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Bestiari: a hypnagogic experience created by combining complementary state-of-the-art spatial sound technologies, Catalan Pavilion, Venice Art Biennale 2024

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ABSTRACT

Bestiari, by artist Carlos Casas[1], is a spatial audio installation created as the Catalan pavilion for the 2024 Venice Art Biennale. The installation was designed for ambulant visitors and the use of informal seating arrangements distributed throughout the reproduction space, so the technical installation design did not focus on listeners' presence in a single "sweet-spot". While high-quality conventional spatial loudspeaker arrays typically provide excellent surround-sound experiences, the particular challenge of this installation was to reach into the proximate space of individual, dispersed and mobile listeners, rather than providing an experience that was only peripherally enveloping. To that end, novel spatial audio workflows and combinations of reproduction technologies were employed, including: High-order Ambisonic (HoA), Wavefield Synthesis (WFS), beamforming icosahedral (IKO), directional/parametric ultrasound, and infrasound. The work features sound recordings made for each reproduction technology, e.g., ambient Ambisonic soundfields recorded in Catalan national parks combined with mono and stereo recordings of specific insects in that habitat simultaneously projected via the WFS system. In-situ production provided an opportunity to explore the differing attributes of the reproduction devices and their interactions with the acoustical characteristics of the space – a concrete and brick structure with a trussed wooden roof, built in the late 1800s for the Venetian shipping industry. The practitioners' reflections on this exploration, including their perception of the capabilities of this unusual combination of spatial technologies, are presented. Design, workflows and implementation are detailed.

[1]Curator: Filipa Ramos, Artist: Carlos Casas, Sound Recordist: Chris Watson, Spatial audio design and implementation: Tony Myatt, Mixing: Tony Myatt, Chris Watson, Armand Lesecq, Carlos Casas; Technical realisation: Tony Myatt, Armand Lesecq, Craig Cieciura.

*Equal paper contributions.

1 Introduction

Bestiari was commissioned by the Institut Ramon Llull as the Catalan pavilion for the 2024 Venice Biennale of Art, one of the world's largest contemporary art exhibitions. A forty-minute focused spatial sound composition combining a variety of state-of-the-art spatial sound reproduction devices, with synchronised video, it references a masterpiece of Catalan literature (Disputa de l'ase) by author Anselm Turmeda (1355–1423) and celebrates the natural soundscapes of Catalonia. It is preceded and followed by continuous Ambisonic soundfield recordings of Catalan national parks.

Bespoke recordings of the animals described in Turmeda's text are featured alongside high-quality spatial representations of natural soundscapes. A variety of spatial audio technologies, listed below, are used in combination to provide an immersive experience that supports ambulant listeners, as is often the case for installations, rather than stationary, seated listeners.

The multiple integrated spatial audio reproduction elements of the installation consist of:

- Ambisonic reproduction system: 3rd-order horizontal and 1st-order vertical, stereo sub-bass, using Meyer Sound X20 full-range loudspeakers and Meyer Sound 650 subwoofers;
- bespoke infrasound generator: Volt Loudspeakers RV4554 infrasound driver mounted in externally-ported cabinet, designed to operate 8Hz-20Hz;
- 32-channel Wavefield Synthesis (WFS) system (Schlenkertec);
- beamforming icosahedral loudspeaker: the IKO Sonible, with plugins by Mattias Kronlachner;
- Four ultrasound directional loudspeakers: 2× Focusonics, 2× Hypersound;
- Four bespoke Futura loudspeakers, with a dual sculptural and sonic contribution.

Combining the technologies and using them to realise the artistic intention of the experience was both a technical and creative challenge. All audio and video reproduction was implemented within Max/MSP including spatial audio decoding for Ambisonic and WFS arrays using IRCAM's Spat5 externals.

Concerning the artistic aims, the exhibit enquires about life and memory, interspecies relationships, conservation and creation. It also has contemporary resonance: of ecology and of the intelligence of nature and harmony with the world around us. Detail concerning the conception, stories and background of the exhibition can be found at https://www.llull.cat/monografics/bestiari/en/prehome.cfm.

In the following sections, we detail relevant background and prior work (Section 2); the characteristics of the reproduction space (Section 3); a description of the reproduction systems, motivation for inclusion and layout of their installation (Section 4); the production stages, workflows, signal flow and mixing/spatialization (Section 5); and reflection, by the practitioners, on the experiences created (Section 6).

