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Virtual reconstructions of the Théâtre de l'Athénée for archeoacoustic study

Brian FG KATZ [(1)], David POIRIER-QUINOT [(1)], Barteld NJ POSTMA [(2)]

[(1)]Sorbonne Université, CNRS, Institut Jean le Rond d'Alembert, *Lutheries - Acoustique - Musique*, Paris, France, *
[(2)]dieBauingenieure - Bauphysik GmbH, Karlsruhe, Germany

Abstract

The French ECHO project studies the use of voice in the recent history of theater. It is a multi-disciplinary project which combines the efforts of historians, theater scientists, and acousticians. In the scope of this project an audio-visual simulation was created which combines auralizations with visualizations of former Théâtre de l'Athénée configurations issue from a series of renovations, enabling researchers to realistically perceive theater performances in foregone rooms. Simulations include the room, 2 actors on stage, and an audience. To achieve these simulation, architectural plans were studied from archives providing various details of the different theater configurations, from which the corresponding visual and room acoustic geometrical acoustics (GA) models were created. The resulting simulations allow for 360° audio-visual presentations at various positions in the theater using commercial standard hardware.

Keywords: Archeoacoustics, Archaeological Acoustics Auralization, Virtual Reality

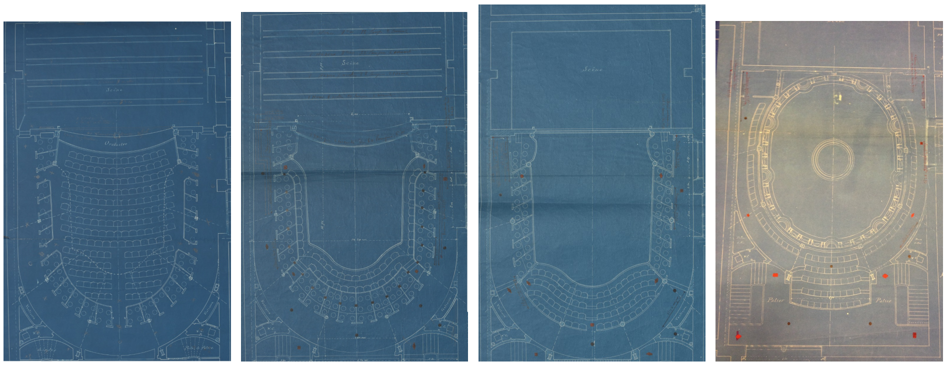
1 INTRODUCTION

The ECHO project studies the use of voice in the recent history of theater. This multi-disciplinary project combines the efforts of theater scientists, historians, and acousticians. In order to enable theater scientists and historians to study the use of voice in historic theater conditions an audio-visual framework which enables virtual reality visits to historic configurations of the Théâtre de l'Athénée-Louis-Jouvet[1] was created.

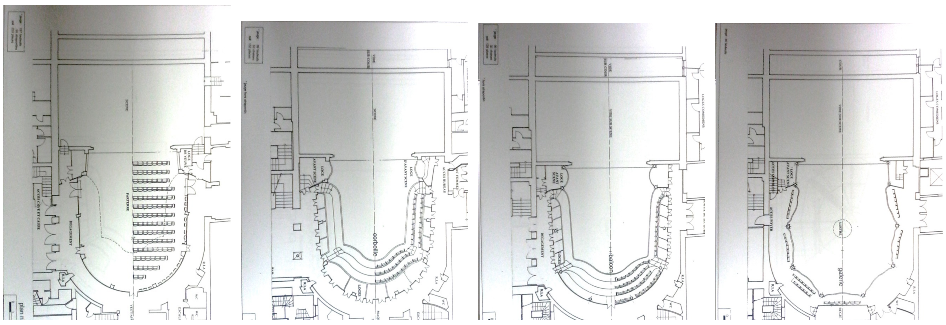
For this purpose, first the architectural history of the theater was studied (see Sec. 2). Based on these studies three Geometrical Acoustic (GA) models were created corresponding to different epochs of this theater (see Sec. 3). These various models were used to compare the acoustic conditions across renovations. As studies have shown that visuals influence the room acoustical experience, the auralizations of the GA models were combined with visuals employing an audio-visual framework (see Sec. 4).

