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Acoustic Atlas – Auralisation in the Browser

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***Abstract*— The *Acoustic Atlas* project, funded by the European Commission, explores a new model for experiencing acoustic heritage data in the form of room impulse responses (RIRs), as real-time auralisations. The browser-based Web Audio application functions on any smart mobile device or computer running a web browser. It utilises the built-in microphone and headphone output of the device to transport the user to a selected heritage site via headphones and a live microphone feed. Users are able to emit sounds to hear the reflections from a first-person point-of-hearing.**

Researchers in the field of heritage acoustics have advocated for the importance of acoustical studies and their historical, artistic and spiritual value. However, heritage sites still prioritise dissemination through visual means, such as maps, 3D models, photographs and videos. Where acoustic research is available, it is mostly published in text form through the analysis of objective acoustical parameters. When attempting to access auralisations, the search becomes difficult and fragmented. *Acoustic Atlas* provides real-time auralisations to wide audiences, beyond those already working in the field of heritage acoustics and, as a result, contributes to the awareness of the importance of listening and the preservation of sonic heritage.

The present paper explores the web architecture of the project that utilises the Web Audio API and Tone.js which currently enables auralisations at acceptable latency. It also looks into achieving synchronisation between B-format RIRs and 360 head positioning in the browser, in real-time.

Keywords*— *Auralisation, Heritage Acoustics, 3D Audio, Immersive Audio, Web Audio, Composition

I. Introduction

Acoustic Atlas is a real-time auralisation application connected to a growing archive of room impulse responses (RIRs) from natural and cultural heritage sites. These sites are displayed on an interactive globe map user interface (Fig.1). Similar to browsing Google Earth, a user can search via the globe interface or via text for locations in the database. The system utilises a document-oriented database that contains all relevant text and media information and files (Fig. 2 and Fig. 3). Version 2.0 gives researchers access to upload and manage their own RIR data, field recordings and sound art directly. Each location has a unique URL, thus allowing researchers and creators to embed a location into their own presentations or websites, to encourage it to be widely used.

In addition to its incorporation of acoustical data, *Acoustic Atlas* also seeks to integrate environmental field recordings as well as music compositions inspired by the acoustic data of the archive. A prominent part of *Acoustic Atlas* will be its ability to showcase musical works based on acoustic data, demonstrating its potential as a source of inspiration. As a result, *Acoustic Atlas* will curate a series of compositions created using the acoustical data available as prominent musical material. Compositions will include newly created work by the first author, who is exploring resonance tones, infrasound vibrations, as well as spectral and spatial phenomena, while also drawing from the mythology surrounding the sites as well as pre-existing and new field recordings.

Most smart mobile devices are becoming increasingly sophisticated in terms of their audio capabilities, for example most devices ship with a stereo headphones output and also contain a microphone input. This means, an application such as *Acoustic Atlas* can be experienced by a large percentage of people. Due to the vast diversity of devices, relying on the browser for new applications to function across operating systems was considered the most efficient way forward. The Web Audio API (WAA) [1] enables the goals and ideas of *Acoustic Atlas*.

The present article starts with an overview of existing heritage research that feature prominently via the browser and reflects on why it is essential to create audible access to heritage acoustic research, as well as how this is connected to more general aspects of open access of scientific data. The next section provides a description of the *Acoustic Atlas* experience, including information on the signal flow and general infrastructure of the web audio application. Section IV focuses on 360 mouse or headtracking interactivity matched to corresponding spatial room impulse responses and sound fields, in the browser.

Fig. 1. Globe UI for *Acoustic Atlas*,

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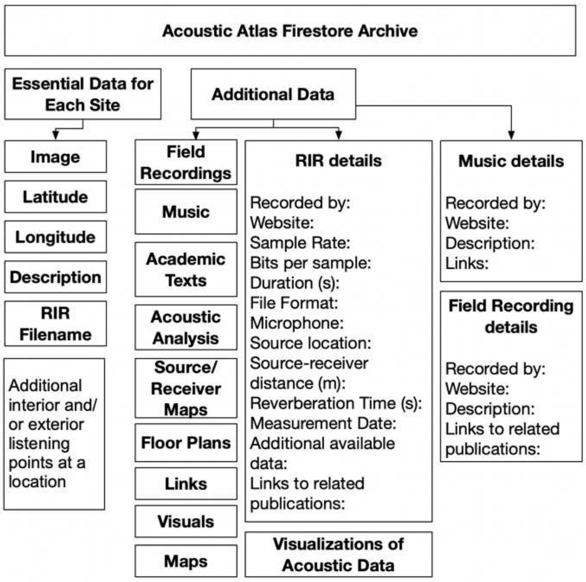

Fig. 2. Firestore Database used in *Acoustic Atlas*.