2 Background and Intention

Much of the spatial audio design concept for Bestiari was informed by theories promoted by Lennox, Myatt and Vaughan (e.g., [1, 2, 3]), along with previous installations and performances by Watson and Myatt since 2009 (e.g. [4]) using high-order ambisonic (HoA) reproduction systems to create detailed spatial reproduction from a combination of spatial audio materials — Ambisonic, Double MS, Quad, MS, stereo and mono audio recordings. The latter approach was adopted to achieve two main aims: to retain as much spatial information, pertaining to the animals and habitats recorded, as possible, and to establish multifaceted soundscapes which can appeal to human spatial audio perception. Following this approach as the experiential backbone of the experience, sound recordings in the national parks of Catalonia were commissioned consisting of a range of background ambiences and the specific animals described in Turmeda's text captured in the above formats, edited and combined.

While many large-area spatial audio reproduction arrays of loudspeakers, such as good quality HoA reproduction systems, provide excellent surround-sound experiences for listeners, few are capable of projecting into the proximate space of individual listeners. Surrounding soundfields can appear to be perceptually remote; peripheral through enveloping soundfields. Previous attempts to integrate technologies, such as WFS, with Ambisonic reproduction systems have sought to evoke perception of sound sources inside the peripheral loudspeaker array. In this installation, a range of approaches were applied to cause listeners to localise sounds around and within the space, described in the following sections.

Myatt, Watson and Casas [4] in collaboration with EMPAC, Troy, USA , realised two performances that

combined a high-order Ambisonic reproduction system with Wavefield Synthesis sound projection. This combination aimed to project carefully chosen recorded materials, i.e. those related or complementary to the audio content of a peripheral Ambisonic soundfield, within the surrounding loudspeaker array. In collaboration with IRCAM, EMPAC have developed a large WFS system [5], consisting of 558 loudspeaker units. This system can project audio objects up to 9m in front of the loudspeaker array. In the 2019 performance cited above, two arrays of 248 loudspeakers were used, mounted 8m above a seated audience, projecting downwards and within a surrounding 5th-order Ambisonic loudspeaker array. The nature of the WFS reproduction allowed listeners to hear sound objects projected throughout the audience, and in some cases in close proximity to their own body.

The success of combining Ambisonic and WFS technologies prompted further investigation in the context of the Bestiari installation project. To that end, an Ambisonic system was combined with WFS, infrasound, a beamforming icosahedral loudspeaker and four ultrasound directional loudspeakers — installation of which is described further in Section 4.

The combination of materials captured in a range of spatial formats, replayed via a combination of different spatial reproduction systems with varying spatial — including directional — and timbral characteristics, met the artist's intention of offering a multitude of aural encounters across the full extent of the reproduction environment.

3 Reproduction Environment

The setting, Figure 1, is an ex-industrial space built in the late 1800s for the Venetian shipping industry. Measuring 354 m^2, with a peak height of 6.8 m, the room is narrow with its length approximately 5$\times$ its median width. It has a concrete floor, brick walls and a trussed wooden roof leading to a noticeable reverberation of approximately 1.5 s.

The unusual architecture offered an opportunity to experiment with interactions between the range of spatial audio reproduction technologies and the acoustical characteristics of the space.



Fig. 1: View from the rear of the reproduction environment. Image copyright gerdastudio and reproduced with permission.

4 Reproduction Systems

The layout of the reproduction systems listed in Section 1 is presented in Figure 2. In this section, the technical characteristics of each system and motivation for inclusion are presented. The specifics of their use, from a production standpoint, is described in the following Section 5.

4.1 Ambisonics

Building on the prior work described in Section 2, the foundation of the audio reproduction in Bestiari is via an Ambisonic reproduction system with 3rd-order horizontal resolution and 1st-order vertical resolution.

Localization performance in humans is known to be superior within the horizontal plane, in which perception of localisation is formed via interaural cues (time and level) and various monaural cues. Considering this alongside practical considerations, large rooms are typically longer than they are tall, a system with greater spatial resolution in the horizontal plane was specified.

