# Play the place: Web-based experience of an architectural space using 3D audio


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## ABSTRACT

Assessing the acoustics of an architectural space before its physical construction is of interest to architects and structural engineers. In this work, we present a browser-based interactive app enabling sonic interaction in a virtual environment modeled after a small studio architectural design for music ideation and creation made by architects Stephan & Eric Zimmerli, called ‘Studiolo’. We first describe our ideation and design process involving pilot testing in the New Atlantis online environment for collaborative sound and music experience. We then describe the implementation of the ‘Studiolo’ web app prototype supported by Javascript packages (Tone, Resonance Audio, Three, and Tween) and the Web Audio API. Room acoustics is modeled using the EVERTims framework providing a real-time auralization engine for binaural room impulse response approximation. A critical analysis by one of the architects highlights the importance of multimodal factors, from visual mapping textures and lighting quality to more sensitive and responsive timbres addressing the “tactile dimension” of music creation.


## 1. INTRODUCTION

Acoustic properties play an important role in establishing the purpose of a space. Before amplifiers were invented, finding ways to increase sound level using natural reflections of a space was of prime importance for the architectural design of buildings aimed at addressing an audience. Ancient Roman amphitheatres were designed so that speech and music could be heard very clearly even from the back of the space [6]. Modern computational methods enable the modeling of room impulse responses (RIRs) which act as acoustic fingerprints capturing the sonic qualities of a physical space. Being able to hear how sound would project in a designed space virtually can allow architects to make informed decisions and be more efficient in improving a space’s acoustics. Computing methods enabling the simulation of the sonic experience of a physical environments find a wide range of application in Virtual and Mixed Reality (VR/MR). The present work attempts to provide a web-based interactive simulation of a specific architectural space designed for music composition, called “Studiolo”. The Studiolo Klein Leberau project lead by architects Stephan and Eric Zimmerli, was born out of a commission to develop small studio houses for artist residency and creation, integrated into a rural French farm environment. Away from the cityscape, the studios are aimed at individual artists or a small group with a bespoke design using wooden material. We developed a virtual Studiolo environment based on the architectural model to let users experience the space virtually using web audio and 3D graphics technologies. The acoustic qualities of the space are simulated using computational techniques. First, we generated simplified room impulse responses, and then added interactive musical instruments leveraging web audio for sonic exploration of the space. This paper discusses our design methodology and 3D audio and visual choices to support musical interaction in the browser. The remainder of this paper is organised as follows: Section 2 discusses works on acoustics and architectural design, room auralization, and interactive virtual instruments; Section 3 presents the architectural project and describes design stages for the virtual environment from initial prototyping to a web app based on a Node.js client/server architecture.




*Web Audio Conference WAC-2021, July 5–7, 2021, Barcelona, Spain.*




## 2. RELATED WORK

### 2.1 Acoustics and architectural design

Often in architecture emphasis is placed on functional, ergonomic and aesthetic qualities focusing on spatial and visual aspects whilst acoustic qualities remain in the background. If an architect or designer lacks acoustics knowledge and no acoustic consultant is involved, aural qualities of the designed space face to be neglected [10]. In recent years, however, it has been common practice for architects to work with acoustic consultants who provide acoustical analyses of a designed space using various computing technologies before physical construction gets approved. However, it remains challenging to get an interactive experience of the acoustics of a space which is the focus of this work. Past research has shown that less noise and good acoustics in a workspace can drastically improve quality and productivity due to reduction of cognitive stress and disturbance [18].

### 2.2 Room auralization

Digital room impulse response (RIR) generation has been an ongoing field of research in sound and music computing. The image source method introduced by Allen & Berkley in 1979 in their breakthrough paper [1] enables RIR computation. A RIR as a transfer function between a sound source and an acoustic sensor in a given environment. The method provides a realistic and fast way to calculate the transfer function [1]. It is based on mirroring sources according to reflecting surfaces to generate corresponding specular reflections. A specular reflection can be simplified by assuming that sound propagates only along straight lines or rays when it is reflected back from a surface. Under this assumption, the intensity of a sound in each ray decreases following an inverse-square law ($1/r^2$ where $r$ is the distance to the source). The image source method uses a high pass filter to remove the apparent non-physical behaviour of the model at zero frequency [1]. Several improvements of the method have been proposed over the years. [17] describes various Computerized room acoustics modeling techniques and discusses their advantages, disadvantages and limitations.