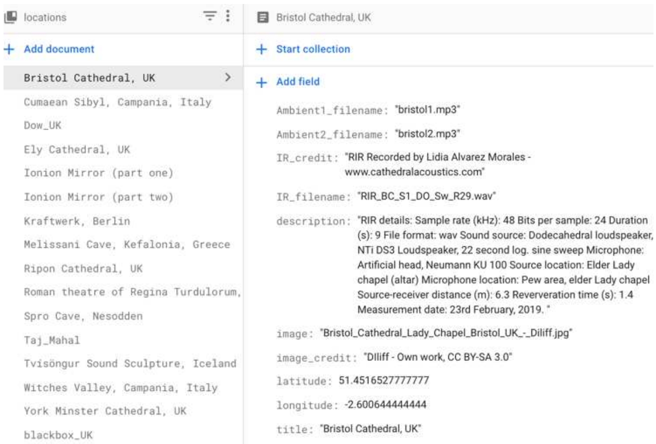

Fig. 3. Example of Database Section in *Acoustic Atlas*.

II. IMPORTANCE OF AUDIBLE ARCHIVES OF ACOUSTIC RESEARCH

In the context of intangible heritage, virtual reconstructions of world heritage sites are becoming increasingly useful to allow for multi-sensory immersive access, research and conservation [2-4]. Examples of uses of auralisations include simulations of ancient and historic sites, to support archaeological, architectural, anthropological and historical research [5-9]. Uses also include various interdisciplinary performance- and media art projects [10-11]. The number of both natural and cultural heritage acoustic measurement work is increasing. Sites ranging from cathedrals, ancient theatres and ruins to caves and other natural soundscapes are being acoustically measured [12-14]. To date, however, vast amounts of digital visual data such as maps, 3D models, and photographs of heritage sites, still outnumber available and accessible auralisations.

It is essential to create audible access to heritage acoustic research, because the act of listening is different to the act of reading about a subject. A vast majority of acoustic and heritage acoustic research still gets published predominantly as text in journals, conference papers and books. Even where acoustic measurements clearly have been conducted (since it is written about in great detail), only a small percentage is audible.

Connected to this topic are more general aspects of open access of scientific data. By sharing such research in interactive audible formats, the audience and reach of these projects vastly increase. Accessibility is expanded, as people who wish to simply travel the world virtually through the web can experience it, and no specialist knowledge is required to enjoy the auralisations.

The tools to enable such experiences are now readily available. With the high-level JavaScript (JS) WAA comes a built-in convolver node, that enables stereo convolution reverb in the browser [15]. With current and recently developed JavaScript libraries such as JSAmbisonics [16], Google Omnitone [17] and HOAST [18] it is now a realistic option to embed first and higher order ambisonic (HOA) virtual acoustics in audible and user-friendly ways, into the browser, in order to experience acoustic data in audible format. JS Open Acoustic Impulse Response Library (OpenAirLib) allows WAAPI-compatible programmatic access to the OpenAIR RIRs collection [19]. Various examples can be found of projects playing first order ambisonic (FOA) audio together with full spherical video in YouTube via the use of FFMPEG [20].

Noteworthy projects that utilise listening experiences in the browser include *The Soundscapes of the York Mystery Plays* [21], and the *Soundgate App* [22]. Then there are also browser-based heritage creative tools such as *Pluggy* [23] that encourage the public to participate more actively in digital cultural heritage activities by creating *Pluggy* immersive experiences, with all kinds of tools to create and socially share immersive sound driven experiences.

Acoustic Atlas aims to be a useful and fun listening experience, in which research can be shared and sonic experiences enjoyed. *Acoustic Atlas* hopes to make accessible as many of these projects as possible via its web application. In the next two sections more details follow describing various of these mentioned tools and how they are used.

