referred to as gestural spatialization. In the former, which he identifies as historically linked to elektronische Musik, "space is imposed on spatially neutral material at the time of composition, thus becoming a fixed and quantifiable part of musical discourse, together with frequency (pitch and timbre), duration and amplitude."[145] (Harrison, 2000). The second, historically affiliated with musique concrète and acousmatic music, applies, on the contrary, "an organic attitude to spatial organization at the time of composition", using "compositional procedures that benefit and develop" the "internal properties (including spatial ones) of sound objects"[146] , which will ultimately be reinforced in diffusion (Harrison, 2000).

A particularly interesting perspective, as it lies on the border between kinematic spatialization and gestural spatialization, is that of composer Mario Mary. His polyphony of space is based on a line of thought analogous to Trevor Wishart's spatial counterpoint: based on the concept of electroacoustic orchestration - which he uses to designate the construction of great densities of simultaneous elements, working the timbre from the perspective of the perceptual phenomena of spectral fusion and fission - he makes simultaneous movements through various spatial trajectories, which he divides into circular, spiral, diagonal and stereophonic planes (Mary, 2013). This spatial polyphony - present in works such as Signes émergents [2003] and 2261 [2009], both crystallized for an octagonal loudspeaker configuration - is, according to him, one of the most important procedures in his compositional process (Mary, 2013). The clarity in the perception of the movements, defined geometrically, informs the spectromorphological differentiation of the sounds that will be spatialized in counterpoint, which denotes a kinematic approach to spatialization. However, Mary insists on the idea that "the movement of a sound must be proposed by the sound itself", "it must be coherent with its morphology and value its most important characteristics"[147] (Mary, 2013), in a clear affiliation with what was defined above as the gestural approach to spatialization. Signes émergents and 2261 are therefore works that are on the border between kinematic spatialization and gestural spatialization.

In many, many ears [2011], by Rui Penha (co-author of this Report), explores gestural spatialization in its performative aspect, seeking the convergence of the performer's physical gesture, musical gesture and spatial gesture. auditorium [2012] uses the tendentially iterative and deferred character of the process of defining kinematic spatialization as the main element of the performance's formal structuring.

The terms statics and kinematics designate two branches of classical mechanics: statics deals with the static equilibrium of bodies under the action of forces and kinematics studies the characteristics of the movement of bodies by their geometry, without taking into account the forces that give rise to it. The traditional division of classical mechanics also includes another branch: dynamics, which studies the forces that cause a body to move. When Wishart chooses to use dynamic imagery to describe accelerated movements, in contrast to the geometric - i.e. kinematic - language used before that, he suggests that the forces that cause a body to move are part of his imagery of this type of movement. This becomes particularly relevant when he

[143] As will be analyzed in subchapter 4.6.

[144] Giving rise to an iterative process of listening to feedback and correcting the instructions entered into the spatialization software. This process is identified in the first element of the "Source - Medium - Receiver" model, which links the composer's imagination to the listener's spatial cognition (Begault, 1986) and which will be analyzed in chapter 3. At the time this model was published, a significant part of the software available for, for example, sound synthesis also required an analogous iterative and delayed process, due to the lack of processing capacity to achieve synthesis in real time, so this limitation could be seen as an intrinsic consequence of composing with computers.

[145] "In this model, [...] 'space' is imposed on spatially neutral material at the time of composition, thereby becoming a fixed, quantifiable part of the musical discourse, along with frequency (pitch and timbre), duration and amplitude.", in the original (Harrison, 2000, p. 4).

[146] "By contrast, an organic attitude to spatial organization at the compositional stage is characteristic of a musique concrète-informed acousmatic approach, which builds externalized structures from the internal properties (including spatial ones) of sound objects. The internal space of sound objects is elaborated through compositional procedures which enhance and build on such intrinsic cues, and this, in turn, is elaborated in an analogous way in the performance domain, the ultimate aim being to offer a better rendition of the character of the component objects for more members of the listening audience.", in the original (Harrison, 2000, p. 5).

[147] "That's why I insist that the movement of a sound must be proposed by the sound itself. It has to be coherent with its morphology and value its most important characteristics.", in the original (Mary, 2013, p. 14).

considers these movements as capable of conveying a greater sense of intentionality to the movement, and are therefore more gestural. Bernhard Leitner's Raum-Wiege series [1975-1980] is another interesting example of the use of dynamic thinking in the conception of spatial gestures capable of imposing a recognizable articulation on pre-existing sound objects.

Today, the simulation of physical models in a digital environment allows them to be easily controlled in real time, making it possible to generate sound morphologies from their movement in a similar way to what happens in the performance of Pendulum Music [1968], by Steve Reich, and Speaker Swinging [1982], by Gordon Monahan. Using these spatial gestures as a starting point for composition will open the door to the generation of musical gestures based on models of forces such as gravity, calling on models of movements and accelerations that are part of the empirical observation of any person from birth. Dynamic spatialization then refers to the placement of sounds in space by generating spatial gestures based on physical models of the forces that affect their movement. As with kinematic spatialization, in dynamic spatialization spatial gestures can be imposed on musical gestures - in a parallel, competing or disruptive way - or themselves articulators of musical gestures, when their temporal morphology becomes dominant.

Francis Dhomont's Vol d'Arondes [1999] is an example of a work of gestural spatialization that is close to the border with dynamic spatialization, since the origin of the spatial gesture is to mimic the behaviour of swallows during flight. It is not uncommon for composers to use dynamic imagery to describe movements that accelerate their spatial gestures, as in the vocabulary proposed by Trevor Wishart (1996), or even the morphologies of their musical gestures. The behavior of everything around us is inevitably subject to physical laws, so it would be natural to use this empirical knowledge about the world as a metaphor for movement in the musical context. However, in the context of classical mechanics, dynamics introduces precisely the interaction between bodies, translated into forces. Dynamic spatialization then refers to the use of dynamics as an effective source of spatial gesture, either through interaction with real dynamic systems, as in Speaker Swinging, or through interaction with their simulation using physical models in a digital environment. pendulum [2012], by Rui Penha (co-author of this Report), is a study of dynamic spatialization as a primary element of the composition process.

The diagram in figure 2.34 illustrates this taxonomy of spatialization in electroacoustic music, starting from the division between the existence or not of spatial gesture and subdividing the types of approach to spatialization with spatial gesture. For each type of spatialization, the origin of the thought leading to the definition of the spatial gesture is specified and, when it exists, the relationship between the spatial gesture and the musical gesture.

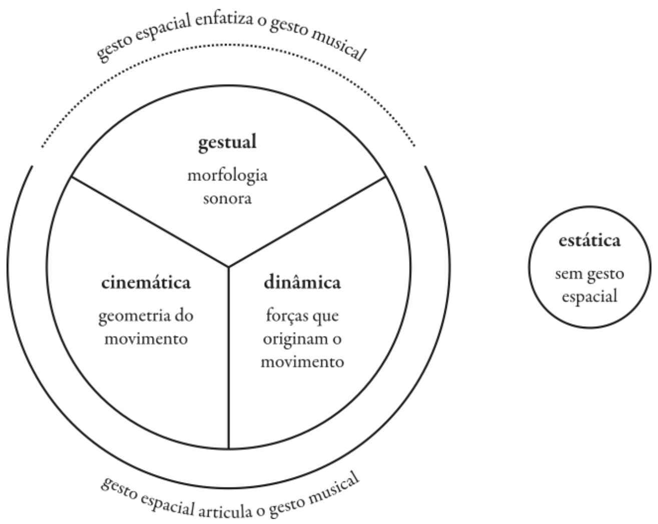

Figure 2.34. Taxonomy of spatialization in electroacoustic music.

3. Sound recording: an art

3.1 Introduction

From the very beginnings of sound recording - going back to Edison - it is possible to consider the technological achievement of reconstructing the sound field as an art. During the period of recording on wax cylinders, an enormous effort was made to position the performer appropriately and to control the dynamics of the performance so that the diaphragm and needle of the gramophone could mechanically register the sound waves in the grooves of the wax. Not only did the performer adapt to this "new" performance practice, which was completely different from a performance, for example, in a concert hall, but the rooms in which these recordings were made were also altered to adapt to dry acoustics that would end up helping the recording process (Toole, 2008, pp. 13-14). Adapting to these new conditions allowed for changes in the performance of music, thus contributing to the art of music and, at the same time, producing a new art form (i.e. sound recordings) incorporated into the medium in which it was presented. Sterne argues "that sound reproduction is always already a kind of studio art" (Sterne, 2003, p. 223). Today's sound recording efforts are not so far removed from those of the early days; it is the "evolution" of recording technology and techniques that explains the changes in aesthetic appreciation of the artistic performance that is associated with the art of sound recording.

Sound recording technology has evolved despite the repeated assertion that the technological achievements of the equipment needed to capture and emit sound were already at the peak of their capabilities. If we look at the advertisements of some of today's audio equipment manufacturers, we can see that marketing lines such as "hear the truth in great sound" (www.jbl-com), "true to the original" (www.bostonacoustics.com), "realistic multichannel surround sound" (www.dolby.com) are not very different from the Victor Talking Machine Co. ads of the 1920s, which read "the human voice is human in the New Orthophonic". Audio manufacturers have repeatedly claimed that they have achieved perfection in sound recording, not only by comparing with rival companies, but also with their own product line. This persistent quest for perfection in sound recording also applies to the techniques used to record the sounds. For example, sound engineers often claim that using certain microphone techniques will necessarily be better than others (Gerzon, 1971; Griesinger, 1985; Lipshitz,1986).

The search for the best possible sound in recordings has not only been the raison d'être of sound technicians and audio manufacturers, but also of performers who demanded a "perfect" sound in the recordings they made. The artistic achievements in the recording process must be as demanding as those of a live performance. It's worth pointing out that music recording has not generally evolved in the direction of ever more exact physical reconstruction. On the contrary, it has developed in order to facilitate ever greater control over the characteristics of the reconstructed sound field (Sterne, 2003, p. 242; Swedien, 2009), the pursuit of which leads to the eternal question "how can it be made to sound better?"

3.2 From "dead" acoustics to "living" acoustics

In Edison's time, sound recordings were made in very controlled and acoustically "dead" rooms (i.e. with reflections reduced as much as possible). The fact that the presentation of reverberant sound in relation to monophonic reproduction sounded very muddy and overemphasized (i.e. less tolerant of reverberation levels) (Streicher & Everest, 2006), the need to control environmental noise was a contributing factor to the choice of such recording rooms. In addition, very insensitive recording systems, such as the first phonographs, meant that the performer had to be as close to the microphone as possible, resulting in recordings in which direct sound was dominant. Direct sound should be understood as the first sound wave that arrives from a source at the ears of a listener or a microphone, traveling a direct path without being reflected by any surface (Everest & Pohlmann, 2009). This technical and artistic approach was the norm and practice in the early days of sound recording. Although listeners like to hear music in "good environments" (i.e. good acoustics), which contribute to creating an uplifting sound for musical performances, it seemed that these acoustically "dead" recordings nevertheless created a pleasant illusion. The fact that this sound illusion worked can be explained by the fact that the overall recording system was able to reproduce/communicate meaning and emotion. Toole explains that listeners have at some point felt "that tingling sensation that tells you that you're experiencing something special and emotionally moving. What is 'real'? Was it a "reproduction"? Good or bad sound? Does it matter? The fact that these sensations happen confirms that the [global recording] system works." (Toole, 2008, p. 5). However, if any sound recording can contribute to an emotional feeling, will a spatially more complex sound recording contribute even more to evoking a greater depth of feeling? Studies have shown that a performance in an acoustic environment has a more preferred impact than the same music played in a "dry" environment. It has been found that listeners' preference is more related to a lively and spacious performance environment (Ando, 1985). Consequently, there is an argument to be made that adding a spacious quality to sound recordings can lead to a greater preference for the resulting reconstructed sound fields. The audio industry has been developing more and more tools and proposing more and more techniques to perform complex reconstructions of sound fields, which helps answer the question "how can you make it sound better?". Toole (2008) proposes the following explanation for manipulating the impact of the reconstructed sound field "by understanding the perceptual dimensions and the technical parameters that give them control [sound recordings], it may be possible to give artists tools that allow them to move into new creative areas, expanding the artistic palette." (p. 5)

The sound processing tools that exist today are numerous: from dynamics control to sound filtering and modulation, from pure correction to the (re)creation of new sounds, and from monophonic to stereophonic reconstruction, in which the direction and spatial attributes of the sound field can be controlled and manipulated. Amplitude, which will be discussed in the following chapters, is one of the perceptual parameters that can be controlled and which has been found to contribute to a greater appreciation of the art of sound recordings. Similarly to Toole (2008), Read & Welsh, in their book "From Tin Foil to Stereo" (1959), report the statement written in 1951 by Edward Tatnall Candy in his "Saturday Review of Recordings":

> "'Liveness,' the compound effect of multiple room reflections upon played music, is-if you wish-a distortion of 'pure' music; but it happens to be a distortion essential to naturalness of sound. Without it, music is most graphically described as "dead." Liveness fertilizes musical performance, seasons and blends and rounds out the sound, assembles the raw materials of overtone and fundamental into that somewhat blurred and softened actuality that is normal, in its varying degrees, for all music.
> Disastrous experiments in "cleaning up" music by removing the allessential blur have long since proved to most recording engineering that musicians do like their music muddied up with itself, reflected. Today recording companies go to extraordinary lengths to acquire studios, churches and auditoriums (not to mention an assortment of artificial, after-the-recording liveness makers) in order to package that illusively perfect liveness."(p. 378)

This statement helps draw attention to the fact that not everything that sounds measurably correct will be appreciated as art or, in the case of the topic in question, as a good sound recording. It is therefore important to understand the auditory characteristics that are "missing" in recorded and reproduced sound, such as "liveliness", a term that has been extended to the science of hearing amplitude (Streicher & Everest, 2006, p. 12), and to provide the technological means to deliver these characteristics.

3.3 Creating and recreating sonic "illusions

Since the "birth" of stereo in the 1930s, the spatial experiences that could be conveyed in sound recordings have contributed to a better sound experience. Although critics of stereo sound claimed that there was no need for 2 channels, since mono was able to convey a guaranteed impression of the recorded performance, stereo was able to develop thanks to the persistence of just a few audio technicians, researchers and artists who were enthusiastic about the capabilities of the stereo system. Swedien quotes an executive at a major record label as saying that "stereo is like taking a shower with two shower heads - and you wouldn't take a shower with two shower heads, would you?". Ha! Ha! Ha!" (Swedien, 2009, p. 39). This comment demonstrates the lack of vision of stereo's potential to provide a more uplifting experience, similar to that experienced in concert halls, and also to allow for a "sonic fantasy" in which new "stereo spaces" could be created and new emotions experienced. Eighty-three years after its introduction, stereo is still one of the most widely used recording formats, although, in the author's opinion, its potential has not yet been fully exploited (Lipshitz, 1986; Swedien, 2009).

The location or placement of sound objects in the stereo field is of great importance in creating sound illusions. The fact that sounds can be perceived through apparent locations from left to right in a stereo sound field is a significant improvement over the reconstruction of monophonic sounds. But sonic illusion is not just a question of exact localization. Bruce Swedien comments "... that really good stereo music reproduction is not just about one sound source coming out of one speaker and a different sound coming out of the other speaker", in fact, for him, the feeling of the music can be reproduced "in a more emotional way using the stereo recording technique" (Swedien, 2009). It can be considered that if the perceptual characteristics of an acoustic environment, such as amplitude, are conveyed within the sonic illusion, listeners are likely to enjoy the experience much more. Griesinger stated that spaciousness is as important for sound recordings as it is for concert halls and that one of the main tasks of a sound recording engineer should be to create the impression of spaciousness (Griesinger, 1985). In short, auditory amplitude is the perceptual impression of sound in an enclosed space. Adding a reflected sound in advance of a discrete, direct sound source (e.g. a musical instrument) to a listener's ears will create a sound impression of a space that will differ according to the strength and detail of the reflected sound (Barron, 1971).

In order to create and recreate illusions with sound recordings, it is important that the characteristics required for the sonic illusion to occur are fully understood. An accurate image, a good sense of space, tonal quality and instrumental balance are just some of the characteristics that are important in a good sound recording. How can these characteristics be controlled in a recording? Should the recording space and microphone techniques used during production provide these characteristics? Is it possible to artificially create these characteristics? These and other questions have arisen since the dawn of the art of sound recording, and although over the years some solutions have been presented/suggested, many questions remain, with even more questions/further research following on from the answers given.

3.4 One capture point vs. multiple capture points

Recording techniques have more or less evolved into two different styles. The first is the singlepoint recording technique, which uses a set of microphones positioned at a point in the room that points towards the sound source. In this case, the idea is to capture the sonic properties of the performance, including the acoustics of the space, in a minimalist, almost "purist" approach. The second approach consists of using a multiplicity of microphones that may or may not include a main array and several accent microphones that target specific instruments or sets of instruments. The feeds from these microphones are then mixed in a (re) creative way, resulting in a natural approach to the original soundstage or a "new" soundstage. The two approaches discussed here relate to the recording of classical ensembles (e.g. orchestras and chamber ensembles) performing music with a score. Although these different styles of recording techniques can also be used in the recording of jazz, pop and rock music, "multimicing" is the technique preferred by sound engineers and producers of these styles of music (Bartlett & Bartlett, 1999).

Over the years, recording techniques have been debated and defended by those who prefer the single point and those who prefer multi-micing. Those who advocate the latter approach, as discussed by Gerzon, are more or less "objective", while those who advocate single-point matrices tend to make their claims based on a more "subjective" analysis of the more "realistic" and "pleasing" results (1971). The fact is that evaluating the results through a purely objective analysis cannot be done alone, since the results of the recordings depend on the desired musical effect. If it is accepted that stereo is incapable of reproducing a realistic soundstage (i.e. close to the actual performance in the acoustic space), then it will always be a subjective judgment when judging one technique as being more realistic than another (Gerzon, 1971).

What is important here is that the different characteristics of the recorded sound reach the listeners' ears in such a way that the intended feeling and emotion can be appreciated.

So is it possible to transmit all the perceptually significant aspects of a sound field from a primary room to a secondary listening environment using any of the recording techniques? If the perceptual characteristic of auditory amplitude is examined, it is possible to discuss whether a recording is producing an adequate sensation of amplitude or not (Furlong, 1989), and this discussion is sometimes made without any knowledge of whether it (i.e. the recording) is a single-point recording or a "multi-microphone" recording. Some experiments carried out by Griesinger (1985), and later by Gerzon (1986), have rediscovered and provided information on how it is possible to manipulate recordings produced with any of the techniques previously discussed, so that the perception of auditory space can be altered.

3.5 Conclusion

Despite the technical achievements in the field of sound recording, there is and always will be an artistic dimension involved in capturing sound. The audio equipment and techniques developed for use in the sound recording process are only relevant if the necessary perceptual characteristics are taken into account. The persistent question of "how can you make it sound better" is motivated by the notion that sound recordings can communicate emotions and perceptual impressions. It is therefore important that research carried out in the field of sound recording also focuses on controlling the perceptual effect of the reconstructed sound field, and not just on the physical effectiveness of the reconstruction. In other words, the physical reconstruction of the sound field should be approached using perceptually significant physical characteristics.

The following chapters will examine one of the perceptual characteristics of the sound experience, namely hearing amplitude, which has been widely studied in concert hall acoustics. Listeners, both in concert halls and in reproduced sound fields, appreciate this characteristic.
It is therefore considered worthy of detailed study.

4.Spatiality

4.1 Introduction

According to the Merriam-Webster dictionary, Spacious means:

1. Vast or ample in extent;

2. Large or magnificent in scale;

From these meanings, it can be quickly understood that the word spacious refers to sensory impressions that can appear spatially enlarged or large to observers. This is also true of auditory events that perceptually seem large. When listening to a large room, isn't the sound field experienced as being sonically extended or, in other words, spacious? Human beings have the ability to interpret sound fields in enclosed spaces and seem to be very interested in doing so, even if it happens on a subconscious level. But how are sound fields interpreted? What are the factors that contribute to such expressions (taken from anecdotal evidence), such as: "...this concert hall sounds very spacious", "...the cello has a spacious sound that fills the room", "...there is more space in the sound of this recording compared to that recording".

The study of auditory amplitude has been widely addressed in research on concert halls, which has made a great contribution to a better understanding of the auditory perception of concert hall sound fields. Researchers such as Schroeder et al. (1974), Barron & Marshall (1981), Ando (1985) and Blauert & Lindemann (1986) have identified the auditory components that determine listeners' assessment of the quality of concert hall acoustics, with amplitude being strongly correlated with a positive judgment of good concert hall acoustics. More recently, research in the field of sound recording has investigated the effects of amplitude on sound reproduction systems or stereo recordings, where the contribution of concert hall acoustics can be taken as the main reference (Kendall, 1995; Tohyama, Suzuki & Ando, 1995; Toole, 2008).

The objective study of concert hall acoustics has developed enormously since the pioneering work of W.C. Sabine at the beginning of the 20th century (Sabine, 1923). Reverberation time (RT) was the first objective parameter that allowed the acoustic characterization of rooms and spaces. However, this parameter, which determines the time it takes for a sound to decay by 60dB in a room after a sound source has been interrupted, is only one of many parameters in concert hall acoustics. Over the last 100 years, many studies have been carried out on concert hall acoustics, all with the aim of better understanding the subjective experience of music halls, performing arts and movie theaters. It was discovered that judgments about the "good acoustics" of concert halls are not limited to the optimum RT (Blauert & Lindemann, 1986). If two halls with identical RT are considered, a distinction of preference can be made between them. To try to resolve this type of issue, acousticians have engaged in time-consuming experiments to identify subjective perceptual preferences regarding the acoustics of concert halls. One characteristic that has attracted particular interest is the auditory spatial impression (Potter, 1993). This characteristic is related to amplitude, and can be described as the sensation of space (i.e. the impression of an extensive sound field) that a listener can have when exposed to a sound field, the definition of which is not far from the meaning of the word amplitude, identified earlier. What is of great importance is that this sensation is a perceived effect and is related to a subjective understanding of the sound stimulus and the environment in which this stimulus originated.

4.2 Impression of the Auditory Space

There has been much discussion about what is the best term to describe the perception of auditory space. One problem is that a listener tries to verbalize their subjective impression of a sound field they have been exposed to, and another problem is that different listeners may use different terms to characterize aspects of a sound field that are in fact similar. Terms such as spatial impression, ambience, apparent source width, sense of involvement and spaciousness can refer to the same or different characteristics that listeners are trying to express when characterizing a listening experience in a concert hall or a reproduced sound field (Griesinger, 1985; Potter, 1993). Listeners' expectations and the context of their listening experience may be the cause of the verbal ambiguity that complicates efforts to improve sound fields in relation to the listener's experience. However, there is a widespread opinion among acousticians that "good acoustics" is strongly related to the overall spatial impression of a room (Schroeder, Gottlob & Siebrasse, 1974).

Schroeder et al. (1974) identified a subjective preference related to an objective measure that was almost unrelated to reverberation time. In their conclusions, this subjective impression is described as follows: "...can be mediated by a more pronounced sensation - of being immersed in the sound...". Blauert & Lindemann (1986), Reichardt & Lehmann (1978) and Kuhl (1978) suggested that auditory spatial impression is related to listeners' exposure to appropriate sound fields, which can occur in spaces that present listeners with surrounding reflected sound components. These reflections somehow give the listener an idea of the type and size of a real or simulated space. Simulation is important here, as will be seen below. The spatial impression, according to these authors, is based on different perceptual attributes of auditory events, including two of the main attributes: reverberance and auditory amplitude. Reverberance is the temporal dilution of auditory events that results from reflected energy arriving late from the walls of the enclosed space. Auditory amplitude is related to the propagation of auditory events, and this effect is mainly caused by early lateral reflections. Spatial impression has also been described as the subjective sensation associated with early lateral reflections (Barron, 1971; Barron & Marshall, 1981). Prior to this, Marshall (1967) had already discussed the importance of early lateral reflections as a means of obtaining the desired spatial effect and, consequently, a greater subjective preference when exposed to this spatial effect. Other authors (Morimoto & Maekawa, 1989; Beranek, 1996; Potter, 1993; Bradley & Soulodre, 1995a) have suggested dividing spatial impression into three components: amplitude, size impression (i.e. the notion of the type and size of a space) and reverberation. Amplitude is then divided into apparent source width (ASW) and listener involvement (LEV). ASW is described as the width that a sound source can be perceived as having when performed in a concert hall, and LEV is described as the perceptual sensation of being enveloped by the sound field, which is related to late arriving reflections. However, this is not related to the perception of reverberance. Contrary to this, Griesinger (1999) suggested that the association between amplitude and ASW should be abandoned, and that amplitude and envelopment are synonymous. Griesinger (1996) also stated that it is the sound field that gives the impression of a large, enveloping space, i.e. "the sound field of an oboe may be spacious, but an oboe is not".

So it seems that the spatial impression may be caused by the fact that the sound reaches the listeners from all the surrounding boundaries after the direct sound is triggered and reflected from these boundaries. It should be noted that human beings do not hear these components (i.e. the direct sound and the reflections from the walls) as discrete elements. Instead, they are grouped into an overall spatial impression that relates to both the perception of the spatial aspects of the sound source and the enclosed space (Bregman A. S., 1990; Blauert, 1997).

Although there has been extensive research over the years, the subjective impression of concert hall acoustics and the terms used to describe these impressions have not been systematized in a uniform way. There is a persistent ambiguity in the terminology related to the perception of spatial effects. "Spatiality" or spatial impression can be used as a single descriptor for this perception. However, spaciousness is the perception of being surrounded by a large, enveloping space (Toole, 2008). It is therefore important to clarify that, for this study, spaciousness should be treated according to the perception of the spatial extent of the performance environment, i.e. that the sound field gives the impression of a large, enveloping space in which a sound source is being presented.

4.2.1 Spatial Impression in Reproduced Sound

In the previous section, a description was given of spatial impression in concert hall acoustics. The aspects of spatial impression for reproduced sound will now be analyzed. The concepts of ASW, image enlargement, early spatial impression, spaciousness and envelopment have evolved in the context of the concert hall. The challenge of the work carried out in Marco Conceição's PhD thesis (co-author of this report) was to translate these descriptors into the context of reproduced sound (Toole, 2008).

The perception of the spatial impression of reproduced sound can be different from the spatial impression felt in concert halls. Contemporary surround sound systems aim to give the impression that listeners are enveloped and surrounded by sound. But when it comes to reproduced sound, a more general question arises related to the following questions: does the spatial impression created by the reconstruction system need to be an exact and realistic reconstruction of the spatial impression felt in a performance space? Or is the intention to allow the creation of a spatial "illusion" and consequently generate a different/new spatial impression that is not an exact physical reconstruction of a primary recording space?