Several auralization tools exist. For instance, CATT-A (Computer Aided Theater Technique - Acoustics) is a commercial software used to generate binaural or Ambisonic room impulse responses. In [4], CATT-A is used to simulate the impulse responses of a historical site in New York. The outcome was compared with in-situ impulse response measurements using another Room Acoustics Software called ODEON [11] and were found to be very similar (except by one of the listeners involved in the evaluation). Postma et al. [16] conducted a virtual reality performance in a simulation of the 850 years old Notre-Dame cathedral in Paris using binaurally-convolved room impulse response in third order Ambisonics generated using the CATT-A [4] software. The authors created a 3D rendering of the cathedral and allowed for virtual navigation during the concert to provide a completely immersive experience. The CATT-A system uses predicted octave-band echograms and converts them into binaural impulse responses. These impulse responses are then convolved with real-time audio to give the listener an impression of how the modelled room would sound. EVERTims [15] is another software tool offering similar features and according to [12], comparing calculated room acoustic parameters between CATT-A and EVERTims showed that they both perform similarly. EVERTims extends the image source method and uses a binaural engine to generate binaural room impulse responses in real time.

We adopted the EVERTims open source framework as the auralization engine for our system presented in Section 3**??**.

## 2.3 Interactive virtual musical instruments

Cadoz, Luciani, and Florens (1993) [3] proposed the CORDIS-ANIMA system, a programming language for modelling and simulating audio and physical systems using physics-based synthesis. It can be used for computer-generated sound and animated visualisations of physical systems that are perceptually congruent. More recently, Serafin et al. [19] discussed several design considerations for interactive virtual reality musical instruments (VRMIs). Deacon et al. [5] conducted an exploratory study assessing VRMI user experience. The study highlights that basic interaction problems and confusion with system functionality that prevented some users from reaching a flow state, i.e. feeling completely immersed in the activity with an increased feeling of energized focus. Other studies have been made with 3D widgets which enable simultaneous control and visualisation of musical processes in 3D immersive environments [2]. Maki and colleagues [8] explored physics-based synthesis methods to create an air guitar and a virtual xylophone in VR. The authors extensively discuss the quality of the synthesis model, the efficiency of the model and the learning curve, a factor also outlined in [7] on instrument design.

# 3. FROM STUDIOLO ARCHITECTURAL DESIGN TO WEB APP

**Figure 1: Small-scale wooden Studiolo model (courtesy of Stephan and Eric Zimmerli, architects)**

## 3.1 The Studiolo Klein Leberau project

The Studiolo Klein Leberau is a project crossing over the realms of architecture and music. It is essentially, a retreat for a musician to focus, compose, perform and record music. A small-scale, Spartan shelter in which to be alone and invent music, with just a few chosen musicians.

The term Studiolo refers to a small studio in Italian. Small studios were common during the renaissance and were meant for studying, private conversations, or writing. They were also used as a place to collect art and books. The central idea of the Studiolo habitation discussed in this paper is to accommodate artists in a rural space where they can explore their creativity away from busy urban locations. In 2017, the singer, songwriter and guitarist Rodolphe Burger, who operates a recording studio and artist residency in his family's farmhouse near Sainte-Marie-Aux-Mines (Alsace, France), asked Stephan Zimmerli and two other architect-musicians to design a group of three acoustic cabins, inspired by the Renaissance "studioli", in the tradition of XIXth century writer's and philosopher's cabins. These micro-architectures, about 25 square meters in surface, would contain just the bare essentials, to allow for comfort, rest, silence and offer views of the open landscape of the Vosges Mountains.