Chosen loudspeakers were the Meyer Sound X20, frequency response 62 Hz–16 kHz (-6 dB) with horn directivity of 110°–50°, and two Meyer Sound 650 subwoofers, with frequency response of $\pm$ 4 dB from 28 Hz to 100 Hz. This choice of loudspeakers was informed by the need for a high-quality listening experience, both timbrally as well as spatially. In the authors prior experience, they have observed that the

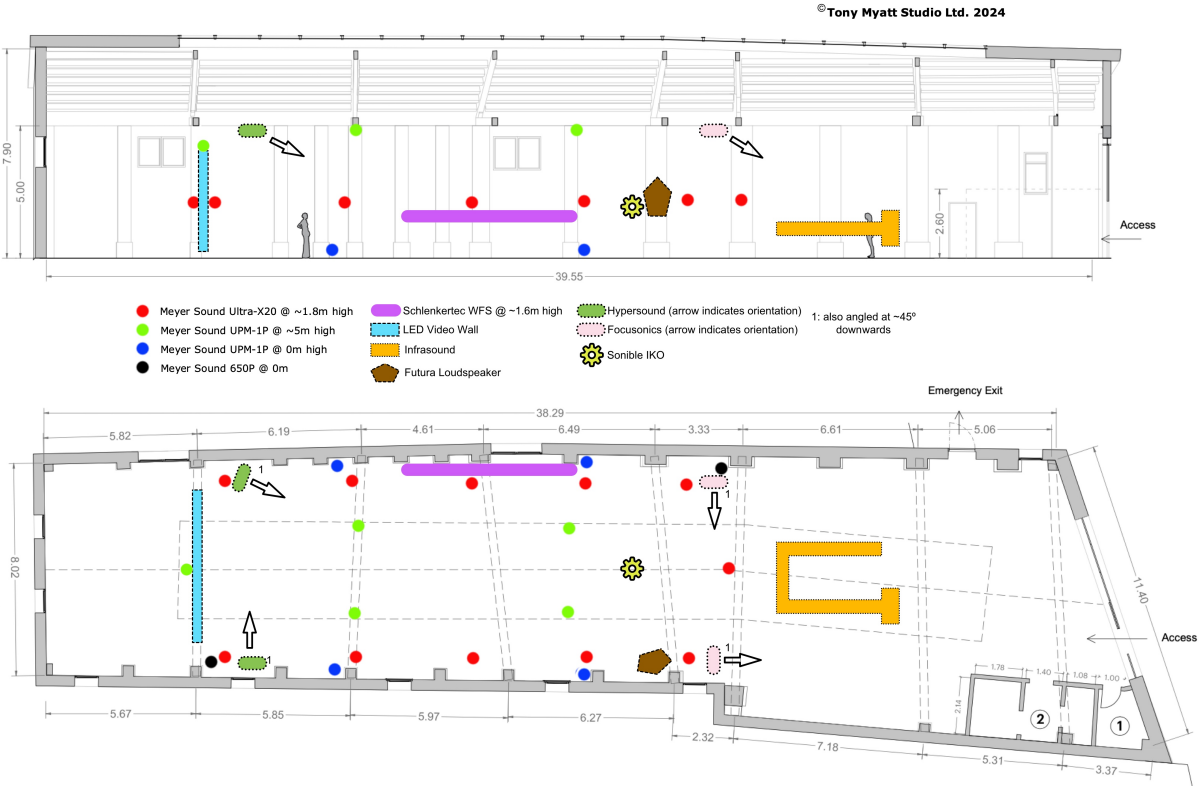


Fig. 2: Diagram of loudspeakers installed at the Catalan Pavilion, Venice Biennale 2024. Labels are for positional reference only and either do not reflect true sizes or are only loose approximations. Original diagram copyright Tony Myatt Studio reproduced and altered with permission.

use of lower quality loudspeakers, which may offer a less-than-natural sounding reproduction, can draw the attention of the audience out of the provoked experience and to the physical devices themselves, vastly reducing their immersion.

4.2 Infrasound

The bespoke infrasound generator, pictured in Figure 3 consisted of a speaker cabinet of 100L volume and housing a Volt Loudspeaker RV4554 18" studio sub-bass unit, designed for infrasound reproduction. The basic port length is a quarter wavelength at 10 Hz = 8.5 m (8.6m with end correction) curled in a U-shape to eliminate harmonic resonances. The overall system resonates at 15.4 Hz. The port is constructed from 300mm diameter Twinwall pipe (non-perforated) in three sections, which also facilitates transport.

The infrasound generator was originally designed and built to facilitate the reproduction of <20 Hz frequencies generated by elephants, featured in *Cemetery* [6], which contain strong fundamentals around ∼8 Hz, Figure 4 displays a sonogram of one of the recordings.