There has been some research related to the spatial attributes of reproduced sound, some of which has been summarized in (Rumsey, 2001) and, more recently, has been systematized in (Toole, 2008). Following Rumsey, Nakayama et al. (1971) present one of the few examples of subjective spatial quality tests carried out for multichannel surround reproduction. The study focused on the subjective effects of 1-8 channel reproductions in an anechoic chamber, using recordings made with unidirectional microphones of performances in a concert hall. The arrangement of the microphone arrays was identical to the arrangement of the loudspeakers. These sets were placed at three different distances from the orchestra. Other microphone configurations, such as an MS pair, were used in conjunction with a multichannel mix of closerange microphones.

The subjective evaluation was based on two different approaches, in which 13 different loudspeaker arrangements, from 1 to 8 channels, were used to present the recordings to the listeners. The first approach consisted of presenting a single sound stimulus, where listeners made a preference judgment on a seven-point scale, ranging from "very good" to "very bad". The second approach consisted of using a comparison between paired sound stimuli, in which listeners were asked to judge the similarity between the stimuli, also on a seven-point scale, ranging from "the same" to "very different". A preference distance scale was constructed from the results and the similarity scores were converted into similarity distances between all the combinations. All this data was then subjected to a multidimensional analysis.

From the results, important subjective factors were interpreted, such as the depth of the sources, fullness and sharpness. An analysis of the results suggests that fullness is very similar to what others have called envelopment, since it is strongly perceptible for loudspeakers placed to the sides and rear of the listener, but weak for two-channel stereo. The depth of the sources, following Rumsey's interpretation of the author's results, seems to be related to the proximity or closeness of the sources. The depth of the sources seems to be related to the proximity of the sources, which changed considerably as the recording position of the microphones moved closer to the orchestra. Sharpness was found to be related to the acoustic parameter D50 (Definition) measured in concert halls (i.e. it compares the sound energy arriving in the first 50 ms with the energy arriving later), which is clearly an indication of the relationship between direct sound and reverberant sound (Rumsey, 2001).

Based on the work carried out by Nakayama et al, an equation was formulated that relates listeners' quality ratings to the three attributes, weighting the factors appropriately. The equation suggests that fullness was the most weighted attribute, followed by depth of sources, with clarity being the least weighted.

It is clear that the perception of spatial impression in concert halls has a parallel in reconstructed sound fields. Listeners prefer a sense of extended space in both concert halls and stereo reproductions if more loudspeaker channels (e.g. side and rear loudspeakers) are added to the basic stereo reproduction arrangement (Tohyama & Suzuki, 1989). If these loudspeakers are fed with signals capable of providing differences in auditory signals, it is possible to induce illusions for listeners that suggest a more spacious sound. The fact is that supplying lateral sound sources will create differences between the left and right ear signals, which is the determining point in amplitude perception (Blauert, 1997).

4.3 Effects of reflections

Research into reflections and how they affect the perception of a sound field has been underway for several decades. One of the first standard references, according to Toole (2008), is Haas' doctoral thesis from 1949 and later translated from German into English in 1972 (Haas, 1972). His main experiment consisted of investigating the perceptual effect of a single reflection added to a direct sound.

In a semi-anechoic room, two loudspeakers were used which, according to Haas (1972), were positioned at± 45° on the left and right side of a listener. A previously recorded speech signal was sent to both speakers, and a delay could be introduced into the signal sent to one of the speakers. Leaving the sound level of both speakers the same, listeners were asked to judge the location of the sound source when a delay was introduced in one of the speakers. If no delay was applied, the listeners considered that the speech came from an intermediate point between the speakers (i.e. creating a phantom image placed in the center). When the delay varied from 0 to 1 ms, listeners considered that the location of the speech moved to the previous speaker, as if the source moved from the center to one of the sides. This is called summation localization and is the basis of the phantom source image in stereo reproduction, assuming that the listener is in a position where the loudspeakers are equidistant from the listener (i.e. in the "sweet spot") (Blauert, 1997). However, if the delay was increased beyond 1 ms to around 35 ms, in most cases the source appeared to radiate from the preceding loudspeaker, although this tendency to locate the source can also be influenced by the nature of the source signal. The precedence effect has a number of parameters that influence its manifestation, but in general it can be simplified to say that the wavefront that arrives first will dictate the location of the perceived source. It should be noted that, for Haas' study, this 35 ms limit is for the case of speech, for signals of equal level in both speakers. When the 35 ms limit is exceeded, listeners begin to judge two distinct sound sources, one after the other (in other words, an echo is perceived). Haas also tested, for each delay, the intensity of the delayed signal in relation to the non-delayed signal, before the delayed signal was perceived as the location of the source. It turned out that the delayed sound had to be 10 dB louder for the delayed source to be perceived as the source location. This was described as an "echo suppression effect".

Haas also observed auditory perceptual effects that had nothing to do with location. He was able to determine that the addition of a second sound source, with a short delay, increased the intensity of the sound and that there were some changes in the quality of the sound, which he called "liveliness" and "body" (Haas, 1972, p. 150), and a "pleasant broadening of the primary sound source" (p. 159) (Toole, 2008, p. 76).

Following Haas' work, Ando & Kageyama (1977) carried out subjective preference tests with a single simulated reflection in an anechoic chamber in order to find out the preferred properties of sound fields. From their research, they were able to plot the percentage of subjects who preferred the simulated sound, in this case speech, with a single echo depending on the direction of the reflection. Ando then correlated the subjective preference of early lateral reflections with the objective parameter of Inter-Aural Cross Correlation (IACC), as shown in Figure 8 of his work (Ando, 1977, p. 1440), and was able to determine that the magnitude of IACC is almost independent of the source signals used, including noise sources (Ando, 1977, p. 1437). Objective measures that relate to subjective space preferences are discussed further in Chapter 4. Other experiments conducted by Ando & Gottlob investigated the effects of multiple reflections in sound field preference tests and concluded that a single reflection gave almost the same results as those obtained with multiple reflections (Ando & Gottlob, 1979). Blauert (1997, p. 355) also states that amplitude is not significantly affected by whether one or several reflections are used.

Barron (1971) had already discussed the subjective effects of first reflections and their importance for good acoustics in concert halls. Figure 3-1 summarizes his findings, showing the range of levels and delays for a desirable amplitude effect in connection with musical signals.

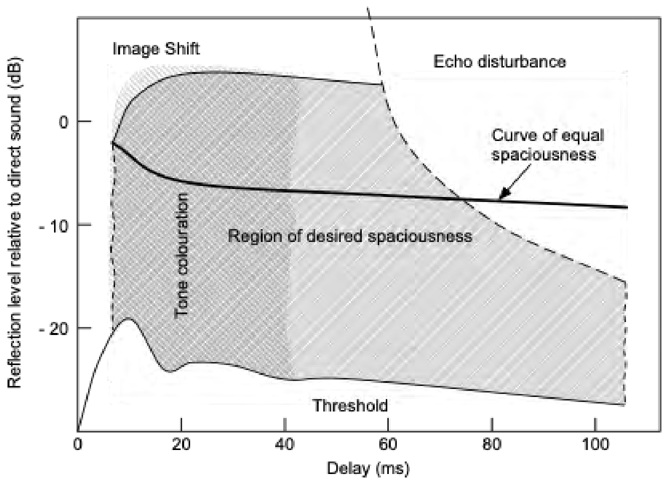

Figure 4.1. The subjective effects for music of a single lateral reflection (azimuth angle of 40°) as a function of reflection level and delay in relation to the direct sound (adapted from (Barron, 1971)).

In Barron's experiment, only one early lateral reflex was used. The sensation of space occurs immediately above the masking threshold when the delay of the reflection exceeds about 5ms, and becomes stronger as the amplitude of the reflection is increased. However, if the amplitude of the reflection is increased so much that it becomes stronger than the direct sound, image deviations will occur. It can also be seen that the reflection delay does not significantly alter the desired amplitude effect. Apart from a reflection time of around 50 ms, echo disturbances can occur if the reflection is strong enough. In Figure 3-1, you can also see a curve of equal amplitude, as evaluated by paired comparison using a reflection with a delay of 40 ms and an amplitude of -6 dB as a reference condition, in which, for shorter delays, the level of the reflection has to be higher to produce the same perceptible effect. Tonal coloration is also observed for shorter delay times.

Barron & Marshall (1981) carried out several physical measurements in which artificially created early lateral reflections were used that changed in level and arrival time in relation to the direct sound. These reflections were created by means of loudspeakers positioned at an angle to the right and left of the loudspeaker reproducing the direct sound (the measurements were carried out in an anechoic chamber). The measurements were designed to assess the subjective effects introduced by the early lateral reflected sound. Barron & Marshall's results showed that, as the level of reflection increased, the hearing test subjects noticed an increase in their perception of space. Their results also showed (confirming Barron's (1971) earlier findings) that changing the delay of reflection did not result in any significant change in the impression of space (see Figure 3-1). Barron & Marshall's studies involved subjective testing and evaluation of the impression of space due to early lateral reflections, and used the physical measurement of lateral energy fraction (LEF). However, this test can be carried out effectively using the peak values of the IACC, as it has been well established by Okano et al. (Okano, Beranek & Hidaka, 1998) and others that the normalized peak value of the IACC is an indication of the amplitude impression, where a value of 1 means a strong correlation between the auditory signals from a dummy head, while a value of 0 means that there is no correlation between the auditory signals, thus indicating a high level of amplitude. Analysis of the signals received in the ears of a dummy head allows an objective assessment of amplitude. Using the IACC makes it possible to determine the degree of similarity between the signals received in the ears. The available data therefore supports the idea that it is the differences between the signals that reach the listeners' ears that are most important for the perception of space.

The experimental setup adopted for the studies carried out for this thesis was based on the approach used by Barron (1971). However, as will be shown, the first objective was to check whether the set-up and experimentation could justifiably be carried out in any of the different rooms available.

It should be noted that Ando's experiments were carried out in anechoic chambers and that the simulation of discrete reflections was added to a direct sound. The subjects' judgment of these simulated sound fields was a preference for the presence of early lateral reflections which gave an enhanced impression of the listener being in a three-dimensional space.

4.4 Conclusion

It has been established that spaciousness is strongly appreciated as a positive and desirable component in concert hall acoustics; this has been confirmed by extensive studies.

Strong early lateral reflections added to direct sound are preferred by listeners and contribute to the perceptual sensation of spaciousness, a characteristic that is associated with listeners' interaural differences. It is certainly the reflections that increase the listener's "preference" when judging sound fields and when describing what led to this preference, which is generally related to various spatial effects, such as apparent lateral propagation, the widening of the sound source or the impression of being immersed in a large reflective space (Toole, 2008).

The spatial impression of sound reproduction systems seems to have a parallel with the impression felt in concert halls. Listeners like to feel surrounded by sound, which leads to a more spacious sound impression. For sound reproduction systems to contribute to this effect, side-placed loudspeakers have been found to be important.

Although there is much debate about the terminology that best describes the auditory perceptual sensations related to early and late reflections, the term spaciousness will be used in this study specifically in relation to the perception of the spatial extent of the performance environment, i.e. that the sound field gives the impression of a large, enveloping space in which a sound source is being presented.

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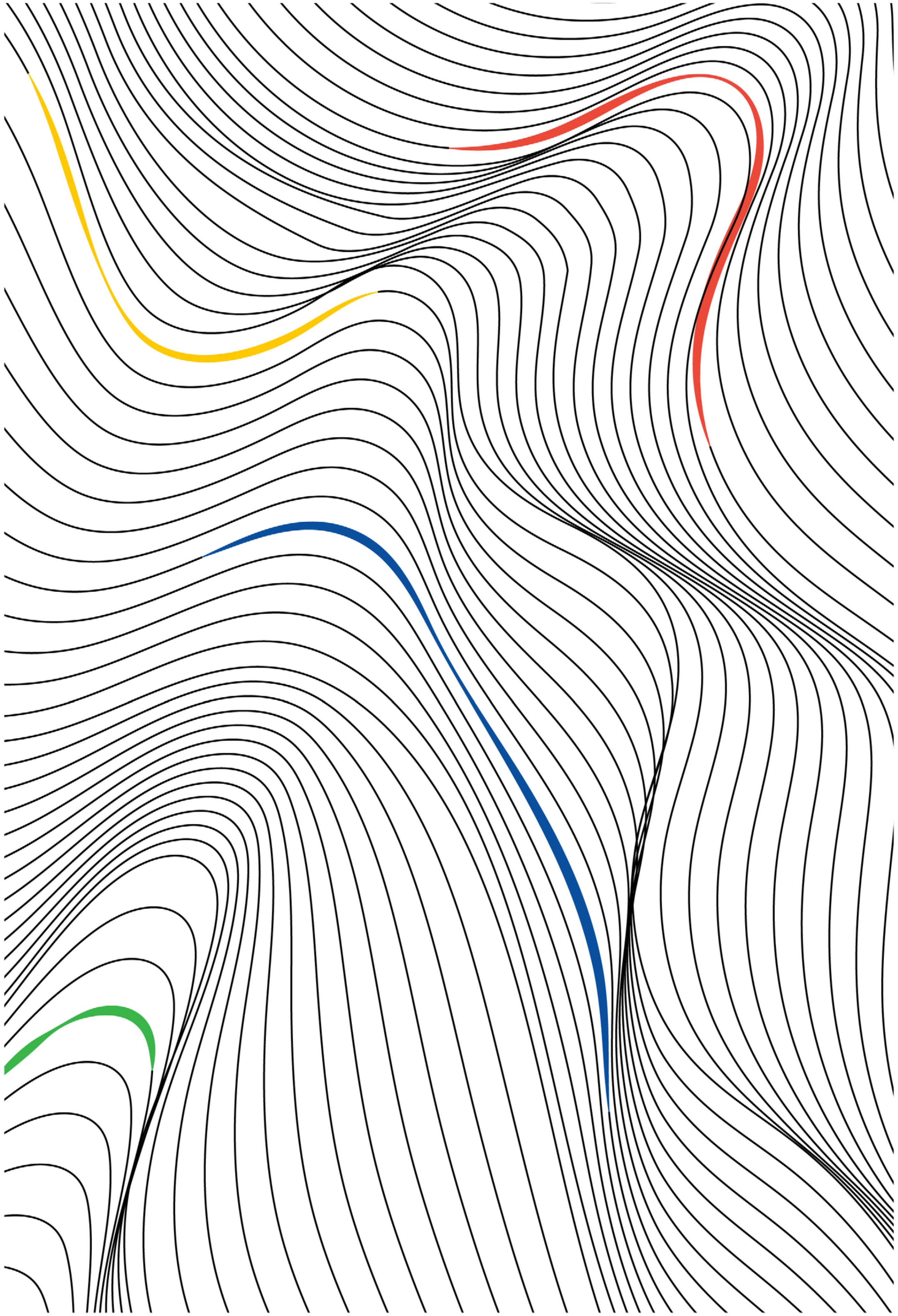
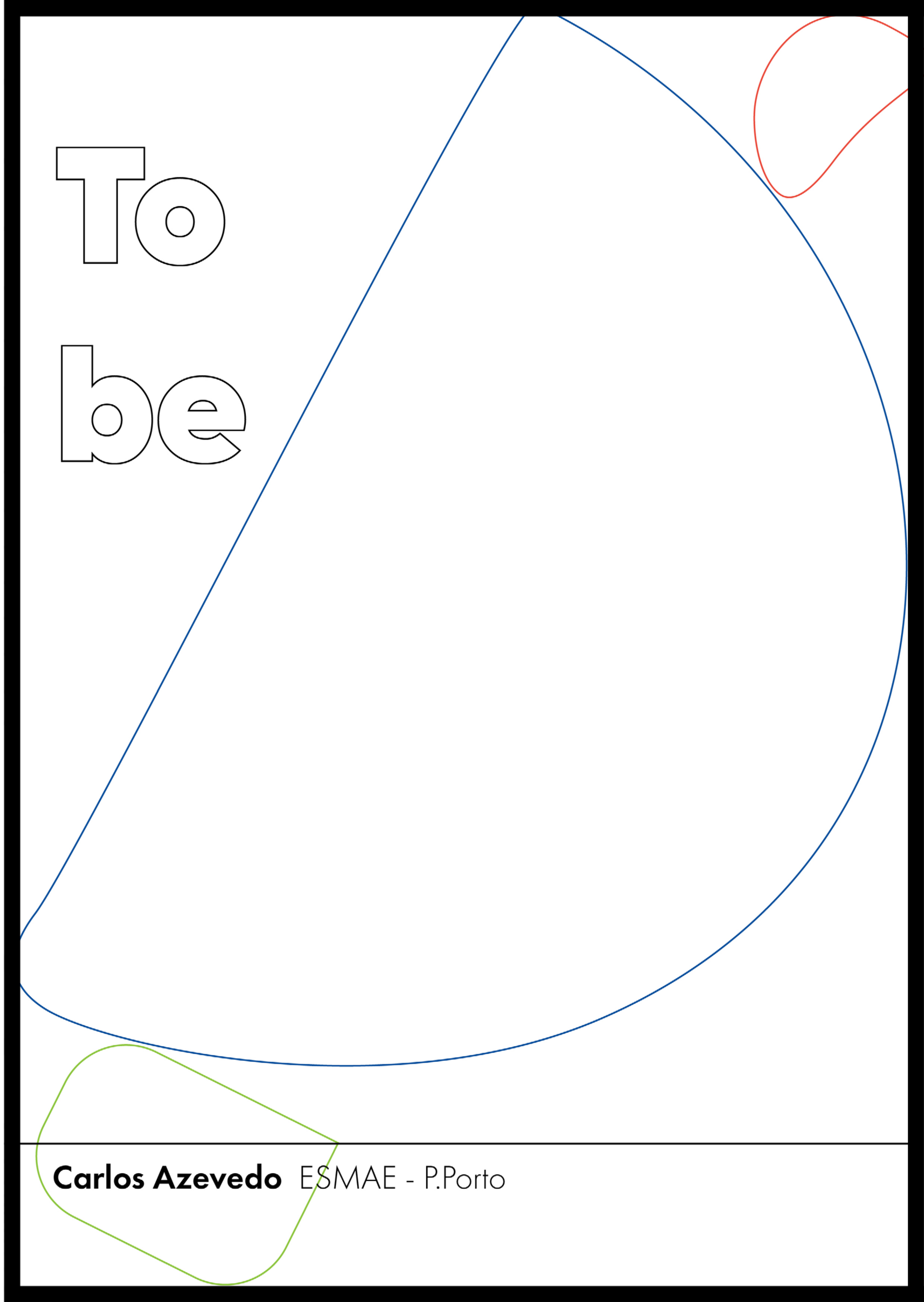
Descriptive Report




To
be
Carlos Azevedo ESMAE - P.Porto

To Be… – Carlos Azevedo

Duration: 7'

Over the past few years, I have been gathering a collection of micro-sonic fragments derived from my practice as a composer and pianist. This body of material includes takes excluded from final mixes, as well as small instrumental gestures which, once removed from their original context, acquire new expressive potential. The present work emerges from an assemblage of these elements, structured through the manipulation of fragments of drums, piano, and electric guitar.

The piece's sonic fabric is built upon a continuous electric guitar feedback, which serves as a constant textural foundation throughout the entire composition. Layered onto this matrix are multiple sonic strata, with particular emphasis on the drum, piano, and electric guitar sections, which engage in relationships of contrast, superposition, and complementarity. The macrostructure of the piece is shaped by repetitive cycles (loops), with percussive patterns standing out most clearly in the formal framework.

The SkyDust synthesizer is deployed across two independent channels: one serving a harmonic function, integrating into the piece's modal architecture; the other dedicated to the generation of textures with a stochastic character, through the modulation and layering of multiple sine waves.

The processing techniques employed act upon both temporal and spectral parameters, relying primarily on reverb, delay, and time manipulation (through expansion and contraction of sonic events), thereby contributing to the fluidity and ongoing transformation of the sonic material.

Vibrating for Violin and Fixed Media

Dimitrios Andrikopoulos ESMAE - P.Porto / CESEM

Vibrating for Violin and Fixed Media – Dimitrios Andrikopoulos

Duration: 7′

Vibrating for Violin and Fixed Media is a short study entirely based on the *Vibrating* preset from Skydust. The piece explores the outer limits of the preset's pitch range, aiming to extract maximum expressivity from minimal compositional material.

Absolute Altitude – Into an Immersive Voyage

Ângela da Ponte ESMAE - P.Porto / CESEM

Absolute Altitude – into an immersive voyage - Ângela da Ponte

Introduction

This chapter refers to the work "Absolute Altitude" composed with the plugin synthesizer SkyDust 3D. The piece was developed and mixed at the Superior School of Music and Performing Arts (Porto) studios and premiered at the Helena Sá e Costa Theater on the 13th of March 2025.

This text will describe a practice-based approach to sound spatialization, sound design and musical discourse to recall an imaginary experience that can resemble a voyage in an airplane. Further, it will also be discussed about the software elements, its usage and personal challenges when interacting with its interface and functionalities.

This project started in 2023 where the download of several updates of the software was made until the conclusion of the work. The piece was developed on Macintosh computers[148] using REAPER as the main DAW for hosting the plugin. The work was conceived to use 3rd order ambisonics making advantage of the fantastic conditions at Studio C which is equipped with Genelec speakers up to 16 channels and a subwoofer.

My practice over the last 10 years, composing electroacoustic music, was concentrated on the use of several software, where I would record or generate, then process and finally spatialize to acquire a final musical product. These programs being used throughout the years are GRM Tools, Max/MSP, Surge XT, ReaSurroundPan[149], SpatGris, just to name a few.

The experience of operating with SkyDust made room for another artistic possibility as the workflow during each session felt very organic and natural. Of course, I cannot say that I will never use again the other mentioned software, but not having to switch between different programs, to process and spatialize sound during the composition, was a major point score. This possibility brought more focus during the process of creation, but especially to the sound design. Having many aspects concentrated on one program brought greater clarity and organization to my framework.

One of the main aspects that pop up when we launch "SkyDust 3D" is its beautiful visuals. With moderate colors and sober look, the plugin gives us the feeling of a relaxed environment, and the main window lets us know very clearly the general parameters that are accessible in the software. This is indeed an incredible tool that offers a flexible range of electroacoustic techniques, built within one plugin.

Air, turbulence and immersion

"The term Absolute Altitude, in aviation, defines the maximum safe distance from the ground. Inspired by this concept, this piece takes the listener on an aerial journey, exploring the nuances of flight – from the takeoff to weightlessness at maximum altitude, until returning to earth. In a dreamlike sound environment, the music tries to evoke the sensation of elevation, freedom and contemplation of ethereal landscapes seen from above, alternating with moments of tension/turbulence, which often influence the experience of flying."

This was the program notes for the premiere in March. To balance the ideas between calmness and turbulence, the piece was divided into four main parts, where peaceful moments are alternated with energetic and stressful events. Hence, we can feel smaller parts of the four main sections where these prepare for major events:

TABLE 1 – Formal division of the piece

Timeline	Section 1	Section 2	Section 3	Section 4
0:00-0:20	Take off			
0:20-3:45	Contemplative experience of flight			
3:45-5:10	Disruptive events, accumulation of tension			
5:10-6:32		1st climax, Turbulence		
6:32-8:50			Calm, suspenseful feel, apprehensive though.	
8:50-9:43			Preparation for the 2nd climax	
9:43-11:33				2nd climax, stressful feel, with unexpected clashes
11:33-12:40				Fadeout

Source: Da Ponte, Absolute Altitude. Porto, 2025.

The DAW's final project counted with 18 tracks just using SkyDust plugin. There are tracks where more than one oscillator are explored to create a specific texture and others where one oscillator is sufficient. Six tracks were programmed to perform as samplers while the other tracks use the plugin as wave and noise synthesizers (Fig. 1 and Fig. 2).

The technical approach was very simple and near to an «old school» practice. I used a MIDI keyboard to facilitate MIDI note input and automation is controlled through changing envelopes on tracks. With SkyDust, we also have the possibility to use its own effects[150]. To get the most out of the software, I decided to not use external plugins for effects and work only with its built-in ones.

Mostly, I have implemented the reverb and distortion effects on the samplers and noise oscillators. This is very clear at the beginning of the piece: noise oscillators (suggesting air and airplane turbines) and urban soundscape are blended with **Bit crush** effect (Fig. 4), so the sensation of roughness and heavy lifting is present. This implementation also facilitated masking the urban soundscape, as I wanted to have a sound mass, but did not want it to be fully recognizable. It enabled me to have a more dramatic and expressive sound.

[148] Initially using a personal Macbook Pro, moving later, near the conclusion of the piece, to the University's studio iMac.

[149] REAPER's own plugins for spatialization.

[150] The plugin enables the following: reverb, delay, distortion, bit crush, equalizer, flanger, chorus, vibrato and phaser.

FIGURE 1 – Overall project, demonstration of the plugin organization and automation.

Source: Da Ponte, *Absolute Altitude*, overall timeline of the project in REAPER. Porto, 2025.

When using the oscillators, for harmonic and melodic contour, several waveform presets are combined to achieve different textures and spectrum richness. Some oscillators use simple waveforms such as sine or triangle wave for a more mellow/soft quality, others use presets where the spectrum gets higher harmonics and a shriller characteristic (Fig. 3). These sounds were explored, for example, in **Section 2**. Also, to get a more realistic feel of an airplane above our heads, a **Chorus** effect is added to track 7 (sampler with five oscillators with sounds with granular characteristic, such as leaves and cups). The **Chorus** is modulating the samples with a 4 ms **delay L**, 5 ms **delay R**, a frequency with **rate** of 0.11 Hz, a **depth** of 1.05 ms, **feedback** of 12.8% and **dry/wet** being automated (from 0%-70%).

The parameters for transposition and detuning were also explored on several occasions. Near the end of the piece, tension is suggested by using sinewaves detuned from one each other, creating beatings. The sensation of release is achieved when the frequencies are becoming, gradually, in tune.

FIGURE 2 – Example of using five oscillators as samplers.

Source: Da Ponte, *Absolute Altitude*, SkyDust 3D plugin in track 2. Porto, 2025.

FIGURE 3 – Example of four oscillators using the software's waveform presets.

Source: Da Ponte, *Absolute Altitude*, SkyDust 3D plugin in track 2. Porto, 2025.

FIGURE 4 – Example of using built-in effects to the samplers and noise oscillators.

Source: Da Ponte, *Absolute Altitude*, SkyDust 3D plugin, tracks 10 to 15. Porto, 2025.

One of the most satisfying results I have achieved in this piece was the design for suggesting air movement. The **EG** and the **LFO** envelope integrated in the filter tab enabled several layers of noise with an independent "life" (Fig. 5). Each noise oscillator was programmed to have its own filter with different cutoff frequency and resonance. The organic and natural movement derives from the articulation that was controlled through the rate and depth of the filter's **LFO**.

FIGURE 5 – Example of using filters on the noise oscillators.

Source: Da Ponte, *Absolute Altitude*, SkyDust 3D plugin, tracks 10 to 15. Porto, 2025.