Each of these cabins, built and cladded with local wood, is designed according to an acoustic idea, in order to develop a specific sound signature and atmosphere prone to songwriting. The Studiolo designed by Stephan Zimmerli can be seen as a musical instrument into which one can enter. It focuses on one main phenomenon: reverberation, of sound but also of light. The Studiolo consists of a room, 4 x 5 meters, with a bench and a table, protected on three sides and opened on its South side by an ample view on the surrounding valley. Above this room, a high vertical space towers at 7m at its peak - a high pitched hollow roof containing a mezzanine where two people can rest and sleep, culminating in a zenithal skylight opening that sheds a soft Northern light onto the songwriting table below. The mezzanine itself works as an acoustic resonance chamber: it can be opened or closed to allow for variations in the resonating volume of the structure. The design is driven by the experience of Stephan Zimmerli as a songwriting musician within his band, Moriarty[1], and takes inspiration from some acoustic, synaesthetic reminiscences from the venues and diverse places where the band has performed acoustically: wooden chapels and auditoriums, narrow libraries, barns and attics.

As seen in the miniature wooden model in Figure 1, the Studiolo provides high ceilings and an aperture on top for natural sunlight, ventilation and light exposure to sounds from the surrounding nature environment from the inside. The ceiling is raised so that the space can act as a reverb chamber. The front door of the habitation is made out of glass. Insulation wool is laid in-between wooden walls and the floor to provide thermal and acoustic insulation. The building can be described as a 'wooden refuge' for musical writing. The space is acoustically designed to accommodate reverberation and acts as a 'a life sized echo chamber'.

## 3.2 Studiolo VE design criteria

Our design goal was to create a virtual environment (VE) simulating the acoustics of the Studiolo by integrating several VRMIs into the VE so that users (including architects) could assess the environment sonically. A number of considerations from [19] were employed to inform the design of the VRMIs. Sound design choices for interactive spaces should enable (i) easy interaction, (ii) reduced latency, and (iii) expressivity. It is also expected to keep the goals clear and provide good feedback to balance the unpredictability by providing a sense of control to users so that they can lose track of time and enjoy the experience.

The environment in which the Studiolo space will be located should be reflected in the VE. Susini et al. (2014) [22] propose that sound design should make intentions audible in a given context. Sound design of the VE should embody a rural environment and represent it aesthetically through a soundscape. Separating the room acoustics from the background soundscape is crucial for the auralization of the environment. To create a better sense of position, the user has to be able to experience static sound sources accurately from different positions and rotations, so it is necessary to couple an audio listener engine with the user's navigation controls to be able to spatially pan the audio.

## 3.3 Room impulse response generation

A room can be seen as a linear time-invariant (LTI) system responding in a certain way to input audio. A room shapes sounds based on various factors including its frequency response. To virtually generate the audio fingerprint of the Studiolo space, we used the EVERTims framework which combines different computational room acoustics modelling techniques,

"wave-based methods are used for low frequencies, image source methods for the early part of the room response for mid and high frequencies, and radiance transfer methods for the rest of the response" [20].

[1] https://moriartyland.net/

The EVERTims open source framework for real-time auralization in VR uses the image source method as a basis to generate early reflections and then constructs late reflections using an iterative refinement procedure. EVERTims is available as a Blender plugin enabling to position an audio source inside a virtual room and generate an impulse response in the .wav audio format based on the listener's position. The audio file can be used in convolution reverbs to simulate the acoustic qualities of the room. Convolution reverbs are standard audio effects that convolve the input audio signal with the transfer function provided as an impulse response to generate audio that carries the sonic characteristics of the room. EVERTims also provides functions to specify the material and absorption coefficient of the different components used the room, which were extracted from the GLB Studiolo model.

