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Listening to the Anthropocene: A Queda do Céu

Abstract: This article discusses the algorithmic design and implementation of A Queda do Céu, a sound installation and kinetic sculpture related to the Soundlapse project. In it we provide an overview of the project and go on to describe the main computational challenges related to the installation, which included a variety of real-time processing, interpolation, and mapping algorithms. We contextualize the work in relation to regional ecological and political debates, as well as the global climate crisis. In doing so, we echo other sound and field-recording artists in proposing that artworks have an important function as experimental arenas in which new technological applications can be probed and where new modes of listening can be investigated, reconfigured, and exercised. In closing, we lay out an overview of the current challenges being tackled by the Soundlapse project, specifically the development of a refined version of the sonic time-lapse method that incorporates machine learning routines and user-defined spatialization capabilities.

> Listening affords us a different sense of the world and of ourselves living in this world; it affords a different relationship to time and space, to objects and subjects, and to the way we live among them (Voegelin 2014, p. 10).

This sounds like a nice fantasy, does it not? Pop on your headphones, and in five minutes you can hear the complete works of Beethoven, or every song that was played at your high school prom, or everything your parents ever told you (DuBois 2011, p. 249).

In this article, we discuss the design and implementation of A Queda do Céu, a sound installation and kinetic sculpture that invites us to bear witness to large-scale changes in wetland soundscapes. Installed in 2020 as part of the Soundlapse project, the work drew from an extensive library of field recordings that were collected in southern Chile in the preceding years, and it used a variety of real-time processing, interpolation, and mapping techniques to provide its viewers with a unique and ever-evolving perspective on those ecosystems.

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Inspired by technoecological authors (Allan et al. 2018; Kluitenberg 2012) and other contemporary field recording projects (Watson 2003; Maher 2010; Riley French 2021), our work departed from a simple thought experiment: What would happen if our bodies were such, and our perceptual capacities were such, that we could sit still and listen to an environment for a whole year? What perspectives would be open to us? At a time where emerging media provide us with radical new avenues for taking positions, these questions speak to the lingering challenges of confronting elements of our perspective that are deeply ingrained in our way of navigating the world as humans—for example, our ontological status as transient, wandering creatures whose perspective is not rooted in the ground. Echoing Salome Voegelin in her book *Sonic Possible Worlds* (Voegelin 2014), we suggest that listening offers a prime vantage point from which to interrogate our surrounding environments and to understand our positions within a world that is itself at a crossroads.

Although speculative in nature, the question of such a sustained listening experience placed us in dialogue with a host of sound and media artists working with large-scale manipulations in the time domain. Beyond the previously mentioned soundscape artists, we found precedents to our work in Luke DuBois's time-lapse phonography techniques (Dubois 2011) and in artists working with sonification techniques that place time at the center of the translational processes (Angeler et al. 2018). And yet, despite the multiplication and democratization of audio processing techniques that operationalize duration (e.g., granular synthesis, phase vocoding, and spectral modeling) the scope and questions driving our project led us to a cascade of practical and technical challenges. Initial tasks related to the Soundlapse project included carrying out a massive documentation program of wetland soundscapes around Valdivia, Chile, and developing a real-time application for calling out and interpolating field recordings (Espejo et al. 2021). Work was also carried out by biologists and conservationists to identify and map out the animal life in those wetlands. Since 2022, the project has focused on (1) implementing machine-learning routines to develop more-refined versions of the sonic time-lapse (STL) method; (2) incorporating new recording formats such as Ambisonics; and (3) developing applications that allow for a greater degree of user interaction, allowing for creative control and real-time spatialization of soundscapes. Running along these developments, artists have also played an important part in the Soundlapse project, designing sound installations that could function as both proof of concept and a space for the broader public to experience and learn about the southern wetlands.

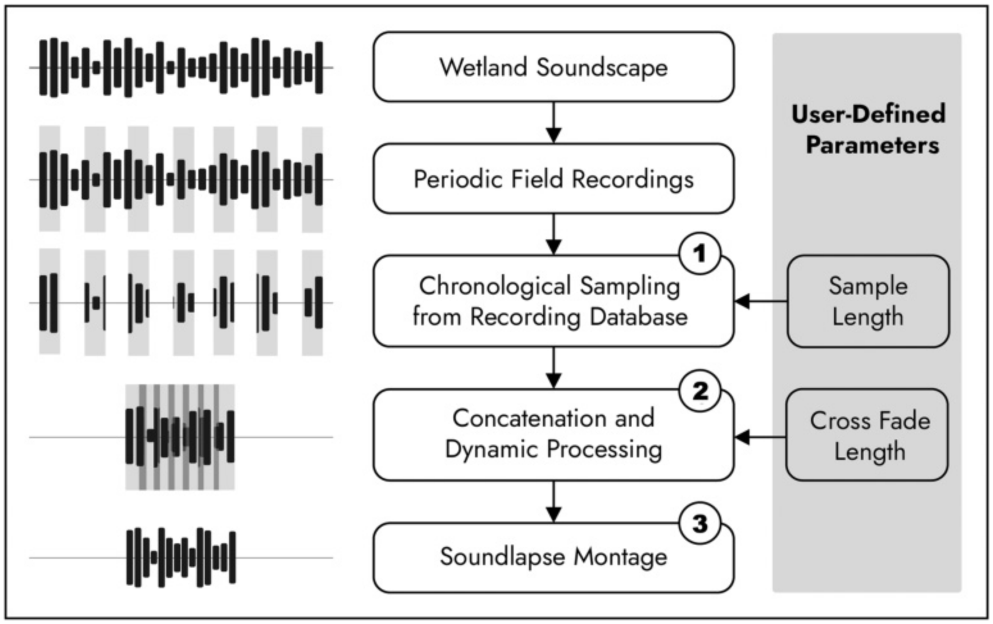
Shortlisted for the 2021 Lumen Prize Global South Award, A Queda do Céu is the first installation associated with the Soundlapse project. The work focused on the experience of the passage of time in the Valdivian wetlands, providing its viewers with a multimodal perspective on the rhythms of change and on human intervention over a speeding soundscape. In the following sections we provide a contextual account of the work's role within the project, as well as a detailed description of the installation's acoustic and algorithmic architecture, with particular emphasis on its technical setup and on the interactive relationship between the sculptural modules and the work's immersive sound environment. Finally, we provide a brief discussion of where we locate the work within the global ecological context and discuss the opportunities it provides to exercise a new listening regimen that answers to our current contingencies.

