A Community Moving with Air in the Immersive Sound Installation HUELLAS DE AIRE (Traces of Air)

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Figure 1: Audiences in the installation. Photo by Ron Herrema

Abstract

HUELLAS DE AIRE is an immersive interactive sound installation that invites audiences to immerse in a soundscape where breath and air intertwine with memory, emotions, and urban ecology. The work explores the profound emotional connection between human breathing, air, and memories in the urban environment of Medellín, Colombia. It displays sound traces of air left by fourteen participants who experienced a three-Day workshop involving Deep Listening, data sonification and sound sensor interaction at the Museo de Arte Moderno de Medellín, fostering an attentive and inclusive awareness of the soundscape and their memories of breathing in the city. The work is activated by eight proximity sensors and one microphone sensor surrounding the sides and ceiling of the exhibition space. Audiences can move guided by poetic invitations projected on the wall and immerse in the listening of sonic variations while activating the data from PM 2.5 particles measured in the city. The space becomes a collective interface for relational listening that changes sound frequencies and generative sounds according to the movements of people in the space, which randomly triggers prerecorded sounds of individual and collective breathing experiences of participants in the workshop. Although commissioned as a solo artist installation, the layers of community engagement with the installation (ideation, implementation, and interaction) activated a complex

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interface for collective listening that led to experimentation with body movement and sound combinations, using Pure Data/BELA, sonification of air data, and ambisonic sound spatialisation, engaging us in a communal environmental dialogue using critical pollution data with a poetic approach for a human emotional experience.

Furthermore, emergent metaphors from the audience experience leads us to develop interfaces for relational listening as a collective instrument to engage with environmental data as tacit presence of the vital air we breathe.

Keywords

Sound Installation, Ambisonics, Collective Interface, Relational Listening, Deep Listening, Air Pollution Data, Breathing

1 Introduction

The artist Ximena Alarcón-Díaz was commissioned to develop an experimental artistic installation in relation to the air pollution of Medellín, Colombia, to be offered to a diversity of audiences for a period of four months[11]. With the idea of involving people in an educational process engaging in questions of listening, scientific understanding of such data, sonification and interactive technologies, the artist, whose research explores Interfaces for Relational Listening - INTIMAL [2], proposed a three-day workshop to listen to breathing, and to experiment with data sonification and embodied interaction using Pd and BELA hardware and software in collaboration with the composer, creative technologist and educator Ron Herrema. The workshop engaged fourteen students from different universities, as well as some interdisciplinary artists to come together in an experience of listening to air, which follows previous experimental artworks at the Museo de Arte Moderno de Medellín (MAMM) in bioacoustics. It was thought this experience of listening, sharing and learning with different technologies might inform an artwork for general audiences.

The artist's questions were the departure for this work:

How to feel and listen collectively to the air that permanently fills our living and relational environment and mediates among all beings living on this planet earth?

What relationship do we establish with the air quality index data, in an installation to aid understanding air, a material we can't touch, we can't see, and that doesn't sound, but that is eminently relational between us?

This article describes the process of community engagement exploring answers to these and other different questions, in the three different phases of the creative process and how these informed the installation:

1) the three-day educational workshop with fourteen participants experiencing a collective process of listening to memories of air, immersing in a scientific understanding of the data in the air quality index, the experimentation with BELA hardware and software using proximity and touch sensors, and sonification of such data.

2) The implementation of the artwork with a dedicated team working on signal processing, sensor response, ambisonic amplification, lighting and an electronic setting for a resilient and engaging interaction from a diversity of audiences.

3)The experience of spontaneous and guided audiences in the installation.

As we describe the different phases of the installation, we infer from the community layers that emerged in its creation, and the creative, and technical challenges we experienced to reflect on the rich embodied experiences with air to be offered to general audiences. We interwove characteristics of communities of practice [16], such as listening , collective ideation, art and technological training, and leadership. The writing of this paper, in itself, is for us a stimulus to reflect and explore future avenues of creation with the communities that were seeded in the making of HUELLAS DE AIRE.

2 A Three-Day workshop

2.1 Day 1: What inspires you? - Listening to Memories of Body, Air, and City

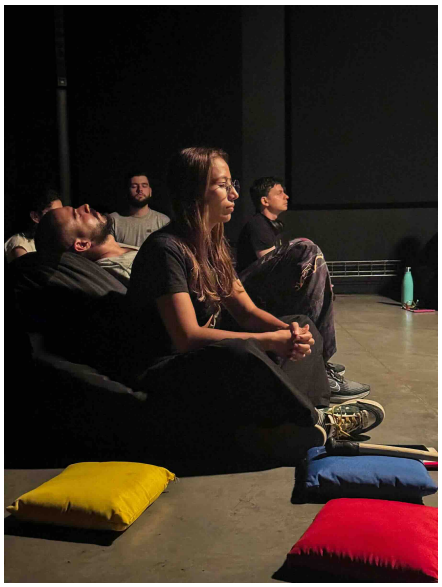

Figure 2: Participants in a listening meditation. Photo MAMM

First, participants engaged with the artist in a full day of Deep Listening [12] experiences (Fig. 2), exploring embodied memories left by air and breathing. Prompted by the question, "Who inspires you?", they responded with an emotional energy that embraced in their memories family members, their community, and places of vibrant nature. They explored breathing, by listening within their body as it feels in the present moment, and also by listening to the memories of breathing in the city. They drew imprints of these experiences (Fig. 3) that were understood as graphic notations to be sounded with voice and aspirated sounds, first individually and then collectively. They reported on the sensations and sounds of their breath as an inner journey that permeates the body and the surrounding space.

When collectively sharing a listening walk in the city, they encountered moments in which interactions mediated by air called their attention; this was intended as a meditation between their own breaths and the breaths of humans and more-than-human beings along their path. At the end of the day, the artist introduced recordings of songs of an endemic bird called Cacique Candela, inviting participants to listen and improvise with sounds, amplifying their imagination of what it would be like to become a bird. They used various folk wind instruments and also homemade wind instruments. This improvisation unfolded an invocation rising in the air like breaths of soul and wings, that supported a

Figure 3: Trace of air. Participant's drawing on breathing experience. Photo MAMM

collective meditation on more-than-human beings that share the air with us.