EVERTims uses a room acoustic modeller unit written in C++ that generates accurate sound wave reflection path visualisations and provides an auralization engine built on the JUCE platform. The auralization engine inside EVERTims contains multiple image source units the encode the audio into an Ambisonic format and an input and output audio buffer. It also encloses an Ambisonic decoder that translates the encoded audio into a listenable format which is then fed into the output audio buffer. The EVERTims tool contains a ray tracing client that can accurately trace the propagation of audio from the source inside the given room model. Ideally, for binaural applications these impulse responses are convolved with a head-related transfer function (HRTF) to generate a Binaural Room Impulse Response (BRIR) to obtain 3D audio audio with azimuth and rotation. In order to obtain an accurate auralization for a listener moving in a space, the room impulse response should ideally be recomputed for every source-listener position. As this would be computationally very expensive, a simplified model would be to use interpolated room impulse responses between a fixed set of source-listener positions. Although this is an interesting approach, in the implementation presented here, only one room impulse response was used. Hence, the auralization used in the prototype is only accurate for one position in a strict sense (this was set as the listener position at the entrance of the room).

## 3.4 Initial prototyping in New Atlantis

An Autodesk 3ds Max model (.3ds format) of the Studiolo was provided by Stephan and Eric Zimmerli. It contained a 3D model and labelled components of following materials: mahogany wood, oriented strand board (OSB) wood, pine wood, insulation wool, parquet for the floor, and roof tiles.

The 3D model was imported into Blender, an open source 3D graphic application for scaling, shading and conversion. For the 3D model to be useful in a web environment that uses the Three.js Javascript package, it can be converted into the GL Transmission Format (glTF) or its binary equivalent, the GLB format. glTF is a common, extensible format for 3D assets which is highly interoperable with modern web technologies. The GLB format stores both the material information and the structural information of any 3D model.

An initial prototyping stage was carried out using the New Atlantis (NA) web framework, an online virtual world for collaborative sonic exploration developed by Sinclair, Tenant and colleagues [21]. New Atlantis' first aim is to provide a platform for audio-graphic design and practice, for stu-

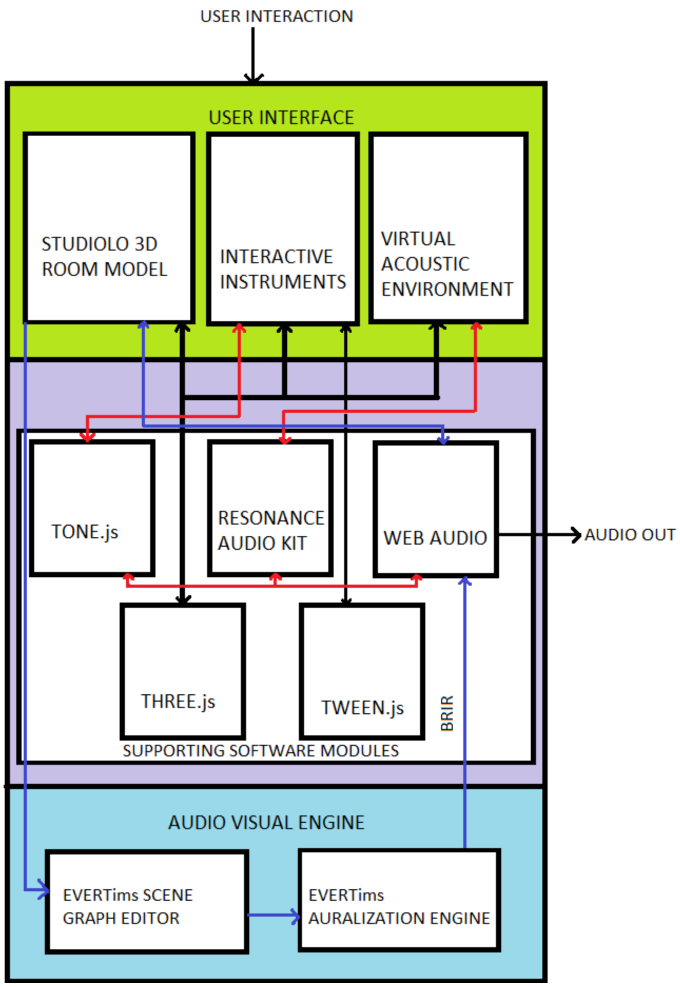


**Figure 2: Web app architecture**

dents as well as artists and researchers, engaged in higher education art or media curricula.