The phenomena of emotional response to an acoustic emission which is *felt* rather than just heard is familiar to any who have attended any sort of performance with substantial low frequency reinforcement. Within the natural world there are numerous examples of creatures whose communication exists outside of the range of human hearing, of which elephants are one. On location, capturing sound materials for *Cemetery*, the crew were observing a herd of elements when they felt a shared sense of unease which was followed by the immediate standing and departure of the entire heard. Reviewing the sound recordings, an infrasonic communication between the members of the herd was identified, believed to be the signal to depart. A subset of these recordings were incorporated into *Bestiari* including these gentle calls from the matriarch to depart, contact calls (emit-



Fig. 3: Infrasound generator in-situ. Image copyright gerdastudio and reproduced with permission.

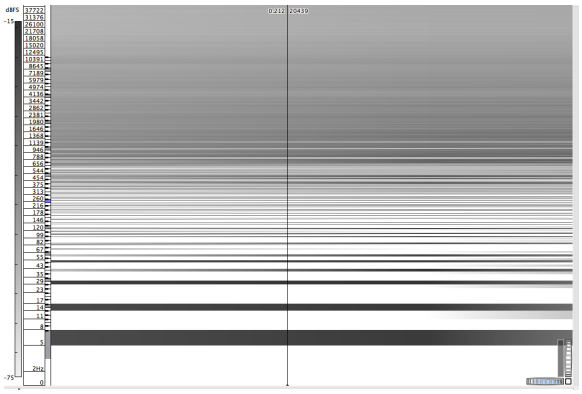


Fig. 4: Sonogram of elephant calls captured in a Kenyan national park. Measurement microphones and preamps with extended low frequency response were used.

ted by adult females when separated from their group) and answers, and others by both males and females.

Installed at the rear of the reproduction room, the infrasound system provides the extreme low end of the experience, and can be heard throughout the space. The unusual construction, and very large driver, also provides a sculptural element as visitors enter provoking curiosity about the experience within.

4.3 Wave Field Synthesis

With the combination of Ambisonics and WFS used in prior works to reach into the peripheral space of the listener, a thirty-two channel WFS system was installed

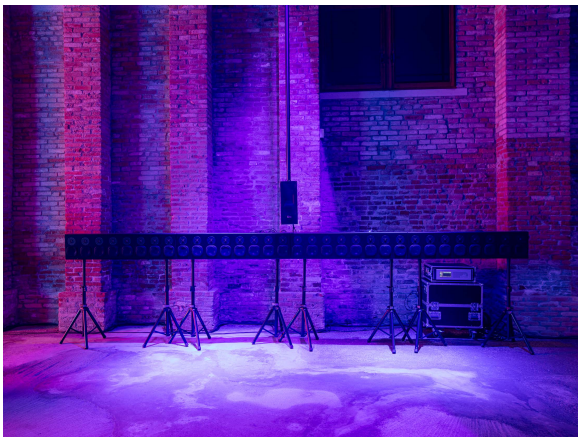


Fig. 5: WFS system in-situ. Image copyright gerdastudio and reproduced with permission.

at the right hand side of the main listening area, picture in Figure 5. This enabled project of sounds across the space and around and between ambulant audience members.

The manufacturer was Schlenkertec GmbH, now defunct, which emerged from the Fraunhofer Institute for Digital Media Technology in the mid-2000s. This system comprises panels and a power supply maintained by the Centre for Vision, Speech and Signal Processing (CVSSP) at The University of Surrey.

Each panel measures 1.4 m across and contains eight woofers and tweeters with a centre spacing of 175 mm. The panels also contain eight channels of digital to analog conversion and amplification. Four panels were used in the installation. Mono and stereo sources were reproduced, decoded by the WFS objects within Spat5.