Adding to this feature, the spatial parameter also influenced the natural feeling of wind. For this, I used the spatial presets **Random Rotations, Spiral, Randomness** and **Rotations**. Personal spatial design was programmed for tracks 13 and 14, on noise oscillators, for static and specific movement directions. The approach was to start with a spatial preset and search for other solutions by changing its **Final Position**, **Movement, diffusion** and **LFO** parameters. Polyphony was helpful too, making the illusion of a smoother movement between speakers. Regarding sinewaves and other wave oscillators, they were programmed to have a more static movement and specific speaker location, as in stressful sections, these sounds were thought to evoke alarms.

FIGURE 6 – Example of spatial design and diffusion.

Source: Da Ponte, *Absolute Altitude*, SkyDust 3D plugin, tracks 10 to 15. Porto, 2025.

Compositional Challenges and Considerations

Composing with SkyDust 3D brought to me a novel experience regarding sound design and spatial organization. With movement and energetic models for source position, workflow was highly optimized. Gestures that would take me an amount of time building and designing, now were easily mapped. By using several oscillators with flexible possibilities[151] the creation of timbre richness was easily crafted with one MIDI note. Having also the possibility to route each oscillator for a specific spatial path brought more freedom but also organization to my framework, as mentioned before.

[151] As wave oscillator or sampler.

One of the foremost aspects in SkyDust's spatial features is its flexibility to choose speakers' output layout. I have used Dolby Atmos[152] and Sound Particles[153] before for spatial design, but as stated before, switching programs can be time consuming and drive killer. By a simple click I could choose to work or to export from 7.1 to 5^{th} order ambisonics. Last minute requests/necessities can be granted without losing the work, definition and spatial design. In fact, for the premiere of this work, Marco Conceição suggested me to level up from 3^{rd} order ambisonics to 5^{th}, as we had that possibility for the speaker system at Teatro Helena Sá e Costa Hall.

When composing, one feature that I felt I could benefit from was applying effects to individual oscillators, instead of having all oscillators through a general effect. Another attribute, not functionally relevant but organizational useful, is to be able to edit oscillators tags. It shows the name of the wave preset or sample name but editing the name for compositional functions or characteristics makes sense for me. One aspect of the synthesizer in which I still feel that did not completely master it was the spatial element. The **EG** for spatial movement was not an intuitive parameter for me and I feel that I did not take full advantage as I would wish. Therefore, the use of presets and simple modifications upon those were made. It is a parameter I still need to dive in and master.

Absolute Altitude exposes compositional thoughts and technical approaches to SkyDust 3D that combines the use of presets and search for personal solutions to convey a musical discourse within an acousmatic music aesthetic. Although the result was highly satisfactory, there is room for improvements regarding control over specific parameters, as previously discussed. With this work, we hope to make contributions to the academic community as well to the development of SkyDust 3D software for its groundbreaking approach to spatial design.

Acknowledgements

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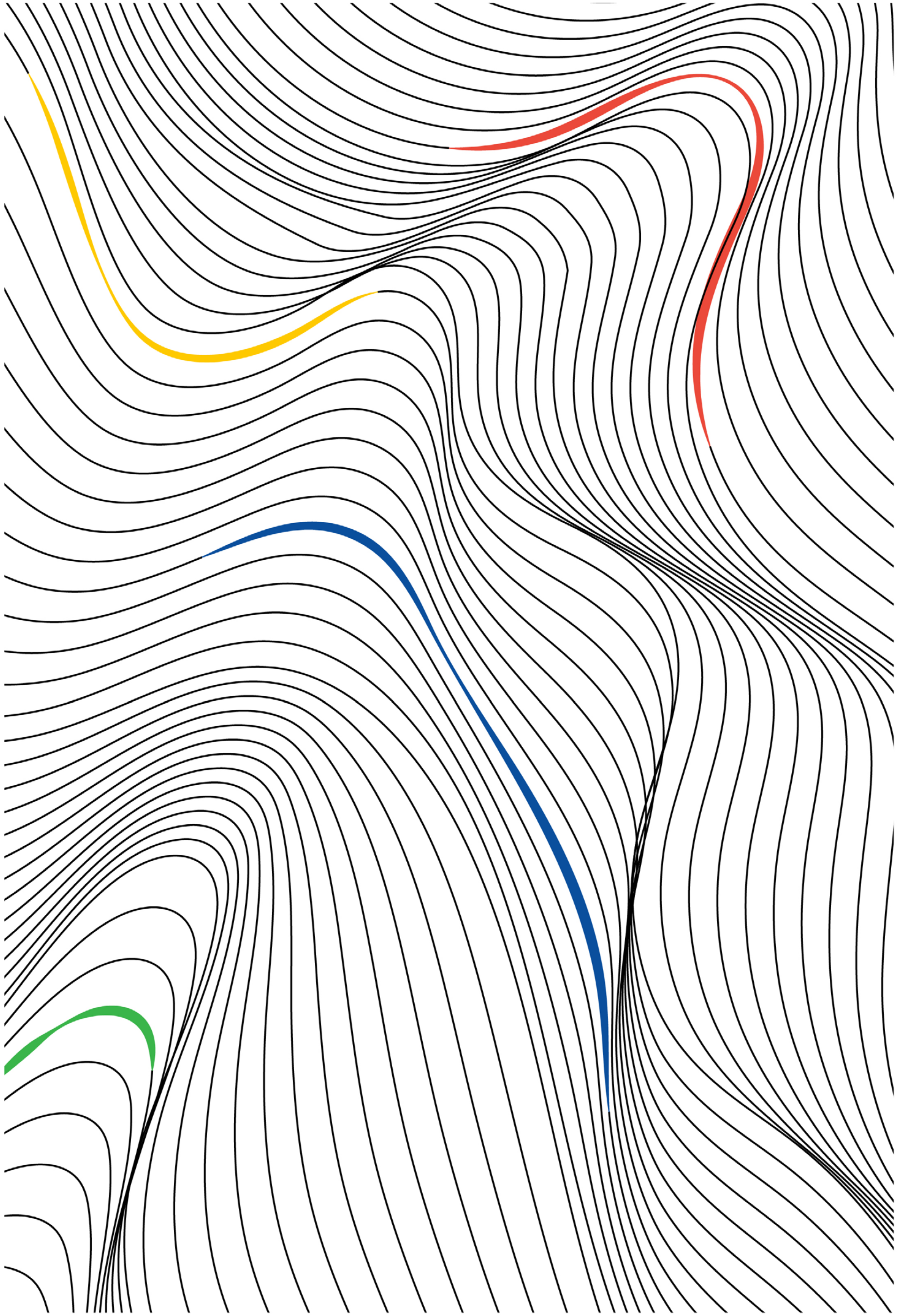
[152] Dolby Atmos Composer Essential is a 3D audio plugin.

[153] Sound Particles is a "3D audio software capable of generating thousands of sounds in a virtual audio world."



O Segredo do Farol Abandonado

Introduction
Sound Design Development
References

Diogo L. Franco ESMAE - P.Porto

O Segredo do Farol Abandonado – Diogo L. Franco

Duration: 7'

Introduction

In March 2023, *Sound Particles*, a company created by Nuno Fonseca and formed by a team of experts, fundamentally passionate about technology, music, art, sound, and sound spatialization (Sound Particles, 2025) , and the Escola Superior de Música e Artes do Espetáculo do Instituto Politécnico do Porto (ESMAE/IPP), represented by a group of students and teachers from the Department of Music and the Department of Theatre, whose research interests are also related to the same themes mentioned above, launched the *Spatial Synth* Project, developed within the scope of the Compete 2030 Program.

Faced with the challenge of exploring and composing a sound piece using the *Sky Dust* synthesizer from *Sound Particles*, I decided to immediately create a sound design based on the following narrative, written by me specifically for this purpose, entitled "The Secret of the Abandoned Lighthouse":

> *Lucas has always been fascinated by stories from the past and, when hehears murmurs about the lighthouse located at the end of the village of Nova Maré, he decides to investigate. The lighthouse, once an aid to navigation, is now abandoned. Many of the villagers avoid talking about it, noting that it is a cursed place.*
>
> *The calm and serenity are interrupted when, on a stormy night, strange lights are seen coming from the lighthouse, and mysterious sounds are heard that echo through the village. Fishermen mention that the sea is unusually rough, and some even claim to have heard singing and whispering coming from the depths.*
>
> *Determined to discover the truth, on a certain quiet day, Lucas ventures across the sand to the lighthouse. Gentle sea waves are heard and seagulls cawing. Upon entering, Lucas finds himself in a haunting environment full of echoes of the past: first he hears an ethereal song, then disturbing whispered or muffled voices, the footsteps of a child running and laughing, the jingling of keys, running water and the ticking of a clock. Inside, he still hears the sea crashing against the rocks, but distant. Suddenly, the danger intensifies with sounds of thunder, torrential rain and sounds of violent waves, forcing Lucas to flee.*
>
> *Somewhere in the lighthouse, it is revealed that there is a magical crystal which has the power to control the sea and storms, but it has been corrupted by an evil spirit that now haunts the place. Lucas follows the haunting, repetitive lullaby melody, which seems to echo through the lighthouse, to a secret room, where he finds the crystal, which, in addition to the captivating melody, also emits sounds of pulsating light and mesmerizing vibrations.*
>
> *By touching the crystal, Lucas awakens the evil spirit, a shadowy, nebulous figure, which manifests itself through sounds of wailing and raging winds, with sound transitions involving the fading and fluctuating sounds of the crystal's melody. Lucas faces the spirit and they both fight with swords. Lucas, knowing that the only way to restore peace to the village is to purify the crystal, kills the spirit, causing evil sounds, storms and disturbing sounds to begin to dissipate and the light of the crystal to become clear and pure, regaining the power to control the sea and storms.*
>
> *Closing the box containing the crystal, Lucas returns to the village and the atmosphere changes completely. The sea calms down, and a feeling of peace sets in. Peace is gently celebrated, and the lighthouse is restored as a symbol of protection and guidance for the community.*

The synopsis of this story became:

> *In a remote coastal village where the sky and sea meet, there is an abandoned lighthouse which many believe to be haunted. Lucas, a young historian and passionate about mysteries, decides to unravel the secrets of the lighthouse when a series of strange events begin to occur, affecting the lives of everyone in the village.*

To make this project possible, I used the *Reaper* Digital Audio Workstation from *Cockos Incorporated*, the *Sky Dust* synthesizer from *Sound Particles*, the *Dolby Atmos Composer Essential* plugin from *Fiedler Audio* to program the final spatialization of each of the sound objects, the *MFreeFXBundle* plugins from *Melda Production* to simulate the acoustic conditions of the entire story, and the *Multiply Chorus* plugin, from *Acon Digital*. Initially, I worked with a 7.1 sound reproduction system and later with 9.1.6.

On March 13, 2025, the presentation of the works composed by the ESMAE/IPP students and teachers involved in the project was held at the Teatro Helena Sá e Costa, located at ESMAE/IPP. The final audio of my sound design resulted from the rendering of the 9.1.6 project on 16 individual tracks, whose signals were then respectively routed to the sound reproduction system consisting of 16 *Meyer Sound Ultra-X20* speakers distributed nearly in a circle around the two audiences on the horizontal listening plane, 8 *Meyer Sound Ultra-X20* speakers also distributed almost in a circle on a higher plane, and 4 *Meyer Sound 750-LFC* subwoofers, 2 placed on the left side, and 2 on the right side of the proscenium.

Sound Design Development

Dramatic Tension Curve of "O Segredo do Farol Abandonado"

After writing the story and implementing the same working method that I usually propose to the students to whom I teach Sound Design, I created the dramatic tension curve of the story, in which the value 0 (zero) represents the minimum tension and the value 100 (one hundred) represents the maximum tension on the vertical axis (see figure 1). The curve starts with a relatively low value consistent with an initial feeling of tranquillity experienced in the coastal village. The tension increases as Lucas enters the lighthouse and is faced with a haunting atmosphere. There is an intensification of the sense of danger caused by the storm in moment 3. With Lucas's attraction to a crystal through its lullaby, the tension rises slightly, until the climax is reached in moment 6, in which Lucas fights with the spirit that haunts the crystal.

The resolution of the conflict, and consequently the drop in tension, occurs with the death of the spirit at moment 7. With the purification of the crystal and the restoration of peace in the village, the tension remains practically the same as at the beginning of the story.

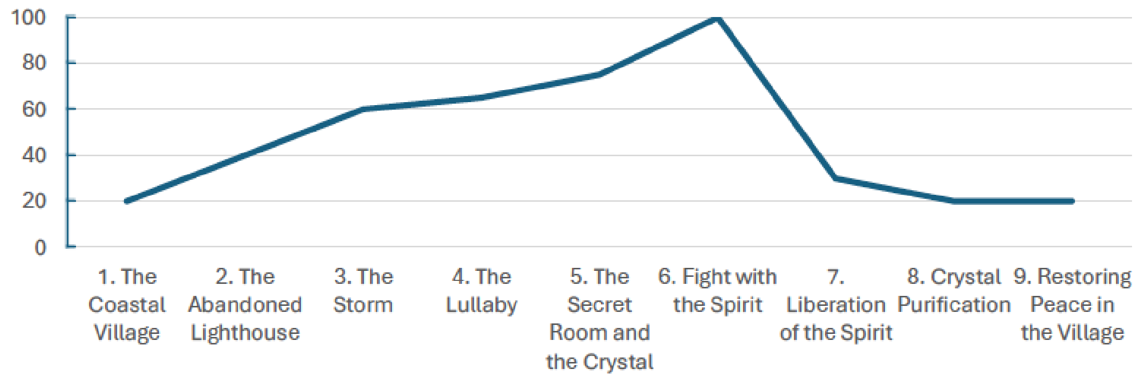


Figure 1 - Dramatic tension curve of "The Secret of the Abandoned Lighthouse".

Analytical Table of "O Segredo do Farol Abandonado"

I then created an initial analytical table, presenting a list of explicit and implicit sound objects in the text, by moments, with the respective prediction of dramatic intentions. Over time, this table was naturally readjusted, until reaching the following result (see Table 1):

Table 1 - Final analytical table of "The Secret of the Abandoned Lighthouse".

Moment	Explicit Sound Objects	Implicit Sound Objects	Intention
1. The Coastal Village	Gentle ocean waves	Music with a cheerful and comforting melody on a transverse flute	Creating an initial sense of tranquility
	Steps on sand	Church bell in the distance	
	Seagulls cawing	Flapping of wings	
2. The Abandoned Lighthouse	Echoes of the past (use of reverb and delay): ethereal singing, whispered or muffled disturbing voices, children's footsteps running and laughing, jingling keys, running water, ticking clock	Lucas opens heavy wooden door	Creating a spooky atmosphere: Lucas ventures to a lighthouse and enters it
	Distant sound of the sea crashing against the rocks	Lucas's footsteps on wood	
		Mysterious and dark voices	
3. The Storm	Thunder sounds	Lucas's footsteps running on wood	Intensification of the feeling of danger
	Torrential rain	Lucas's panting while running	
	Sounds of violent waves		
4. The Lullaby		Lucas's footsteps running on wood	Lucas's attraction to a crystal: While exploring the lighthouse, Lucas hears a haunting lullaby that seems to be coming from nearby
	Creepy, repetitive lullaby melody of a crystal that seems to echo through the lighthouse	Music box melody (crystal), in the minor key mode	
		Lucas's panting while running	
5. The Secret Room and the Crystal	Pulsating light sounds from the crystal	Lucas's footsteps running on wood	Encounter with the crystal: Lucas follows the melody to a secret room where he finds a haunted crystal (key in minor mode)
	Hypnotizing Crystal Vibrations		
	Captivating Crystal Melody	Crystal melody in the minor key mode	
	Lucas's touch on the crystal	Lucas gasps as he touches the crystal	
6. Fight with the Spirit	Furious winds	Voice of the spirit awakening	Representation of the spirit
	Laments of the spirit	Lucas's steps	
	Sounds of swords	Lucas's panting while fighting	Fight with a Spirit: Lucas touches the crystal and sword fights a spirit that haunts the crystal
	Sound transitions involving fading and floating sounds of the crystal melody		
7. Liberation of the Spirit		Voice of the dying spirit	Death of the spirit: Lucas kills the spirit with the sword, causing the evil sounds of the spirit to dissipate
	Evil sounds, storms and disturbing sounds begin to dissipate	Sounds of swords and laments that turn peaceful	
		Brief silence	
8. Crystal Purification		Crystal melody, in major mode, suggesting protection and peace	Crystal purification: Crystal becomes pure (major mode key)
	Closing the box containing the crystal		
9. Restoring Peace in the Village	Gentle ocean waves	Music with a cheerful and comforting melody on transverse flute, with classical guitar and conga rhythm	Peace restored in the village: Lucas returns to the village and the restored peace is gently celebrated

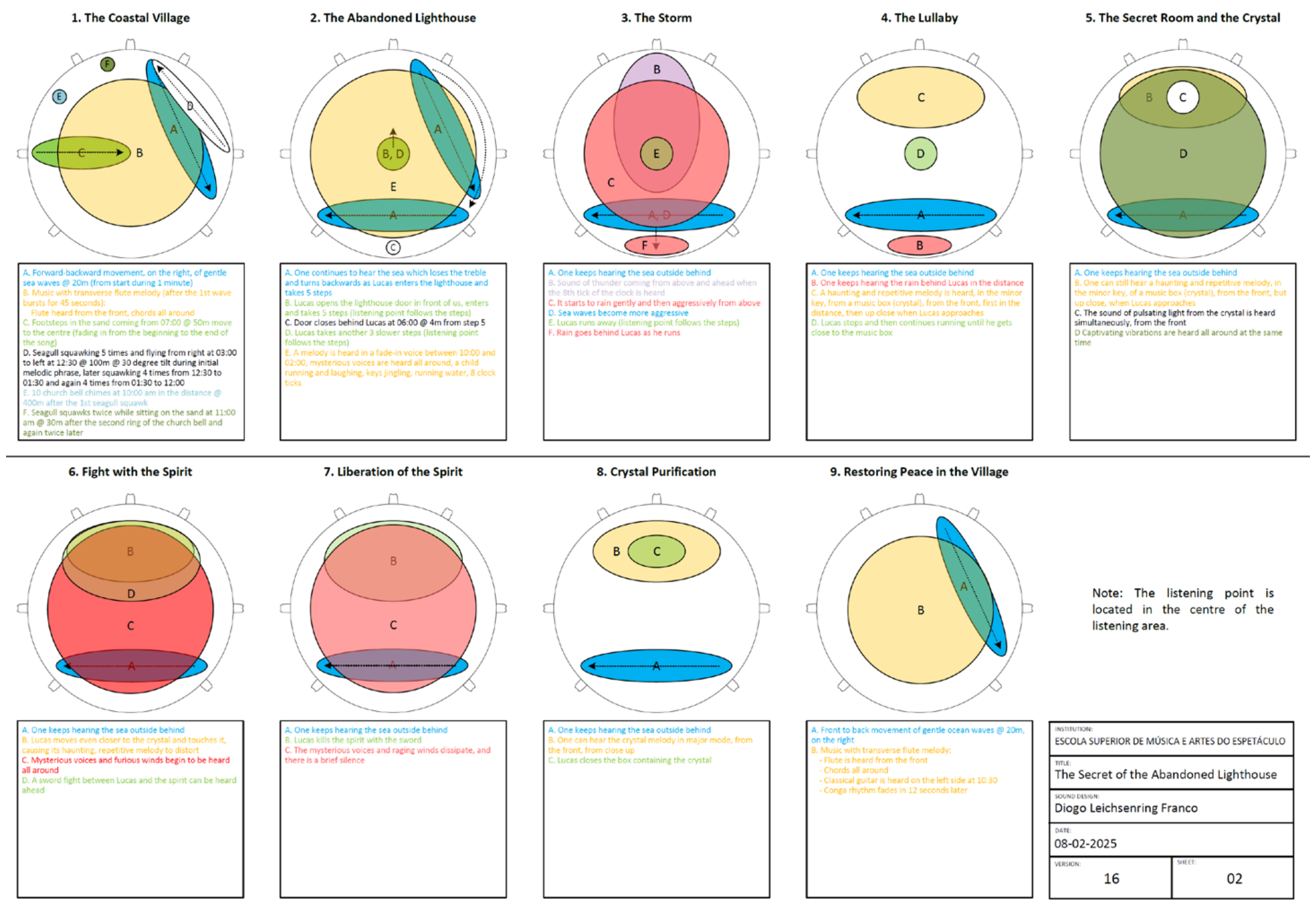
Sound Storyboard of "O Segredo do Farol Abandonado"

To help enhance and develop the sound images of this text, knowing that the final receiver would only be provided with the sound component to recreate the visual images of this sound design with his or her ears (Moore, 2019, p. 18), I produced a sound storyboard, that is, a visual guide consisting of simple and objective drawings or images with observations or comments, arranged in sequence, with the aim of graphically showing the desired location, distance and movement of the sound objects at a given instant, in each moment of the story, taking into account the central listening point in the acoustic space synthesized by the sound reproduction system. Like what happened with the analytical table, the sound storyboard was also readjusted over time (see figure 2 and appendix 1).

Exploring and Creating Presets on the Sky Dust Synthesizer

After carefully reading the manual (Sound Particles, 2023) and after a period of exploration of the *Sky Dust* synthesizer, I started to develop my own presets, with the aim of creating all imitative and synthetic sound objects through the application of different synthesis techniques and the use of up to 8 oscillators available in a single preset, and the respective selection of parameters for each of the oscillators, such as waveforms, levels, filters, amplitude envelopes, filter envelopes, frequency envelopes, modulators, and 3D spatialization, as well as the possibility of using a sequencer or an arpeggiator, and effects for the set of oscillators.

Figure 2 - Final sound storyboard of "The Secret of the Abandoned Lighthouse".



During this process, I naturally considered the mechanisms that the human auditory system uses to locate sound sources in space, knowing that it can be influenced by the position of the physical or phantom sound source and the type of signal produced. It therefore depends on the horizontal angle (azimuth, in the horizontal plane), and the vertical angle (zenith, in the vertical plane), bearing in mind a system of spherical coordinates centred in our head as a reference, and on the distance (for static sources) or speed (for moving sources, in which the Doppler effect can be observed) (Franco, 2018, pp. 79-95). In this project, the influence of speed was purposely not considered, since it is only at about 50 meters per second that the Doppler effect becomes more prevalent (Franco, 2018, p. 43). The human auditory system is best at localizing sounds in the horizontal plane, reasonable in the vertical plane, and worst at distance, so distance estimation depends on the ratio of direct sound to reverberated sound, the loss of high-frequency components with distance, and thus the loss of detail with distance, and the loss of signal level with distance.

The use of native waveforms from the *Sky Dust* synthesizer, such as sine waves, sawtooth waves, square waves, triangle waves, white noise and pink noise, was performed in the following cases:

1. "The Coastal Village": gentle waves of the sea, harmonic base of the initial music, footsteps on the sand, seagulls cawing
2. "The Abandoned Lighthouse": distant sound of the sea crashing against the rocks, Lucas's footsteps on wood, mysterious sound, running water
3. "The Storm": sounds of thunder, sounds of violent waves, Lucas's footsteps running over wood
4. "The Lullaby": Lucas's footsteps running over wood
5. "The Secret Room and the Crystal": Lucas's footsteps running over wood, sounds of pulsating light from the crystal, hypnotizing vibrations from the crystal, Lucas's touch on the crystal
6. "Fight with the Spirit": furious winds, Lucas's footsteps
7. "Restoring Peace in the Village": gentle ocean waves, harmonic basis of the final music

The importation of audio files into the synthesizer, resulting from samples prerecorded by me, from sounds of individual notes of musical instruments played by my two children, Inês and Diogo, and by me, and from recordings of my own voice, was applied in the following moments of the story:

1. "The Coastal Village": sound of a transverse flute note which was used to play the initial cheerful and comforting melody, flapping of wings (capture of the movement of multiple plastic bags inside a plastic bag wrapped in fabric – Foley technique), sound of a church bell
2. "The Abandoned Lighthouse": heavy wooden door opening, Lucas's footsteps on wood, ethereal singing, unsettling whispered or muffled voices, mysterious and dark voices, children's footsteps running and laughing, keys jingling, clock ticking
3. "The Storm": Lucas's footsteps running over wood, Lucas's panting as he runs, torrential rain
4. "The Lullaby": Lucas's footsteps running on wood, Lucas's panting as he runs, the sound of a music box note that was used to play the haunting and repetitive lullaby melody of the crystal in the minor key
5. "The Secret Room and the Crystal": Lucas's footsteps running over wood, the sound of a music box note that was used to play the crystal's melody in a minor key, Lucas's touch on the crystal, Lucas's gasp as he touches the crystal
6. "Fight with the Spirit": voice of the spirit awakening, laments of the spirit, sounds of swords, Lucas's footsteps, Lucas's gasp as he fights
7. "Liberation of the Spirit": sounds of swords, voice of the dying spirit, laments that become peaceful
8. "Crystal Purification": sound of a music box note which was used to play the crystal melody in a major mode, closing the box where the crystal is located
9. "Restoring Peace in the Village": the sound of a transverse flute note that was used to play the joyful and comforting melody already heard in the first moment of the story, the sound of a classical guitar note that was used to create the chords supporting the melody

The audio of the conga rhythm ("Shaker, Woda, Conga, Bongo, Templeblock.wav"), used and imported in full into the synthesizer for the last moment of the story ("Restoring Peace in the Village"), was extracted from https://freesound.org/s/34115/, and was authored by kwazi (license: attribution 3.0).

Below are some of the most relevant presets created.

Soft Ocean Waves Preset

For the first moment ("The Coastal Village"), I tried to recreate the sound of gentle sea waves, using a more realistic approach, and, for this, 3 oscillators with pink noise waveforms (formation of sea waves) and 2 oscillators with white noise waveforms (water sliding on the sand) (see figures 3 to 8). These waveforms were selected from scratch because their very dense spectra are very similar to those of ocean waves (Farnell, 2010, p. 431).

Figure 3 - Soft Ocean Wave Preset: 5 Oscillators.

Figure 4 - Oscillator 1 of the soft ocean waves preset.

Figure 5 - Oscillator 2 of the soft ocean waves preset.

Figure 6 - Oscillator 3 of the soft ocean waves preset.

Figure 7 - Oscillator 4 of the soft ocean waves preset.

Figure 8 - Oscillator 5 of the soft ocean waves preset.

Knowing that the phenomenon behind the sound of sea waves is turbulence (Farnell, 2010, p. 429), I therefore tried to recreate the main moments of the formation, development, breaking, and sliding of the water of gentle sea waves on the sand at a hypothetical distance of 20 meters from the listening point with the 5 oscillators, some activated at different times with different ADSR and DAHDSR amplitude envelopes, with different levels, filters, and spatialization, thus being able to tell, as it were, a story of the sea waves within the main story, using a MIDI controller and the recording, in a somewhat random way, of several MIDI notes that tend to be long (see figure 9).