The Soundlapse Project

The Soundlapse project was conceived in 2018 as an interdisciplinary initiative bringing together artists, biologists, and computer scientists, with the aim of studying the wetland soundscapes of southern Chilean (Otondo 2018). Wetlands are important sources of biodiversity, playing a key role in the survival of various kinds of plants and wildlife. In recent years, they have become a hot political issue in Chile, owing to illegal dumping and the lack of a robust legal framework for the preservation of these natural habitats. Based in Valdivia, a city surrounded by five urban marshes extending over an area of 1,524 acres (MMA 2022), the project aimed to address these regional debates. Under the umbrella of Soundlapse, various initiatives have been carried out in recent years, including an extensive documentation program, the development of new computer applications, and original sound installations. Since its inception, the project has received two operational grants from by the Chilean National Fund for Scientific and Technological Development, and its current cycle will run until 2025.

The first part of the project involved the design and implementation of various field-recording techniques to capture the temporal evolution of wetland soundscapes over long periods of time and across various spatial audio formats. This was done in accordance with best practices in soundscape ecology (Farina 2014, pp. 11–13; Hong et al. 2019) and the ISO (2017) guidelines on data collection and reporting requirements. In line with recent relevant ecology studies using passive audio recorders (Bellisario and Pijanowski 2019; Farina and Gage 2017), periodic short, five-minute stereo recordings were made every hour for 365 days in the Parque Urbano-El Bosque, Angachilla, and Miraflores wetlands in the city of Valdivia (Soundlapse 2022). These recordings were carried out using weatherproof Wildlife SM4 monitoring stations specially

Figure 1. Schematic representation of the sonic time-lapse (STL) method. The three numbered steps are described in greater detail in the text.



design for bird recordings in harsh weather conditions (https://www.wildlifeacoustics.com). Parallel to these periodic recordings, Ambisonics and binaural recordings were made in strategic locations of these three wetlands where there was considerable acoustic activity.

The next step saw the development of the STL method, which can be described as a sample-based concatenation routine related to the principles and parameters of granular synthesis. As such, the method has antecedents in work by Barrie Truax (2012) and, more obviously, in the documentation of the Grant-Kohrs Ranch soundscapes in the United States made by Robert Maher (2010). The samples for the STL came from a large database of periodic five-minute recordings, which functioned as raw materials for the time-lapse engine and produced short audio files that maintained the morphological features of the original soundscape. As described in Figure 1, the algorithm involved the following stages: (1) chronological sampling from the recording library; (2) concatenating samples and dynamic processing (cross-fade); and (3) producing a stereo file of the Soundlapse montage.

A Queda do Céu

Work on A Queda do Céu began in late 2019, under the umbrella of the Soundlapse project at the Universidad Austral de Chile. The development of the work was led by the authors in collaboration with technicians, acoustic engineers, and independent artists in Valdivia who are named in the Acknowledgments section. Having coincided with the onset of the Covid-19 pandemic, work on the project faced significant operational challenges. Despite these logistical difficulties, both the field recording schedule and the installation forged ahead and, in October 2020, the piece was installed at the main hall of the Centro de Innovación y Emprendimiento 14k, on the university's Miraflores Campus. Although public access to the work was limited, A Queda do Céu remained open to the campus community for 16 days. Work on the project, including interviews with the authors, was captured by Francisco Ríos Anderson and subsequently published as a short video (https://vimeo.com/535113434).

An important issue at the onset of Soundlapse was the degree in which recordings were being compressed along the *x*-axis using the STL method described in Figure 1. This variable raised the question of the balance between the presentation and the representation of wetland environments, with important conceptual and aesthetic implications. The challenge came down to discovering how much of the original soundscape we could afford to lose in the processes of recording, editing, translating, and weaving together the sound lapse that formed the basis of A Queda do Céu. From an informational standpoint, there is no denying that the sonic sound-lapse method is lossy: It curates the auditory landscape of the wetlands. What the STL method leaves out, however, are nonperiodic, idiosyncratic events—what has been described as moments of informational entropy (Christian 2009). Although these problems are being addressed in newer, more-sophisticated versions of the soundlapse algorithm, A Queda do Céu is concerned with general, high-level identity markers and the way they intersect with time and change.