4.4 Beamforming Icosahedral Loudspeaker (IKO)

The IKO, produced by Sonible[1], consists of 20 high quality 6-inch diameter full range drivers. Utilising spherical harmonic beamforming, sound *beams* are produced which can be reflected from room surfaces. First-order reflections provide convincing localisation from areas of the room which do not contain visible reproduction devices, including perception of distance when beams are reproduced from the opposite side of the IKO to the listener's current position. This localisation, combined with the high-quality drivers, creates an ethereal effect which was further complimented by the

[1] https://iko.sonible.com/en.html

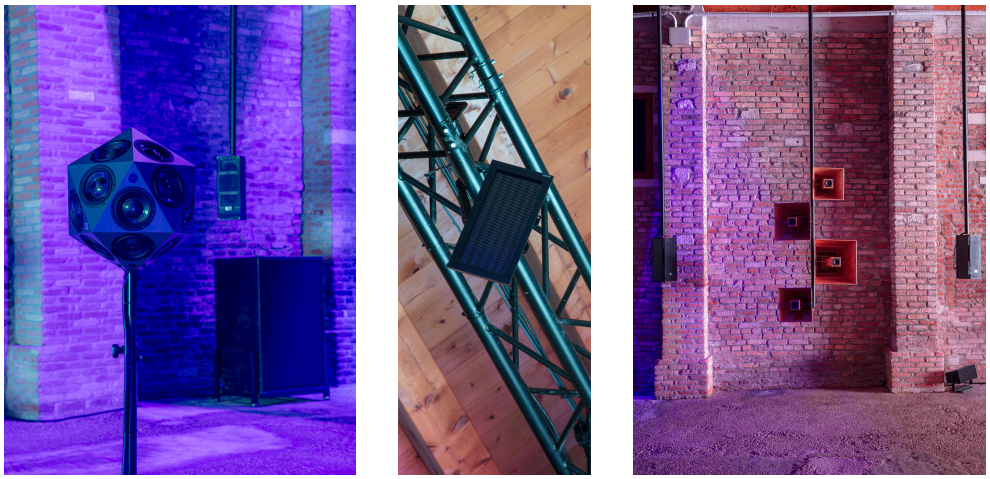


Fig. 6: In-situ loudspeaker systems: (a) IKO, (b) directional Hypersound HSS300, (c) Futura Research "Parrot". Images copyright gerdastudio and reproduced with permission.

particular characteristics of the reproduction environment which consisted of hard reflective surfaces and a high ceiling. Zotter et al. [7] provides detail on the development, design, construction and intended usage of the IKO loudspeaker.

As well as a capable spatial audio reproduction system, the physicality of the IKO offers a sculptural aspect due to its subjectively alien appearance with dimensions similar to that of an adult human. Figure 6(a) illustrates.

4.5 Directional Loudspeakers

Four ultrasound directional loudspeakers were installed in the reproduction space, with orientations illustrated by arrows in Figure 2. These included one each of Focusonics[2] model A and B and two Hypersound[3] Model HSS3000, as in Figure 6(b). All of the directional loudspeakers employed the same fundamental technologies, amplitude modulating an ultrasonic signal with an audio signal. Self-demodulation occurs, due to the non-linearity of air, resulting an the audio signal being produced within a narrow directivity [8].

Within the installation, the ultrasonic loudspeakers were used to produce spatially constrained sound experiences with high directionality and localisation.

[2]https://www.focusonics.com/

[3]https://hypersound.pro/products/

4.6 Futura Research *Parrot* Loudspeakers

A late addition to the experience, the Futura Research[4] loudspeakers consist of four loudspeakers, mounted together, combining small woofers (only) and large wooden waveguides. The resultant effect is band-limited, with prominent mid-frequencies and significant presence within the space optimised for their purpose of reproducing the sounds of tropical birds. Their presence extended to the visual, due to their dramatic appearance, displayed in Figure 6(c).

5 Production

The production stages consisted of:

1. Recording spatial audio materials and soundfield components, spatial audio recordings were made specifically to support the approach;
2. Pre-production and composition of sub-elements of the work, e.g., background soundfield and foreground elements;
3. Pre-production assembly, decoding, beamforming, convolution, control routing for in-situ production using a DAW (Reaper) and Max/MSP
4. In-situ mixing, editing, experimentation, video synchronization and audio spatialisation;
5. Render to multichannel soundfiles for exhibition playback and control.

[4]https://futuraresearch.xyz/

The intention, from the beginning of the design of the installation, was to perform several days of production on location in the venue. In the authors' prior experience, creating spatial audio installations in unusual spaces with complex acoustical characteristics, facilitating this final stage of production on location is a crucial contributor to creating an experience which extends from a somewhat typical immersive audio reproduction to one which fully realises the vision of the artist, is highly refined, subtly nuanced and considers the complex characteristics of the reproduction environment.

For this installation in particular, a range of spatial audio reproduction systems with significantly varying capabilities were being combined and for the first time. Final production on location facilitated an experimental approach and exploration of the interplay between the experiences offered by the different systems, independently and in combination, and in their interaction with the acoustics of the reproduction environment – detailed in Section 3.