These sonic experiences were recorded by the artist and by the participants in ambisonic format, and informed the first dataset of sonic material of the installation, labelled according to the recording and sounding exercises as Traces of Air 1, 2, 3, and 4. This communal experience set the basis for the practice and ideation of the following days where technologies became the center of experimentation.

2.2 Day 2: Understanding Air Data and exploring sonification

On the second day, with the artist's collaborator we delved into the data that measures air quality in the city, We asked the group: *how can we sonify an annual sequence of air pollution data in Medellín as a sonic meditation on effects and affects on humans and more-than-human beings?*

A scientist from the metropolitan agency of Medellín, Sistema de Alerta Temprana de Medellín y el Valle de Aburrá (SIATA) who carries out the measurements of air quality in the city, explained to us the air quality index, the particles in the equation, and the complexity of effects of the air. How, from our surroundings, it moves to the sky, and how harmful particles that accumulate cannot be easily evacuated because of the city's singular geographical location. Among the particles, the largest effects are made by the PM2.5 particles. These are so small that they cannot be filtered through the nose, thus directly affecting the lungs.

In 2017, the city suffered one of its highest air pollution crises. One of the participants showed us a photo taken with an immense cloud of gray covering mountains, buildings, and the trees. The PM2.5 particles are generated by motor vehicles without particulate filters and by factories. Any urban intervention, such as the current accelerated building construction, influences the circulation of particles. Weather phenomena also affect particles: the rain at night cleans the air, while the rain in the evening influences the movement of particles in a different way. Also sand of the Sahara desert could influence the cycle of the air quality in the city.

We wondered about the relationship between air pollution and noise in the city. Sources of air pollutants also produce acoustic levels that prevent us from hearing our own breathing. Birds are affected by the high decibels reached by motor vehicles, and their heart does not resist these frequencies. We wondered about other effects also in humans.

The understanding of data in the index of air quality in the city (Fig. 4) left us with a complexity of the situation and wondering what are the subtleties of this interactive sonic experience, how to create with this data through relationships between sounds, emotions, and interactivity, and how to stimulate both understanding and agency in audiences.

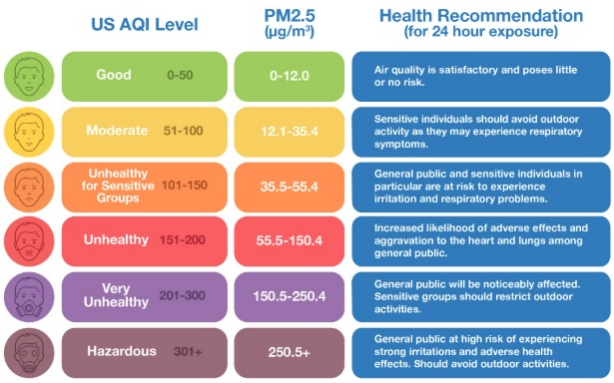

Figure 4: Chart of Air Quality Index of PM2.5 and effects on human health. Taken from IQAir

When explaining sonification, we asked a simple question: 'what is the sound of data?'. We suggested that there were roughly four possible objectives when sonifying data: to monitor, to research, to educate, or to make art (i.e. 'extraordinary experiences'). We also offered participants a range of examples of data sonification—for example, a realtime generative website ('weatherhum') [9] that visualises and sonifies the user's local weather conditions; a set of Pd patches [10] that visually demonstrate the flow of data; an interactive website [5] that sonifies human emotion; an artwork [8] that sonifies cyber attacks; and a live telematic performance that incorporates the sound of breathing data[3][7]. We then reflected on how we might sonify data ourselves.

The sound of data opens the way to aesthetics and transmission of acoustic senses that elevate its descriptive element to envelop us in a sensory experience. The transmission in real time, or with predetermined times, might add rhythms and interventions of values that fluctuate, and that also make sense through their repetition. Numerical abstraction could give sound meaning, and textures to the behavior of particles that we cannot see, using variables that measure air quality. With this in mind, we had two options of retrieving the data: either through the Excel table of accumulated data provided by the metropolitan agency, or by focusing on one of the stations providing data in real time. We noted the interactive challenge of using real-time air quality data, to be sonified, as it is typically measured and reported on an hourly basis. Our intention was thus to offer one year of data to develop sound sequences that ultimately function as meditations on this complexity.

We wanted to use free and open-source software and thus chose Pure Data (Pd) as the principal means of instruction and experimentation. As the range of expertise with audio software in the assembled communities was variable, we offered a basic Pd patch (called Medellín patch) that could be elaborated and modified. (The patch used a band-pass filter that used data to modify the sound of a combined noise and sawtooth wave.)

The diversity of skillsets and perspectives of the varied communities and participants produced a variety of results, which we were then able to audition and reflect on. This served the dual purpose of providing a basic working knowledge of the technology while also stimulating ideation, leading to proposals that would be more consolidated the day after with the introduction of BELA and sensors, such that the data and sound could be affected by body movement.

2.3 Interaction with Pure Data/Bela: proximity and touch

Figure 5: Group 4 working with sensors and BELA. Photo by Ron Herrema

On the third and last day of the workshops, we asked about the interaction: *how do we navigate deeply, between the air traces that are left by humans and more-than-humans in an installation space?*

To introduce BELA hardware and software to participants we focused on two types of sensors: proximity sensors and touch sensors. To work with a group of fourteen participants we had three BELAs, a TRILL craft sensor, and two proximity sensors. We used workshop materials such as conductive copper tape, connected to conductive thread already connected to the TRILL craft. We also used breadboards, paper, pens, fabrics, and worked in a large, inspiring space surrounded by textured windows with a view to the city. These materials shaped the collaboration that needed to be developed among four groups of participants developing an interactive idea, incorporating the data that had been introduced the previous day, together with the sensory experience of the first day (Fig. 5).

We suggested that participants think of ideas of distance and touch, and approaches to interaction in a sound art installation inspired by works developed using BELA [4] [17], and asked them to work on an idea incorporating sounds recorded on the first day, generative sounds using the data of PM2.5 in Pure Data (Pd), and physical interaction using BELA.