Description

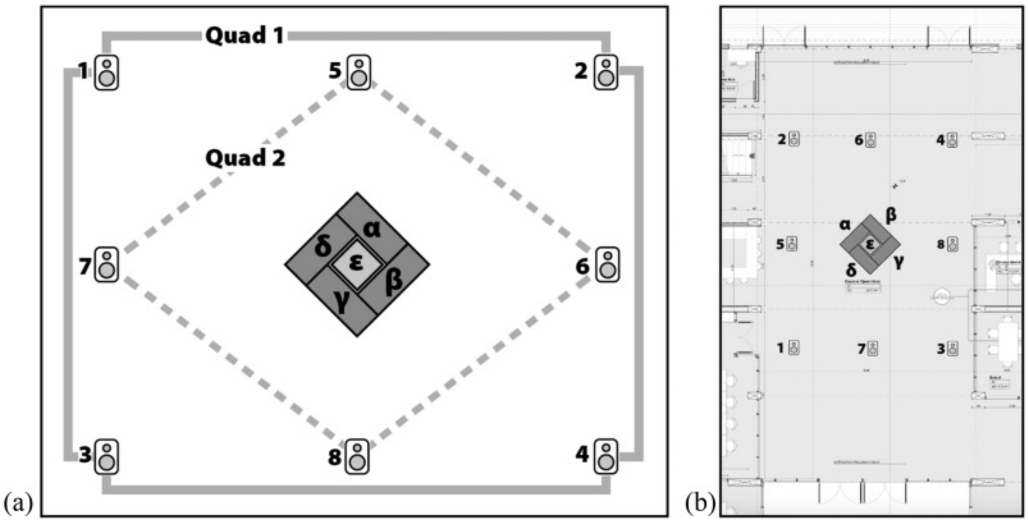
The installation consisted of an immersive soundscape and a sculptural centerpiece made up of a series of modular kinetic sculptures that interacted with their sonic environment via mechanical exciters. The work was made possible by the extensive repository of field recordings that were collected as part of the Soundlapse project (Otondo and Rabello-Mestre 2022)—in particular, a set of 8,760 five-minute recordings carried out at the Angachilla wetlands between March 2019 and March 2020. Using a variety of real-time processing, interpolation, and mapping techniques, the work was designed to provide its viewers with a multimodal experience of sound and movement related to the passage of time in these southern South American wetlands.

In the installation, the relationship between the auditory and the kinetic presented itself in a real-time choreography of algorithmically translated, computer mediated signals that made themselves visible in water and strings. This process of mapping the soundscape onto each sculptural module was achieved by a computational process that operated in two stages: (1) extracting and parametrizing aspects of soundscape morphology, and (2) utilizing these parameters to control low-frequency oscillators that were physically connected to the installation. This later step was achieved using a variety of mechanical exciters attached to each of the installation modules.

These modules consisted of four "lagoons" and a suspended metal plate from which hundreds of wooden pieces hung attached to nylon strings. Beyond their visual role, each module acted as a sound source, producing a dynamic variety of noises that accompanied the shifting moods of the soundscape. From the lagoons an attentive listener would distinguish a low rumble and, on occasion, the sounds of splashing water. From the central module of hanging wooden pieces, the listener would hear a percussive texture of crisp, resonant attacks resulting from the colliding blocks. These large sculptures hummed and "clicked" along, orchestrating the field recordings with sonic textures that were most often gentle but sometimes abrasive and industrial in nature.

However important or visually imposing the centerpiece of the installation was, the most important feature of A Queda do Céu was the immersive soundscape that enveloped and traversed the sculptures, acting as a *primum mobile* to all other elements in the installation. The stream of recordings, featuring hourly samples of the wetland's sonic environment across a full year, was algorithmically stitched together using the soundlapse method described in the Soundlapse Project section. Along with the mechanical murmuring of the central sculpture, both provided the auditory dimension of the work. The result was an aural landscape in which the "here and now" remained a faithful documentation of the original soundscapes, but in which time (i.e., our perceptual and macroscopic unit of change) advanced at an expedited rate, compressing months into minutes, years into hours. It is at this crossroads of stillness and change that the experience of A Queda do Céu lay: In the tension between the presentation of natural environments, as we have access to them, and their schematic evolution in a way that is only possible in a big-data, highly compressed, computer-mediated world.

Figure 2. Installation setup (a) and disposition in the hall (b).



A number of other compositional features, such as the reflective surfaces and the choice of natural materials, also connected the work back to the Valdivian wetlands. Characterized by its vast stretches of water interspersed with vegetation, these ecosystems are notable for their mesmerizing visual displays—particularly in the early morning or under the thick fog that covers the region during most of the year. With an exterior of clear water and mirrored surfaces, A Queda do Céu reached out to the environment and presented it back to passersby. Installed under a high wooden ceiling and bathed in natural light, the installation materials merged: Mirror would turn into water, water into mirror, mirror into wood.

Technical Setup

The sound sources of A Queda do Céu were made up of two separate systems: (1) an immersive sound setup, peripherally positioned around the space, consisting of two quadraphonic setups using loudspeakers; and (2) a central sculpture, divided into five modules, each powered by a mechanical transducer. This section provides a detailed breakdown of how sound was produced, controlled, and distributed across the installation space.

Spatial Sound

Eight FBT J 5A loudspeakers, arranged as two intercalated quadraphonic setups, were responsible for reproducing the soundscapes of the work. They were positioned around the installation modules and along the 9.54- × 19.90-meter boundaries of Centro 14k's main hall (see Figure 2). The distance between the speaker array and the centerpiece allowed for ample walking space, as well as a sense of auditory immersion. Nevertheless, the setup dimensions were not so large as to omit—or even separate—the loudspeakers from the public's perception of the work. This arrangement made technology an important part of the installation's statement and aesthetics.

As described in Table 1, both quadraphonic setups had a complementary role that combined a high-fidelity representation of wetland soundscapes and a "stylized" version of the same recordings. The first of these quadrophonic setups consisted of a pair of stereo files played with a 125-msec delay between them and presented the audience with the unaltered soundlapse montage. The second setup, again, consisted of two stereo files, but here they played a soft and heavily filtered version of the soundlapse. These filtered versions of the soundscape, being subject to real-time stochastic

Table 1. Breakdown of Loudspeaker Setup

Setup	*Audio Processing and Control*	*L/R*	*Ch. Out*
Quadrophonic Group 1	No processing	L	1
		R	2
	Adjustable delay (30–200 msec)	L	3
		R	4
Quadrophonic Group 2	High-pass filter (800 Hz)	L	5
	Adjustable EQ (tone shaping)	R	6
	Autonomous stochastic volume control	L	7
		R	8

Controlled by a single computer choosing samples from a database of stereo field recordings, these recordings were played in two intermeshed quadrophonic groups with different processing and, from there, distributed to the loudspeakers, as shown in the last two columns of the table.

operations, were not consistently heard during the installation, but presented themselves only occasionally. Ultimately, these two combined setups had the effect of immersing the audience in a high-fidelity soundscape reproduction of the Angachilla wetland that always changed—in balance and content—and sporadically "denounced" itself as an artful representation of natural environments by distorting the frequency spectrum of those recordings.