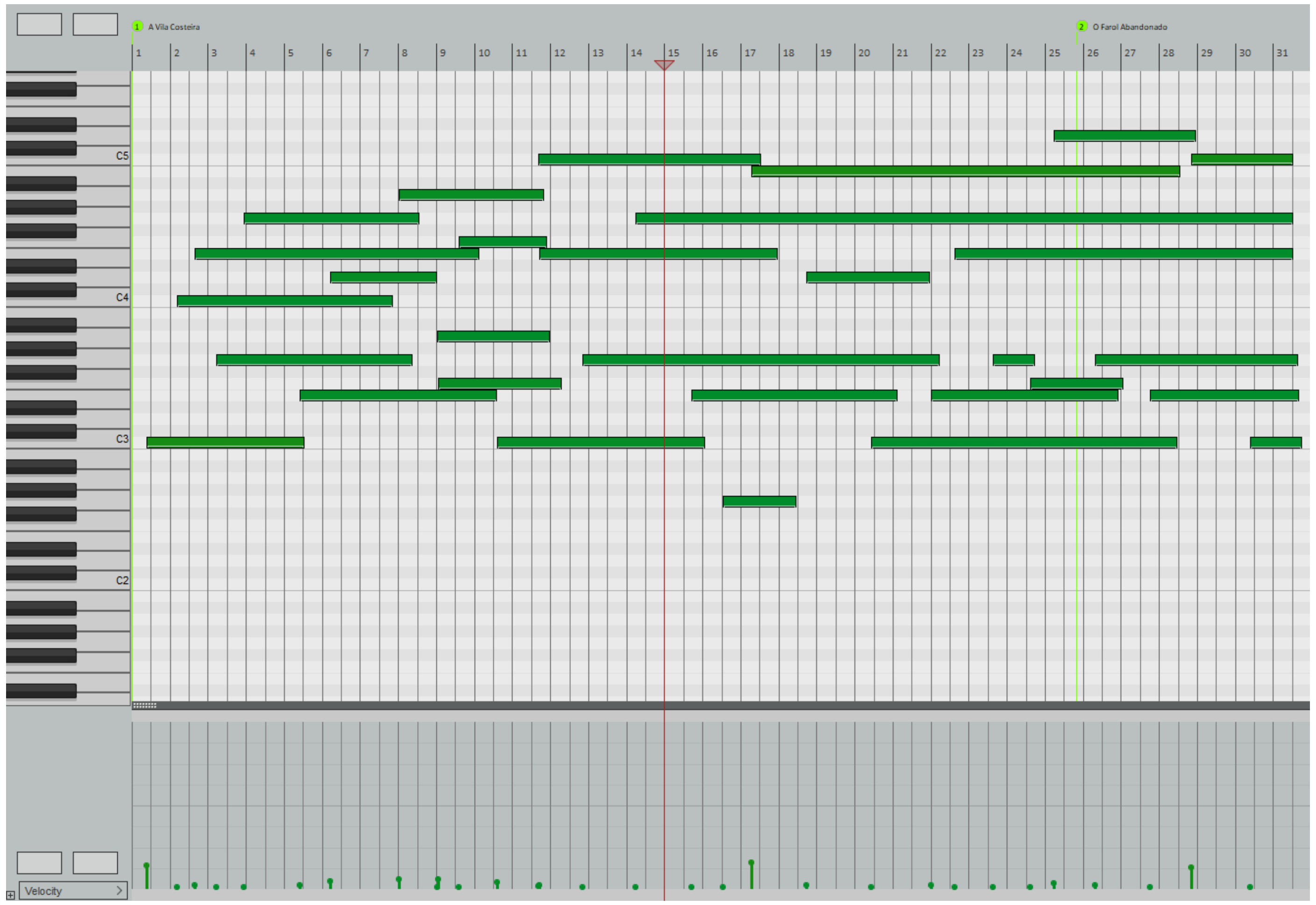


Figure 9 - MIDI notes used in the recreation of gentle ocean waves.

The filters, filter envelopes, and modulators used in each oscillator are then shown (see figures 10 to 14).

Figure 10 - Oscillator 1 filter of the smooth sea waves preset.

Figure 11 - Oscillator 2 filter of the smooth sea waves preset.

Figure 12 - Oscillator 3 filter of the smooth sea waves preset.

Figure 13 - Oscillator 4 filter of the smooth sea waves preset.

Figure 14 - Oscillator 5 filter of the smooth sea waves preset.

Regarding spatialization, the intention was to give the idea of the movement from front to back, to the right of the listening point, of gentle sea waves, considering a hypothetical distance of 20 meters (see figures 15 to 19).

Figure 15 - Spatialization of oscillator 1 of the soft ocean waves preset.

Figure 16 - Spatialization of oscillator 2 of the soft ocean waves preset.

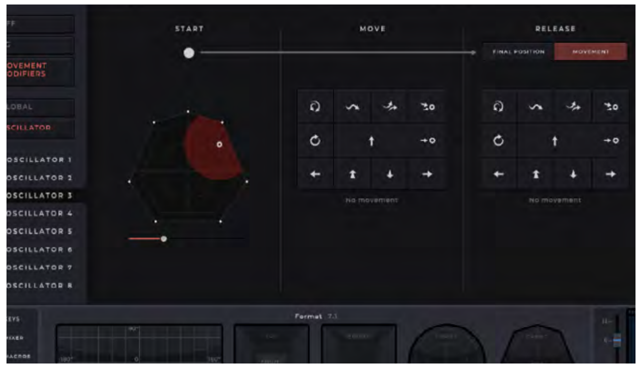


Figure 17 - Spatialization of oscillator 3 of the soft ocean waves preset.

Figure 18 - Spatialization of oscillator 4 of the soft ocean waves preset.

Figure 19 - Spatialization of oscillator 5 of the soft ocean waves preset.

Initial and Final Music Harmonic Base Preset

In this preset, 3 oscillators were used, each with a different waveform, respectively, sawtooth wave, square wave, and triangular wave (see figures 20 to 22).

Figure 20 - Oscillator 1 of the music harmonic base preset.

Figure 21 - Oscillator 2 of the music harmonic base preset.

Figure 22 - Oscillator 3 of the music harmonic base preset.

To make the final sound of the preset more interesting, oscillator 1 was slightly detuned by +14 Cents relative to oscillator 2, with both being one octave below oscillator 3.

Low-pass filters were applied to the 3 oscillators to make the result of the preset less aggressive (see figures 23 to 25). Thus, this could be used in the harmonic basis of the initial and final music of the story and the melody of the transverse flute could stand out clearly.

I just applied the frequency envelope to oscillator 2 to create some dynamic texture in the long sounds of the harmonic base of the music (see figure 26).

Regarding spatialization, I wanted the sound of this preset to be heard all around the listening point (see figure 27).

Figure 23 - Oscillator 1 filter of the music harmonic base preset.

Figure 24 - Oscillator 2 filter of the music harmonic base preset.

Figure 25 - Oscillator 3 filter of the music harmonic base preset.

Figure 26 - Frequency envelope of oscillator 2 of the music harmonic base preset.

Figure 27 - Spatialization of the 3 oscillators of the music harmonic base preset.

Footsteps on the Sand Preset

Like what I did in the soft ocean waves preset, in this one I also intended to tell its own story within the main story, that is, a story of Lucas's steps on the sand on Nova Mare beach. For this purpose, 5 oscillators with native *Sky Dust* waveforms were used: white noise and pink noise (see figures 28 to 33).

Figure 28 - Footsteps on the sand preset: 5 oscillators.

Figure 29 - Oscillator 1 of the footsteps on the sand preset.

Figure 30 - Oscillator 2 of the footsteps on the sand preset.

Figure 31 - Oscillator 3 of the footsteps on the sand preset.

I considered that a foot in the sand makes a noise that changes as the foot enters the sand and moves it away in all directions. This dynamic was achieved by applying different amplitude envelopes and filter envelopes (see figures 34 to 38).

To make the sound more convincing, I used the *Sky Dust* synthesizer's equalizer, available in *FX Effects*, lowering the energy in the low frequency region (see figure 39). The *Bit Crush effect* allowed to provide the necessary energy to obtain the desired result.

Figure 32 - Oscillator 4 of the footsteps on the sand preset.

Figure 33 - Oscillator 5 of the footsteps on the sand preset.

Figure 34 - Oscillator 1 filter of the footsteps on the sand preset.

Figure 35 - Oscillator 2 filter of the footsteps on the sand preset.

Figure 36 - Oscillator 3 filter of the footsteps on the sand preset.

Figure 37 - Oscillator 4 filter of the footsteps on the sand preset.

Figure 38 - Oscillator 5 filter of the footsteps on the sand preset.

Figure 39 - Effects applied to the footsteps on the sand preset.

Cawing Seagulls Preset

One of the types of seagull cawing was achieved by using 2 oscillators with native waveforms from the *Sky Dust* synthesizer: triangle wave and sine wave (see figures 40 and 41).

Figure 40 - Oscillator 1 of the cawing seagulls preset.

Figure 41 – Oscillator 2 of the cawing seagulls preset.

The same filters and filter envelopes were applied to the 2 oscillators (see figure 42) and a frequency modulated envelope was applied to oscillator 1 (see figure 43) to imitate the initial rapid rise and fall in the frequency of a seagull's caw.

Since the caws are relatively fast, I chose to select a global positioning for the two oscillators that could still vary slightly in position (see figure 44).

Figure 42 - Oscillator 1 filter of the cawing seagulls preset, being the same for oscillator 2.

Figure 43 - Oscillator 1 frequency envelope of the cawing seagulls preset.

Figure 44 - Spatialization of the 2 oscillators of the cawing seagulls preset.

Figure 45 - Effects applied to the cawing seagulls preset.

The *Bit Crush* and *Distortion* effects of the *Sky Dust* synthesizer were decisive in achieving the desired caws (see figure 45). Notes G#5 and C6 played slightly out of phase did the rest.

Thunder Sounds Preset

The thunder sounds were achieved using 8 *Sky Dust* oscillators, this also being a preset in which I tried to tell a story within the main story (see figures 46 to 61). Oscillator 8 generates the initial low-mid attack, oscillators 1 and 7 simulate the initial high-pitched electrical effect contained in the thunder sound, oscillator 4 generates the turbulence of the initial low-mid electrical effect contained in the thunder sound, oscillator 2 generates the deep, low-pitched sound of the initial shaking of the air, oscillator 3 produces the slightly higher-pitched sound of the little later shaking of the air, oscillator 5 is responsible for the low-sub-bass and long sound of the final thunder tail, and oscillator 6 simulates the mid-range sound of the final air turbulence due to the initial electric effect.

Figure 46 - Oscillator 1 of the thunder sounds preset.

Figure 47 - Oscillator 2 of the thunder sounds preset.

Figure 48 - Oscillator 3 of the thunder sounds preset.

Figure 49 - Oscillator 4 of the thunder sounds preset.

Figure 50 - Oscillator 5 of the thunder sounds preset.

Figure 51 - Oscillator 6 of the thunder sounds preset.

Figure 52 - Oscillator 7 of the thunder sounds preset.

Figure 53 - Oscillator 8 of the thunder sounds preset.

Figure 54 - Oscillator 1 filter of the thunder sounds preset.

Figure 55 - Oscillator 2 filter of the thunder sounds preset.

Figure 56 - Oscillator 3 filter of the thunder sounds preset.

Figure 57 - Oscillator 4 filter of the thunder sounds preset.

Figure 58 - Oscillator 5 filter of the thunder sounds preset.

Figure 59 - Oscillator 6 filter of the thunder sounds preset.

Figure 60 - Oscillator 7 filter of the thunder sounds preset.

Figure 61 - Oscillator 8 filter of the thunder sounds preset.

Figure 62 - Spatialization of oscillator 1 of the thunder sounds preset.

Figure 63 - Spatialization of oscillator 2 of the thunder sounds preset.

Figure 64 - Spatialization of oscillator 3 of the thunder sounds preset.

Figure 65 - Spatialization of oscillator 5 of the thunder sounds preset.

Figure 66 - Spatialization of oscillator 6 of the thunder sounds preset.

Figure 67 - Spatialization of oscillator 7 of the thunder sounds preset.

Figure 68 - Spatialization of oscillator 8 of the thunder sounds preset.

Figure 69 - Effects applied to the thunder sounds preset.

Since the sound of thunder is quite chaotic, I intended for this to be reflected in the spatialization as well. The spatialization is relatively similar in all oscillators, except in oscillator 4, in which no parameterization was made because it was considered not justified due to the chaos already achieved (see figures 62 to 68).

The *Bit Crush* and *Reverb* effects of the *Sky Dust* synthesizer allowed me to give the preset its final shape (see figure 69).

Transverse Flute Preset

As already mentioned in section 2.4, the audio of the sound of a musical note from a transverse flute was imported into the *Sky Dust* synthesizer (see figure 70). I had to detune oscillator 1 by +23 Cent to conform to the tuning of the harmonic base of the beginning and ending music (see section 2.4.2).

I only applied the *Bit Crush* effect from the *Sky Dust* synthesizer to get the desired result (see figure 71).

Figure 70 - Oscillator 1 of the Transverse Flute preset.

Figure 71 - Effect applied to the Transverse Flute preset.

Classical Guitar Preset

In the case of the Classical Guitar preset, the audio of the sound of a musical note from a classical guitar was also imported into the Sky Dust synthesizer, as already mentioned in section 2.4 (see figure 72). I also had to detune oscillator 1 by +23 Cent to conform to the tuning of the harmonic base of the beginning and ending music (see section 2.4.2).

I applied the *Sky Dust* synthesizer's *Bit Crush* effect once again to get the desired result (see figure 73).

Figure 72 - Oscillator 1 of the Classical Guitar preset.

Figure 73 - Effect applied to the Classical Guitar preset.

Sound Composition

Initial and Final Music

Since the story takes place in a coastal village, for the initial moment I opted for a calm atmosphere with a selective realistic approach (Kaye & Lebrecht, 2009, pp. 19-20), that is, an approach in which some sounds representative of a wider environment are used, while still trying to create an immersive atmosphere that reflects the natural elements of the town, such as the waves of the sea, seagulls cawing and flying, and the church bell ringing (compare table 1). To complement this moment, I decided to compose a short music with a happy and comforting melody, working as a framing effect (Kaye & Lebrecht, 2009, pp. 22-23). For this purpose, I selected the sound of a transverse flute, accompanied by a harmonic base with a sound close to that of a pipe organ (see section 2.4.2), so that both could give the suggestion of a sea breeze, however vague.

In the final moment, peace is gently restored and celebrated in the village, so I chose to use the same short song from the opening moment, but with the addition of classical guitar chords and a light conga rhythm (see section 2.4).

I chose the key of G major for the music with a happy melody, since the emotional characteristic of joy tends to be related to the scales of the major mode of the tonal system (Levitin, 2006, pp. 36, 38) and the emotion of courage, confidence, and celebration tends to be conveyed by this key as well. The harmonic progression of the song then consists of the following mainly consonant chords:

||: A Major – D Major – C Major – G Major :|| E minor – B minor – C major – A major – G major – C# half-diminished – C major – D major – G major || (see figure 74).

Figure 74 - Harmonic basis of the initial music.

As for the tempo of the music, I chose a tempo of 100 beats per minute, as it still offers a certain idea of tranquillity and moderate energy, using four-time signatures (4/4).

I used a syncopated rhythm in the transverse flute melody to provide a sense of fun and liveliness, using different dynamics of the notes played to emphasize this (see figure 75). Starting with an ascending Perfect 4th interval (E – A), the antecedent of the initial melodic phrase, consisting of the first 4 bars, develops until the interval closes on the note G in the 3rd bar, ending then in a descending manner on the note D in the 4th bar. The consequent of this phrase (bars 5 to 8) ends, in turn, in an ascending manner on the note B, as if it were a question, to give continuity to the following melodic phrase. In the latter, the same principle was applied regarding the intervals between notes, ending up closing the intervallic leaps on the note G in bar 17.

Figure 75 - Melody staff of the transverse flute.

Transition between the 1st and 2nd Moment of the Story

The transition from the 1st to the 2nd moment of the story begins to be prepared with the slow crescendo of Lucas's footsteps on the sand, which can initially be heard on the left side. The 2nd moment of the story effectively begins with Lucas opening the heavy wooden door of the lighthouse. From then on until the final moment of the crystal purification (moment 8 of the story), the listener's listening point in the centre of the sound reproduction system becomes Lucas's own listening point.

Entrance to the Abandoned Lighthouse

As Lucas enters and takes 5 steps into the lighthouse, the sound of the ocean waves loses its high pitch and turns behind Lucas. From the moment the door closes behind him, I insert a moment of silence of approximately 2 seconds, to increase the tension.

Creation of the Mysterious Voices and the Voice of the Spirit

After the door closes behind Lucas, he takes 3 more steps and stops suspiciously. A melody then begins to be heard in the distance in a crescendo in front of Lucas, followed by mysterious voices all around, a child running and laughing, the jingling of keys, water running, and 8 clock ticks. The mysterious and dark voices, as well as the voice and laments of the spirit in moments 6 and 7 of the story ("Fight with the Spirit" and "Liberation of the Spirit"), were created based on the ghost voice effect used in the 1982 American supernatural horror film *Poltergeist*, directed by Tobe Hooper and written by Steven Spielberg, Michael Grais and Mark Victor, based on a story by Spielberg (Wikipedia, 2025). This effect consists of recording a voice on an audio track, reversing its audio, generating a new audio file with the addition of reverb to the reversed audio, and finally reversing this last audio file again. I therefore used my voice for this purpose in the story.

Transition to the 3rd Moment of the Story

The storm begins with the sound of thunder coming from ahead and above when the 8th tick of the clock is heard. First it starts to rain gently, but then it rains aggressively, and the sea waves become more violent when the 2nd louder thunder is heard. This leads the listener to follow Lucas running away, hearing the rain moving away behind him.

Transition to the 4th Moment of the Story

After Lucas gets a good while away from the storm, he stops to rest a little. But a haunting and repetitive melody begins to be heard coming from the front, in the minor key, from a music box that represents the crystal. First from a distance, then up close as Lucas approaches the crystal in the secret room. The minor key was selected to give the impression that the crystal is haunted.

Transition to the 5th Moment of the Story

As Lucas approaches the crystal in the secret room, the melody and the pulsating light sound of the crystal can be heard more intensely from the front, as well as its captivating vibrations all around. For Lucas's touch on the crystal, I used the *Sky Dust* synthesizer to produce an electrifying signal during the contact and a delayed (echo) tuning fork signal after the contact with the crystal.

Transition to the 6th Moment of the Story

As Lucas touches the crystal, one begins to hear mysterious voices and furious winds all around, as well as the voice of the awakening spirit that haunts the crystal. The sword fight between Lucas and the spirit ensues. Meanwhile, the crystal melody is distorted with the help of the *Multiply Chorus* plugin, from *Acon Digital*.

Transition to the 7th Moment of the Story

The liberation of the spirit occurs when Lucas kills the spirit. The mysterious voices and raging winds dissipate, leaving a brief silence from the crystal.

Transition to the 8th Moment of the Story

With the death of the spirit, I decided to represent the purification of the crystal with the return of its melody in the major key. After the box containing the crystal is closed, there is a moment of silence that announces the approach of the end of the story with the restoration of peace in the village (moment 9).

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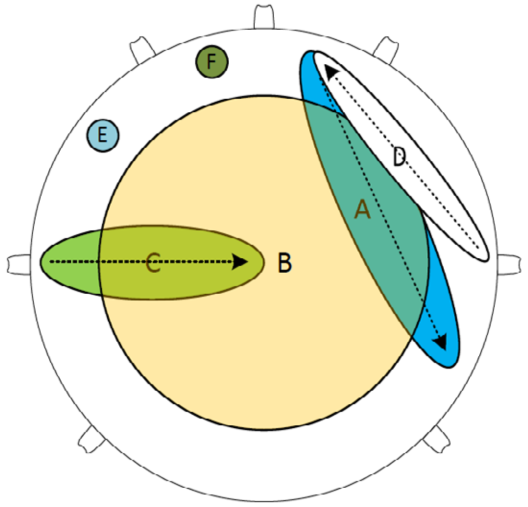
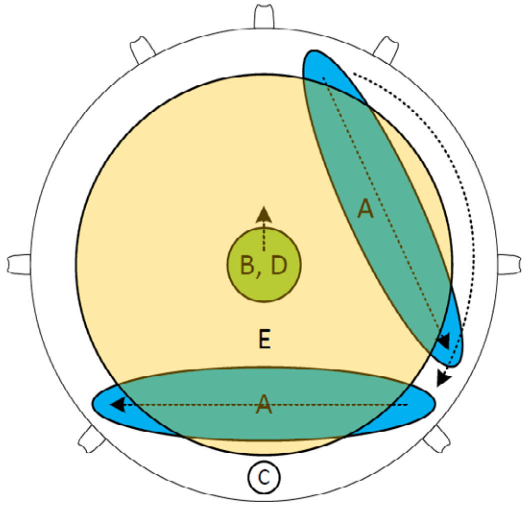
1. The Coastal Village



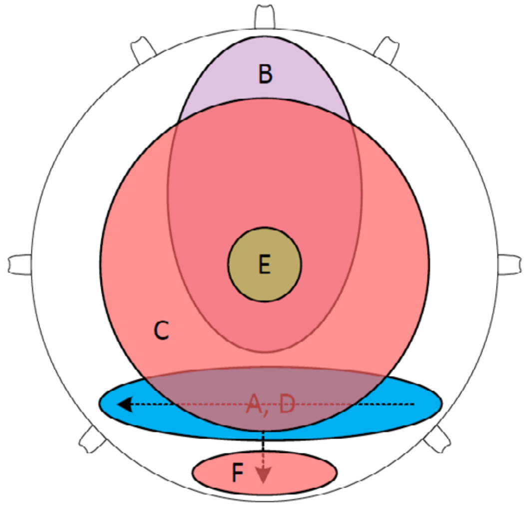
A. Forward-backward movement, on the right, of gentle sea waves @ 20m (from start during 1 minute)
B. Music with transverse flute melody (after the 1st wave bursts for 45 seconds):
Flute heard from the front, chords all around
C. Footsteps in the sand coming from 07:00 @ 50m move to the centre (fading in from the beginning to the end of the song)
D. Seagull squawking 5 times and flying from right at 03:00 to left at 12:30 @ 100m @ 30 degree tilt during initial melodic phrase, later squawking 4 times from 12:30 to 01:30 and again 4 times from 01:30 to 12:00
E. 10 church bell chimes at 10:00 am in the distance @ 400m after the 1st seagull squawk
F. Seagull squawks twice while sitting on the sand at 11:00 am @ 30m after the second ring of the church bell and again twice later

2. The Abandoned Lighthouse



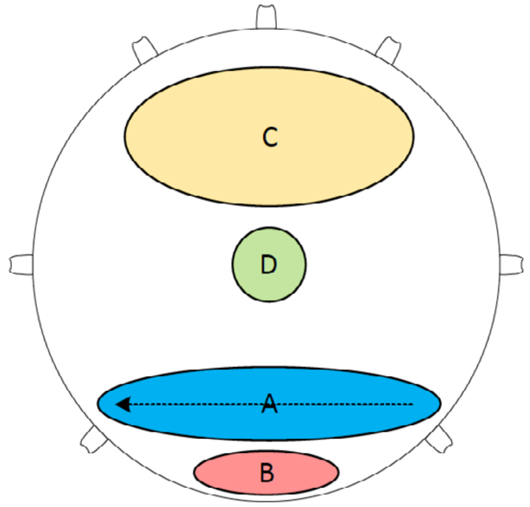
A. One continues to hear the sea which loses the treble and turns backwards as Lucas enters the lighthouse and takes 5 steps
B. Lucas opens the lighthouse door in front of us, enters and takes 5 steps (listening point follows the steps)
C. Door closes behind Lucas at 06:00 @ 4m from step 5
D. Lucas takes another 3 slower steps (listening point follows the steps)
E. A melody is heard in a fade-in voice between 10:00 and 02:00, mysterious voices are heard all around, a child running and laughing, keys jingling, running water, 8 clock ticks

3. The Storm



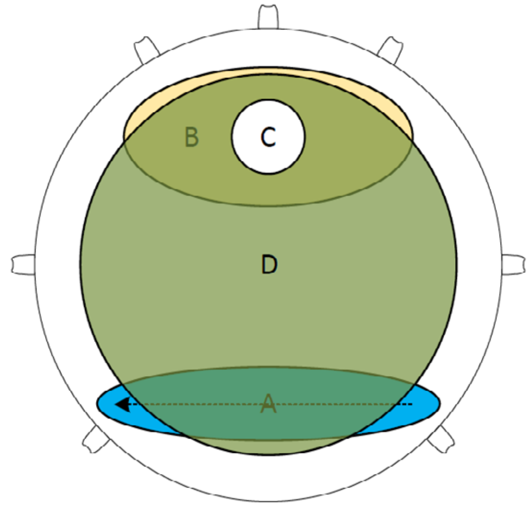
A. One keeps hearing the sea outside behind
B. Sound of thunder coming from above and ahead when the 8th tick of the clock is heard
C. It starts to rain gently and then aggressively from above
D. Sea waves become more aggressive
E. Lucas runs away (listening point follows the steps)
F. Rain goes behind Lucas as he runs

4. The Lullaby



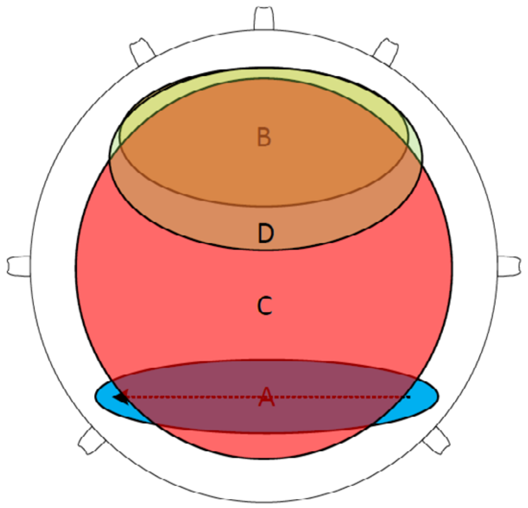
A. One keeps hearing the sea outside behind
B. One keeps hearing the rain behind Lucas in the distance
C. A haunting and repetitive melody is heard, in the minor key, from a music box (crystal), from the front, first in the distance, then up close when Lucas approaches
D. Lucas stops and then continues running until he gets close to the music box

5. The Secret Room and the Crystal



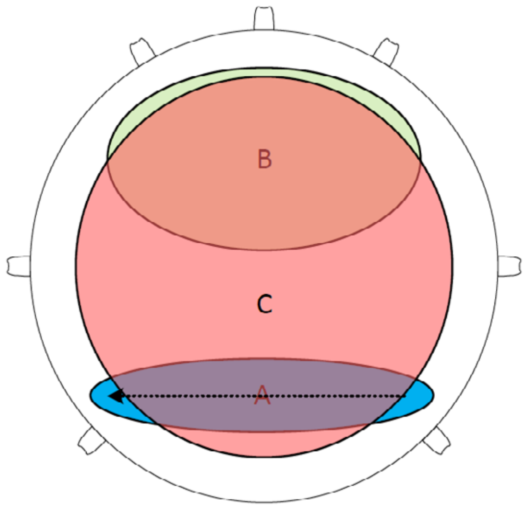
A. One keeps hearing the sea outside behind
B. One can still hear a haunting and repetitive melody, in the minor key, of a music box (crystal), from the front, but up close, when Lucas approaches
C. The sound of pulsating light from the crystal is heard simultaneously, from the front
D Captivating vibrations are heard all around at the same time