The process of ideation included graphic tools for the drafting of a space, based on the actual space where the installation would take place, with a proposed trajectory that audiences could follow, as well as the definition of points that could be activated by interacting with the body, generating the playback of sounds, sonic amplification, and the use of image if needed. We thus included a 'script' to help place and think of possible interactions (Fig. 6) (Fig. 7).

Sounds	Air Data	Interactivity, Materials Sensors - Relations
Ambisonics: **Air Traces 1 (Body),**	E.g. Can be heard when there are less particles	E.g. Conductive thread tape
Air Trace 2 (Memory of Place)		
Air Trace 3 (Sensitive places - walk)		
Air Trace 4 (improv with bird sounds),	E.g. Can be heard when there are less particles	E.g Proximity sensor
Slow walk.	E.g. For less particles, walk slow, less consumption, less speed	
Huellas de Aire 2 (Memoria), Place	E.g Associated to each area of memory	
Mono: **Puntos sensibles (de mobile phone)**	Area MAMM	E.g. Map of memory
Sonificación Datos Aire: Sonido generativo (PD) **Relationships between different data, rhythm, texture,**	Orange or Red: high peak Sound variation: musical and dissonance Amplitude variation: More density of certain sounds and less density of sounds	

Figure 6: Table to aid the writing of an interactive script. Provided by the artist

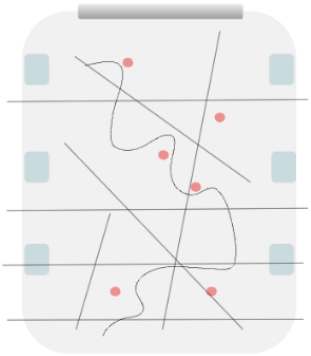

Figure 7: Graphic for ideation of movement in space. Provided by the artist

In the dynamic of group work, some of the participants focused on the planning of the installation by choreographing how these might work with body movement and audiences. Others, who already had technical skills to engage in Pd and Arduino, found easier the use of BELA, and focused on the making with the technology. At the end of the day, three groups reported on their proposals for implementation (Fig. 8):

2.3.1 Group 1. "The proposal is to offer a space whose base sound is the sonic representation of SIATA data, which translates pollution levels. There is no silence. If the levels change from yellow to orange or another color, the sound intensifies in volume. It's possible to propose a switch, like a light switch, that can be activated to stop the ambient sound. This would make it perceptible, in sonic terms, what would happen if the level were green. But it would activate automatically after 10 seconds (for example).

However, the most interesting aspect is approaching the complexity: that it's not just one thing (cars, industry, or buildings),

Figure 8: Group 1 showing proposal. Photo MAMM

but that other factors, such as fires in other regions or the sands of the Sahara, influence and connect us to the air (and the land and water) of all places.

In parallel, the ground (which is the earth) reacts sonically to weight or friction, depending on the type of sensors. Activating different types of soundscapes: birds, leaves rustling in the wind, a distant song, an ocarina, sonic memories of individuals, breathing in different circumstances: meditating/walking, running, having sex, feeling fear.

Then the conflict between the ambient sound (which sonifies the state of the air) and the soundscapes activated by walking, sliding, or jumping, is the problem. If the air quality were green, there would be no conflict. But if it's yellow or orange… it becomes difficult to hear the other sounds. So, the switch has to be turned off. If there are several switches and the intervals are short or randomly set… something could be composed between the soundscapes activated by weight or friction (the dance) and the ambient sound, which is the sonification of the SIATA data."

This proposal brought to the artist's attention the lack of silence, because the particles are always present in the air. The saturation of PM2.5 will produce some changes in the sound as people interact with the space. This would take us to a poetics of human agency in the face of the pollution. The ground as an interactive space reacting to weight and friction was interesting, and difficult to bring to the installation considering time, complexity and resources. Following the complexity of the influences of the air, this proposal highlighted human agency and imagination with a switch, randomly bringing different soundscapes recorded in the workshop.

2.3.2 Group 2. "The proposal is to depict the evolution of how human activity has affected nature through a three-stage timeline, each stage representing different periods in history. The first stage represents the prehistoric period when human interaction did not have significant repercussions on nature. The second stage reflects a transitional period in which human activity began to affect how nature develops. Finally, the third stage represents the current state of history in which air quality is highly influenced by our fast-paced lifestyle.

In each stage, it will be possible to interact with each sound recording using the conductive tape and the BELA. The sound recording will vary depending on the number of people interacting with each stage.

In the first station, songs of the Cacique Candela bird are played. When people interact using the conductive tape, the sounds recorded in Trace of Air number 4 will be played, thus representing the interaction of humans with nature in prehistoric times. In the second stage, using the Medellin patch, air quality data will be sonified with a sound similar to rain. The more people interact with the conductive tape, the more rain sounds will be heard, along with samples from Trace of Air 1 . The Trace of Air 1 samples represent the most direct human interaction with nature.

In the third stage, the current situation will be represented by recordings of the walk. By sonifying the real-time SIATA data, the current air quality situation can be conveyed. The sonification will be done using samples, creating a soundscape based on the air quality at that moment. When people interact, the samples from the sensitive points will be played.

The green square represents the entrance, while the blue, purple, and red squares represent stages 1, 2, and 3 respectively. Each orange circle represents the sensors with which people will interact. (Fig. 9)"

From the artist's perspective, this group had a clear pedagogical idea about historical moments in human time in relation to nature. Real time data is ideally proposed for the awareness of air quality in the city, displaying recordings that in the workshop were called "sensitive points," implying an awareness developed during the listening walk of how humans and more-than-humans are interacting with the air. In fact, stations that measure air quality data update every hour. For this reason, working with real time data could not bring sufficient dynamics to the installation.

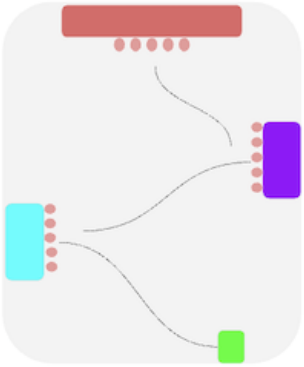

Figure 9: Trajectory of installation proposed by Group 2

2.3.3 Group 3. The third group explored movements in the air using proximity sensors, extending body movements into distance-oriented interaction. These movements were inspiring for the artist, as participants were drawing the space with the movements. The artist envisioned the option of having proximity sensors in different areas of the room that could surround the entire compass of the body, specifically sensing arm and hand movements, and taking into consideration different body heights (Fig. 10) (Fig. 11). (There was one sonification idea by a participant who requested that we exclude the description from this paper, which we have respected. The authors valued this creative idea but did not incorporate it in the composition.)