2 ARCHITECTURAL HISTORY OF THE THÉÂTRE DE L'ATHÉNÉE

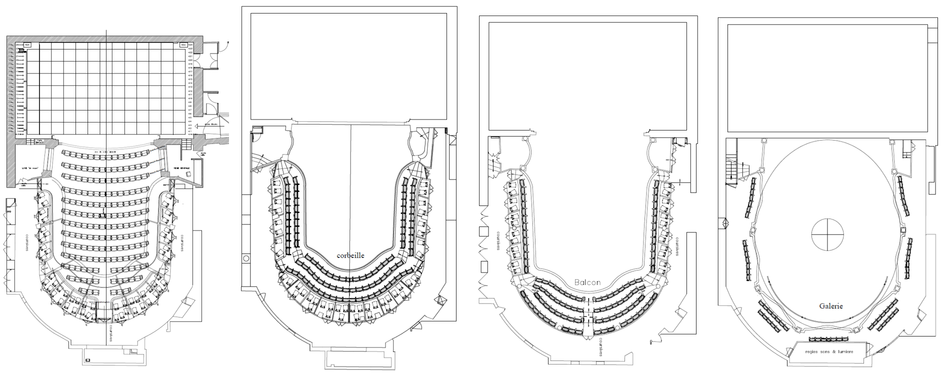
On 7-Jan-1883 the Éden-Théâtre was inaugurated in Paris. The 4000-seat theater suffered from continual financial difficulties and was therefore closed in 1894 and demolished in May 1895. In 1893 a foyer of the Éden-Théâtre was converted into a much smaller theater called the Comédie-Parisienne which was inaugurated on the 31-Dec-1894. The architect was Stanislas Loison, with further modifications carried out under the architect Paul Fouquiau's guidance in 1894. This newly created four-floor theater seated approximately 600 attendants. It was closed again on 9-May-1895, after two bankruptcies. In 1896, the Athénée Comique took possession of this room which was renamed the "Comédie Parisienne" on 28-Dec-1898, and then on 25-Oct-1899 as the "Athénée" [9]. When Louis Jouvet became director of the theater in 1934, the room changed its name for the last time: the Théâtre de l'Athénée-Louis-Jouvet.



(a) 1st, 2nd, 3th, and 4th floor of the Théâtre de l'Athénée in the original configuration.



(b) 1st, 2nd, 3th, and 4th floor of the Théâtre de l'Athénée in the pre-1995 configuration.



(c) 1st, 2nd, 3th, and 4th floor of the Théâtre de l'Athénée in the current configuration.

Figure 1. Floor plans of the Théâtre de l'Athénée at different periods.

2.1 Original configuration

In the original configuration (see Fig. 1(a)) there was an orchestra pit meant for ≈ 25 musicians. Walls were covered with light velour and seating was lightly upholstered. During the first years of the Théâtre de l'Athénée, there was no amplification. With the appointment of Louis Jouvet in 1937 the theater underwent its first physical alterations [7]. Under his guidance, the stage was rebuilt, the old electrical fixtures rewired, and the electrical

*brian.katz@sorbonne-universite.fr

[1] For brevity called Théâtre de l'Athénée here.

power increased to support stage lighting. Furthermore, Louis Jouvet decided to install more luxurious chairs. Finally the Théâtre de l'Athénée was brought completely up to date with a loudspeaker intercommunication system.

A second larger renovation was carried out at a yet undetermined time. Pictures and plans show that it was carried out between 1962 and 1985 (see Fig. 1(b)). The stage edge was straightened and the orchestra pit was removed. On the first floor the loges were replaced by folding seats and the orchestra pit by regular seating. The loges at the second and third floor were moved back, accommodating regular seating. The fourth floor back wall seating was replaced by a glass-framed technical room for sound and light direction.

The Théâtre de l'Athénée underwent its third renovation between 1995-1998 (see Fig. 1(c)). An orchestra pit was re-installed in front of the stage: larger than its predecessor, it could now be covered by extra rows of seats when no orchestra was needed. Furthermore, the loges on the first floor were reinstalled and lightly upholstered chairs were brought back. The other floors of the theater remained as they were.