NA was chosen for initial prototyping because it provides a pre-generated environment with built-in functionalities to position, play and transform sound sources, and add 3D models with reverberation based on RIRs. Inside NA, a nature-based virtual environment was designed consisting of an island with trees and grass designed with Blender from open source 3D objects. This enabled to test out the GLB format 3D model and listen to sound sources in the space.

In NA, users can move around in space and interact with objects in a social setting. NA uses a simple distance-based method to simulate sound sources' position which works seamlessly. In the initial Studiolo prototype within NA, audio sources where placed across the generated land environment so that users would experience different audio sources as they navigated the space.

The sound environment of the Studiolo in NA was created using Three.js objects. However, the development of sonic interaction features was limited to in-built scripting inside NA. The interactive instruments inside the space were created using basic shapes from Three.js and were positioned so as to be clearly visible as soon as a user enters the Studiolo space. A set of cube models scaled like piano keys were laid out with colors responding to mouse clicks. The Tween.js library was used to add animations to the object upon interaction (e.g. downward/upward motion of a piano key). A web audio player located inside a 3D piano model was added with a corresponding impulse response applied locally. The audio player was programmed so that it would start playing when the user clicked on the piano, and as the user moves away, the audio would fade out slowly based on the position of the user. Even though this translated well the distance between the source and the listener, it did not take into account the boundaries of the room, so it was necessary to apply higher sound level roll off coefficients to cut the sound outside the space. Also, the temporal and spectral content of the audio source would degrade over distance. Similarly, the amount of background noise that would leak into the Studiolo space also had to be controlled.

Due to its shared multiplayer nature and the impossibility to modify the internal audio engine, it was not possible to develop a dedicated 3D space featuring interactive virtual musical instruments with the NA web framework. We developed a second prototype as described in the next Section.

## 3.5 Second prototype: the Studiolo web app

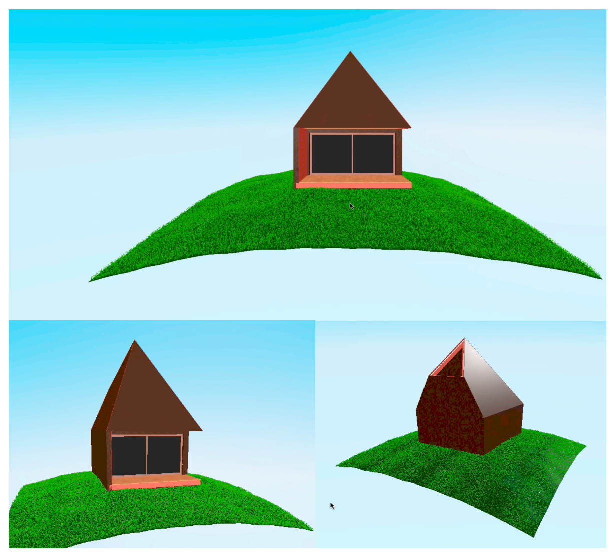

**Figure 3: Studiolo web app environment**

### 3.5.1 *Software environment*

After initial testing making use of the New Atlantis environment, a second prototype was developed using HTML5 and Javascript with Three.js, Tone.js, Tween.js, the Web Audio API, and the Resonance Audio web API. Please see Figure 2 for the software environment architecture.

- **Three.js**: open source API with functions useful for implementing 3D graphics and audio on the web.
- **Tone.js**: open source framework for creating interactive music in the browser; an older version of Tone.js is used here (r10) to make use of its multiplayer sampler.
- **Web Audio**: used to control audio on the web.
- **Resonance Audio**: used to encode spatial audio on the web using an Ambisonic decoder.

- **Tween.js**: animation library focused towards tweeting actions between two states.