6. Fight with the Spirit



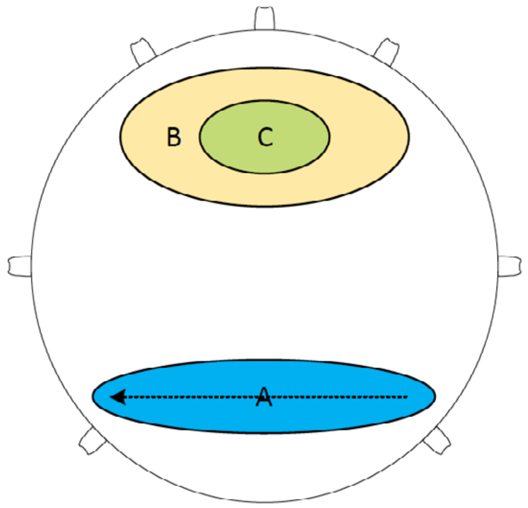
A. One keeps hearing the sea outside behind
B. Lucas moves even closer to the crystal and touches it, causing its haunting, repetitive melody to distort
C. Mysterious voices and furious winds begin to be heard all around
D. A sword fight between Lucas and the spirit can be heard ahead

7. Liberation of the Spirit



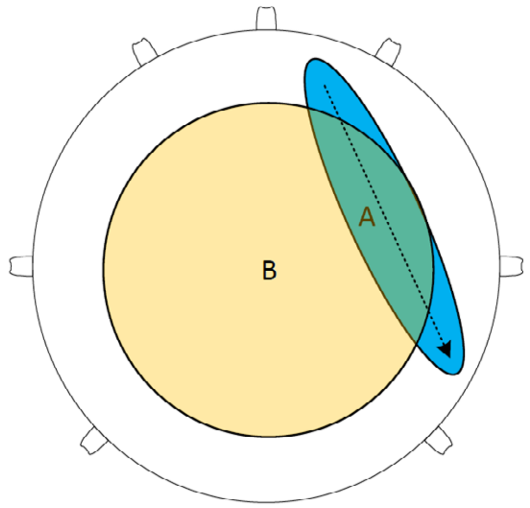
A. One keeps hearing the sea outside behind
B. Lucas kills the spirit with the sword
C. The mysterious voices and raging winds dissipate, and there is a brief silence

8. Crystal Purification



A. One keeps hearing the sea outside behind
B. One can hear the crystal melody in major mode, from the front, from close up
C. Lucas closes the box containing the crystal

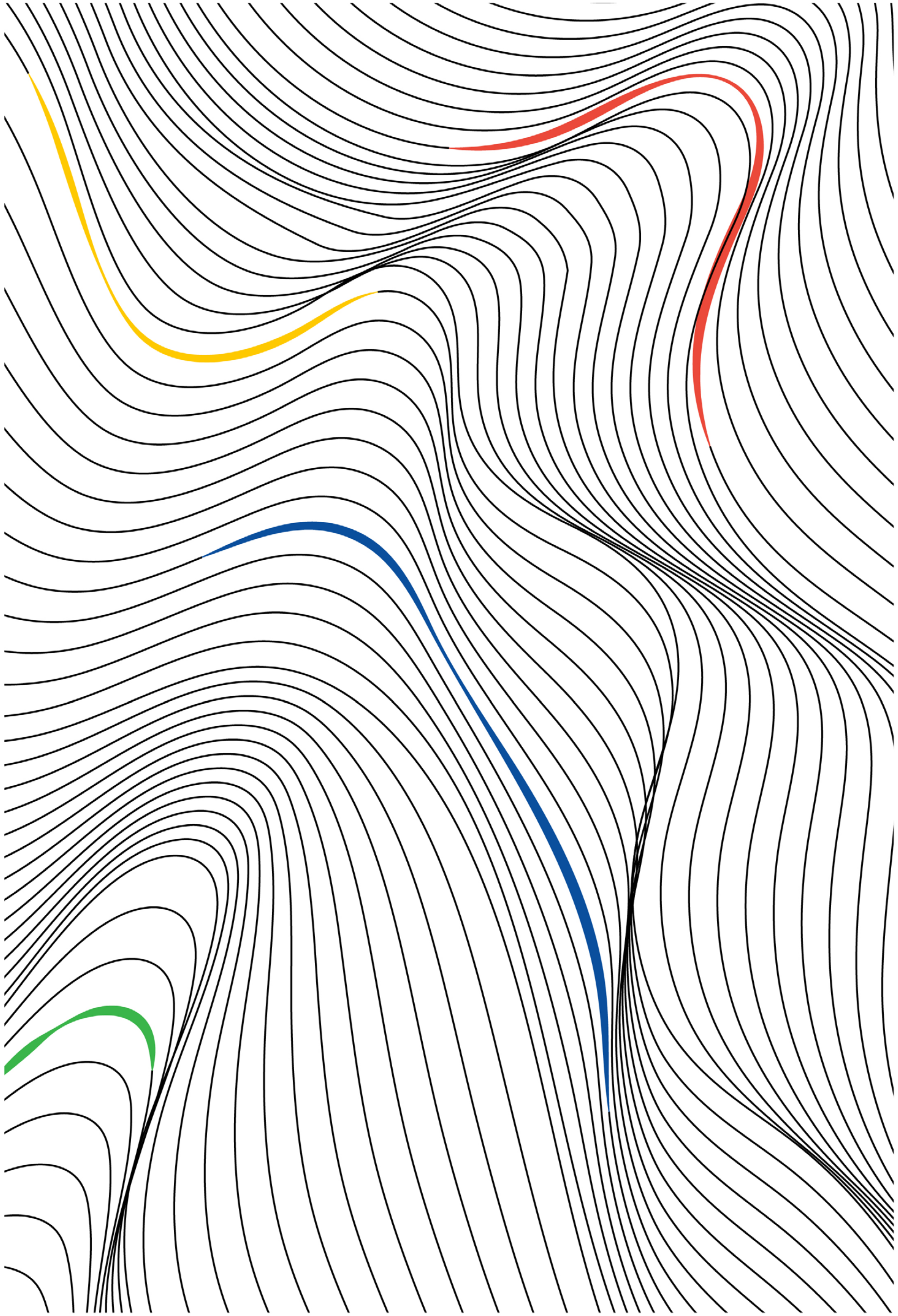
9. Restoring Peace in the Village



A. Front to back movement of gentle ocean waves @ 20m, on the right
B. Music with transverse flute melody:
- Flute is heard from the front
- Chords all around
- Classical guitar is heard on the left side at 10:30
- Conga rhythm fades in 12 seconds later

Note: The listening point is located in the centre of the listening area.

INSTITUTION: ESCOLA SUPERIOR DE MÚSICA E ARTES DO ESPETÁCULO
TITLE: The Secret of the Abandoned Lighthouse
SOUND DESIGN: Diogo Leichsenring Franco
DATE: 08-02-2025
VERSION: 16
SHEET: 02



Counterclock

Telmo Marques ESMAE - P.Porto

Counterclock – Telmo Marques

Duration: 6'

Counterclock is a six-minute electroacoustic piece that explores temporal inversion and the perception of sound space, inspired by Philip K. Dick's novel Counter-Clock World. The work develops in an acousmatic flow in which the sound matter seems to reverse itself, evoking a universe where time runs in reverse. Using the SkyDust synthesiser and the advanced spatialisation provided by Sound Particles, the sounds emerge, dissipate and reorganise themselves in a dynamic play of layers and three-dimensional depth. Between granular textures, spectral resonances and deconstructed melodic fragments, Counterclock challenges auditory linearity, inviting the listener to an immersive experience where past and future become indistinct.

Nothing Beside Remains... For Fixed Medium

Hugo M. Moreira ESMAE - P.Porto

Nothing beside remains... for Fixed Medium – Hugo M. Moreira

Duration: 6'

In the following section, I will detail the process and means by which the work *Nothing beside remains...* was created.

In October 2024, at the beginning of my Master's in Composition, I — among several other colleagues — was selected for the COMPETE 2030 project, "Spatial Synth — Sintetizador Espacial". As I was briefed at the beginning of the research grant, the project entailed becoming familiar with SkyDust, a plugin developed by Sound Particles, S.A. and, essentially, beta-testing it. The output of the grant was to be twofold: two original compositions and the creation of the very same book you are reading right now. As for the compositions, *Nothing beside remains...* was the first, and was presented at Teatro Helena Sá e Costa in Porto, Portugal, on March 13, 2025.

Are you familiar with the expression "to take to something like a duck to water"? Well, whatever the opposite of that is is happened in regards to this project. I must confess that, unlike my more technologically-abled colleagues, I struggled a bit in the beginning. I found the interface clunky, the workflow obtuse, and, quite frankly, found that the plugin answered a problem that wasn't even there to begin in. After all, there exist already a plethora of tools by which to spatialise music, some of which are explained at length elsewhere in this book, and I found that SkyDust made the process no simpler or more efficient.

Early on, despite my reservations, I decided to be as *faithful* as possible in my approach, perhaps even to my own artistic detriment. I decided to use the plugin *as-is*, making use only of the factory presets. I felt that doing otherwise — be it by tinkering with the presets or creaitng new ones — would be a bit like cheating. In doing so, I backed myself into a corner, perhaps, but I thought that that would be the more honest approach. In composition, and in life in general, we are taught to first learn the tools, before breaking them.

My approach was, perhaps, unusual. Because of the specific nature of the plugin and the peculiar workflow it entailed, I decided to first compose the work entirely in Dorico, my preferred notation software, rather than directly on a DAW — as one would typically go about doing these things. I set about writing a piece for Piccolo, (Bass) Clarinet, Horn, Percussion (Timpani, Glockenspiel, Vibraphone and Tubular Bells), Mezzo-soprano, 2 Harps, Violin and Cello. Because the work was not never meant to be performed in a live setting by acoustic instruments, I wasn't particularly concerned with things like instrument range or the feasibility of what I had written.

Material-wise, a lot of it came from trimmings I had collected from a previous, never performed, piece for Mezzo-soprano, Clarinet, Horn, Percussion, Harp and Viola, based on Percy Bysshe Shelley's *Ozymandias*. Below are some sections of the piece as initially notated:

Figure 1. Section A, featuring some acoustically impossible requests: a crescendo on a sustained note on the Vibraphone and a particularly high B on the Bass Clarinet.

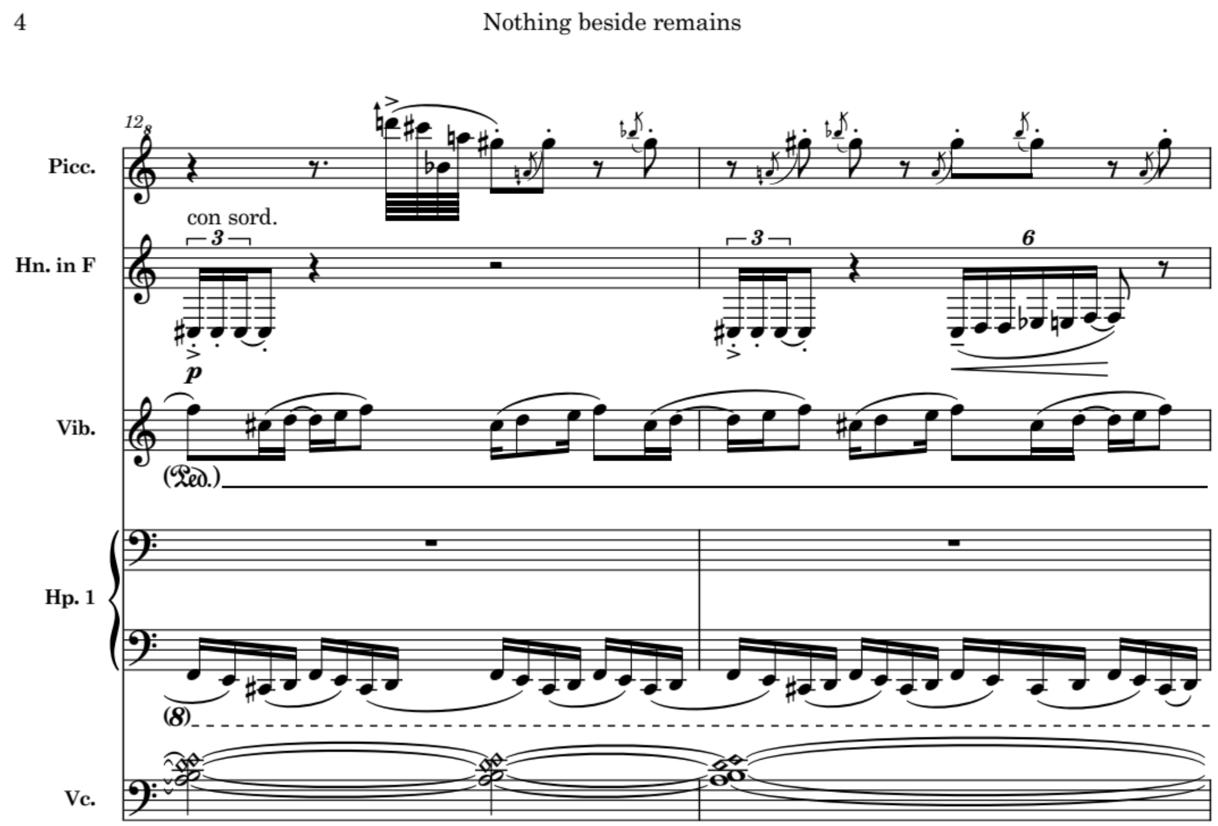


Figure 2. Section B, featuring more improbabilities if not outright impossibilities: rapid eighth tone figurations on the Piccolo and sustained quarter tone artificial harmonics on the Cello.

After carefully notating the piece, I exported the MIDI tracks for each instrument and imported them to Reaper, my chosen DAW. I then applied the SkyDust plugin on each track and assigned a different preset to each in order to more or less match my intended orchestration. For example, the Harp was the "Broken Harpsichord" preset, the Vibraphone the "Ethereal Keys" preset, and so on. Lastly, I tried to play around with the dynamics of each track using the automation tools provided by Reaper. Finally, I patched everything through an Ambisonics Bus and rendered the project in 64-channels (7^{th}-order Ambisonics).

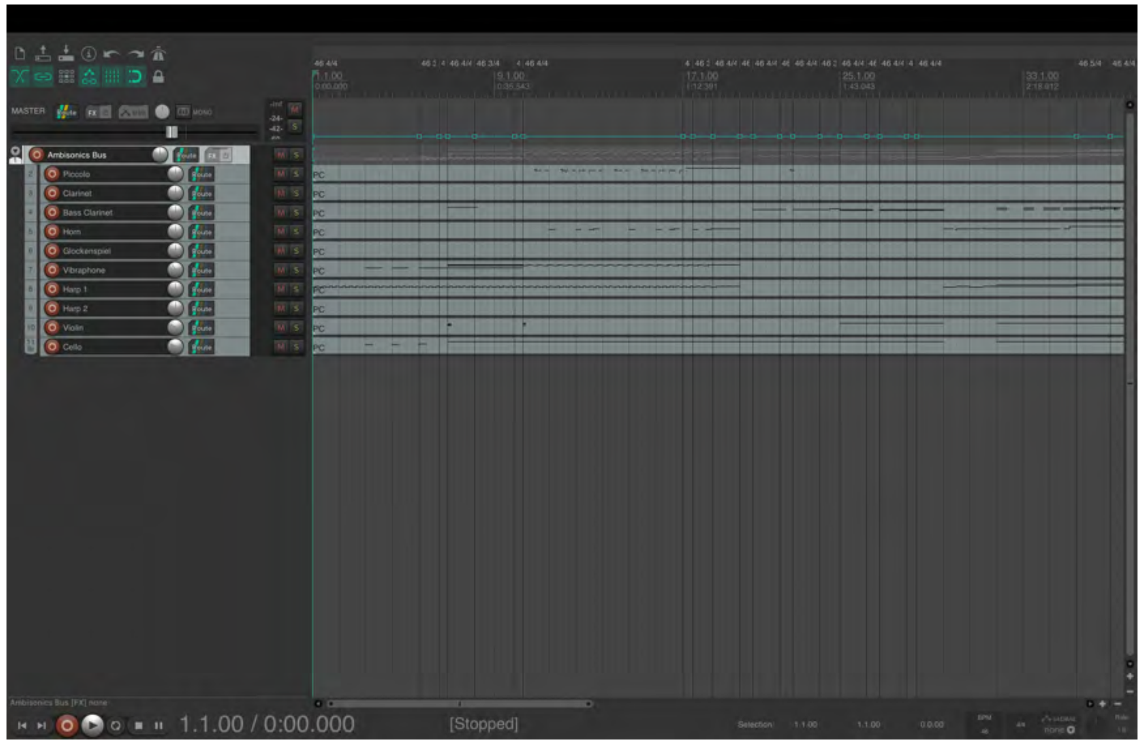


Figure 3. MIDI track appearance after importing into Reaper.

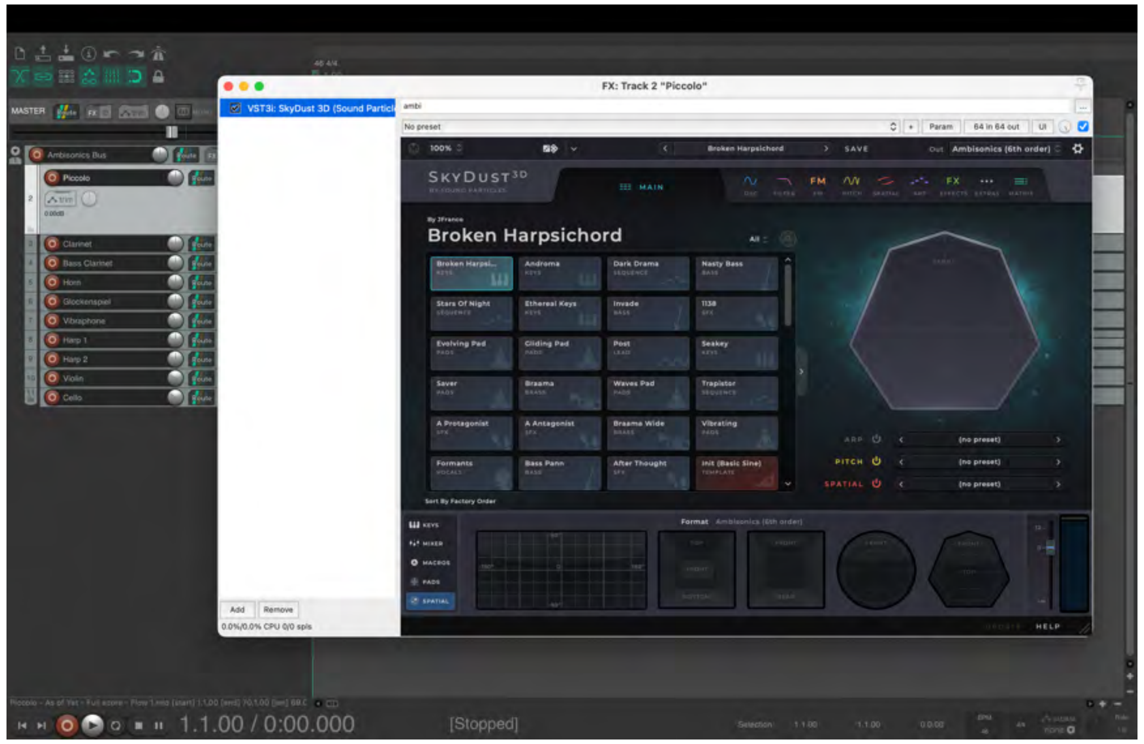


Figure 4. SkyDust plugin appearance and preset list.

Cachaça, quindim. Choro no além-mar

Sann Gusmão ESMAE - P.Porto

Cachaça, quindim. Choro no além-mar – Sann Gusmão

Duration: 8′

In this chapter, I will address the composition process and provide some context about the ideas behind the sound piece *cachaça, quindim, choro no além-mar*. The piece was produced as part of the COMPETE 2030 program – *Spatial Synth – Sintetizador Espacial*, coordinated by ESMAE (Escola Superior de Música e Artes do Espetáculo, of the Polytechnic Institute of Porto) and Sound Particles, S.A., and presented on March 13, 2025, at Teatro Helena Sá e Costa, in the city of Porto, Portugal.

Sea as image and choro as meaning

The sound of the sea enveloped me, first as a nostalgic evocation, then as a body in constant transformation. My fascination with the sea led me to spend several years recording its sound on the beach that borders the city where I was born. Nearly a decade has passed since I last lived in that city, and I felt the urge to return to those recordings to begin developing this
piece I was to compose.

I felt the presence of the sea should be literal, to avoid attempting a mimetic representation through synthetic sound, and also because I believe that, although my intention as a composer is relevant to my choices in shaping the material, this interpretative dimension should be minimized. That is, for the listener, what matters is what is there, rather than what I might supposedly be trying to say. Nevertheless, I focused on the image of the continuous undulation, a mutating identity, that the sea suggests to me.

Choro emerges as a fold—not just a thematic addition, but an inflection in the sonic field, an intensification of its multiplicity. Here, choro manifests both as gesture—the act of crying, fragile, affective, bodily—and as the Brazilian musical genre. This polysemy is not a semantic accident but part of the piece's differential operation.

In the piece, this overlay of meanings—crying and playing *choro*—acts as a sonic image of nonconformity. The crying-gesture, when intertwined with the *choro*-genre, undoes the possibility of a single interpretation. Instead of reinforcing a specific emotion (like sadness), the piece allows this double meaning to produce deviations. Sadness, if it exists, is not directed.

It is traversed. The genre, if present, is not thematized. It is strained. This use of *choro* expands the differential field already proposed by the sound of the sea. Both elements—sea and *choro*—operate as intensive forces that escape representational logic and together construct a sonic plane in becoming.

"Let it act," I thought. This guided my process. I tried to let the image formed between recorded and synthesized sounds—concrete or musical—suggest a constellation, an assembly of points at different scales, distances, and relations. Seemingly disparate quotations, but juxtaposed, that despite the musical form's obligatory linearity, do not resolve into a single narrative.

Spatial technologies in the poetics of gesture

Space is not a neutral stage or merely an external dimension where sounds are located. I rather like to understand sound spatialization as more than just the distribution of sound sources in space: beyond serving to give room to the sounds or create compositional complexity, or to simulate a specific real-world or natural acoustic experience. I want to explore the poetic aspect of how the body and technology mediate the experience of the world.

The piece was composed in 3rd order ambisonics, in ESMAE's immersive studio, which features 16 speakers and a subwoofer. Thus, I was always immersed in this three-dimensional sonic space, and without a doubt, the experience was entirely decisive in how I received and shaped the form of the sound. Space, in this case, is a constitutive part of the piece—a vibrational body that responds to and transforms with the sound. But it's a two-way path: it's in how sound summons the body—and also how that body, in listening, produces the space.

It is important for me to define this aspect of technology as going beyond the technicalscientific apparatus, as a mode of modulating the senses, a way of articulating between the body and the world. Because it is from this experience that I approach the software, aiming to invent my compositional space—more so than simply perceiving algorithmic codification or understanding spatialization software functions.

In this way, my choice of spatialization parameters is secondary to my understanding of the technology. And perhaps, before showing practical applications, I want to make clear that as a composer, I am also this body that listens and is traversed in/by space and, at the same time, constitutes it. It's at this point that technology dissolves into the embodied experience of listening, and space emerges not as a geometric figure, but as a sensitive force. Thus, the spatialization of the piece, although technologically coded in ambisonics, is realized in listening as dynamic perception. The body does not merely occupy space—it forms its own sensitive field. Each act of listening is an invention of space. And if there is a poetics here, it lies in the experience of getting lost and remade within that field: listening as one who gropes for some world.

On the compositional process

As I mentioned before, I appropriated the idea of image to gradually build the structure. I tried not to anchor myself to any predetermined form of thematic development—even though I invoked the choro genre, it participated more by suggesting instrumental timbres and some rhythmic markings. The compositional gesture emerged from a material and plastic relationship with sound—closer to sculpture than to linear writing. A sculpture made with found, provoked, transfigured sounds—not sounds meant to say something, but sounds meant to form something. Something that only exists in relation, never in isolation.

The first impulse came from the mandolin—I asked a friend, mandolinist Fernando Duarte, to record some chords and single notes, chosen according to a criterion of randomness. These fragments served as the initial raw material, treated like plastic objects: cut, stretched, granulated, and glitched. Their internal musicality, inevitable, was not denied but rather tensioned—or better, absorbed into the piece's general logic as a first sonic body around which others clustered.

The use of field recordings inscribes the "noise of the world" into the fabric of the piece—not as documentary reference, but as a texture of presence that refers to itself, without idealization or reduction to a "sound object."

Besides the mandolin, the instrumentation—as already mentioned—absorbed timbres associated with choro: flute, saxophone, pandeiro, surdo, and snare drum. What interests me is the friction between the recognizable and the displaced: sounds carrying stylistic memories but articulated in unusual ways (this also applies to my use of concrete sounds). They enter and exit without adhering to complete phrases, like moving ruins of a language.

In some moments, these sounds are material for synthetic granulation, as heard at the beginning and in the final sections with the mandolin. In other moments, the process is simple and even rudimentary, resembling sampling with tiny cuts and collages—though still recognizable (longer than half a second, not a grain; for the purposes of this text, I call them "micro-samplers"). This can be heard, for instance, around 1′50″ to 3′, in the montage between pandeiro, mandolin, saxophone, and flute.

In these cases, where I worked with recorded sounds (musical or otherwise), I used three different methods for spatialization. The most efficient for handling micro-sampled elements was the IEM ambisonics encoder. The other two involved Sound Particles S.A. software: the Sound Particles program, where the grain concept is expanded; and Sky Dust, which allowed spatial composition through the option to use an imported sound file as an oscillator.

In the following two images, I present an example of spatialization using various complementary tracks. The first image shows an overview of the specific section with the pandeiro, where there is a mix of stereo tracks spatialized using the IEM encoder and 3rd order ambisonic tracks created in Sound Particles. The second image shows one of the tracks composed in Sound Particles.