3 CREATION AND CALIBRATION OF THE GA MODELS

To create GA models for the various architectural and acoustic configurations of the theater, a base model was created and calibrated from room-acoustic measurements performed at the theater in its present state. For details of this procedure, see [13]. GA models of the former configurations were derived from this model, adapting its geometry and materials to match the observations reported in Sec. 2

3.1 Creation

The geometry of the Théâtre de l'Athénée's current configuration was determined from architectural plans (see Fig. 1(c)) and sections (minimum modeled dimension = 0.34 m). Figs. 2(c) and 2(d) compare the interior of the room to the geometrical model. The stage opening of this 4-floor theater is ≈ 7.7 m, stage depth ≈ 7.8 m, and height over the stage ≈ 13.8 m. The audience area is *'horse shoe'* shaped with a maximum width of ≈ 11.0m, length ≈ 14.3 m, and height ≈ 13.6 m. Box seats are present on the side and back walls on the first, second, and third floor.

For the original configuration, an orchestra pit was modeled in front of the stage, the loges on the second and third floor were modeled according to Fig. 1(a). For the pre-1995-1998 configurations the loges along the side and back wall of the first floor were replaced by seating and the stage was straightened.

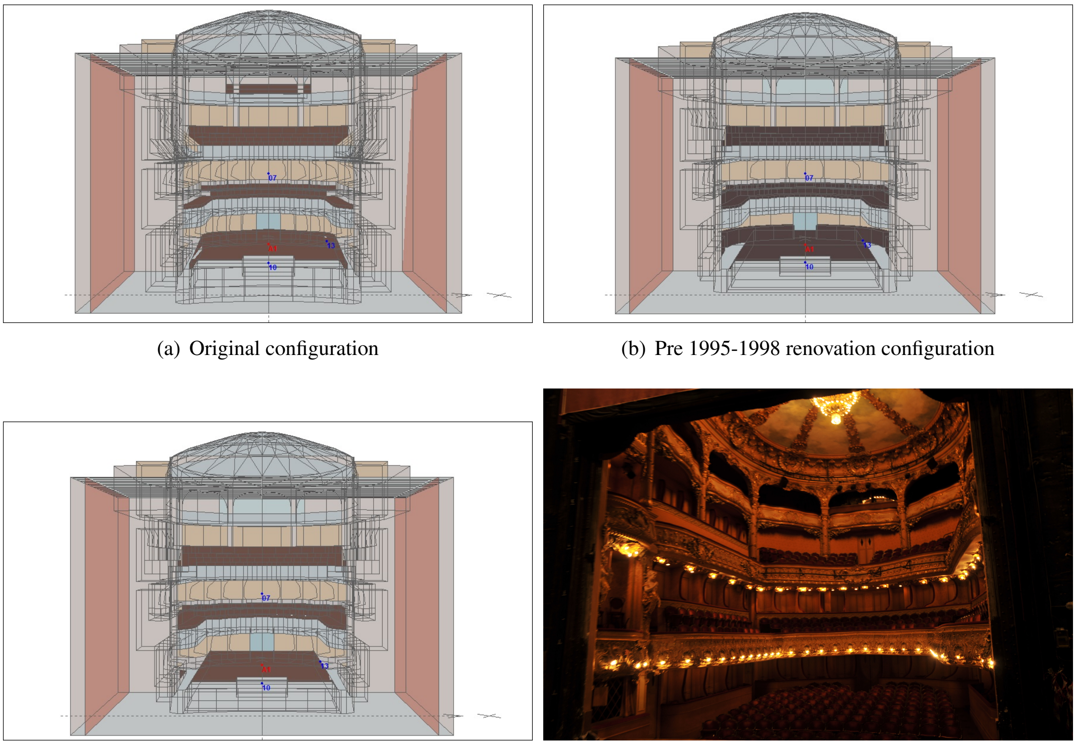
The modular design of the GA model ensured coherence of the unmodified elements between configuration (see Figs. 2(a), 2(b), and 2(c)).

Surface materials were determined from visual inspection. The Théâtre de l'Athénée has a wooden stage floor and concrete side and back stage walls. The audience area has a wooden floor, light velour walls, plastered balcony fronts, and plastered ceiling with a large chandelier. Upholstered chairs are positioned throughout the room. Few changes were observed in material usage throughout the history of the Théâtre de l'Athénée. The pre-1995-1998 renovation contained heavier upholstered chairs, modeled as medium upholstered [2].