III. THE EXPERIENCE

This section provides a quick overview of the user experience in *Acoustic Atlas.*

A. General Experience Description

The *Acoustic Atlas* platform can be understood as a sonic "google-earth-for-acoustics" prototype. The application can be experienced at https://acousticatlas.info [2]. Upon selecting a globe location, an interior view of the site is loaded, either in the form of a still image, a 360 panoramic image, a 3d image or an artistic drawing/sketch. The visual image orientation, or point of view, (where this information is known) corresponds to the RIR listener position (or microphone position). Selecting a location also turns on the audio signal chain, unmutes the microphone and activates the convolution reverb with the corresponding RIR. The user can now listen to their voice as a real-time auralisation from the mic input. They can also choose to record their sonic output and save this to their own device (for privacy and practical reasons the website does not keep any such recordings and the buffer is cleared upon refreshing the website). The user is able to switch to any other interior or exterior listening points within a site by clicking on photo icons at the bottom of the screen allowing the sound to smoothly fade into the next scene (Fig. 4). Additionally, the user can play/loop and control levels for the embedded field recordings and/or music compositions.

At the moment the experience focuses on having the listener/participant in a single sonic sweet spot, with the ability to move their head in 360, but not virtually 'walk through' a space. The latter may come at a later time when the archive has more sites with sufficient source/listener positions and fast enough processing to handle such a task in the browser. Where multiple source/listener RIRs are available, version 2.0 allows the user to either select the different listening positions or to select 'autopilot' mode, which allows for the system to morph (crossfade) between RIRs. In the background there are two locations running with the master output being crossfaded to create the morph effect. The user can set the morph duration (or crossfade duration) via a slider control and a future version of the webapp will explore more ideas around morphing and controlling this algorithmically. In composition such transitions or morphs are interesting parameters to explore subtle to extreme changes in the virtual acoustic listening experience.

B. *Perceptual Challenges within Acoustic Atlas*

With a first-person point of view or listening comes a bit of a conundrum: psychoacoustically, the source and listener positions are technically the same position since our voice and ears are close in proximity and additionally psychoacoustically interconnected. In contrast to this, in typical acoustic measurements the 'ears' or microphone 'listener' position and the voice or 'source' position are placed a distance apart, to replicate a sound source that is separate from the listener [25, 26]. In order for the auralisations to be equivalent to a real-life experience, the source should be placed in the centre of the space (or the point of view of the corresponding image) with the microphones (or listener position) being in the same place. However, this is problematic, since the source would be too close to the microphone, and either result in a clipped recording or have a too low signal to noise ratio.

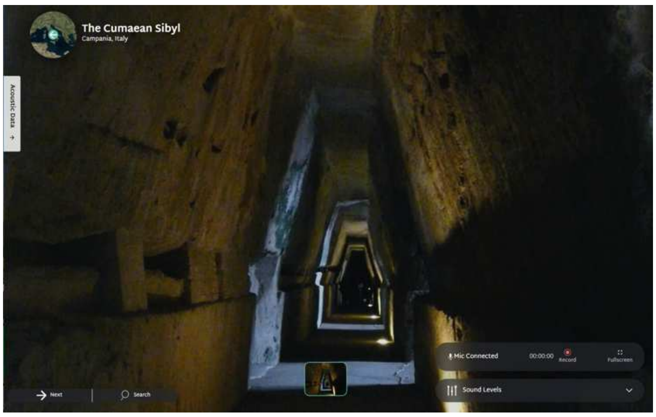

Fig. 4. Inside a selected site.

When convolving the microphone input signal with the impulse response, experimenting with and without the direct sound during the development phase, demonstrated that the removal of the direct sound creates a more realistic auralisation. Therefore, this has been applied to the platform's RIRs.

As a result of these changes and applications, technically, the virtual acoustic experience presented in the *Acoustic Atlas* is not completely accurate. The experience however, is still convincing, perhaps due to the fact that the virtual acoustic experience has an important factor in common with reality: in both cases, the user still hears (and feels the vibrations of) their own voice inside their own head and chest. For example, when singing or speaking in a really large empty cathedral, even though the level of 'envelopment' and spaciousness is dominating, we have a strong sense of our dry or direct voice inside our heads. On the other hand, when we listen to a choir singing in the same cathedral some distance apart from the listener, we hardly hear any direct sound. Instead, the reverberations of the space take prominence [27]. With added HOA RIR spatiality achieved via JSAmbisonics [28], the experience of space inside *Acoustic Atlas* feels realistic.