Finally, regarding the immersive soundscape of the work, it is worth highlighting a specific feature of the installation's surrounding environment. Located in the Miraflores neighborhood of Valdivia, the Centro de Innovación y Emprendimiento 14k is itself surrounded by an urban wetland, which envelops and ultimately merges with the campus. Its vegetation is an important feature of the landscape, and wildlife can be heard from most university buildings, as shown in Figure 3. This intersection—between the natural word, the installation, and the built environment—provided viewers with a porous experience that seamlessly blended naturally occurring environmental sounds, field recordings, mechanical murmuring, and daily life.

Mechanical Modules

The mechanical parts of A Queda do Céu consisted of five kinetic modules that together formed the sculptural component of the work. All modules were adjacent to each other, resulting in a continuous structure placed in the center of the hall. Each unit was associated with an audio channel and was assigned a Greek letter—alpha, beta, gamma, delta, and epsilon—to avoid using the numbers already referring to positions in the loudspeaker setup (see Table 2). Modules were divided into two groups: (1) the lagoon cluster, which included four modules; and (2) the metal plate, which consisted of a single structure. This section provides a breakdown of how these structures were assembled, what signals they were fed through the mechanical exciters, and what they sounded like.

All modules of the lagoon cluster were identical: They consisted of four containers, filled with water, dark on the inside and reflective on the outside. They were built using plywood boards, epoxy resin, and acrylic mirrors. All nonreflective surfaces were spray-painted with a matte black hue, which in early prototypes was shown to be particularly effective as a background color to highlight water disturbance by the mechanical exciters. Each module measured 170 × 70 × 24 cm and was powered from below by a Dayton audio BST-1 Tactile Bass Shaker that was screwed directly to the surface of the wood. Each lagoon was then raised from the group by 15 cm by a supporting structure, with precautions being taken to minimize contact with the vibrating surface of the modules by using high-quality automotive rubber to prevent dampening and noise.

Figure 3. Frontal view of the installation modules, with the Miraflores wetland in the background (a). Image from Ríos Anderson's documentation showing the relationship between the installation's central module and the environment (b).

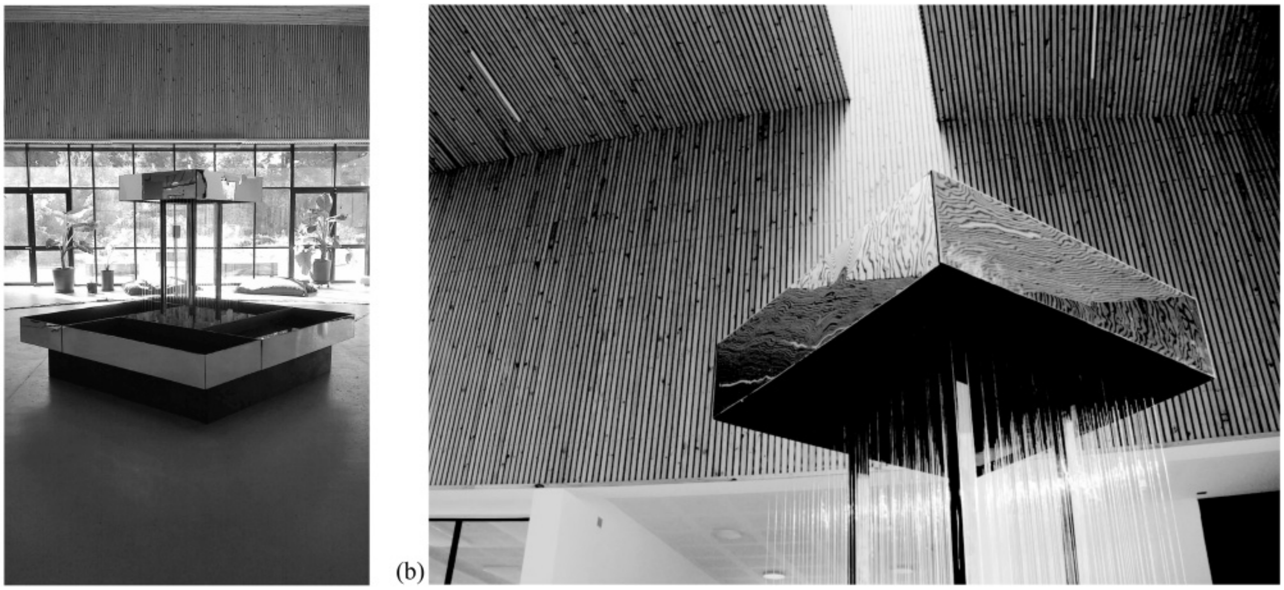


Table 2. Breakdown of Mechanical Modules

	Pitch	*Amplitude*	*Channel*	*Module*
Lagoons	Stochastic pitch control oscillating between 5 and 50 Hz with adjustable portamento length	Amplitude mapping based on parameters extracted from the soundlapse morphological analysis	1 2 3 4	α β γ δ
Plate	Varies between frequencies 28.3 Hz, 34.1 Hz, 42.6 Hz, and 49 Hz	Stochastic amplitude control	5	ϵ

A second computer generated five low-frequency sinusoidal oscillators that were processed and distributed across five kinetic modules labeled with Greek letters. The modules were in two categories: four "Lagoons" and a "Plate." All modules were driven by high-powered amplifiers.