The educational experience introduced avenues for composing interactive sound installations, interfaces and/or instruments for new musical expression. Committing to a particular design

Figure 10: Group 3 in ideation of movements in the installation. Photo by MAMM

Figure 11: Group 3 in ideation of movements in the installation. Photo by Ron Herrema

proposed by the different participants in a three-day workshop proved challenging for only one installation, as occurs in any creative collective space. Spatialisation, being an important technical part of the work, was not offered in the workshop because of the time constraints. However, our communal experience seeded forms of teaching these possibilities to a variety of practitioners, whose ideas offer diverse aesthetics and options to expand in the future, according to the means and artistic or educational purposes, as well as the time available for such workshop series. Eventually, some of participants' ideas were, in fact, tested and incorporated into the installation proposed by the artist.

Reflecting on the type of co-creation exercise we experienced, we use Simon's [14] discussion of levels of audience participation, mentioned in Cuenca-Amigo and Zabala-Inchaurraga´s review on co-creation in museums [6]. We realised that the three days of educational workshops took the form of "contribution" from the participants, in the sense that participants proposed ideas for a commissioned work of the artist, while the process of implementation functioned as a form of "collaboration" with the authors of this paper. We think that, in this context, a process of co-creation—in which the goal of the exhibition is decided and implemented by the participants and the artist, supported and commissioned by the museum—would have demanded a longer period of time to enable the development of ideas and skills, as well as forms of implementation.

3 Implementation

The implementation team consisted of the artist, two sound engineers, Esteban Henao and Juan Felipe Amaya Álvarez, and the MAMM installation team, managed by the curator Jorge Barco. The implementation team invited one of the participants in the workshop, Adriana Maria Gutiérrez Grisales, to assist in the acquisition and placement of electronic components, gaining a technical understanding of the project, and physically realizing the artist's conceptual proposal. This experience provided a practical application of prior learning. This team became a community of creative and technological practice, sharing skills, solving problems and learning further to work with BELA CTAG Beast, a relatively new technology for us, in a challenge of using a large number of sensors and ambisonic amplification for nine loudspeakers, all controlled from this microcomputer. Collaborative work proved fundamental to this process. The integration of diverse knowledge enabled the collective construction of solutions, highlighting the value of situated and shared learning. This collective dimension broadened the understanding of the installation not only as a technical object, but also as the result of a network of interrelated knowledge. Likewise, the experience reinforced the importance of attentive listening in the operational dimension of the installation. Precise understanding of instructions, task coordination, and effective communication within the team were crucial for the installation's proper functioning.

3.1 Composition, movement and sonic experience

The installation HUELLAS DE AIRE, as developed by the artist, drew on the collective reflection of the three day workshop, and offered an artistic perspective that invited audiences to experience rituals of listening, aided by poetic prompts (Fig. 12). The position of the sensors in the space was intended to create exploration of free body movement vertically and horizontally, and to consider solo and collective interactions.

The space was intended to be understood as filled with traces of air, emotions, and physical particles, to be activated and transformed into sound by the movement of the visitors, also revealing the relationship between polluted air and human emotional memory of breathing. The experience was seeking to raise awareness about the impact of air on people's lives, inviting such reflection through listening and movement.

Initially the artist proposed an installation with ten proximity sensors, each with a range of approximately 50cm, surrounding the audience from the sides, and from the ceiling (Fig. 13). These would respond to the audience's proximity and to play generative sounds changing with distance (Fig. 14). The PM2.5 data would run and change in speed activated by distance. Also, some sensors

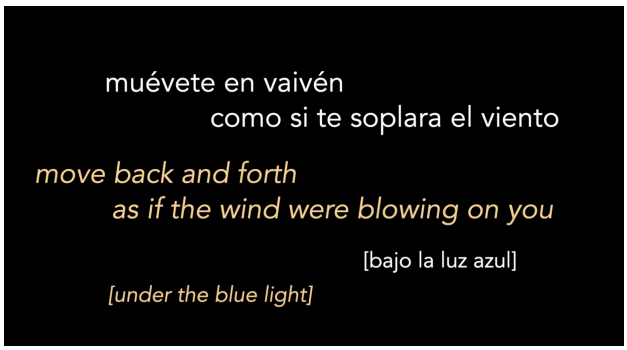

Figure 12: Poetic Score. Still from video by Ximena Alarcón Díaz

would activate Traces of Air 1 individual and collective sounds. The sound composition was written on a chart of relations, together with the sound mapping for interaction with sensors and amplification, to be understood by the implementation team (Fig. 15).

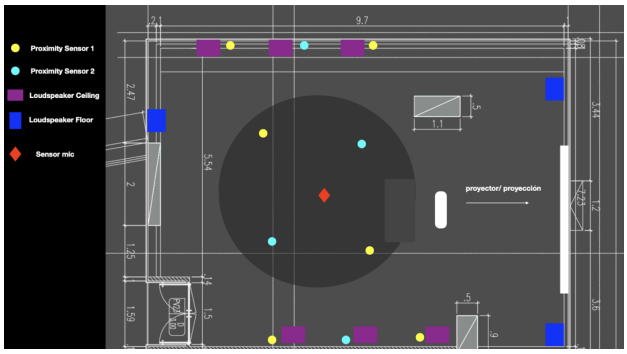

Figure 13: Layout of the space proposed by artist. Graphic by Ximena Alarcón Díaz

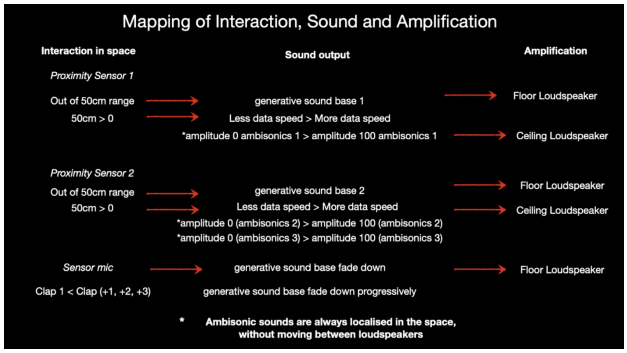

Figure 14: Sound composition. Graphic by Ximena Alarcón Díaz

Eventually, and testing the capacities of BELA, the installation employed eight proximity sensors that reacted to audiences' body movements, and a microphone to be activated by 'clapping'. By moving within the space, visitors influenced the soundscape, modifying the speed of data generating variations in sound that created a sound texture. This texture became denser at closer proximity, almost bubbling, and lighter at further proximity. Without