The frequency-dependent scattering coefficient ($scatt_{coef}$) was estimated as a function of a given characteristic depth ($char_{depth}$) representative of the surface's depth variations or roughness. The estimation algorithm (see Eq. 1, [4]) is available in CATT-Acoustic via the *estimate* function, though specific values can also be directly assigned as a function of frequency.

$$scatt_{coef}(f)\Big|_{\geq 0.10}^{\leq 0.99} = 0.5\sqrt{\frac{char_{depth}}{\lambda}} \tag{1}$$

where λ is the wavelength. This method of defining $scatt_{coef}$ was selected as it provided a more intuitive and physically relevant control parameter and reduces the possibility of creating unrealistic frequency variations in scattering properties for general materials. Employing this formula results in an increasing scattering with higher



(a) Original configuration

(b) Pre 1995-1998 renovation configuration

(c) Current configuration

(d) Photo of the current configuration

Figure 2. (a), (b), and (c): Geometrical model of the Théâtre de l'Athénée. Volume ≈ 2500 m^3, ≈ 1300 planes. (d) Photo depicting the audience area as seen from the stage (22-Jul-2014).

Table 1. Average T20, EDT, C50, and C80 of the measurement in the Théâtre de l'Athénée for various frequency bands (in Hz).

	125	250	500	1000	2000	4000
$\overline{T20}$	2.06	1.74	1.53	1.31	1.17	1.03
$\overline{EDT}$	1.91	1.81	1.56	1.30	1.20	0.98
$\overline{C50}$	1.71	1.04	1.08	1.63	1.93	2.57
$\overline{C80}$	2.32	1.73	2.40	3.45	3.28	4.99

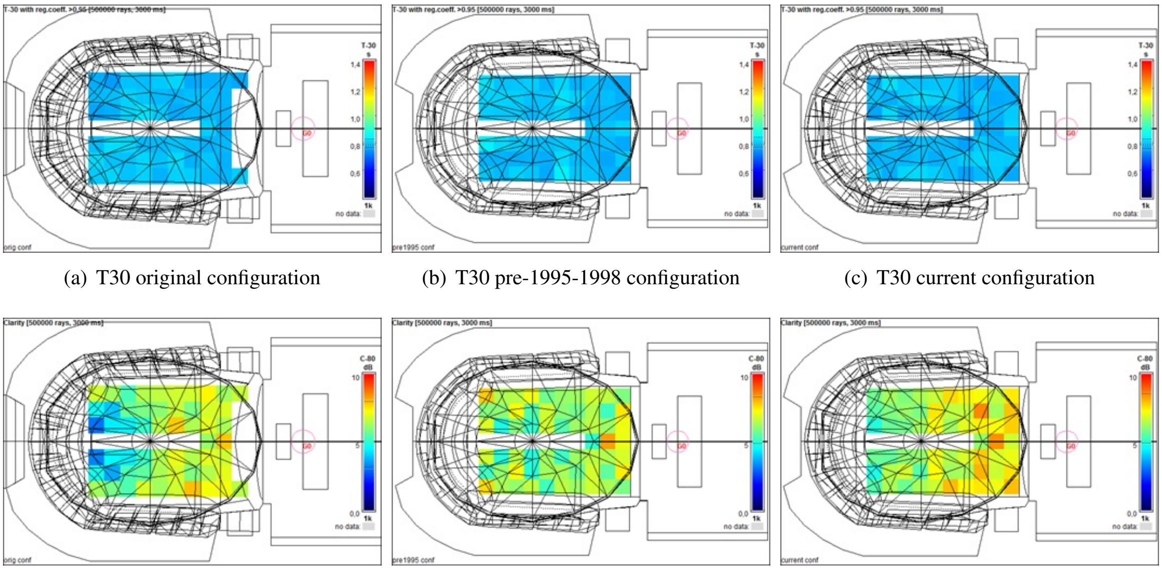
frequency, as is typically found in scattering measurements.

3.2 Measurement

A room-acoustic measurement was performed in order to serve as a reference for the calibration. A summary of the calibration reference values are provided in Tab. 1. Full details of the calibration measurements are provided in [15].

3.3 Calibration

Details of the applied calibration procedure can be found in [13]. The procedure consists in adapting the acoustic surface parameters to minimize the mean error on simulated acoustic parameter estimation (EDT, T20,



(a) T30 original configuration (b) T30 pre-1995-1998 configuration (c) T30 current configuration

(d) C80 original configuration (e) C80 pre-1995-1998 configuration (f) C80 current configuration

Figure 3. Reverberation time T30 and Clarity C80 simulation results for 1 kHz-octave band. 500 000 rays used, ray truncation time 3000 ms.