Movement on the surface of the water was prompted by low-frequency sinusoidal signals that were sent to the bass shakers. How the water interacted with the incoming signals was dependent on both the amplitude of the signal and how closely it approximated the modules' resonating frequencies. These frequencies drifted constantly between 5 and 50 Hz and underwent a process of amplitude modulation linked to the morphological characteristics of the surrounding soundscape. These material and programmatic dependencies meant that water activity was not continuous, and coordination between lagoons emerged from the interaction of determinate and indeterminate factors. The result was a form of "visual heterophony" that gave the installation a sense of liveness and continuous variation—a perception that was further amplified by the lagoon's expressive range: Lagoon behavior differed wildly both in intensity, which varied from the slightest disturbance to

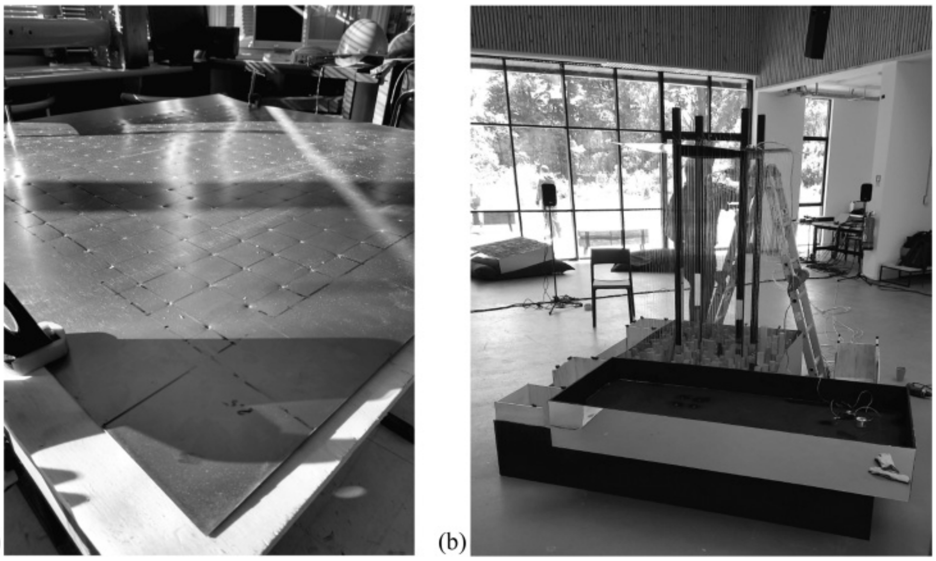

(a) (b)

Figure 4. Perforated grid on metal plate prior to assembly (a); installation of the central module at the Centro de Innovación y Emprendimiento 14k (b).

actual splashing, and in how they produced visual patterns.

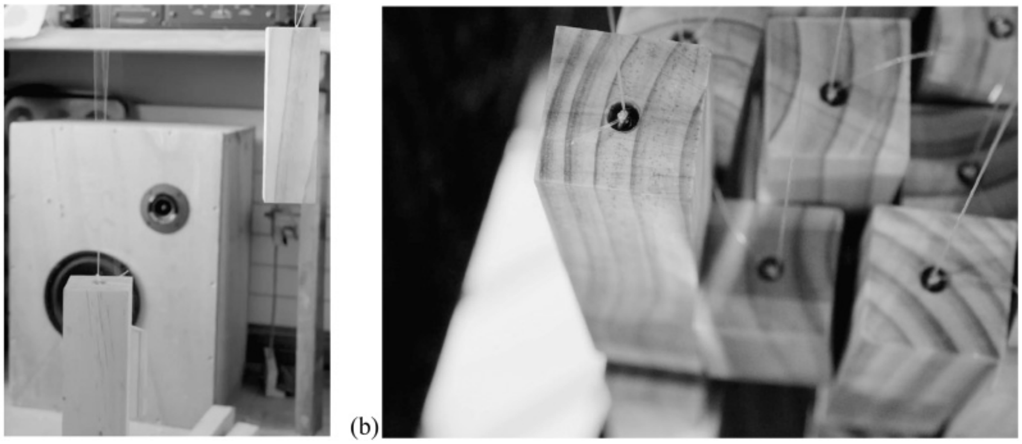
The second kind of module consisted of a single 99 × 99 × 0.1 cm metal plate from which 320 wooden blocks were suspended using transparent monofilament fishing line. Wooden blocks were dispersed equally around a two-dimensional 18 × 18 grid, with grid positions separated by 4.5 cm on the *y*- and *x*-axes (see Figure 4a). The wooden blocks had a rectangular shape, with a depth that varied from 8 to 30 cm, against a horizontal face of 4 × 4 cm. Like the lagoon modules, the metal plate was powered by a tactile transducer—in this case a 40-W Dayton Audio DAEX32EP-4 Thruster 32-mm exciter—which was screwed to the surface of the plate from above. Although original sketches of the work had the module suspended directly from the ceiling, the plate came to be held up by four wooden posts, which placed it at a height of 190 cm from the ground (Figure 4b).

Like the lagoons, movement in the plate module was produced through a similar electroacoustic chain, with a sinusoidal low frequency oscillator being fed to an amplifier and, finally, to a mechanical exciter. This motor was in turn responsible for radiating the signal through the plate, producing different nodal regions according to the oscillator frequency. This process led to an intricate choreography in the nylon strings, which oscillated anchored by the wooden pieces. Excitement across the 320 strings was uneven, depending on their position on the plate, the signal frequency, and the weight of the blocks. Vibration on the strings produced no sound, except for the gentle, high-pitched percussion of the hanging pieces (see Figure 5). This module behaved independently from the soundscape and relied solely on stochastic processes for its operations, a factor that added a layer of complexity to the behavior of the sculpture.