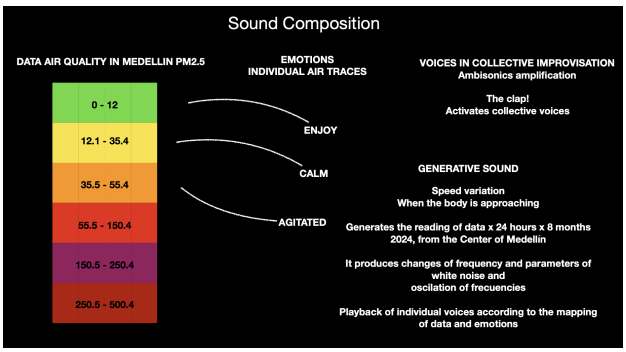

Figure 15: Algorithm for Interaction. Graphic by Ximena Alarcón Díaz

requiring a precise interpretation of environmental meaning, the randomness of these movements unfolded in such a way that the complexity expanded according to the number of sensor activations triggered by more people interacting simultaneously in the space.

To establish sonic distinction in each sensor, we assigned a different frequency, which was activated upon entering the angle perceived by the sensor. This created a gentle undulating sound as people moved back and forth beneath or beside each sensor. When several people activated all eight sensors, a subtle drone of sonic texture was generated.

Some sensors triggered pre-recorded individual breathing soundings from participants in the workshop, with a diversity of emotions. These were heard through speakers placed at an average height for the audience, generating direct communication of that presence in the space. Additionally, when a concentration of audio frequencies arised, resulting from dense sound activation, or when a loud, or collective clapping occurred, recordings of collective sound improvisations were activated and heard through six speakers placed on the ceiling, creating an immersive sound experience using ambisonic techniques.

The sonic experience involved a complex technical development using Pure Data and BELA, and an adaptation of an amplification system described below.

3.2 Pure Data/Bela: Control Signals and Sonification Mapping

The system supporting the installation was implemented in Pure Data and executed in real time on the BELA CTAG Beast platform (chosen for ambisonic amplification), integrating eight proximity sensors and a microphone as the main input sources (Fig. 16). Each sensor provides a raw signal associated with the echo delay between an ultrasonic emitter and an ultrasonic receiver, from which the user/object distance is estimated. In general terms, the procedure consists of exciting the emitter with an ultrasonic carrier, capturing the response at the receiver, and converting the resulting measurement into a continuous distance value through calibration, linearization, and scaling to the usable interaction range. Subsequently, each sensor signal undergoes signal conditioning to ensure stability and controllability for sonic mapping. This conditioning includes (i) filtering to reduce noise and fast fluctuations, (ii) temporal smoothing to avoid audible discontinuities, (iii) normalization and rescaling to a unified range, and (iv) limiting to prevent out-of-range values. As a result, each sensor

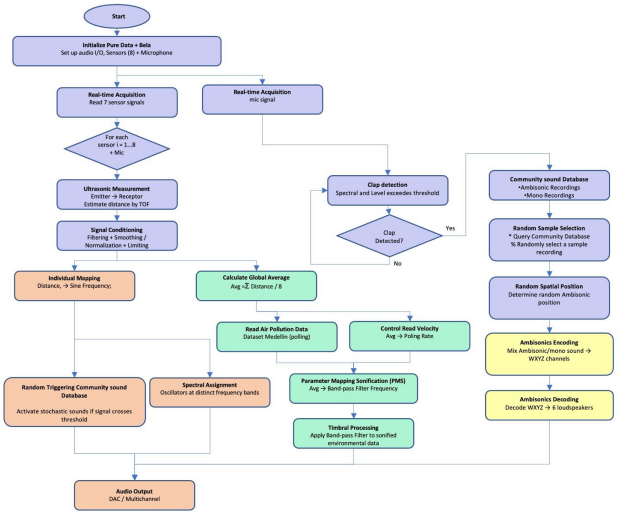

Figure 16: System supporting the installation. Graphic by Esteban Henao

produces a continuous and robust signal that can be used as a control parameter for synthesis and processing.

At the control level, the system computes the global average of the distances (mean across the seven channels), which operates as a macro-control. First, this average controls the data-rate of an environmental data stream based on a historical air-pollution dataset from Medellín, enabling navigation through the dataset at different speeds according to the audience's mean proximity. Second, the same aggregate value is used within a Parameter Mapping Sonification (PMS) strategy, where the average modulates the center frequency of a band-pass filter, dynamically shifting the spectral emphasis of the sonified layer and its timbral perception.

Complementarily, each individual sensor controls micro-spectral parameters: specifically, each one modulates the frequency of a sinusoidal oscillator assigned to a distinct region of the audible spectrum. This band-wise distribution segments the interaction space into seven simultaneous contributions, producing a polyphonic texture in which proximity variations translate into shifts in pitch and spectral density. Additionally, each sensor operates as a trigger for stochastic events: when the conditioned signal crosses a predefined threshold, the system activates sounds randomly (random triggers) through random sample selection with probabilistic control over event occurrence and/or random variation of amplitude parameters. This discrete layer introduces temporal variability and prevents strictly deterministic behavior, complementing the continuous control (PMS and oscillators).

In parallel to the proximity subsystem, the microphone integrated in BELA feeds a clap-detection module based on spectral features and energy level. The microphone signal is analyzed via filtering, and a threshold-based decision criterion is applied to identify the clap event. Once a clap is detected, the system automatically selects, at random, a sound from the community database (material collected during the workshop with the community, including ambisonic and monophonic recordings) and determines a random spatial position for playback.