The Express minimal and flexible Node.js web application framework was used withing the Glitch platform to create an online version of the Studiolo app which is accessible at: https://studiolo.glitch.me/

The Studiolo web app can be used from a web browser using a laptop or desktop computer. Earphones/headphones are preferable for binaural spatial audio (see Section 3.5.5). A screenshot of the app can be seen in Figure 3.

### 3.5.2 Environment and navigation

The virtual model was placed on a grassland under blue sky generated using shaders in the OpenGL Shading Language (GLSL). For navigation in the Studiolo web app, mouse and keyboard inputs were chosen over body gestures or other controls for increased precision.

### 3.5.3 Studiolo soundscape

According to [13], the soundscape of an environment can be composed of biological (biophony), geophysical (geophony) and human-produced (anthrophony) sounds. Soundscapes are an auditory link to the natural environment because they enable listeners to experience the natural environment through their auditory senses. The rural environment hosting the Studiolo is characterised by lower levels of human activity compared to more densely populated environments. A soundscape was composed for the Studiolo web app acting as background atmosphere using sounds sourced from Freesound. A rural soundscape contains less overlapping sounds than a urban one with longer noise-free intervals. Birds and insects typically contribute to the biophony, wind contributes to the geophony. A study on the impact of nature on creativity has shown that nature can enhance creative ways of thinking [9, 14] among other benefits.

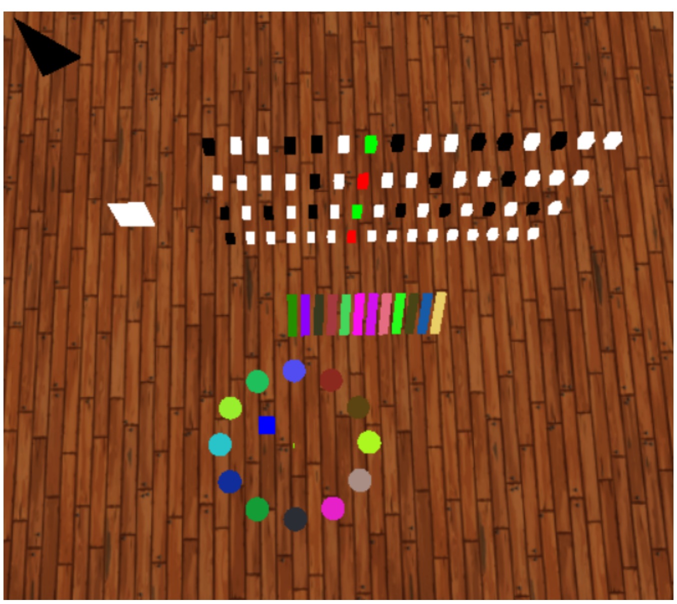

**Figure 4: Three virtual musical instruments inside the Studiolo environment**

### 3.5.4 Virtual musical instruments

Tone.js was chosen as audio engine since it is a standard for web-based interactive audio and provides many generators and effects that can support the creation of VRMIs.

To draw user attention [19] and enable users to experience a varied range of sounds, we developed three different virtual musical instruments with different timbres: a four track 16-step sequencer, and two 12-tone pitched instruments, a struck one akin to a piano and a circular one akin to a steel pan drum (see Figure 4). Visual feedback is provided by highlighting instruments when hovered by the mouse.

The drum sequencer can provide a rhythmic foundation and steady sound source letting the user audition the sounds from different parts of the room while they navigate the space. The current step is highlighted and the instrument provides start/stop and reset controls. The stop button needs to be pressed twice in order to clear the current sequence to make room for a new one. The step sequencer uses Creative Commons audio samples sourced from Freesound.

The piano/keyboard synthesizer trigger short impulsive sounds representative of struck sound very common in modern music. The circle-based synthesiser is inspired by a steel pan drum, however it produces sounds with slower release and longer decays. The blue cube seen in Figure 4 in the middle of the circular synthesiser is a modulation control that alters the timbre of the synth by moving across a confined two-dimensional plane.