Algorithmic Engine

Two computers running separate applications, developed in the Max programming environment, were responsible for the algorithmic programs controlling both the soundscape and the mechanical exciters in A Queda do Céu. These applications involved a variety of computational routines, three of which we will now discuss: (1) the real-time soundlapse montage; (2) the soundlapse amplitude monitoring and mapping; and (3) the two sets of

Figure 5. Vibrating string in an early prototype of the plate module (a); image from Ríos Anderson's documentation showing part of the suspended wooden blocks in A Queda do Céu (b).



stochastic procedures responsible for controlling the parameters of the low-frequency oscillators.

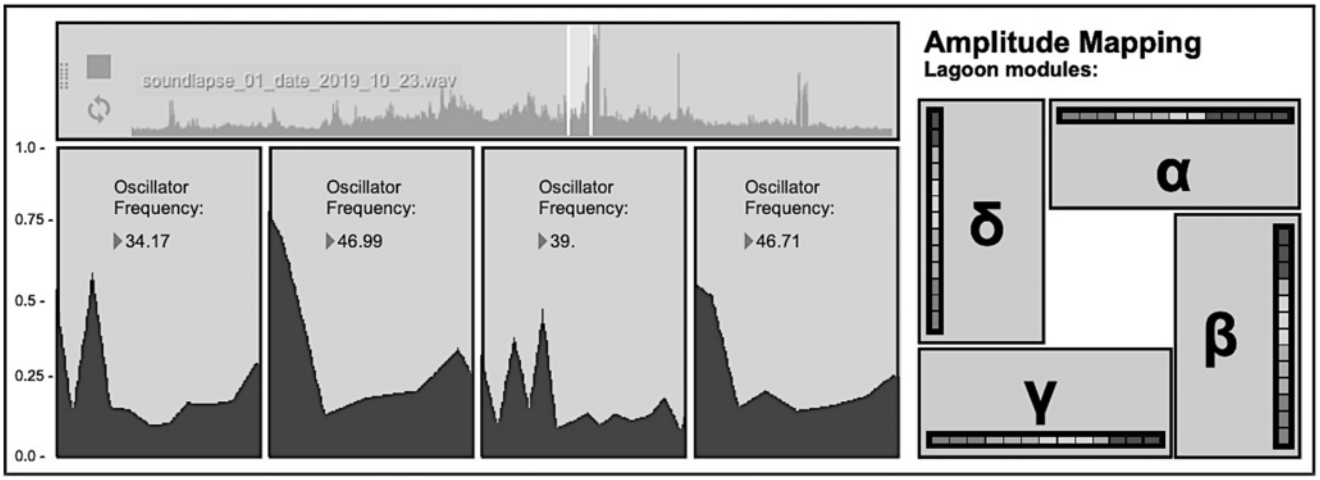
Real-time Soundlapse Montage

This process, described in some detail in the Soundlapse Project section, involved stitching together samples of periodic field recordings, with the goal of producing an expedited version of those longer files while maintaining seamlessness (i.e., smooth transitions between samples), proportionality (i.e., consistency in how time passes), and content integrity (i.e., important features and events are the same in both the original recordings and the montage). A significant computational challenge related to the Soundlapse application was managing the library of field recordings, consisting of 8,760 five-minute stereo WAV files. These demanded that the application load and interpolate external files. The application was constructed such that the most significant parameters affecting the montage were adjustable—namely, the sample length, which ranged from 20 to 300 seconds, and the cross-fade time, which was dependent on the sample length. Control of the first parameter defined the length of the soundlapse and its proportional relationship to the original soundscape, with compression rates ranging from 91.66 to 99.44 percent. Cross-fade times mainly affected the perceived seamlessness of the montage and had to be weighted carefully to avoid exposing the concatenation process. Because earlier versions of the algorithms showed that equal-gain cross-fades produced the most consistent RMS levels (Otondo and Poblete 2020, p. 200), this parameter remained fixed.

Amplitude Mapping

This process referred to the monitoring and mapping of the unprocessed soundlapse montage onto the installation modules, with the goal of producing a perceptible sense of interaction between the auditory landscape and the sculptures. Although earlier phases of development considered including a range of spectral parameters into the mapping process, during the prototyping stages the soundscape's amplitude was identified as the most salient index of auditory activity. Because this parameter could also be mapped directly onto the low-frequency oscillators, the correlation between the soundscape and installation surfaces was deemed to be strong. The most significant challenge with the mapping process was to map out the same audio signal to four different modules, creating enough local variety without steering away from the original input and jeopardizing the perceptual relationship between them. The solution, as shown in Figure 6, was to create separate variations of the same mapping process, based on a variable amplitude mapping rate. In the final version of the program, mapping rates oscillated stochastically between 200 and 1,000 msec, with new values being reached using linear ramps. The indeterminate

Figure 6. Max patch depicting the amplitude mapping process in the lagoons.



and low-resolution aspects of these operations were instrumental in introducing visual variety to the translation process, as well as to prioritize large-scale acoustic events within the mapping process (e.g., fauna, wind, rain, and anthropogenic noise). Figure 6 provides an insight into how each lagoon interpreted the soundscape, producing a kind of visual heterophony tethered in the amplitude-sampling process.

Stochastic Procedures

Indeterminacy was an important part of the algorithmic design of the installation. Stochastic procedures were used in determining oscillator frequencies, mapping resolution, and in controlling many parameters related to the rate of those operations. Motivating factors for incorporating multiple layers of indeterminacy in the program included (1) avoiding repeating patters in surface-level installation behavior, and (2) endowing the work with emerging and "life-like" properties, such as autonomy and self-organization (Bedau et al. 2013). This stochastic architecture interacted fruitfully with the installation's own material and acoustic realities, resulting in a kinetic behavior that felt "alive" and continuously engaging despite being rooted in clear interactive principles.