Spatialization is implemented through an ambisonic signal flow for a six-loudspeaker system, where BELA performs ambisonic encoding (generation of ambisonic components from monophonic sources and/or playback of material already captured in ambisonic format), followed by decoding to the six output channels. Finally, all layers (proximity-controlled oscillators, dataset sonification, stochastic triggers, and clap-triggered events) are integrated into a multichannel mix sent to the reproduction system, maintaining a continuous real-time execution loop.

3.3 Spatial Audio Reproduction System

The installation's sound reproduction system was structured around two complementary subsystems designed to operate simultaneously. Although their combined use is unconventional, the integration yielded strong perceptual results, particularly in terms of spatiality, layer clarity, and the differentiation between sonified material and documentary content. This hybrid architecture enabled an explicit functional separation: one subsystem dedicated to synthesis and parametric sonification (continuous control), and another oriented toward immersive spatial reproduction of the workshop recordings (contextual and narrative layer). The resulting configuration is shown in Fig. 17, where the quadraphonic array in the horizontal plane coexists with the elevated ambisonic system.

The first subsystem is a quadraphonic multichannel system (4 loudspeakers) employing an amplitude-panning spatialization strategy. In this approach, the apparent source position is controlled by distributing gain across the four channels, such that the relative energy sent to each loudspeaker determines the perceived location in the horizontal plane. In Fig. 17, this array is represented as a ring at 0° elevation (square markers), highlighting its 2D spatialization orientation. This subsystem was dedicated to reproducing the system's generative layers: (i) sonification of environmental data via Parameter Mapping Sonification and dynamic filtering, and (ii) sinusoidal waves controlled by the proximity sensors (as well as stochastic triggers associated with threshold events). By concentrating this content in the quadraphonic system, stable spatial behavior and a clear reading of parametric variations were achieved.

The second subsystem is a second-order Ambisonics system decoded to six loudspeakers, installed at an approximate elevation of 6 m. This array was used as an immersive layer for workshop-derived material, primarily recordings derived from the workshop. In Fig. 17, the ambisonic loudspeakers appear distributed in elevation (circular markers), and the relative marker size summarizes the contribution/gain derived from the decoding matrix used in the system. The ambisonic signal flow operated in two modes: (i) encoding monophonic sources into the ambisonic domain by projecting the signal onto spherical harmonic components as a function of the target direction (azimuth/elevation), and (ii) decoding to the physical array by transforming those components through a decoding matrix into loudspeaker feeds optimized for the specific layout. This enables both the spatialization of monophonic audio and the reproduction of ambisonic recordings while preserving their directional information. Overall, the hybrid system operated as a functional, layer-based separation strategy: the quadraphonic system reproduced the generative/sonified material (data plus sensor-driven synthesis), while the ambisonic system handled immersive spatialization of documentary material (recordings from the workshop). This distribution improved the intelligibility of the interactive flow and the sense of spatial presence without sacrificing detail in parametric control.

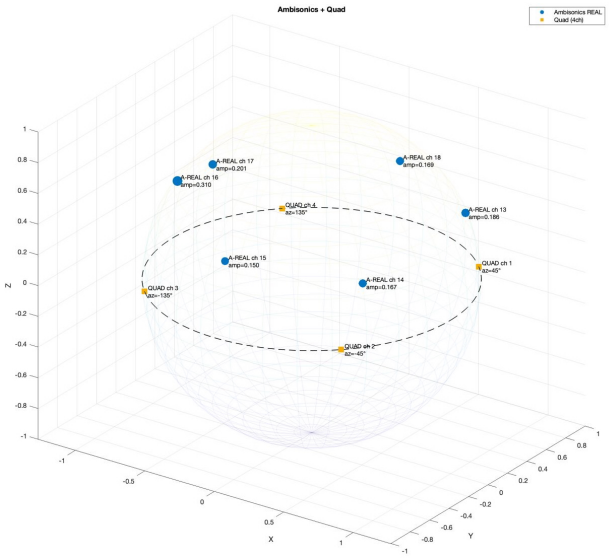

Figure 17: Configuration of amplification system. Graphic by Esteban Henao

3.4 Problem solving, physical routing of cables, and placing the sensors

The physical setting for the sensors needed to be sturdy, for a diversity of audiences, including large groups of children, that could interact with it for the four months that the installation was expected to be open. Adriana Maria Gutiérrez Grisales designed boxes to place the sensors and place the cable wired around the room. We realised that the boxes needed an LED light that indicated the existence of the sensors, thus the boxes incorporated a blue light. We chose the color to keep a calm and inviting meditative listening space. The microphone sensor was distinguished with a red light. (Fig. 18)

Figure 18: Boxes to place proximity sensors. Photos by Adriana Maria Gutiérrez Grisales

Tubes hanging from the ceiling were supporting the sensors and establishing a height in which different people could find levels of interaction by waving their hands. (Fig. 19) We used large cables to route to the sensors, as well as to the loudspeakers, and agreed on a way of labelling those to be understood and troubleshot by any member of the development team. (Fig. 20) (Fig. 21)

Figure 19: Proximity sensors hanging from the ceiling. Photo by Ximena Alarcón Díaz

Figure 20: Array of cables. Photos by Adriana Maria Gutiérrez Grisales

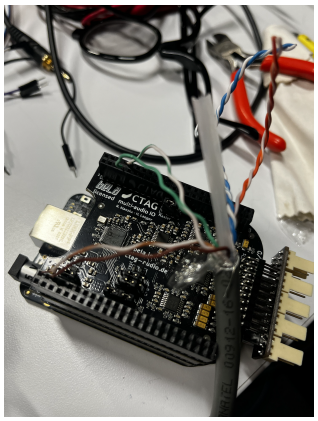

Figure 21: BELA wired. Photo by Adriana Maria Gutiérrez Grisales

The process of implementation allowed for the integration of technical knowledge related to devices, connections, and troubleshooting. In this context, problem-solving was configured not only as an operational task but also as an exercise in critical thinking and adaptation. The experience highlighted the gap between solutions conceived by the artist and the concrete material conditions of the local context. A significant case was the adaptation of an electronic component of the sensors whose original part, available in Bogotá (place where the artist originally purchased it for the workshop), was not found with the same specifications

in Medellín. The variation in the device's dimensions forced a rethinking of previously considered definitive decisions, which allowed for an understanding of the importance of flexibility in the installation and technical design processes. The systematic documentation of the process—through photographic and audio-visual records—allowed for reflective monitoring of the learning process. This documentation exercise fostered the consolidation of technical and conceptual knowledge, as well as the integration of the experience into the artist's own development.