### 3.5.5 Audio engine and spatialisation

The render function in Three.js receives information from the scene and displays them on screen. The camera here is treated as the user and the audio listener it is coupled to represents a user's ears. As the camera moves through space, the position of the listener and the camera are used to pan sounds accordingly. The Audio context holds all the sound components of the program. There are two kinds of sources, the environmental audio and the synths from Tone.js. The environmental audio is processed using the Resonance Audio Ambisonic encoder and decoder before it is sent to the audio destination. The Tone.js synths are coupled with the native panner 3D node inside Tone.js. These receive the position of the camera and hence the listener to pan audio in 3D.

The 3D objects can be classified as interactive or statics. The statics contribute to the environment and are part of the virtual ecosystem (e.g. sky and grass). All the other objects that shape the sonic field of the environment are called interactables (Studiolo 3D model, keyboard and circular synth instruments, drum sequencer along with the transport controls, and the camera). The interactable objects respond either to arrow keys, mouse click or drag/move. The Studiolo app contains event listeners for all the functions mentioned previously and each event performed on different interactables passes a value to the Tone.js synth associated to the VRMI and the Tone.js synth responds to the value passed.

The ray caster function provided by Three.js enables to keep track of intersecting points between objects and the mouse cursor. The ray caster shoots rays towards every object in the scene from the camera and when the mouse cursor interjects that point, that event can be used to inform the program that an object is being interacted with. To make the scene more interesting visually, small animations were added when interacting with objects or when using the transport function. Since the whole audio implementation is done in higher order Ambisonics, it is ideal to experience the environment on headphones/earphones or with a multichannel speaker system.

The Tone.convolver function was used to load the Binaural Studiolo impulse response generated offline using EVERTims into the environment and the convolver is coupled with the Tone.js synths present inside the environment. To create boundaries for audio propagation between the inside of the Studiolo and the outside, the audio source roll off value and the source distance value are manipulated by tracking the listener position. When the listener moves beyond the walls of the Studiolo, audio levels start dropping drastically and the environmental sound fills the space.

Tone.transport acted as the time keeper for the whole circuit but latency was experienced at certain points in the process when all the instruments are playing at the same time since the processes are CPU heavy. There were also audio drop outs experienced due to the network connectivity issues at times, otherwise the latency for user interaction is unnoticeable.

# 4. CRITICAL ANALYSIS

A critical analysis of the Studiolo web app prototype was conducted by seeking feedback from two architects, one of whom is a co-author. Each architect was sent a link to the app with explanatins on how to navigate the space and interact with the virtual musical instruments inside the space. The architects were invited to provide feedback by email after trying the studiolo app, reflecting on the following questions: (i) what aspects of an architectural project may benefit from a tool like the studiolo web app? (e.g. design, testing acoustics aspects, raising awareness about the project and public engagement, remote online music collaborations, etc.,); (ii) what types of creative applications can be envisioned?;(iii) what are the challanges that remain to be adressed to improve usability and user experience ?

**Critcal Analysis Architect 1:** As an architect and musician, working in both fields simultaneously, Stephan Zimmerli is constantly researching conceptual and practical tools that can bridge the gap between these two disciplines - devices and processes that take advantage of deep common structures to invent new forms and imbue them with meaning, thus questioning the essence of elementary concepts shared by architecture and music, such as rhythm and structure, chromatic and atmospherical quality, density and material texture, luminosity and spatiality. The Studiolo web app within the structure of the architecture project is directly addressing this issue. It aims to provide a working tool that deals simultaneously with the material space of architecture and the acoustic nature of music.

Throughout his career as a performing musician, Zimmerli had the opportunity to play concerts or make recordings in over 900 venues, and this led him to acknowledge the seminal, intrinsic connection between music and the space that harbours and conveys it: we often have a tendency to think of music as an abstract - almost mathematical - art, happening in a mental or spiritual realm before being expressed in the physical, acoustic world. But - as David Byrne demonstrated in his essay “How Music Works” (Canongate, 2012) - experience shows that the truly physical, acoustic essence of musical performance is actually informing, influencing or shaping the way we “imagine” music from the start. This feedback process can seem natural when in the context of traditional, acoustic music, and one might question whether the musical production of the electronic age, actually has a “space” to resonate within, other than a digital one.