C50, and C80) compared to those extracted from RIR measurements across source-receiver pairs. Subsequently, a perceptual validation was performed using binaural auralization, ensuring that participants could not distinguish auralizations using the measured RIRs from those using the simulated ones (ratings based on eight perceptual parameters, see [15]).

3.4 Occupied theater

To simulate the acoustics of the theater during actual performances, curtains were added to the back and side walls of the stage in the GA model. In addition to changing the audience absorption between conditions to take into account the change in seating design, values were also adjusted to occupied absorption seating characteristics. Resulting simulated T20 values of the current configuration model closely resembled measured reverberation times in occupied conditions [11].

3.5 Comparative acoustic study

With these calibrated models it is possible to study the influence of the renovations on the acoustical conditions. Fig. 3 presents a mapping of T30 and C80 values in the 1 kHz-octave band for the 3 configurations. The quantified results show that the reverberation time has not changed over time while clarity has improved for positions at the far end of the audience area.

4 AUDIO VISUAL RENDERINGS

Multiple studies have shown the influence of visuals on the room acoustic experience in terms of distance [18, 3, 16, 17], loudness [1, 16], ASW [8], and room size perception [8]. Therefore, attention is subsequently focused on an associated visual model.

A framework was created to compliment the simulated auralizations with visual renderings of the theater, its

(a) Original configuration (b) Pre 1995-1998 configuration

Figure 4. Visual models of past Théâtre de l'Athénée configurations

(a) (b) (c)

Figure 5. 3-walled CAVE with period theater seating (a) without and (b) with projection of the visual virtual theater rendering. (c) HMD conditions.

actors, and an audience. A 3ds Max[2] visual model was provided by the Théâtre de l'Athénée. This model was imported into Blender and adjusted to match the various configurations of the theater discussed in Sec. 2, as illustrated in Fig. 4. While not accurate to every detail, the model does reflect the general visual nature of the theater. The resulting models served as scenery for a Blender Game Engine scene implementation, relying on the OSC protocol for real-time update of both listener position and orientation in a Max/MSP[3] client handling the 2^{nd} order Ambisonics auralizations.

This general augmented auralization framework has been presented in detail in [10]. It has been employed for various perceptual tests [16, 12, 17], and allowed for multiple audio and visual presentations. The visuals can be rendered on either a 3 screen video-wall setup, an Oculus Rift DK2 Head Mounted Display (HMD), or a high definition virtual cave [17] (see Fig. 5). The audio can be presented using either headphones (binaural) or a speaker array (Ambisonic).

In order to create a realistic sound source in terms of visuals and acoustics, a 5 min extract of the play "Ubu Roi", by Alfred Jarry, was performed by two actors and recorded in the Théâtre de la Reine Blanche, using two headset microphones and a Kinect 2 sensor. Voice directivity was incorporated according to [14, 12]. As the direct-to-reverberant ratio is high for close mic recordings, these were employed as approaching anechoic recordings. These close-miked voice recordings were convolved with simulated 2^{nd} order Ambisonic RIRs from the GA models. Voice directivity variations were controlled via gain modulation on the components

[2] https://www.autodesk.com/products/3ds-max/overview

[3] https://cycling74.com

(a)

(b)

Figure 6. Snapshot of actors performing “Ubu Roi” in the virtual Théâtre de l’Athénée for different listening positions, including audience avatars.

of a 12-beam directivity sphere. Source rotation, applied to the gain modulations via a spherical harmonic interpolation, employed the currently speaking actors’ head orientation based on tracking information extracted from the Kinect 2 video. The sum of the 12-beam$\times 2^{nd}$ order Ambisonic convolutions, properly weighted and rotated, resulted in a single Ambisonic stream. The video stream of the Kinect 2 sensor was processed by a script based on the `libfreenect2` library[4], recording both RGB and Depth videos. Both videos were combined during real-time rendering in BlenderVR [5] to produce a 512×424 pixel point-cloud of the actors.