4 Audiences

The installation was part of a large opening of artworks at MAMM. Before the opening, two guest artists working with movement and improvisation, visited the space and played with the installation. Observing their movements in the space, we understood that the installation worked well and that it was ready for the general audiences. The educational team organised daily visits with large groups of people, coming from schools and general visitors, stimulating the interaction. The sensors were activated by the crossing of people in the space, so they were not necessarily aware of the activation. Once they are aware of the system, it becomes more a conscious and playful interface for listening to the relationships between air particles and the emotions that emerge with, and are expressed through, breathing. The poetic invitations of the projected video (Fig. 22) supported specific movement experiences, such as "subtly approach and move away from the blue light".

Figure 22: Visitor interacting with the installation. Photo MAMM

New instruments and interfaces [15] demand appropriation and understanding of interaction and affordances, as well as scores to help guide and understand the sonic interactions. In HUELLAS DE AIRE the space can be understood as the interface, as David Rokeby [13] suggests, that needed to "evolve" with people's movement. Only by watching others moving in the space, while reading the invitations projected on the wall, can audiences mimic others and follow such invitations.

In HUELLAS DE AIRE, audiences initially didn't understand how to interact, because they entered a space that had no objects and only a few blue lights (which were signaling a way to the proximity sensors). These have two holes, which, from an audience perspective, might have afforded touching or pressing like switches. As the audience started to interact with the installation, we made some adjustments regarding lighting: the use of low light to walk safely. We also repaired a box with a sensor, which one user understood as a switch.

The team noticed that audiences needed help interacting with the space, so the artist suggested a graphic instruction, a guide

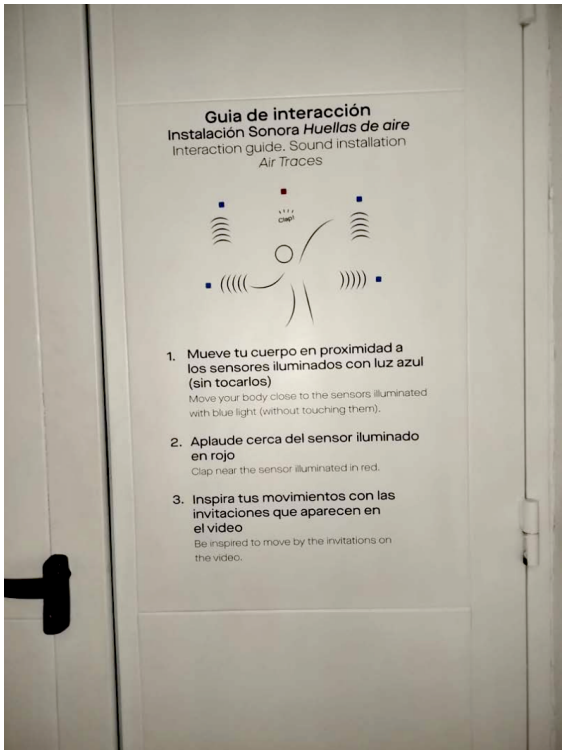

Figure 23: Guide to enter the installation. Photo by Ximena Alarcón Díaz

that brings some playfulness without becoming instructional (Fig. 23). The guide consolidated the potential of the artwork as a collective interface that invites listening and reflection on environmental concerns.

The artist offered a listening workshop and artist talk for a group of people who experienced the installation together. After the workshop, she asked what it was like to be in the installation space, to which participants responded with these metaphors: "I felt as if inside a lung"; "It was like being in the middle of a jungle"; "It was like playing piano in the air".

4.1 Survey

For this paper, authors collected feedback from five people who visited the installation and gathered responses to the following questions:

4.1.1 Could you describe the experience of being in the space of the installation HUELLAS DE AIRE?.

Participants describe the space as an "experience of discovery," one "that invites you to immerse in an invisible landscape, where each movement transforms the air into sound". The space, they say, stimulated "curiosity", "play", a "desire to intervene", and "to get involved physically". Specifically, one participant describes the experience as: "you play as a girl with light and sound, and ask yourself about the world where you live and what you can do for it". The slow involvement in the space is described by one as helping to become "conscious of your breathing and of how your body is affecting what you are listening to, which creates a very noticeable sense of presence. It is not a fast nor immediate experience; it demands a certain degree of attention and intention to slow down, which produces an effect where the

sound is perceived in a wider manner, almost embodied, and not just aural."

Remarkably, one participant described the experience as transformative: "My body became a bridge between the particles of the space, the voices that were floating and the soundscapes surrounding me." (Fig. 24)

Figure 24: Audience movement in the installation. Photo MAMM

4.1.2 What do you think was the relationship between the air quality data in Medellín (PM 2.5 particles), the sounds, and the interaction with your movements?

Most of the responses to this question focused on an abstracted perception of the experience (as was intended by the artwork) rather than on the technical functioning of it. One response - that "the sounds of the air and the particles are in relation to the pollution" - makes the connection explicit.

Responses focused on perception and sensation inferred: "I perceive that the relationship between PM2.5 data, sounds, and movement functions as a kind of sensory translation of something we normally ignore. The fact that pollution becomes sound makes it no longer a distant fact and instead makes it feel like part of the environment you inhabit. When the system responds to your movements, it creates the impression that there is a direct connection between your presence and the state of the environment, even if it's symbolic. I find this effective because it doesn't explain the problem literally, but rather makes it perceptible and, therefore, harder to overlook."

"I think that the air quality in Medellín became visible as a whisper. The particles PM2.5 were like shadows that, when touching my movement, were drawing sounds in the air, as if the breathing of the city were interweaved with my dance."

Responses about lessons learned implied an exercise of consciousness:

"It made me become conscious of the importance of the air not only in Medellín, but on the planet". "Bringing real data to an artistic space, where you can become conscious, because you are in a space where they show you the problem…and you imagine how can you interact…you and the others who live this experience".

4.1.3 Inferences. All in all, and derived from these responses, we infer that the installation HUELLAS DE AIRE becomes more a collective interface for relational listening, than an instrument to be performed following training.