Whilst there is a focus on this final mixing stage, the importance of clear intention maintained throughout each stage must be emphasised. In the case of this highly spatial experience, this manifested as a need to capture and maintain maximum spatial information from initial recording through pre-production. Mix engineers, sound recordist and artist were involved and often present throughout each production stage.

5.1 Production Control and Signal Flow

Once the installation of the audio systems was completed, a production station was installed in the center of the HoA loudspeaker system. A MacBook Pro was used for audio playback and mixing, using Reaper in combination with Max/MSP. Figure 7 illustrates the audio and metadata signal flow.

Control surfaces with faders and rotary encoders were utilised. Faders controlled height and the rotary encoders were used for rotation for a range of source material, much of which was in Ambisonic formats, as well as quad and double M-S. Considering the source material as soundfield layers, which had generally been prepared during off-site pre-production, this production stage consisted of bringing these layers together and manipulating their rotation, height, spread and level, including creating dynamic relative movement, plus adding mono and stereo sound recordings which were

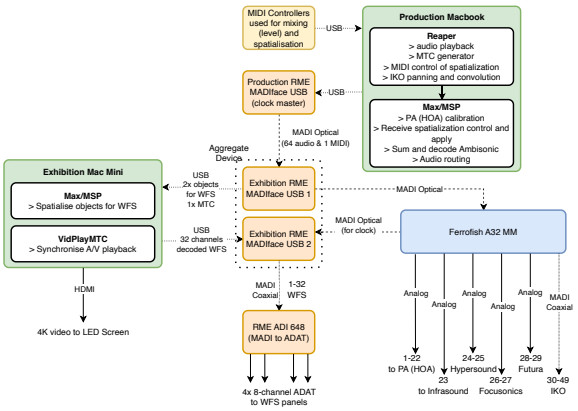


Fig. 7: Signal flow and overview of processes within the production setup. After production was completed, rendered versions of the HOA, WFS and IKO were instead played back from the Exhibition Mac Mini, as well as 4K video. The MADIface USB 1 became the master clock.

often replayed on the other (not HoA) reproduction systems. The spatialisation parameters were captured as MIDI in Reaper, associated with the relevant channels, and then routed into Max/MSP where Ambisonic processing and decoding was performed using, primarily, objects from Ircam's SPAT [9]. Max/MSP was also used for the crucial step of applying a calibration to the HoA system, taking into account distance and level.

The installation was planned as an audio-visual experience but the audio and video components were originally intended to operate independently. A last-minute change required a solution to synchronise the audio and video for final production. This was achieved by generating MIDI timecode (MTC) in Reaper. This was sent via MIDI over MADI utilising the capabilities of the multiple RME MADIface USBs which were present. From the production computer, this, along with the audio, was received by the installation computer running VidPlayMTC which enabled synchronised playback.

5.2 Mixing and Spatialisation

Using the HoA system as the backbone of the experience, soundfield layers, captured within Catalan national parks plus archival material, were manipulated and combined to form believable and emotive background ambiences for each section of the 40 minute piece and to play outside of the composition. Next, recordings of the specific animals described in

Turmeda's text were spatialised via both the HoA system and each of the individual spatial audio systems.

The bray of the endangered Catalan donkey and human voice were introduced via the IKO, which reflected these sounds from the walls and ceiling, resulting in their arriving from unexpected locations. The roars, grunts and rumbles of the endangered African bush elephant and lion were spatialised on the HoA system and reinforced with the infrasound, the extreme low frequency felt in the stomach of the listeners.

High frequency elements were reproduced from the highly directional ultrasonic loudspeakers. These included clicks of Striped Dolphins and Fin Wales, present along the costs of Catalonia, and heterodyned ultrasonic calls from Catalan Common Pipistrelle bats, originally with greatest energy between 41-48kHz, brought into the range of human hearing. Narrow beams were directed to excite specific areas of the architecture and produce unexpected encounters and close proximity sounds for listeners moving around the exhibition space. Careful mixing was performed to incorporate reproduction via these directional loudspeakers as the listener can be both in the sound beam (with a sonic source on themselves) and outside of it (with a sonic source on the floor or wall), creating two very different level perceptions. The first discovery of entrants to the installation is a beam from one of the Focusonics loudspeakers, used to create the effect of a swarm of bees oscillating in a column between the entrance and the main listening area.