Discussion: Listening Both in and to the Anthropocene

Although the status of the Anthropocene as a geological epoch distinct from the Holocene is disputed (Subramanian 2019), the idea of the Anthropocene is an urgent invitation to reflect on the profound ways in which we humans have altered our environment. Playing an important role in this debate are the different ways in which we bring ourselves to bear witness to these changes—from scientific studies to documentaries, from new data-visualization tools to works of art dealing with the realities of the climate crisis (Cucuzzella 2021). It is our hope that the Soundlapse project can offer an additional insight into these changes by focusing on the transformations taking place within this decade. Through the various aspects of this research project, we are seeking to imagine practices of listening to the Anthropocene. Artistic projects like A Queda do Céu are, in this sense, an experimental arena where listening can be itself investigated, reconfigured, and exercised.

Central to these ideas is a recognition of the role of technology in opening new avenues for listening. If we can listen to an environment changing over the course of months and years, it is because machines are listening along with us. Microphones negotiate our perspectives (Westerkamp 2021); in designing a machine listening protocol, again technology will be informing the outcomes. In the works of artists like DuBois, time is manipulated for the listener to investigate both the fleeting moment and the sum of things in the here and now; in A Queda do Céu and through the STL method, the object of listening becomes change itself: the inexorable march of time heard through the lens of the natural soundscapes.

Throughout the Soundlapse project, we are attempting to imagine listening practices which, in line with technoecological authors (Kluitenberg 2012), do not understand technology as standing in some kind of ontological opposition with nature. At the start of our work, we set out to avoid tired binaries of "green versus gray," and the naive narratives that position "Nature" (with a capital N) as an alterity separate from us and the world of technical objects. Despite its idyllic soundscapes, the whole experience of A Queda do Céu balances this connection with our natural environments using a futuristic setup. Furthermore, the work is marked by highly mediated procedures: To come in contact with the installation is to take part in the labyrinthine processes of translation, compression, and mediated embodiment that are already deeply embedded in much of contemporary life.

All in all, this is a project that seeks not only to draw attention to the emerging ways in which we engage with the auditory world through technology, but to reorient ourselves according to the demands of our time and place. The political and ecological dimensions of bearing witness to changing landscapes are necessarily colored by the local contingencies relating to and interacting with the climate crisis. In southern Chile, listening takes place against the backdrop of issues such as water scarcity, rapid urban development, social inequality, and the political unrest that led to the constitutional referendum of 2021. More and more, listening has acquired a political dimension—whether it focuses on the thing that hears (Puebla 2021), on things that are heard (EAS 2019), on things that are absent (Corona Aguilar 2021), or things that are changing.

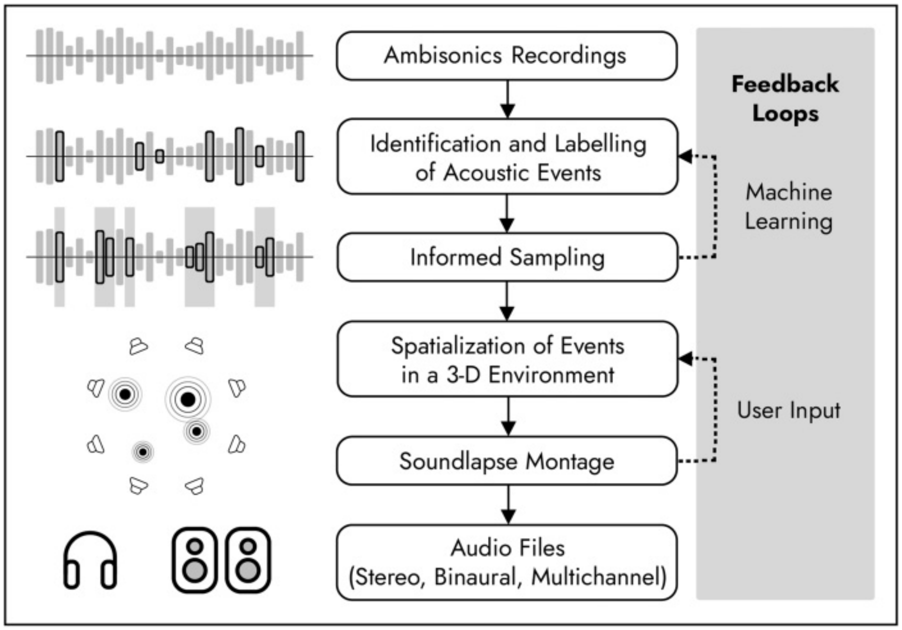
Further Work

In 2022, the Soundlapse project entered a new chapter in its development that will run for four years until 2025. Focusing on three programmatic priorities, we describe the new challenges and opportunities currently facing the project in the fields of machine learning, spatial audio, and artistic research.

Informed Machine Learning Sampling Process

The first stage of the new project will aim to upgrade the time-lapse method to integrate an informed sampling routine that will allow the possibility of generating more-targeted time-lapse files, responding to increasingly specific user input. In line with recent studies that aim to link soundscape ecology methodologies to those of music information retrieval (Bellisario and Pijanowski 2019; Bellisario et al. 2019a, 2019b), a machine-learning algorithm capable of identifying categories of sounds generated by bionic and anthropogenic sound sources will be added to the processing chain of the original STL method, as shown in Figure 3. A proof of concept of the new algorithm was developed by Víctor Poblete and Diego Espejo at the Audio Mining Lab at Universidad Austral de Chile, with the aim of assessing and comparing acoustic habitats of three wetlands of the city of Valdivia and the impact of anthropogenic noise in populations of birds and amphibians (Espejo et al. 2021; Poblete et al. 2021). Taking this prototype as a starting point, a new version of the Soundlapse application is being developed by Gabriel Morales, aimed at identifying common and rare bird species in the three wetlands studied by Espejo (cf. Ruiz et al. forthcoming). The core elements of this algorithm will be used to scrutinize the large database of stereo field recordings mentioned above to identify and tag bird species identified in the 26,280 five-minute recording samples available (24 hours × 365 days × 3 wetlands). Once this training process is carried out, the algorithm will be capable of retrieving specific short audio samples (2–5 sec) that feature various bird species according to previous morphological categorization. With this information at hand,

Figure 7. Schematic representation of the upgraded sonic time-lapse (STL) method.



libraries of short monophonic audio samples related to specific species will be compiled for use as the input for the next steps of the time-lapse process. This will open the possibility of integrating a selective sampling stage into the process, allowing users to create time-lapse soundscape mixes focusing on specific timbral attributes of recordings. Figure 7 shows a schematic representation of the STL method featuring machine-learning routines and informed sampling.