Modern sound engineering can simulate all sorts of reverberations, echoes and sound behaviours digitally. When we record music using such simulations, we “hear” the space it mimics. But we don’t “see” it - and as an architect-musician, Zimmerli often found this frustrating, because the visual, physical, and haptic environment of a place is a synaesthetic kind of ensemble for him: *“when I play, I usually envision or feel the space around me, but in the world of digital simulations, I miss this richness of interaction”.*

Hence the relevance of developing such a tool, which gives shape to a three dimensional space, and the acoustic resonance of the music played within it, simultaneously. As a user, Zimmerli envisions it as an enhanced digital instrument, each note played reverberates in the volume and, in the subconscious, intuitive kind of feedback evoked above, the way it rings affects the notes played next. Changing his position within - or outside - the building can also alter the way he hears the music he plays, just as it would in a real physical space, thus affecting the energy and attack of my notes. Ultimately, the type of acoustic-architectural realm created lets us act in a truly four-dimensional environment (albeit within the limitations of the screen interface of course, which for me remains literally captive of its two dimensions, but that could easily be developed by using more immersive devices).

The program could benefit from some more fine-tuning: visually speaking, Zimmerli argues that the material, atmospherical qualities of the environment, should be as delicately designed as the soundscape (here the raw mapping textures and shrill colours of the instruments were somehow distracting me from the immersive experience he was striving for). Working closely with architectural render specialists can help workout the materiality, but above all the lighting quality of the scene, which plays a decisive role in the “mood” setting for compositional activities. The same thing takes place for the sonic quality of the digital instruments displayed, that could benefit from more sensitive and responsive textures of sound, to start addressing the “tactile” dimension that is so crucial to intuitive composition and performance. In such systems, thinking and designing in a holistic manner, encompassing all five senses, would be key to providing a convincing, “transparent” kind of working tool: an instrument that lets the mind and its intuitions flow freely, without interference, through the hands and the body, into the outer realm and ultimately to the listener.

**Critical Analysis Architect 2:** Reflective feedback was also provided by Raghul Velsamy an architect based in Tamil Nadu, India. He works in a private architectural firm providing design solutions to clients. He mentions that tools like this can be useful for presenting the acoustic experience of the space to a client during early stage of the design process. Providing an architect with a detailed representation of environmental sounds and room reverberation can impact the the way design process works. It enables the architect to make more sound-based decisions. Experiencing the Studiolo virtual acoustic environment through the web app has created a sense of what it might feel like to be inside the real building. Noise level control inside our everyday living spaces can affect the way we work and increase productivity but acoustic quality of a building is not widely considered during the design process unless specifically asked for by the clients. It is often considered a value added service and costs time and money. Having easy access to tools like this through web browsers or even better if the browser extensions can be launched from inside an architectural design software it would integrate acoustic design inside the architects workflow and give every client easy access to good acoustics. Tools like these should be improved to provide smart suggestions on how to improve acoustics of the designed space.

## 5. CONCLUSION

With the use of different web development APIs and the EVERTims open source auralization framework, a simple virtual implementation of an architectural design (small music studio) was achieved in a browser-based environment. If frameworks like EVERTims that can calculate impulse responses of 3D models in real-time can be coupled with web based 3D graphics frameworks like Three.js, An accurate representation of the audio space can be achieved that takes listener position into consideration. Supporting accurate rendering for any source-listener position requires further work to update the RIR according to the position of the listener while supporting real-time use. Latency may be experienced which distracts the user from the interaction. This latency can be controlled using better programming techniques that improve the cost of computing required by real-time 3D graphics and audio rendering. If more accurate immersive systems with soundscapes and interactive instruments become available to the common public in the future, this could contribute to the way architects design spaces and lead to participatory music experiences using web digital technologies

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