The hissing and slithering sounds of the Lataste's viper were reproduced from the WFS array, as well as chirping and buzzing of insects including the Yellow-legged Mining Bee. The "reaching" nature of the WFS projection was used to introduce these sounds within the listening space, creating highly localised sonic phenomena, creating an inward moving closeness contrasting with the more peripheral HoA reproduction. A sculptural and sonic feature, the Futura Research *Parrot* Loudspeakers were used to reproduce the chatter, squawks and songs of the Monk Parakeet. With their physical stature and band-limited response, they deliver significant presence and cannot be ignored, echoing the nature of the chattering parakeets.

These sonic components are utilised in combination and independently to create varying experiences throughout the piece. Attention is called to different zones within the reproduction space, included unexpected directions. Visitors receive a classically high quality audio experience, with excellent timbral and enveloping spatial reproduction via the HoA and IKO systems, as well as a range of aural encounters as they move within the space — choosing to stop and to listen at their own pace.

These aural encounters move the focus further away from a "sweet spot" oriented listening experience, although higher order HoA reproduction is, in the author's experience, somewhat resilient to listening outside of the sweet spot. The HoA loudspeakers are arranged around the central area of the room, with other aural encounters within and external to this area. Outside of this zone, visitors discover reproduction from ultrasonic loudspeakers and the IKO with the main HoA system perceived as somewhat distant. Taking this approach, the gallery is still filled with sound and a strong sense of spatiality and localisation, but there are different encounters with space and different encounters with spatiality around the room.

6 Reflections

In this section we present some reflections and observations on the created experience.

Concerning the realisation of artistic intention, from the conceptual and dramaturgical perspective, every animal has a voice and specific ways of living/perceiving/acting: the piece recreates this heterogeneity by using various loudspeaker types as appropriate for each animal's sound frequency range and spatial nature. Perceptually, the combination of these technologies gives access to a particularly wide range of "spatial morphologies". In combination they enabled the practitioners to deeply shape spatial characteristics, to create new spatial figures and sorts of spatial masses.

Infrasonic frequencies have both the ability to fill in the architectural (outer) space as well as the (inner) "audience's body space". We are not used to perceive infrasonic frequencies without upper harmonics, they create a sensation closer to touch than to hearing. Listeners are, at times, aware of these infransonic frequencies through their departure than their presence.

HoA excels at hiding the presence of the loudspeakers, instead the soundscape becomes parts of the space. It stays true even when the listener is very close to one of the loudspeakers and offers great envelopment.

In the upper loudspeakers, a very good localization was achieved on the recordings of the birds, suggested partially due to our expectation of their location.

The WFS system, reproducing sounds with considerable high frequency content, can produce audible phase artefacts when objects are moved but especially when audience members are in motion. It creates very localised sonic phenomena, with drastic changes in localization when moving the listening position. Recognising this, sounds reproduced from the WFS were static in location, reducing perception of artefacts. Moreover, with a broad stereo source and 2 distant static objects, this issue was partially solved. This could be improved with further refinement. We also note the loudspeaker spacing of 175 mm versus 58 mm (aliasing frequency of 2.9 kHz) for the EMPAC system used prior [5].

Parametric loudspeakers gave a very strong feeling of having a sound object within the space with extreme localization within a small area. Care had to be taken due to the different in perceived levels of sounds reproduced from these loudspeakers when within or without their emission zone.

The IKO was used with both its capability of sending a sound via the space's surfaces (bouncing on ceiling, floor, walls) and as a "totem", clearly identified as the sound source at ear level. It gave compositional possibilities with the human voice, identified as an human-like entity within the space.

7 Summary

The design, installation, production workflows and reflections on an immersive spatial audio experience, designed for ambulant listeners and incorporating a range of spatial audio reproduction technologies has been presented. This installation formed the Catalan Pavilion at the 2024 Biennale of Art.

Building from a background of combining HoA systems, offering a somewhat peripherally enveloping experience, with WFS systems, enabling a "reaching in" with sound into the peripheral space around the audience, infrasound, beamforming icosahedral, ultrasound directional and bespoke sculptural loudspeakers have been incorporated. This combination, with final production in-situ to facilitate creative exploration of the devices capabilities and unusual 19th century building, offer listeners an audio experience which is high quality, in spatial and timbral terms, but also features a multitude of varied aural encounters throughout the full extent of the reproduction space.

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