The idea of an interface for listening within air, both from inner and outer embodied experiences, is achieved. Furthermore, the idea of playing an instrument in the air—rather than, for instance, dancing—brings clearly the potential to consolidate the idea of a collective interface to play with and to become air. Derived from this finding, we envisioned further work in movement choreography and soundings, which will invite audiences to experiment with such an interface: an invitation to explore a diversity of listening experiences with air as interfacing us with all beings: the breath becoming voice, the wind, the birds, in an attempt to connect with the reciprocity of air exchanges, what David Abram calls the "commonwealth of breath" [1].

5 Conclusion

Air, as an environmental space of individual and collective memory of a city, together with the pollution data, becomes the interface. The installation is thus an environment, such as a forest, where we are not aware that we are exchanging information with trees, insects, birds and many other animals. The audience was aware of something that was happening in the active spaces of the installation, even when no one was triggering the sensors.

In a contemporary context where air quality has become a critical concern, the work seeks to raise awareness about the importance of protecting this vital resource, while highlighting the power of art to offer new perspectives on our relationship with the environment and the possibility of transforming it. The installation has invited visitors to reflect on air not only as an essential element for life, but as a living archive of our collective histories of breathing.

This context brought a series of communal moments for listening, understanding scientific data, and creating a sound installation using interactive audio technologies and sound spatialisation.

From a participant 's perspective, who also became a key member of the implementation team, the community and learning experience was summarised as follows:

"the experience reaffirmed the relevance of experiential learning compared to traditional academic assessment methods. In this context, the success criterion was linked to the functionality and coherence of the installation, prioritizing the effective realization of the proposal over a numerical grade. Finally, the learning derived from the workshop and the installation process transcends the specific event and becomes integrated into the individual artistic process. The experience strengthened technical skills, broadened the understanding of collaborative work, and solidified a vision for developing future interactive installations in diverse contexts. Furthermore, it facilitates the transfer of knowledge to emerging artists, promoting interdisciplinary exploration and the expansion of artistic practices based on interaction and listening."

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soundings, and engaged in the ideation of the work to be incorporated in the installation. Special thanks to Mateo Jaramillo Velásquez from MAMM who supported us with the placing of sensors in the installation.

7 Ethical Standards

The MAMM had informed consent from the participants in the workshop for their recordings to be used in the installation, as part of the artwork, and as a documentation of the process. The installation offered public thanks in the installation materials, naming all participants. The following contributors to the ideation exercise in the Groups, expressed their consent for their ideas to be part of this paper: Brenda I. Steinecke Soto, Juan Manuel Mosquera, Julián Cadavid, Esteban Penagos Avendaño, Sofía Marin Ibarra, Juan Camilo Bernal, Isabella Ardila Sandoval, Simón Quintero Gutiérrez, Juliana Pinilla, María Rueda, Daniel Camilo Serna Henao and Yoa Gallego.

References

[1] David Abram. 2014. The Commonwealth of Breath. *Material Ecocriticism* (2014). https://www.davidabram.org/essays/magic-and-machine-65hd4-fj357-hmg7n-r44nk

[2] Ximena Alarcón. 2017-2026. *INTIMAL: Interfaces for Relational Listening.* Retrieved April 29, 2026 from https://intimal.net

[3] Ximena Alarcón-Díaz. 2021. *INTIMAL Documentary.* Retrieved April 29, 2026 from https://vimeo.com/512586450

[4] Tove Grimstad Bang. 2020. *Suspended Circles.* Retrieved April 29, 2026 from https://blog.bela.io/suspended-circles-tove-grimstad-bang/

[5] Alan Cowen, Hillary Elfenbein, Petri Laukka, and Dacher Keltner. 2018. Mapping 24 Emotions Conveyed by Brief Human Vocalization. *American Psychologist* 74 (2018), 698–712. https://doi.org/10.1037/amp0000399

[6] Macarena Cuenca-Amigo and Zaloa Zabala-Inchaurraga. 2018. Reflections on participation as co-creation in the museum. *HERMUS* OCTUBRE-NOVIEMBRE (2018).

[7] Ximena Alarcon Diaz, Paul Boddie, Cagri Erdem, Eigil Aandahl, Elias Sukken Andersen, Eirik Dahl, Mari Lesteberg, and Alexander Refsum Jensenius. 2019. Sensing Place and Presence in an INTIMAL Long-Distance Improvisation. *Journal of Network Music and Arts* 1, 1 (2019). https://commons.library.stonybrook.edu/jonma/vol1/iss1/3/

[8] Ron Herrema, Guy Armitage, Gavin Clark, and Sirves Marko. 2014. *$echo.* Retrieved April 29, 2026 from https://vimeo.com/134888811

[9] Henry James. [n. d.]. *Weather Hum.* Retrieved April 29, 2026 from https://weatherhum.art/about

[10] leadtowill. 2023. *Patch a day 1/30 - Feedback bangs, random to even ordering.* Retrieved April 29, 2026 from https://youtu.be/4qGEo8iKfU8

[11] MAMM. 2024. *HUELLAS DE AIRE Trailer Video.* Retrieved April 29, 2026 from https://vimeo.com/1122696321

[12] Pauline Oliveros. 2005. *Deep Listening A Composer's Sound Practice.* iUniverse, Lincoln, NE.

[13] David Rokeby. 1998. The construction of experience: Interface as Content. In *Digital Illusion: Entertaining the Future with High Technology*, Jr. Clark Dodsworth (Ed.). ACM Press.

[14] Nina Simon. 2010. *The Participatory Museum.* Museum 2.0, Santa Cruz, California. https://participatorymuseum.org/

[15] Atau Tanaka. 2010. Mapping Out Instruments, Affordances, and Mobiles. In *Proceedings of the 2010 Conference on New Interfaces for Musical Expression (NIME, 2010). Sydney, Australia.* 88–93. https://doi.org/10.5281/zenodo.1177903

[16] Etienne Wenger. 2008. *Communities of Practice. Learning, Meaning and Identity.* Camnbridge University Press, NY, USA. https://doi.org/10.1017/CBO9780511803932

[17] Eleonora Oreggia (xname) and Clive Parini. 2020. *Rebus.* Retrieved April 29, 2026 from https://blog.bela.io/rebus/