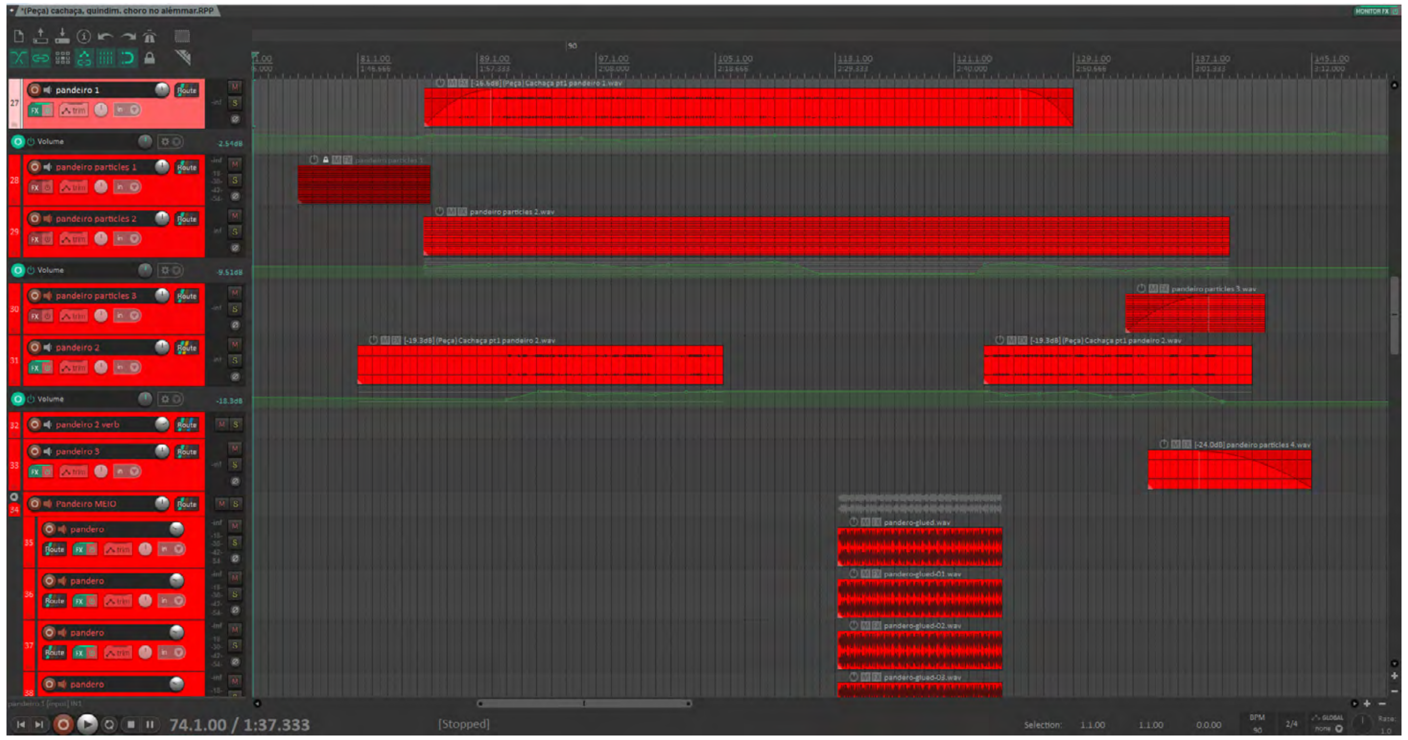


Figure 1: Overview of the pandeiro section.

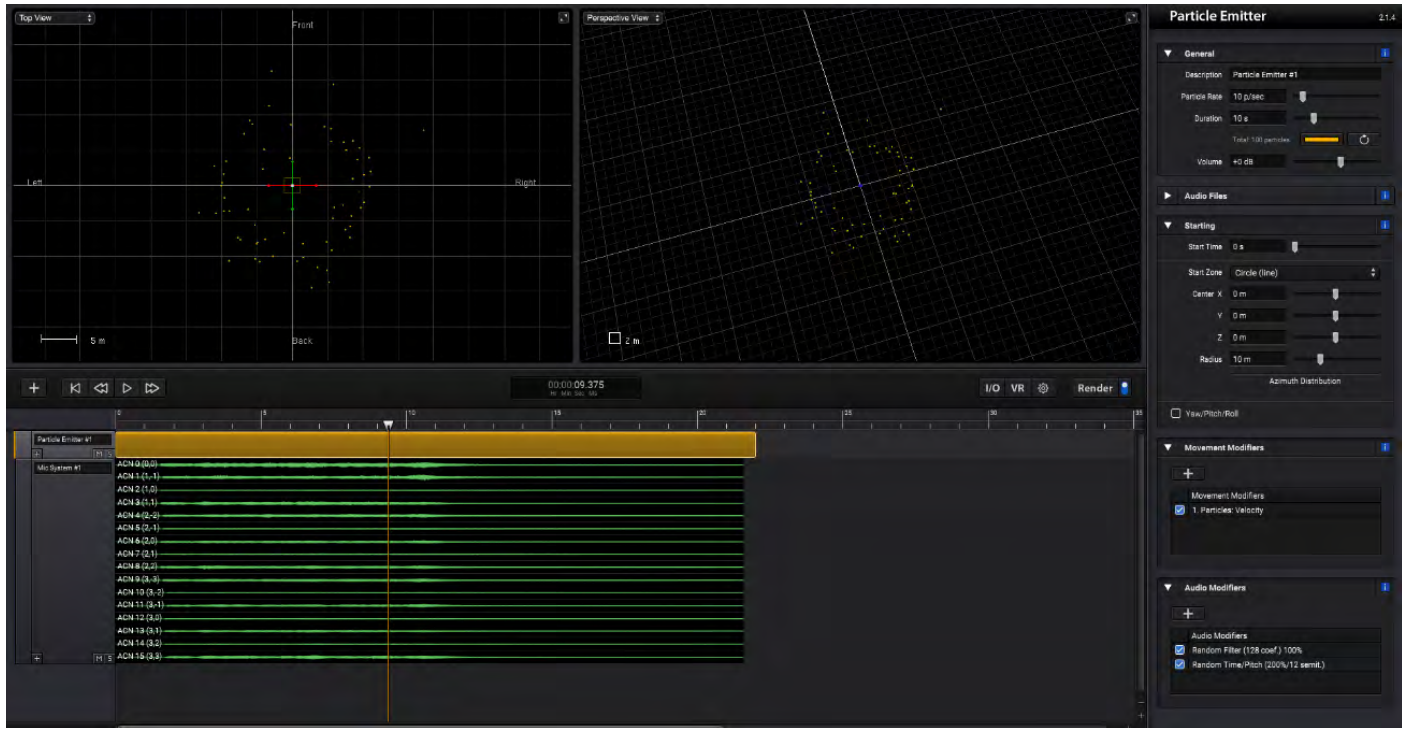


Figure 2: An example of the use of Sound Particles.

In many cases where I used Sky Dust to spatialize a pre-recorded sound, I also duplicated the voices, overlaying different spatialization patterns on the same sonic material. This gave me compositional control almost like a polyphony of space. I realized I could better guide the sound's movement in space by playing with volume automation across tracks occupying different spaces—beyond what the synthesizer's own controls offered.

Figure 3: Use of the Sky Dust oscillator with a pre-recorded mandolin sound file to compose the 3D space.

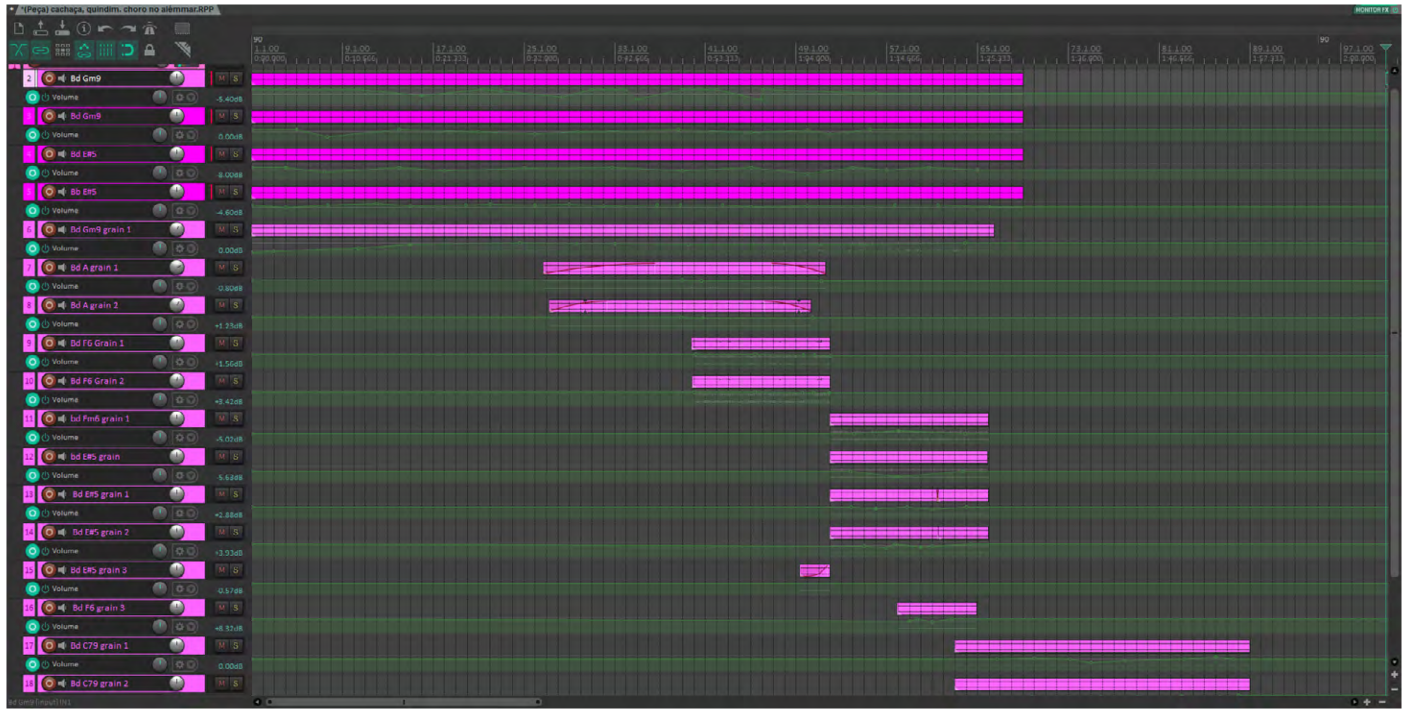


Figure 4: Overview of the initial section with a mix of various mandolin voices.

In another use of Sky Dust, I created lower frequency layers heard from 4’50” to the end of the piece. Here, I used Sky Dust with some of its presets, especially “Pb Bass”, not to construct a specific timbre, but to play with the default pattern and discover a less obvious application for its sound. The surdo and snare drum heard between 3’50” and 6’08” are also Sky Dust presets, respectively “snare” and “timpanee.”

To conclude, I return to the form—shaped by a drift between differentiations and intensities. One sound suggests another, one texture resonates or repels another, and this interplay creates transitions, fractures, extensions. There is continuity, but not through lineardiscursive linkage. Out of preference, I try to view a sound piece as a canvas onto which images are projected, leaving their traces behind.

Técnicas de Natação

David Teixeira da Silva ESMAE - P.Porto

Técnicas de Natação – David Teixeira da Silva

Duration: 12′

Técnicas de Natação was composed at the end of 2024 and the beginning of 2025. It was written as part of the Spatial Synth grant, a partnership between the Porto School of Music and Performing Arts (ESMAE) and Sound Particles, a project co-financed by the European Union.

At an early stage, I started writing a piece that ended up not being performed. The premise of using the SkyDust plugin at the heart of the piece was important at first. However, I think I initially focused too much on this aspect and less on the form and characteristics of the piece. I ended up giving up on that first composition; I ended up trying to schematize things better in a second instance of composition, which ended up generating the work that would become *Técnicas de Natação*. Even so, the fact that I had used the synthesizer before meant that I already had a greater technical knowledge when writing the final piece.

As well as being the title of this composition, Técnicas de Natação is a poem by Jose Manuel Teixeira da Silva, included in the book *Os Pequenos Nós da Tempestade - poemas reunidos e inéditos* (Língua Morta, 2023). Assuming the elephant in the room of being the son of the poem's author, I think the poem is really beautiful and I had already thought about writing a piece inspired by it several times. I established the form of the work based on that of the poem, which is divided into three parts.

When composing a programmatic piece like this one, I'm always afraid of falling into the temptation to be literal or obvious. Despite this, I assumed that there were certain moods and atmospheres that the poem brought to me and that I wanted to be present at the moment of listening. As a first step, I decided to make some field recordings of the sounds of the sea and water in general. I took advantage of the fact that I had recently bought my recorder to make this work also serve as a way of learning new ways of capturing sound, something I wasn't very familiar with. I did some field work, the main part of which was on Leça da Palmeira beach, capturing sound in different ways and at different times, also using my LOM Geofo n to capture bass vibrations in the sand on the beach. I also made some recordings at home, capturing taps, irrigation systems, showers and even some rain recordings. As you can see, in Reaper's project, the field recordings (in red) dominate most of the tracks. These recordings are without much processing, I just adjusted some volumes and used little equalization.

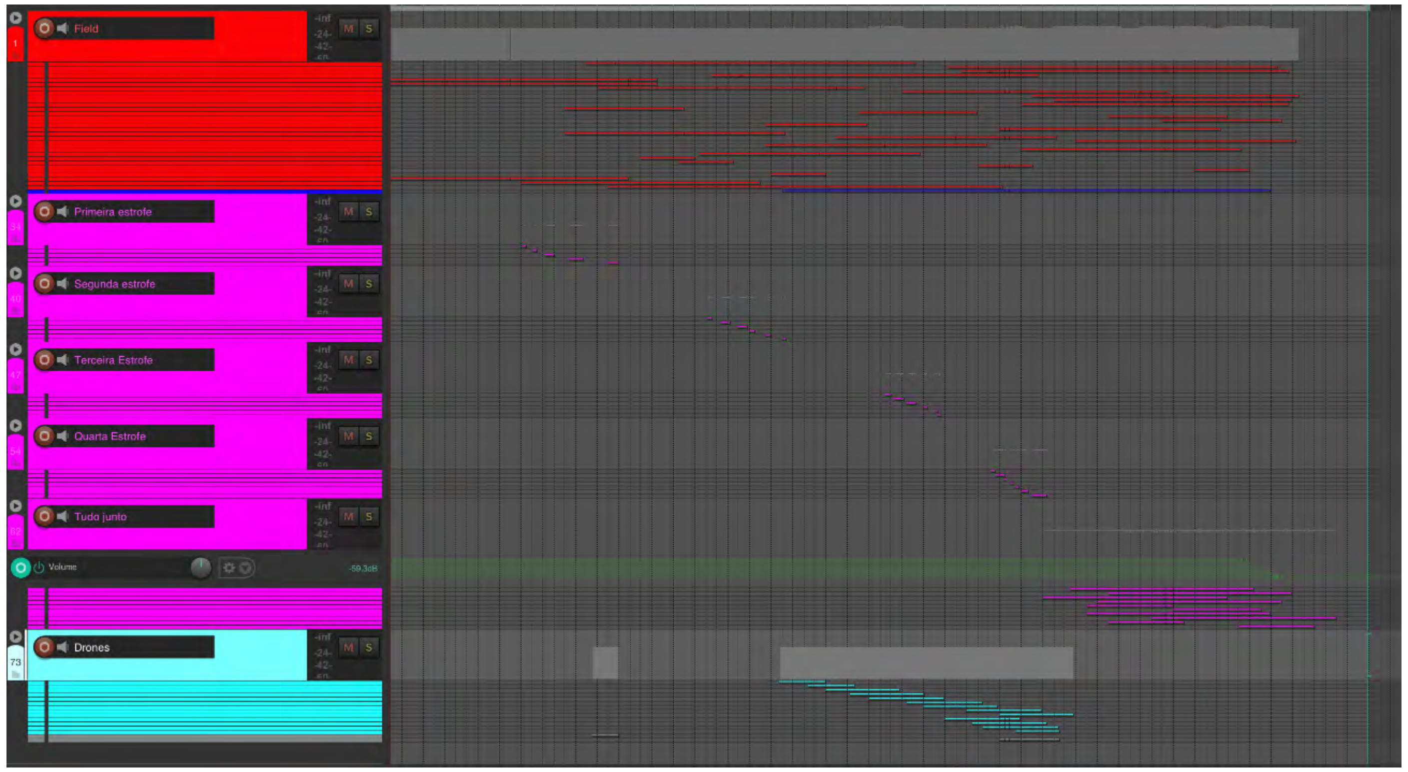
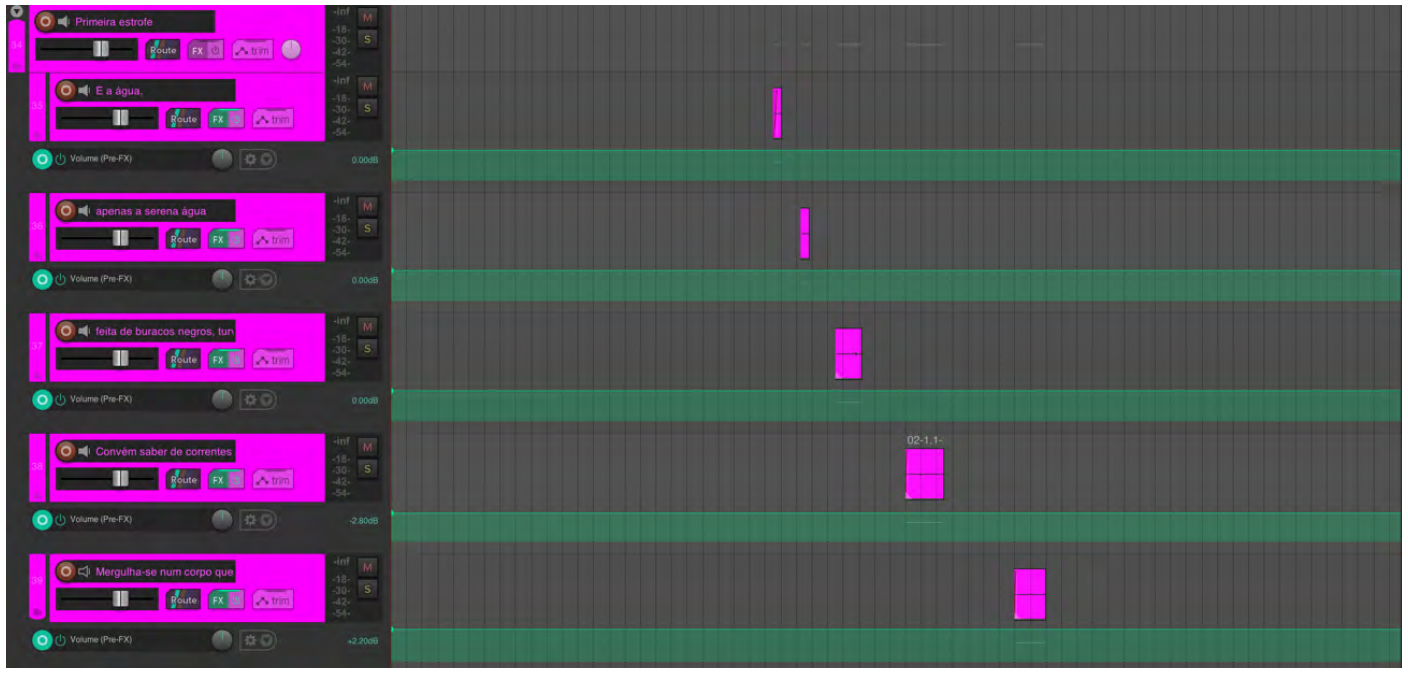


Figure 1: Reaper's Project of *Técnicas de Natação*

When I made the choice to write a piece based on a poem, I decided to do something I hadn't done before: have the poem recited throughout the piece. To do this, I asked my friend and composer Catarina Sá Ribeiro, whose interest in poetry I already knew, to be in charge of the reading. In several takes, the recording was made in ESMAE's studios, so that I could cut the poem during the natural pauses in the reading. The different cuts are visible in the project; this example is in the first stanza:



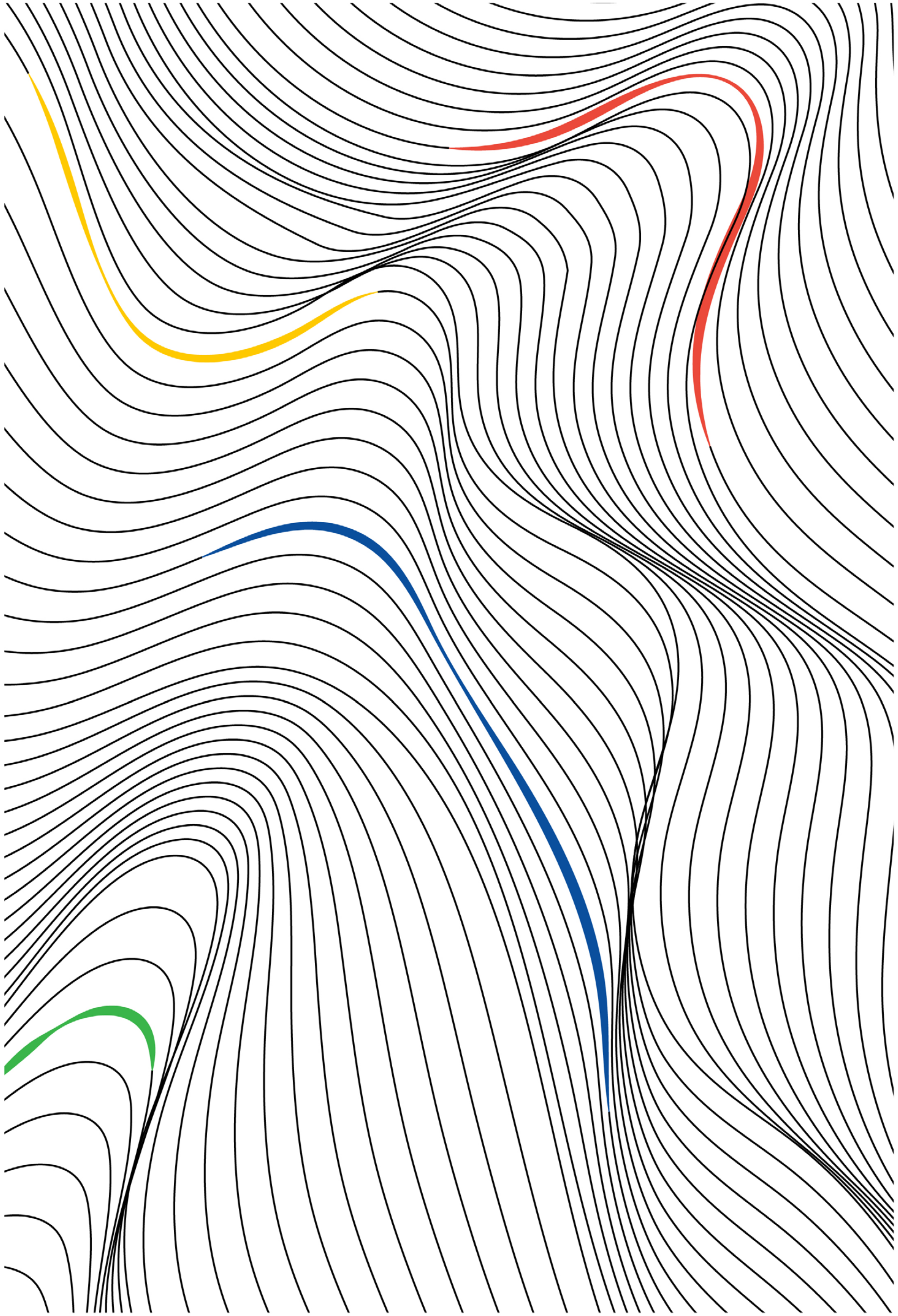
Due to the qualities of the materials in the piece, I thought it best to use SkyDust to spatialize the different sounds rather than as a normal synthesizer. In the different divisions of the voice, I tried to balance the different words in space. To do this, I created just one oscillator (using the "Import Audio File" feature), whose sound source was the recording I wanted to spatialize. In the image below, you can see how I used one of the presets in the spatial section to make the voice rotate a little; I used this option many times and then, in the next verse, inverted the different values so that there was almost a "spatial stereo", almost a question-answer in space:

Figure 3: Example of the spatialization of a voice

As you can see, in Figure 1 there is a cyan blue section called "Drones", which was the last way I used SkyDust. As a support to the piano section (which I'll describe next), it's mostly used for the notes present in the electronics section. Once again, these were spatialized with the help of the presets in the synth's spatial section. I used samples of instruments from the University of Iowa Electronic Music Studios; then I processed them with the Hologram Microcosm effects pedal; finally, I added them to SkyDust, always using the same base note, just with a few fifths.

At the same time as I was writing the electronic part, I chose to use a piano, which was quite soft and set the different moods of the poem to music, being played in real time. I decided that the best way to synchronize the piano with the electronics was to have some reference points in the score, most of which were the text that was being read, as you can see in the following image:

Técnicas de Natação emerged in the context of this research grant and explores spatial dimensions through the duality of acoustic instruments and electronic music. This piece is also researching the links between words and music, creating new environments for sound exploration.



Sonho de Kairós

Ana Rita Costa ESMAE - P.Porto

Sonho de Kairós – Ana Rita Costa

Duration: 7'

Sonho de Kairós began with a haunting question: What do I want to say regarding the tool of spatialization? What is my message? And last, but not least, *What is the role of the artist nowadays?* This questions, simple yet disquieting, led me to revisit *Lisbon Story* by Wim Wenders. In it, the late Portuguese filmmaker Manoel de Oliveira appears, reflecting on art, cinema, and the nature of creation. His voice — timeless, wise, lucid — is a sweet reference for me. I decided to place it in conversation with my own: two voices, two temporalities, suspended in sound, creating like a time machine, where past meets the present and future.

The title refers to kairos, the ancient Greek concept of time not as something measured, but as something lived — the opportune, sacred moment. As opposed to *chronos*, the linear ticking of clocks, *kairos* is the time of intuition, of presence. I wanted to compose with that kind of time — not as structure, but as opportune momentum.

Conceptual Core

The work unfolds in suspension, avoiding linear development in favour of a space that invites listening, resonance, and breath. *Sonho de Kairós* opens an acoustic dreamscape where memory and presence coexist with equal intensity. Rather than following a narrative arc, the piece lingers in moments, allowing time to stretch and fold. In doing so, it functions as a time machine—reviving a voice while reshaping temporal relations, making absence tangible and presence subtly elusive.

It is through spatial motion, dimension, silence and decay that the work finds its form. My voice, intimate and grounded, hovers close to the listener — a whisper from here. Oliveira's, distant and elevated, echoes from above — like a cultural memory speaking from elsewhere. This verticality — earth and sky — has become a metaphor for the relationship between the present and the past. Between the doubts of now and those of the past, which will probably continue into the future.

Through the voice of Manoel de Oliveira, I reflect on the role of the artist — a role that, to me, is not just about producing or performing, but about **creating spaces for questions**. In an era saturated with noise, speed, and consumption, perhaps the artist is someone who pauses. Who listens deeply. Who resists the urgency of productivity in favour of resonance.

Influences

My approach was shaped by several artistic and conceptual references. Adrian Moore's acousmatic thinking, in particular, helped me understand sound as a way of constructing internal landscapes — not bound to image, but unfolding in space and memory.