Improved 3-D Spatial Design

Another important area of further development, as shown in Figure 7, will be the implementation of improved spatial capabilities of the time-lapse application. The reliance on traditional stereo recordings is a considerable limitation of the current system, with significant technical and creative ramifications. Inspired by recent studies exploring the creative potential of Ambisonics technology (e.g., Barrett 2019; Malecki et al. 2020), a new set of tools will be incorporated to the algorithm processing chain to deliver a more flexible spatial design based on an improvement of the original recording and reproduction methods. The first stage of this process will involve a documentation, using second-order Ambisonics, of various wetlands of Valdivia in line with the ISO 12913-2 guidelines (ISO 2017, p. 6). The goal in this case will be to record and assess contrasting, rich natural sonic environments to be used as immersive sonic frameworks for the next stages of the processing chain following an approach similar to that of Hong et al. (2019). The second stage of the process will involve the integration of the Ambisonics recordings with short monophonic and stereophonic audio samples resulting from the machine-learning process discussed in the previous section. The aim will be to develop an accessible virtual sonic environment in which users will be able to select and to position sound sources in space, in order to create rich new auditory environments.

Inspired by studies by Rees-Jones and Murphy (2017) and Malecki et al. (2020), pilot tests were carried out at the Arts and Technology Lab at Universidad Austral to assess the main limitations of free and commercial Ambisonics plug-ins when using a 7.1 surround loudspeaker system. The results of these pilot tests showed two main constraints.

The first restriction involves the level of accuracy in the positioning of monophonic sound sources in a two-dimensional 360-degree environment. Front-to-back confusion and poor spatial accuracy in rear speakers were the more common problems reported by listeners. The second problem was the issue of timbral coloration generated by the different spatial plug-ins, which considerably affected the quality of the final output.

Using a similar methodology, two-alternative "forced choice" listening tests will be carried out using the Spat libraries for Max as a basis for a new spatial-design application. These tests, which will be carried out using headphones and multichannel loudspeaker systems, should allow the possibility of dealing with the problem of timbral coloration generated by commercial plug-ins while allowing for more direct control over the various stages of the encoding and decoding processes. In line with recent work by Berge et al. (2020) and by López, Kearney, and Hofstädter (2022), our goal is to make these tools available to educators in the field.

Creative Applications

Artistic research is an ongoing aspect of the project, so the development of new applications also opens the door for new sound-based works. A future challenge will be to incorporate the spatiotemporal algorithm described earlier as part of an interactive audiovisual installation to be carried out at the De Todas las Aguas del Mundo museum in Valdivia. This will build on previous work by the authors, focusing on the spatial attributes of long wetland field recordings (Otondo and Rabello-Mestre 2022). The goal will be to create an inclusive artwork that allows museum visitors to see and listen to some of the spatiotemporal processes described above in real time. By means of multichannel reproduction and mapping techniques, listeners will be able to appreciate the input and output of the time-lapse system and, in a separate area of the museum, didactically identify the sound sources displayed in the work. The installation will also allow visitors to interact with the system using their mobile phones to select the types of sound sources to be played. Soundscapes in this work will operate in a generative fashion, gradually evolving towards the various audio scenes constructed by visitors.

The design and implementation of the sound design for the installation will be carried out in three stages. The first stage will involve the first version of the installation spatial design in a small, 7.1-m^2 surround studio. The second stage will add elevation as part of the design process in an acoustically treated 110-m^2 listening room using a semispherical 32-channel loudspeaker array. In line with guidelines provided by Frank, Sontacchi, and Höldrich (2010), the spatial design in both cases will be evaluated by a panel of trained listeners who will assess the spatial qualities of the reproduction in terms of position of sound sources, timbral nuances, and degrees of immersion. The third and final stage of the design process will be carried out *in situ* and will be implemented using an adapted multiple-loudspeaker array to fit the size and geometry of the room. The same trained panel will assess, in this stage, the final version of the installation following the same approach to the first and second stages. Members of the public will also be allowed to assess the artistic quality of the installation using a mobile phone application especially designed for this purpose.

Summary

In this article, we have provided an account of the development of A Queda do Céu, a sound installation and kinetic sculpture associated with the Soundlapse project. We have described the main computational challenges in the design of the installation, which included real-time processing, interpolation, and mapping algorithms. We have also attempted to contextualize the work in relation to regional ecological and political debates, as well as the global climate crisis. We have shown that artwork can have an important function as an experimental arena in which new technological applications can be probed and where new modes of listening can be investigated, reconfigured, and exercised. Finally, we provided an overview of the current lines of work in the Soundlapse project, particularly the development of a new version of the sonic time-lapse method that incorporates machine-learning routines and user-defined spatialization.

Supplementary Files

1. A documentation video of the installation, provided by Francisco Ríos Anderson: https://doi.org/10.1162/COMJ_a_00633.
2. A full-day soundlapse of the Angachilla wetlands: https://doi.org/10.1162/COMJ_a_00633.

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