C. *Artistic Considerations*

Although acoustic science and careful considerations related to 'capturing' and 'representing' reality are central to the project, *Acoustic Atlas* is also a vehicle for reflecting on art making and creating immersive illusions and sonic experiences. Acoustics is presented as 'playful' and 'creative.' Said playfulness is expressed by allowing the user to place their own voice in physically impossible scenarios, such as singing back from 100 meters away, deep inside a tunnel, or from above or below. Here again enters the spirit of the mystic, the theatrical and, from an abstract modernist art approach, the purely spatial form to be sculpted over time to create the experience of movement. Working with time and spatiality, the morph function to create change or transformation from one point to another becomes an important parameter to explore. Entering and exiting a space can sometimes be very dramatic sonically – this is one example of a transition that can be created via a RIR crossfade/morph. How fast or slow this transition happens is a parameter already used extensively in drone music. The interface will be of great value to composers, who will no longer be simply using an abstract reverb plugin but will instead be fully aware of the place where the reverb was captured, adding context to the creative process of the artist as well as the active listening process of the audience.

IV. WEB ARCHITECTURE OF ACOUSTIC ATLAS

The auralisation process is enabled by a signal flow specification inside the WAA, a high-level JavaScript (JS) API for audio processing and synthesis rendering in the browser [1]. The main way to understand the API is as a router for structuring audio signal flow, via connecting node objects to create a required signal chain. WAA provides natively a vast array of effects and features and it is also possible to write custom effects directly in JS. The node objects are typically implemented with optimized Assembly

/ C / C++ code where the actual processing most often takes place.

A goal of the WAA creators is to "include the capabilities found in modern game audio engines as well as some of the mixing, processing, and filtering tasks that are found in modern desktop audio production applications" [1] in the browser. For games and multimedia the WAA can be used together with other APIs and elements on the web platform such as XMLHttpRequest, canvas 2D and WebGL 3D graphics APIs.

One of the most useful features is that of modular routing as it allows connections between different AudioNode objects and great flexibility in architecture. Each AudioNode has inputs and/or outputs with mixing rules that can be specified. For example, a mono connection can be up-mixed to connect to a stereo connection via defining the exact mixing rules and rules can be changed for example to suit multi-channel needs. To 'switch' on the audio, the audio context must be started by some user interface element.

In the case of *Acoustic Atlas*, Tone.js is a web audio framework, used as a wrapper around the WAA for various parts of the audio signal flow and in particular for the convolution process. This option was followed because of ease of use as the elements needed were already available. It is worth noting that it is also possible to create the same signal flow and processing directly in the Webaudio API. Tone.js (similar to the Webaudio API) allows for sample-accurate synchronisation and scheduling of parameters. The auralisation signal flow of the audio in Acoustic Atlas can be seen in Fig. 5.

MIC_INPUT > GAIN > EQ > CONVOLVER > MASTER

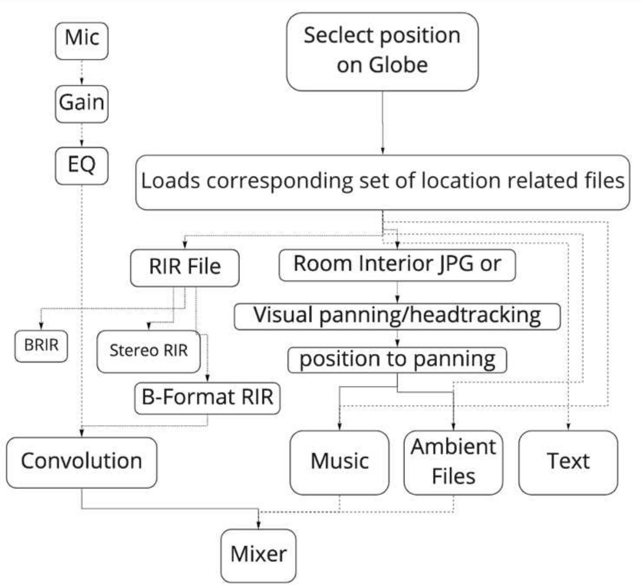

Fig. 5. Signal Flow of UI and Audio Processing in *Acoustic Atlas*.