At the heart of Sonho de Kairós lies the idea that sound can tell stories that words cannot. Not stories in the traditional, linear sense — but stories of textures, of spatial tension, of memory unfolding across time. Here, I was profoundly inspired by the work of Adrian Moore, whose approach to acousmatic composition taught me that sound is not merely a medium; it is a language of its own, capable of shaping internal landscapes and evoking non-linear narratives.

In Moore's work, I found a sensibility that aligns with my own: the sense that a piece does not need to "explain" itself but needs to resonate. It can move between intimacy and vastness, between proximity and distance, between the known and the unknowable. His use of gesture and spatial motion became, for me, a kind of blueprint — not to imitate, but to enter into conversation with.

For Sonho de Kairós, I envisioned the composition as an unfolding acoustic space, where each sonic element is a character, each shift in spatial positioning a chapter, and each silence a breath between lines. The voices — Oliveira's and my own — do not narrate a fixed tale; instead, they create a field of associations, where meaning arises through presence, tension, and release. This approach challenged me to think of sound not as decoration or effect, but as the substance of narrative itself. A rising spectral motion, a circling voice, a sudden drop into stillness — each becomes a narrative gesture, asking the listener to experience rather than decode. It is a narrative felt in the body, in the skin, in the space between one sound and the next.

Sound narrative, for me, is an art of temporal immersion: it invites the listener to linger, to surrender to a temporality outside of clocks and maps. It asks not "what does this mean?" but "what does this open?"

In this sense, Sonho de Kairós is more a listening space — an architecture of sound where voice, memory, and spatial motion intersect, creating a fragile and resonant form of storytelling.

I also drew from:

> **Denis Smalley's** concept of *spectromorphology*, which allowed me to think about sound as evolving shape — a temporal sculpture made of texture and frequency. The art of music is no longer limited to the sounding models of instruments and voices.
>
> **Alvin Lucier's** *I Am Sitting in a Room*, where repetition and resonance reveal the architecture of both voice and space.
>
> **Anna Thorvaldsdottir**, whose temporality feels geological — time not as movement, but as weight. "AIŌN" is inspired by the abstract metaphor of being able to move freely in time, of being able to explore time as a space that you inhabit rather than experiencing it as a onedirectional journey through a single dimension.
>
> I was inspired by **Cristina Carvalhal**'s *Quem Cuida do Jardim* (2023), a theatrical production that

invites us to reflect on the urgency of rethinking the future. The play imagines a dystopian world where humanity stands on the edge of extinction, asking what new patterns or ethics — especially those of care — could guide us forward. This provocation resonated with my own exploration of temporal states and artistic responsibility.

Online resources also helped me guide the technical exploration:

Sound Particles' YOUTUBE tutorials on 3D audio
E-book from Sound Particles "All you need to know about 3D Audio"

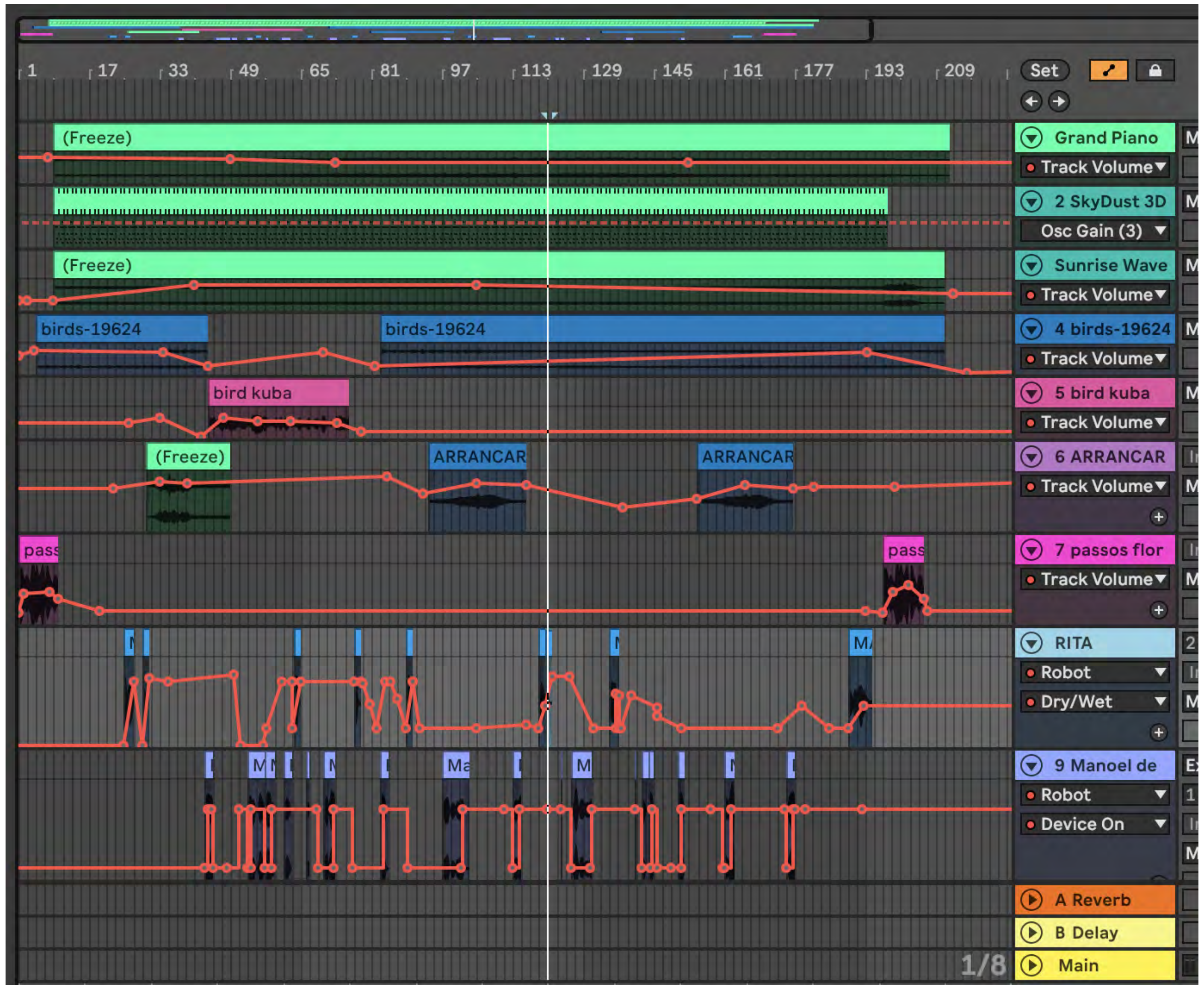


FIGURE 1 – Overall project in Ableton

Process and Practice

The piece was composed across Reaper and Ableton Live, using a combination of ambisonic tools (primarily the IEM plugin suite) and the SkyDust 3D synthesizer. Voice recordings were made using a TASCAM DR-05X field recorder and the MacBook M2's internal microphone.

The multichannel version was finalized at Studio C in ESMAE, using a 16-speaker array with subwoofer, where I could properly monitor spatial diffusion and make adjustments to the trajectories of sound sources. The final performance setup, however, was presented in the Helena Sá e Costa Theatre, using a 24-speaker system and encoded in 5th-order ambisonics (36 channels) — which allowed for a higher resolution of spatial detail and vertical motion.

Throughout the compositional process, I spent considerable time exploring and customizing SkyDust presets. Often, a specific texture or spatial motion discovered through the synthesizer would inspire an entire section or shift in the narrative of the piece. These moments of serendipitous sound discovery played a key role in shaping the emotional contour of the work.

To expand my interaction with SkyDust, I experimented with mapping various parameters to a MIDI controller. This allowed me to explore the synthesizer more physically and intuitively — twisting knobs, triggering envelopes, or panning sound sources across the 3D field in real time. These gestures occasionally led me to lose track of time and space, entering an immersive state of creative flow that paralleled the thematic concerns of the piece itself.

Some of the presets I designed during this process were saved and archived for future compositions. They encapsulate both technical configurations and emotional resonances — sonic sketches of ideas that may resurface in different contexts.

This hybrid approach — intuitive, technical, spatial, and poetic — became the core of my practice for Sonho de Kairós, where sound design and spatial movement were not secondary decisions, but the compositional material itself.

Oliveira's voice was carefully cleaned from a film extract in Audacity, preserving its knonw timbre while removing music and background from the movie. His voice was then spatialised above the listener, while mine remained in front — earthly, almost tactile.

FIGURE 2 – Spatial Format from Manoel de Oliveira's voice.

Oscillators

I worked primarily with two oscillators, blending basic waveforms (sine and triangle) with slight detuning to create subtle beating effects. These were not used for harmonic content, but rather as textural beds, underpinning the voices without drawing attention to themselves

• Oscillator A: tuned low, with mild frequency modulation (FM) to introduce instability and breathiness;
• Oscillator B: panned dynamically in space using LFO-controlled azimuth modulation.

Envelopes and Modulation

Amplitude and filter envelopes were elongated, mimicking the temporal fluidity of the voice material. Envelopes were used less for percussive articulation and more for slow spectral blooming.

• **ADSR Envelopes**: configured with long attack and release (up to 10 seconds) to support the suspended, floating quality of the pad;
• **LFOs**: mapped to spatial parameters (azimuth, elevation, and distance), creating evolving circular orbits around the listener;

Effects

I used a subtle chain of effects directly within SkyDust:

• **Multiband filter** to carve spectral space and define frequencies that I wanted;
• **Reverb** with high diffusion and large room size, simulating spatial decay ;
• **Doppler effect** (mildly) to introduce gentle pitch bending during movement, enhancing spatial perception without creating disorientation.

Spatial Movement

SkyDust's true strength lies in its real-time 3D positioning engine, where each sound particle can follow an independent trajectory. I created multiple automation curves to control:

• **Elevation** (for vertical motion);
• **Azimuth rotation** (synchronized with voice gestures);
• **Distance curves** (expanding and collapsing textures around the listener).

Dark Drama (Keys) preset with arpeggiator for melodic emotion

To add a melodic, emotionally charged layer, I selected the "Dark Drama" preset under the Keys category, activating the arpeggiator. The arpeggiated pattern created a sense of temporal unfolding — a cyclic, shimmering texture that feels both hypnotic and involving.

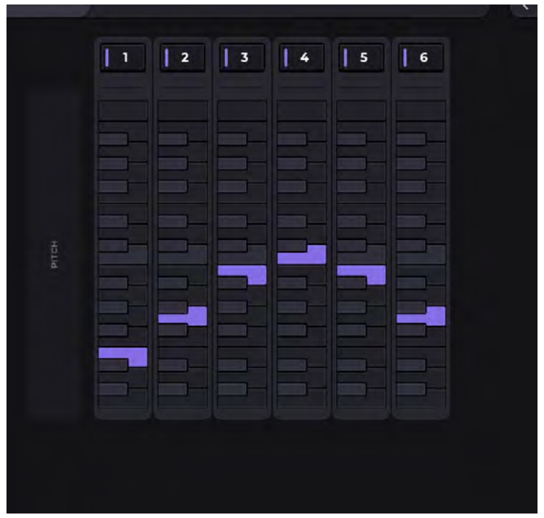


FIGURE 3 – The Arpeggio used with Dark Drama Preset

Arpeggiator Settings:

• Mode: Up/Down
• Speed: Synced to DAW at 120 BPM
• Octave Range: 2 octaves
• Force Scale: C Major

Wind preset with spatialisation across the room (Desolate Wind):

I used a wind-based preset, which was spatially distributed throughout the room using SkyDust's 3D spacial effect. This was essential to create a sense of environment — not just a background texture, but an enveloping sonic space that places the listener inside a breathing, moving atmosphere. The spatial trajectories of the 8 oscillators were set to float gently across azimuth and elevation, simulating the natural drift of wind around the audience.

Spatial Mode: Oscillator mode, random rotation and oscillation
Purpose: To create a surrounding, immersive atmosphere simulating air and impermanence.

FIGURE 4 – The 8 oscillators of the wind-preset

Pad with chorus and reverb for grandeur and pleasant space (Floater III)

A third layer was built using a soft pad enriched with chorus and reverb effects. The chorus introduced slight detuning and depth, while the reverb expanded the sound across the spatial field, creating a sensation of grandeur and open space. This layer functioned almost like an emotional cushion: it embraced the sweetness of the voices and grounded the composition in a comforting but purposeful soundscape. I positioned this pad slightly above the listener (elevation ~20°) to create a feeling of being enveloped from above.

Effects Applied:

- Chorus (3 voices, LFO depth 40%, rate 0.8 Hz)
- Reverb (room size: large, width: 75%, damp: 40%)

Bass line for narrative grounding (Big Ol_ Bass)

Finally, I added a subtle bass line to provide support and narrative weight. Without overwhelming the other elements, this bass acted as an anchor, giving the piece a structural foundation and helping to guide the listener's emotional journey through the dialogue and the surrounding textures. I deliberately kept its spatial position stable to contrast with the moving upper layers, reinforcing its grounding role.

Reflexions

I deliberately integrated several presets and effects from the SkyDust 3D synthesizer to shape both the emotional atmosphere and the spatial architecture of the piece. Each sound layer was chosen and designed for its timbral qualities and also for its movement through space, reinforcing the temporal and reflective nature of the narrative. There were some technical challenges, of course: managing CPU with SkyDust, cleaning Manoel de Oliveira voice, encoding and decoding gestures. But the deeper learning was elsewhere. I learned how to use space as meaning. And above all, listening all the presets, and make decisions – hard part. Definitely I recommendSkyDust 3D to my collegues in music production, and will continue my exploration in different genres of ectronics music (my main area of interest).

Final Thoughts

Working on *Sonho de Kairós* with SkyDust 3D introduced me to a remarkably fluid and intuitive environment for crafting spatial soundscapes. Unlike other tools where technical complexity can slow down the creative flow, SkyDust's interface allowed me to focus on what matters most to me: clarity, simplicity, and the emotional core of the sound, with a lot of presets to explore and get inspiration too.

While some might seek complexity and layering of numerous oscillators, I found that the abundance of options could easily become overwhelming. For this reason, I consciously adopted a less-is-more approach, focusing on a limited set of sounds and movements that could deliver a precise and impactful spatial experience. This minimalism helped me stay connected to the conceptual framework of the piece, ensuring that each spatial gesture had meaning and intention.

A feature I found particularly intuitive was the real-time spatial control, which allowed me to "draw" movements that felt organic, directly linked to the narrative flow, without overengineering the process. However, one potential area for future development — and something I would be excited to explore — is the ability to integrate **live sound input** into the spatial framework. This would open fascinating possibilities for live performances and interactive sound installations, where shifting and transforming incoming sounds in real time could lead to unexpected discoveries. For example, applying spatial effects like delays or doppler shifts to grooves or rhythmic patterns might reshape their perception in space, revealing new rhythmic interactions or emergent harmonics. Similarly, introducing live harmonics or textures and observing how they interact spatially could foster a more exploratory, improvisational approach, where spatialization becomes an active creative partner in sound discovery, not just a post-production tool.

Overall, *Sonho de Kairós* not only consolidated my technical and artistic practices but also deepened my reflection on spatial aesthetics in sound art. It reaffirmed that technology, when well-designed, should empower rather than complicate — offering the artist a canvas where imagination and precision can coexist.

With this work, I hope to contribute to the broader conversation around spatial music and to offer feedback that might inspire future enhancements in tools like SkyDust 3D, ensuring they continue to serve the evolving needs of artists and researchers alike.

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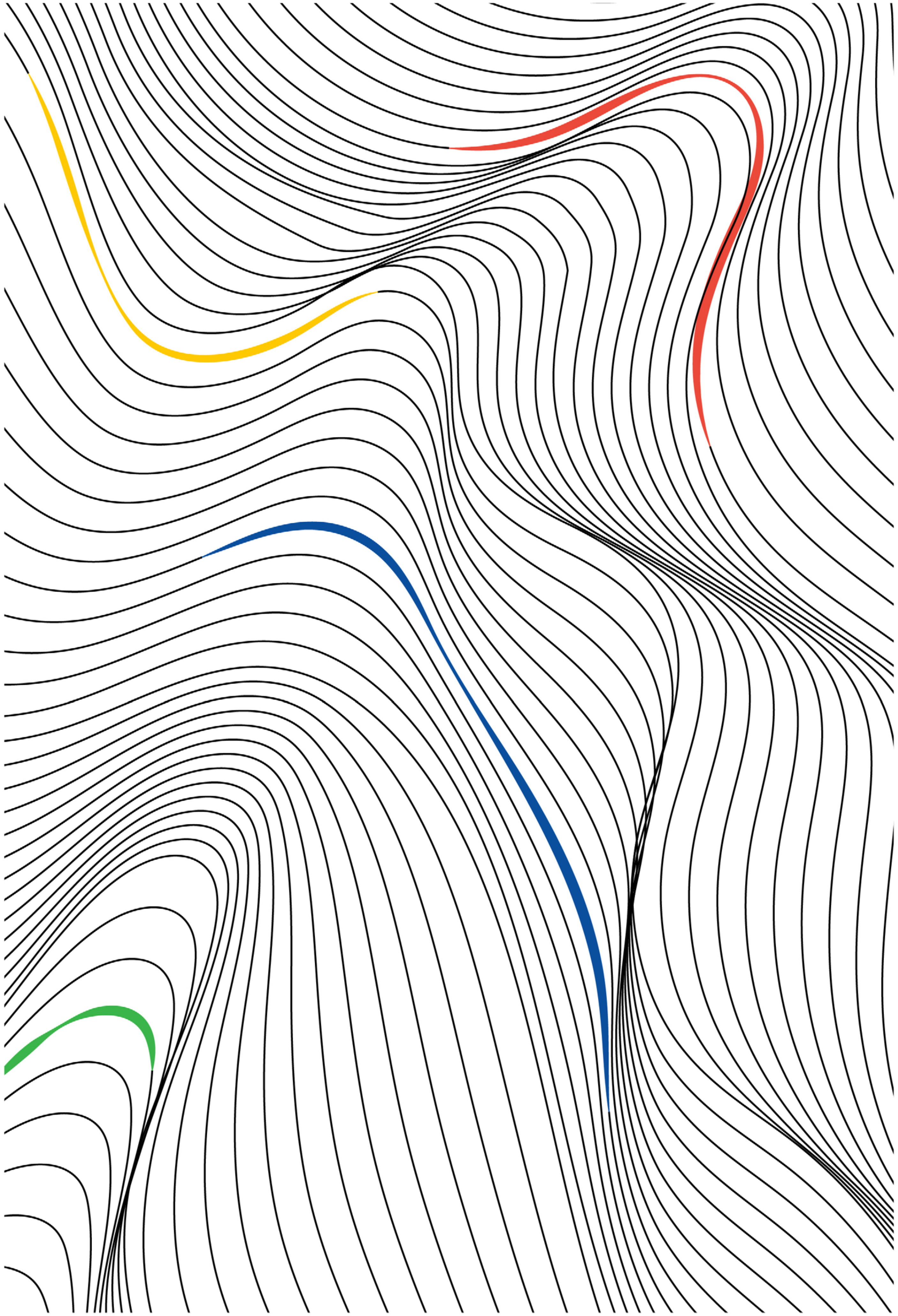

Production [...]

Rúben C. Dias ESMAE - P.Porto

Production [...] – Rúben C. Dias

Duration: 12'

Introduction

Production [...] addresses the relationship between the acoustic sound of the piano and the electroacoustic sound. It is based on the premise that the whole is not just the sum of its parts, but a whole that functions as a cohesive unit[154], contributing to the dilution of the boundary between the artistic object and its context. A context that is perceived, through meaning, by the public in general and by the performer in particular, who, in sharing the artistic object, seeks to promote active and meditative listening. In its final version, the Max[155] software was used, a programming software with a graphical interface, which allowed mainly for the live automation of parameters relating to the SkyDust 3D synthesizer, the main element not only in the final version of the piece, but also in its conception and research.

Exploring the Tools

The conception of *Production [...]* went through several phases. The first involved free exploration of SkyDust 3D, the spatial synthesizer in focus. This tool was explored in detail, paying particular attention to the synthesis capabilities available in the Oscillators and the FM[156] tabs, making use of the various waveforms available and their variations, accessed via the dropdown menu.

Figure 1 Oscillators tab of SkyDust 3D synthesizer

[154] Tradução livre: "A work of art is a unit originally, not by synthesis of independent factor" (Langer, 1953, p. 105)

[155] https://cycling74.com/products/max

[156] Frequency Modulation

In addition to these, the following tabs were also explored: Filter, Pitch, Spatial, Arp, Effects, Extras and Matrix. I personally tend to find the Spatial tab the most interesting, as it is the differentiating element when compared to other synthesizers on the market. It was with and through this feature that, after the free experimentation phase, I began to conceive the piece.

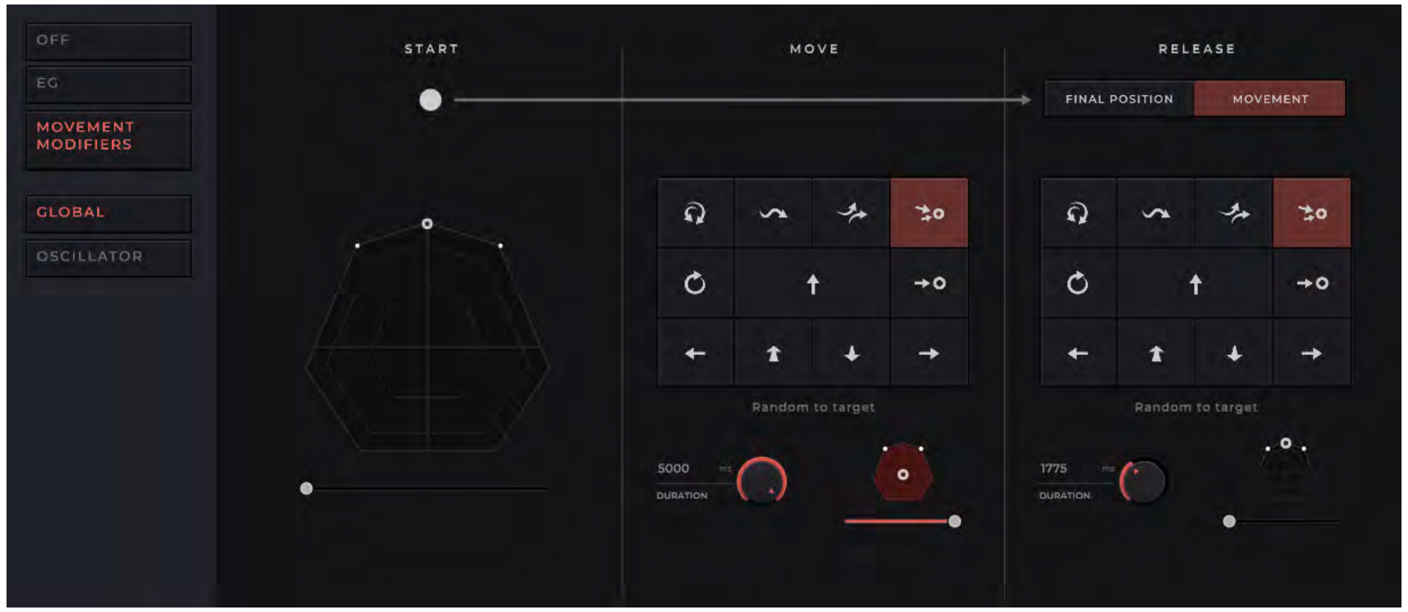

Figure 2 Spatial tab of SkyDust 3D synthesizer

Conception

To compose without any apparent limitations is, in my opinion, a composer's most difficult task. The first limitation I set after the first exploration phase, but which I later broke, was to only use SkyDust 3D in the final version of the piece. All the sounds, not including the very important feature of importing external audio, and all the spatialization had to be the result of a preset or automation of one or more of the synthesizer's parameters. I quickly started to design a sound, combining the tabs described above. I used the DAW Reaper[157] as a framework for this initial phase, as it supports up to 128 channels per track, including the master, allowing me to work with ambisonics easily, and I began to think of the piece as a fixed medium - a piece that would have exactly the same duration regardless of the context in which it was presented, in which the notes and sounds would follow exactly the same sequence with the same duration, and a piece that, for better or worse, would freeze in time. I realized that I wasn't be being honest if I did it this way.

While I was designing the many sounds I was going to use in this hypothetical piece, I began to realize that, because of the way the synthesizer is designed, the same chord or note, produced by adding up the different oscillators available, would sound radically different depending on its position in space. This is because each oscillator, i.e. each part of the complex sound, can be heard in different places in space, unlike what happens in an ordinary synthesizer or even an acoustic instrument: it's not possible to have several parts of a complex sound in several parts of acoustic space. This realization unlocked a

[157] https://www.reaper.fm/

whole process which originated the piece that was heard on 13 March 2025 at the Helena Sá e Costa Theatre in Porto.

In an attempt to solve the problem of my artistic honesty, I gave up the idea of using the DAW to compose the piece for the reasons described above, and opted to use software that, in my opinion, is much more flexible when it comes to programming and automating parameters: Max, from Cycling'74. This software allowed me to write a piece that doesn't just depend on the sequencing of events and that allows interpretative flexibility that isn't possible in DAWs, as well as the possibility to work with the interaction between acoustic instruments and electronic ones, which was the path I chose.

The first step, after this decision, was to figure out how to integrate the SkyDust synthesizer into a Max patch.

Max Integration

Using the *mcs.vst~* object, I was able to define the number of channels available for the synth, in this case 25 channels[158], reaching what I believe to be Max's limit. Using more channels per object, to increase the definition and precision of the moving sound, caused the software to crash, regardless of the computer and buffer size used[159].