As a bridge, Tone.Context is used as AudioContext. Tone.Convolver, Tone.Filter, Tone.EQ3, Tone.Meter, Tone.Gain, Tone.UserMedia, Tone.Master enable the complete signal flow in version. Additionally, the architecture includes NexusUI.js, Cesium.js, firebase-firestore.js and audio-manager.js. JSAmbisonics is included where FOA RIRs or HOA RIRs are available an additional panoramic mode connected to headtracking or 360 panoramic view, this will be described in the next section.

V. B-Format mapped to 360 visual field

The acoustic measurements conducted by the research team and incorporated to *Acoustic Atlas*, will be fulfilled using a Soundfield ST450 microphone that produces Furse-Malham B-Format. Moreover, the majority of the RIRs received by other research teams are also in this format, as it is a commonly used technique for RIR measurements [27].

Ambisonics in the browser is needed for dynamical rendering in terms of spatial position. Real-time rotation is only possible in Ambisonics, not on the rendered binaural RIR (BRIR). JSAmbisonics is a JavaScript (JS) library for FOA and HOA processing for browsers [16], using WAA. It is deployed via Node.js. It is computationally efficient enough to deliver real-time HOA manipulation in the browser [28]. In the case of *Acoustic Atlas*, FOA B-Format is 'upmixed' to 3OA and then converted to the ACN/SN3D format. This is done in order to have a 16 channel 3OA file (which are split into two 8 channel files) that are compatible with the ability to rotate the sound scene of the ambisonic stream, with real-time control of yaw, pitch, and roll rotation angles. Basically the 360 RIR needs to be locked into place with the visual 360 panoramic image and headtracking, or mouse tracking (Fig. 6). Depending on where the user's head is pointing, 3D sound scenes or "soundfields" can be represented as a soundfield centred around a listener.

Ambisonics contain spatial detail that increases at increasing 'orders' which determine the number of channels present. Zero order represents one mono channel. At first order, there are three spatial channels each behaving like a figure-of-eight microphone plus one omnidirectional pressure channel. 2OA adds another five channels to these four. 3OA require 16 channels to represent the spatial data.

The additional channels correspond to the spherical harmonics. In Ambisonics, the coordinate system is normally set up so that X is forwards and backwards, Y is to the left and right, and Z is upwards and downwards. B-Format can be encoded in a few different ways which are mathematically equivalent, but not directly compatible. FuMa, ACN and SN3D are the main ones. SN3D in the ACN channel ordering convention is used in the AmbiX file format and is sometimes known as AmbiX.

Fig. 6. Panoramic 360 viewing of a site

The following WAA nodes are used in the implementation of the ambisonic processing blocks: Gain Node, a simple signal multiplier with user-controlled gain at runtime; the Convolver Node, which performs linear convolution with user-specified FIR filters for the convolutions in the binaural decoding stage.

Next the (N + 1) 2 channels for a specified order are grouped into single streams when sent from an ambisonic block to another, by using the Channel Merger Node, and split again into the constituent channels using Channel Splitter Node when received from an ambisonic block, to be processed. Vector and matrix operations on the ambisonic signals are realised with groups of gain nodes and by summing appropriately the resulting channels [16]. The rotation of the sound field also can be easily linked to the mobile phone's sensor or the on-screen user interaction.

The visual panoramic panning is achieved via the use of Panellum, an open source panorama viewer for the web, built using HTML5, CSS3, JavaScript, and WebGL.

CONCLUSION

Acoustic Atlas provides a platform for sharing and experiencing auralisations of cultural and natural sites, while also exploring their interconnection to field recordings and their potential as sources of inspiration for sonic arts compositions. The present paper explored the research context of the interface, the user experience and web audio architecture. The field of heritage acoustic research merged with that of virtual acoustics and browser-based technology has potential for various applications and artistic outputs in this field. Such data in itself is an important part of our collective heritage, as well as key to studying the ancient past and preserving the acoustics of sites for the future.

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