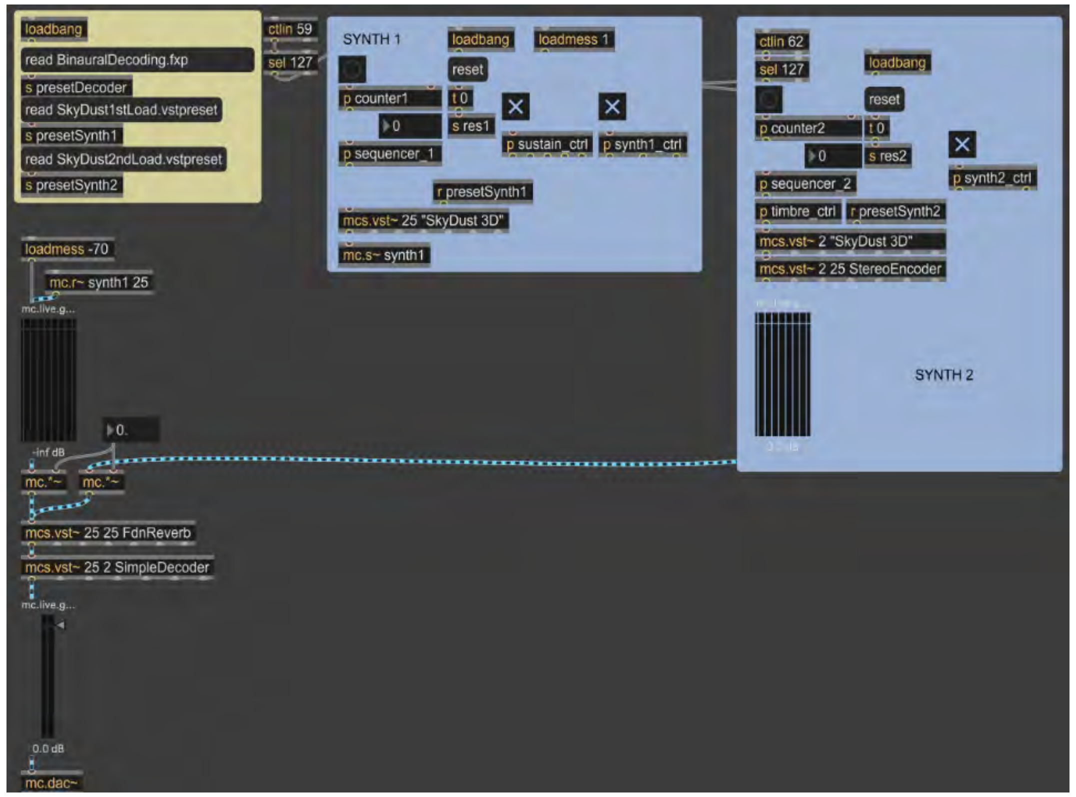

Figure 3 Overview of the Max patch used

[158] 4th order ambisonics.

[159] I couldn't work out whether the crash was due to the SkyDust synthesizer, which is, in itself, a very resource- hungry VST, or to Max itself.

Returning to the above idea of unity as one of *Production [...]*'s main concepts, I designed a sound, based on the Floater II preset that sought to imitate the sound of the piano played by e-bows, but that was able to move slightly away from its reference. The piano was the most natural choice for me, as it is the instrument I'm working with in my Master's project and the one that I felt was right for what I was trying to achieve.

I realized that I could manipulate the sustain of each oscillator to change the timbre of the note and bring the electronic sound closer or further away from the piano sound, achieving the plasticity I was looking for. So I built a patch divided into two very similar modules: one whose SkyDust 3D parameters would be completely automated, and another whose parameters would be controlled live. In essence, both modules are divided into four parts: a sequencer (*p sequencer_1*)[160], a five-oscillator sustain controller (*p sustain_ctrl*), a spatialization controller (*p synth1_ctrl*) and SkyDust 3D embedded into the *msc.vst~* object.

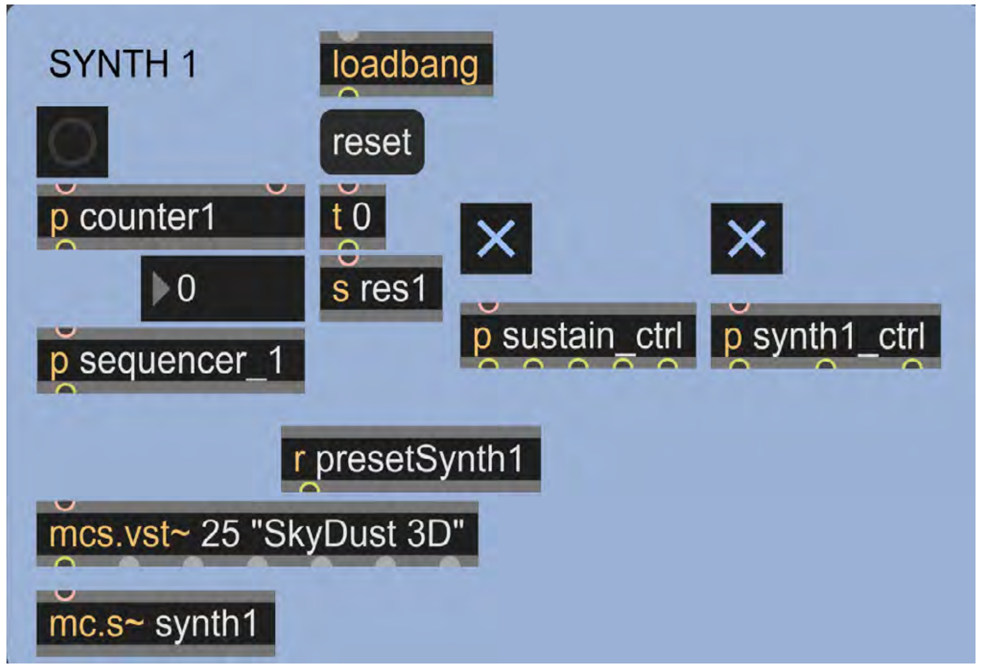

Figure 4 SYNTH 1 module with automations turned on by toggles

In the case of the first module, the one that is fully automated, except for the sequencer, which is controlled via MIDI, I used 5 independent LFO's[161] to automatically control each of the sustains in question and to control the target divergence and target position, on both axis (azimuth and elevation), in the Spatial tab.

The parameters that are automated in the *SYNTH 1* module are controlled with a MIDI controller in the *SYNTH 2* module[162]. As far as SkyDust is concerned, in *SYNTH 2*, I opted to use the stereo output (VBAP) in combination with the IEM stereo encoder, for the directionality of the sound I was looking for, controlling its movement in space (azimuth and elevation) via the *mcs.vst~2 25 StereoEncoder* object. The patch also includes the output with its respective decoding and a module that loads the SkyDust synthesizer presets.

[160] *p* is the abbreviation for the *patcher* object, which allows you to create a patch inside that same object.

[161] Low frequency oscillators.

[162] The p timbre_ctrl object in SYNTH 2 is the same as the p sustain_ctrl object in SYNTH 1.

Production [...] – Sound, Form and Harmony

After this, I focused on writing the piece itself. I built a harmonic sequence based on the upper voices of a J.S. Bach choral, deconstructing it. I transcribed the respective voices (alto and soprano) and, in the manner of tintinabuli[9][165], projected the alto voice and the respective notes for the following tempos and their subdivisions. Below are the original voices of the first phrase of the choral followed by the voices transformed using the method explained above:

Figure 5 Upper voices of first phrase of "Ach Gott, erhör' mein Seufzen!

Figure 6 Harmonic sequence used in "Production [...]"

As mentioned above, digital sound seeks to be identical to analogue sound. It would make sense, then, to imitate the harmonic sequence in both media - acoustic and electronic. This was the only way to achieve a seemingly strict relationship between the two.

To do this, I built a sequencer in Max's patch that follows the chords/intervals of the sequence in question. On the piano part, I chose to extend each chord and interval over time, taking advantage of the common notes between each chord and looking for new interval relationships, including new dissonances, introduced by the extension of a given note in time.

I only used the first phrase of the chorale to write this piece. Due to its arc structure - the piece begins with an interval of perfect fourths and ends in that same interval - it is possible to have the idea of something circular, which leaves and returns to the same place, but this place to which we return is not quite the same as the one from which we left. This idea arises from the Master's project I've been developing, in which music has a slow and introspective character, trying to access what Kramer (1988) calls Vertical Time, promoting active and meditative listening:

[163] "In tintinnabulation, every single note of a melody voice formed by scales (which Hillier calls the M-voice) ideally gets assigned a note of a triad at a certain distance to this M-voice. In the so-called first position above (+1) or below (-1) the M-voice, this produces diatonic dissonances of minor and major seconds and also thirds and fourths; in second position (+2, -2) we get fourths, fifths, and sixths (Examples 4.1a and 4.1b). By this method, a second voice develops consisting exclusively of triad notes which sounds throughout the whole composition like the peal of bells. From this we get the terms tintinnabuli-voice (T-voice), and tintinnabuli triad (T-triad), which itself consists of three tintinnabuli-notes (T-notes)." (Shenton, 2012, pp. 55–56)

> *The more deeply we listen to music in vertical time, the more thoroughly we enter the timeless now of the extended present. But, however much we become part of the music, we do not totally lose contact with external reality. We listen, after all, in a concert hall, or living room, or loft, or some other environment normally associated with experiences that involve past and future, memory and expectation. (Kramer, 1988, p. 376)*

This concept appears at the same time as that of unity, which I have been seeking in the pieces I write. In this piece, the relationship between the piano and the electronics is apparently strict, both from a conceptual and composing points of view. Both follow the same sequence of notes and intervals and the timbre of the sound we hear on the electronics is designed to be identical to the timbre of the sound coming from the piano. However, it is the performer, mediating the relationship between the piano and the electronics, who determines, assisted by the score, the moments when each note or interval is played, both on the piano, through the placement of the e-bows, and electronics, controlling the sound's movement and timbre. In other words, objectively, there is no relationship between the acoustic and the electroacoustic, apart from the fact that they share the same physical space, without the mediator - the performer.

Conclusion

Production [...] tries to encompass various concepts that I have been addressing in my writing: slow, introspective music, which seeks to promote active and meditative listening, supported by the concept of Vertical Time; the relationship between music, or art, and its context, seeking a balance between instrument, performer, music and space. The resulting piece, which was, in one instance, conceived due to a software limitation, the fact that SkyDust 3D cannot process live sound, is a development from previous works who share the same thought process but in a more conscious and context imbued way. Despite having much room to improve, SkyDust 3D proved to be a strong tool to not only design and compose a fixed musical piece but also to be manipulated in real-time.

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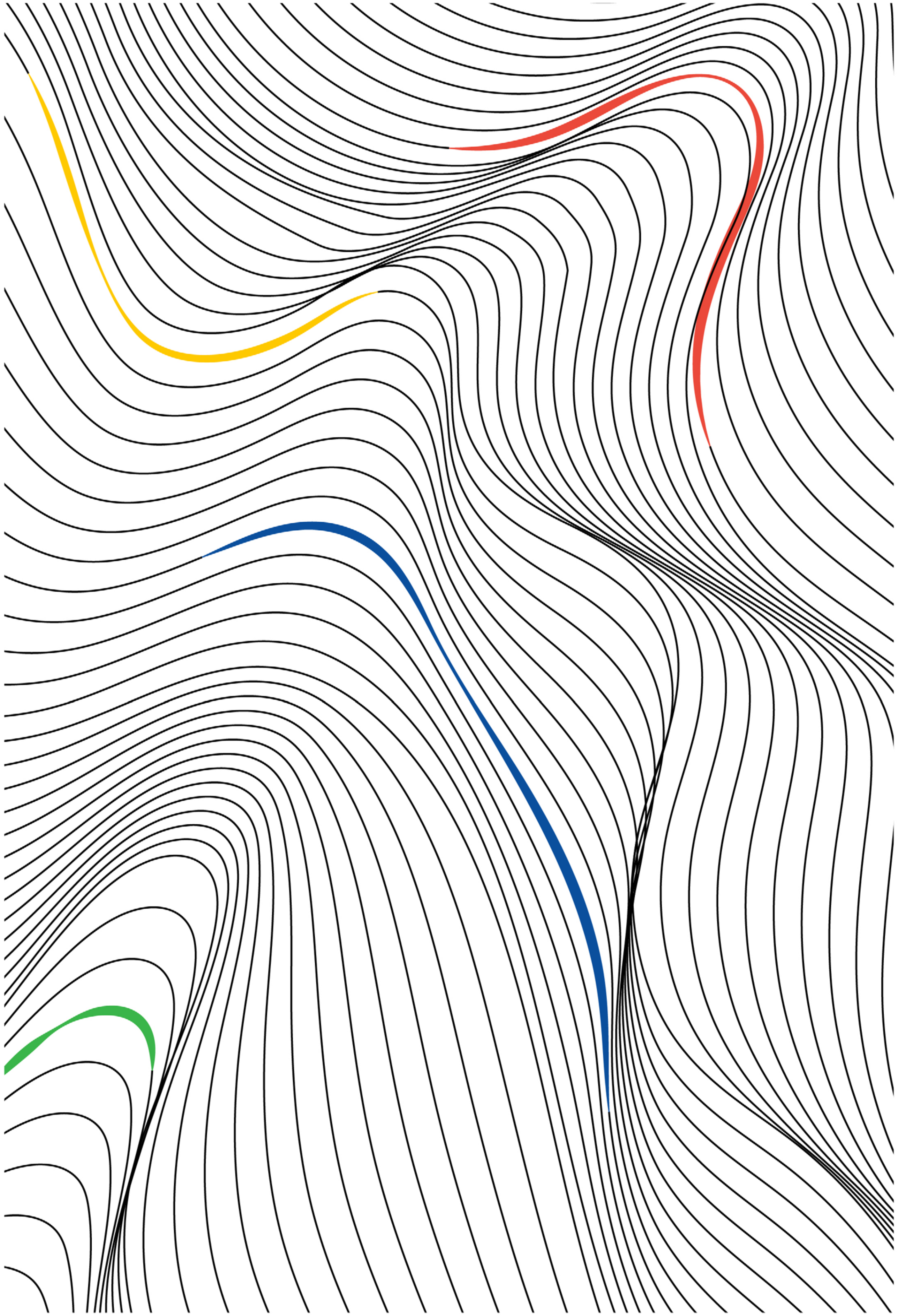


Impromptu For Skydust

Gonçalo Feijão ESMAE - P.Porto

IMPROMPTU FOR SKYDUST - GONÇALO FEIJÃO

Duration: 12′

Introduction

In this piece, I decided to use only the functionalities of Skydust. It was also with this piece that I learned how to use Skydust and had my first experience programming synthesizers.

The idea behind this piece was to create a foundation for improvisation. To simplify the creative process: I experimented on the piano until I found the initial motif, developed it, created space for improvisation, and wrote an ending for the piece.

Improvisation in Skydust:

The initial idea was to be able to improvise using spatialization as well, controlling where each sound would play in real time.
My suggestion for future versions of Skydust would be for the user to be able to choose the graph used for spatialization, that the controls include the axes of the chosen graph, and that these are measured in degrees – e.g.: (X -1, Y 10, Z 4). This way, it's possible not only to control spatialization using the "drag" function on a graph of our choosing, but we can also use MIDI controller knobs to adjust with greater precision.
Even if the result is only an approximation, I believe this suggestion would help me not only with improvisation but also with the composition process.

The Sounds created:

Sub bass

I used 5 oscillators – numbers 1, 3, 4, and 5 are standard sine waves, all in the same octave. Oscillator 2 is a sine wave one octave below the others.

I spatialized them with the same attack point but with different sustain locations to give the impression that the sound disperses. I used the same LFO for spatialization on all of them – "SAW UP" (with Phase Knee (down) at maximum to place everything on the ground).

The LFO controls are as follows:

- Rate: 0
- Delay: 0
- Phase: 0
- Azimuth: 0
- Elevation: 90
- Distance:

Wind

Three Oscilators -

- Oscilador 1 - White Noise

- EG - ADSR
- Attack - 475
- Decay - 100
- Sustain - -0.16
- Release - 0

- FIlter
- Band pass (-12db/octave) - (frequency - 4315hz) (Q - 8.03)
- LFO (Sine) - (Rate - 0.1) , (Depth - 0.52) , (Delay - 0), (Phase - 353)

- Spatial
- Random rotation com liberdade total (GLOBAL)

- Oscilador 2 - Flute FX c3untitled

- Attack - 725
- Decay - 100
- Sustain - 0.16
- Release - 100

- Spatial
- Random rotation com liberdade total (GLOBAL)

- Oscilador 3 - White Noise

- EG - ADSR
- Attack - 475
- Decay - 100
- Sustain - -0.16
- Release - 0

- FIlter
- Low pass (-12db/octave) - (frequency - 418hz) (Q - 0.00)
- LFO (Sine) - (Rate - 0.2) , (Depth - 0.42) , (Delay - 0), (Phase - 59)

- Spatial
- Random rotation com liberdade total (GLOBAL)

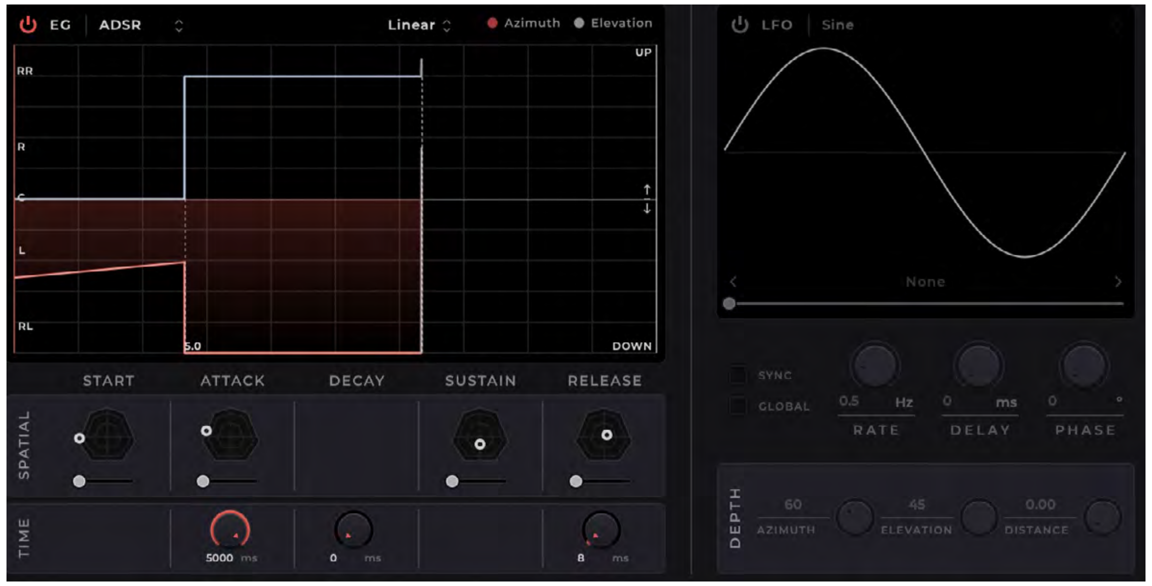
Arpeijos

I used 2 Oscilators -

- Oscilador 1 - Sine

- EG - ADSR
- Attack - 0
- Decay - 100
- Sustain - 0.0
- Release - 783

- Spatial



- Oscilador 3 - Triangle

- EG - ADSR
- Attack - 0
- Decay - 25
- Sustain - -0.81.49
- Release - 542

- FIlter
- Low pass (-12db/octave) - (frequency - 418hz) (Q - 0.00)
- LFO (Sine) - (Rate - 0.2) , (Depth - 0.42) , (Delay - 0), (Phase - 59)
- Spatial
- Random rotation com liberdade total (GLOBAL)

Bass

I used 2 Oscilators -

- Oscilador 1

- Oscilador 2

- Oscilador 3

<u>Melodia</u>

I used 3 oscillators -

- Oscilator 1

- Oscilator 2

- Oscilator 3

- Effects and spatial

<u>Horn</u>

I used 2 Oscilators -

- Oscilator 1 -

- Oscilator 2 -

Effects -

<u>Alarm sound</u>

I used 1 Oscilator -

- Oscilator 1

Bass drum -

I used 5 Oscilators -

- Oscilator 1 -

- Oscilator 2 -

- Oscilator 3 -

- Oscilator 4 -

- Oscilator 5 -
- Spatial and effects

Hi hat

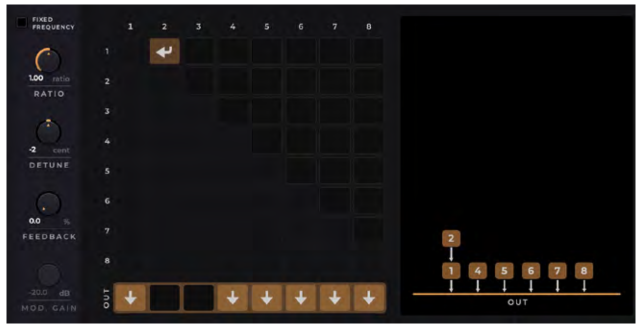
I used 2 Oscilators -

- Oscilator 1 -

- Oscilator 2 -

Solo

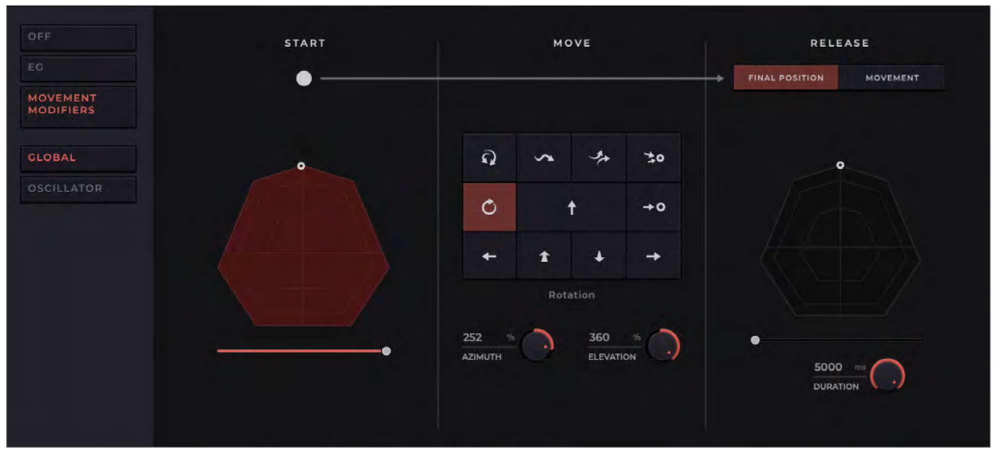
I used three Oscilators -



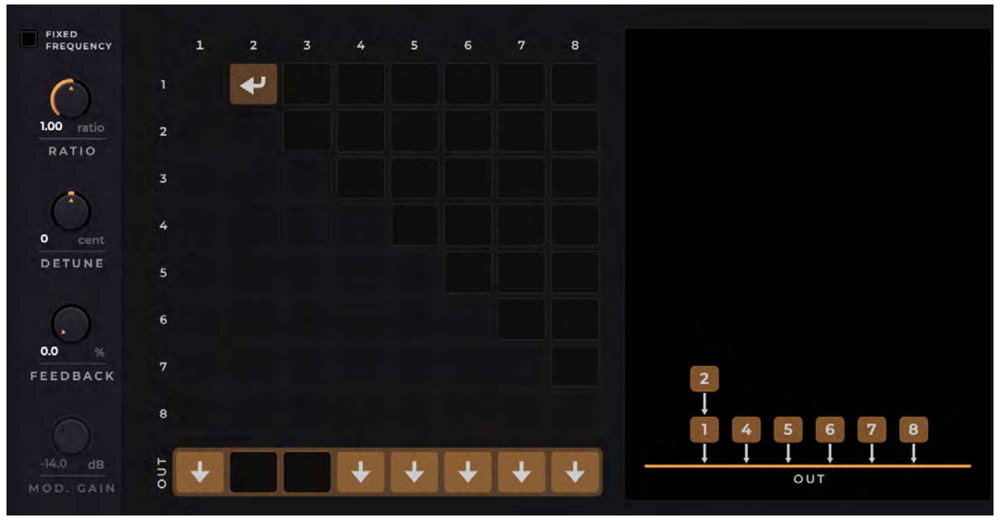
- Oscilator 1 -

- Oscilator 2 -

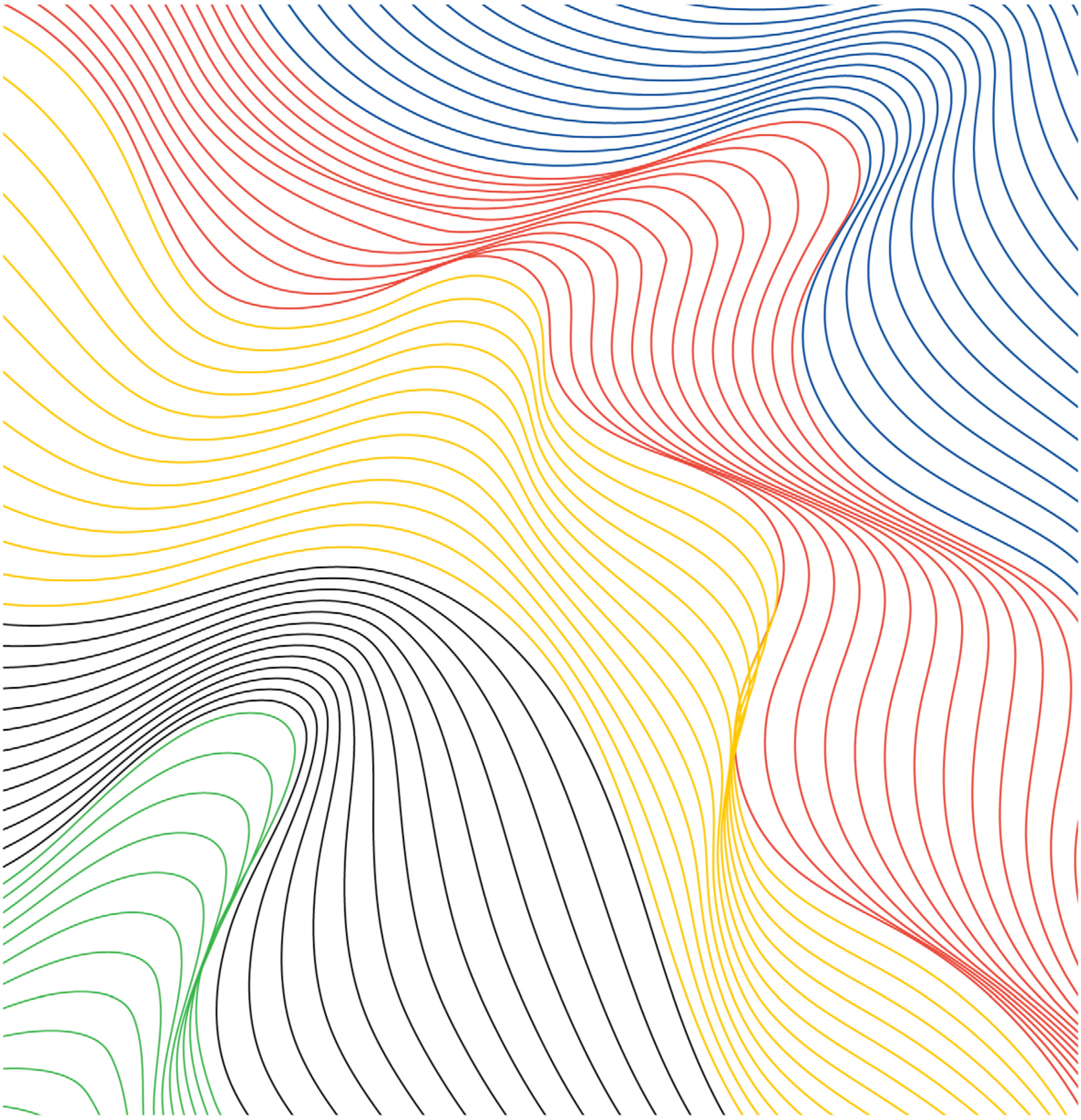
- Oscilator 3 -



- Spatial,Fx and FM



In oscilator 1 I controled Gain, the rate and depth (Pitch), Azimuth and Elevation (Spatial) using the “Midi-Learn ” function.



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