A set of fixed position 360° videos was generated off-line from the same material to support a study on the influence of the listening position on perceived acoustics in immersive renderings. To provide a listening experience more comparable to attending a performance, rather than a rehearsal, animated simplified spectator avatars were added to the visual scene, coupled with audience noise. The audience noise was a collection of randomly played studio recordings made of typical audience activity: moving, rustling, coughing, scratching, mumbling, etc. These dry sounds were convolved with calculated RIRs for source positions distributed throughout the audience areas, further improving the verisimilitude of the overall rendering. The resulting Ambisonic streams were combined with the actors streams and the visual rendering to create 360°-HOA examples. The spectator avatars where animated using the Blender CrowdMaster[5] add-on, assigning different animation sequences to each armatured mesh from a set matching the selected audience noises (scratching, moving, coughing, etc.). The final scene is illustrated in Fig. 6, the 360° videos are available online at `www.lam.jussieu.fr/Projets/CloudTheatre.html`.

5 Conclusion

In order to enable audio-visual perceptual studies in historic theaters, a virtual reality framework was created which enables visits to former configurations of the Théâtre de l’Athénée. Both realistic room-acoustic and visual models were created and calibrated to match the considered configurations of the theater. These were combined using a virtual reality platform relying mainly on BlenderVR for the visual rendering and Max/MSP for the auralization. Subsequent studies in the field of experimental virtual archaeological acoustics will extend this framework to interactive real-time audio processing and an up to date game engine [6].

[4] `https://github.com/OpenKinect/libfreenect2.`
[5] `http://crowdmaster.org/`

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REFERENCES

[1] M. Barron. Subjective study of british symphony concert halls. *Acustica*, 66:1–14, 1988.

[2] L. Beranek. *How they sound: Concert and Opera halls*. Acoustical Society of America, 1996.

[3] E. Calcagno, E. Abregú, M. Eguía, and R. Vergara. The role of vision in auditory distance perception. *Perception*, 41:175–192, 2012.

[4] B. Dalenbäck. *CATT-A v9: User's Manual CATT-Acoustic v9*. Gothenburg (Sweden): CATT, 2011.

[5] B. Katz, D. Felinto, D. Touraine, D. Poirier-Quinot, and P. Bourdot. BlenderVR: Open-source framework for interactive and immersive VR. In *Proc of IEEE VR*, pages 203–204, 2015.

[6] B. F. Katz, S. Le Conte, and P. Stitt. EVAA: A platform for experimental virtual archeological-acoustics to study the influence of performance space. In *Intl Sym on Room Acoustics (ISRA)*, Amsterdam, Sept. 2019.

[7] B. Knapp. *Louis Jouvet Man of the Theatre*. New York: Columbia University Press, 1957.

[8] P. Larsson, D. Västfjäll, and M. Kleiner. Ecological acoustics and the multi-modal perception of rooms: real and unreal experiences of auditory-visual virtual environments. In *Proc. Intl. Conf. on Auditory Display*, pages 245–249, July 29-August 2001.

[9] L. Lecomte. *Histoire des Théâtres de Paris 1402-1904*. Paris: H. Daragon, editeur, 1905.

[10] D. Poirier-Quinot, B. Postma, and B. Katz. Augmented auralization: Complimenting auralizations with immersive virtual reality technologies. In *Intl Sym on Music & Room Acous*, pages 1–10, La Plata, 2016.

[11] J.-D. Polack, F. Leao Figueiredo, and S. Liu. Statistical analysis of a set of parisian concert halls and theatres. In *Proc. of the Acoustics 2012 Nantes Conference*, pages 911–916, 2012.

[12] B. Postma, H. Demontis, and B. Katz. Subjective evaluation of dynamic voice directivity for auralizations. *Acta Acustica united with Acustica*, 103:181–184, 2017.

[13] B. Postma and B. Katz. Creation and calibration method of virtual acoustic models for historic auralizations. *Virtual Reality*, 19(SI: Spatial Sound):161–180, 2015.

[14] B. Postma and B. Katz. Dynamic voice directivity in room acoustic auralizations. In *German Annual Conf. on Acoustics (DAGA)*, pages 352–355, Mar 2016.

[15] B. Postma and B. Katz. Perceptive and objective evaluation of calibrated room acoustic simulation auralizations. *J. Acoust. Soc. Am.*, 140:4326–4337, 2016.

[16] B. Postma and B. Katz. Influence of visual rendering on the acoustic judgments of a theater auralization. *J. Acoust. Soc. Am.*, 141(5):3934, 2017.

[17] D. Thery, D. Poirier-Quinot, B. Postma, and B. Katz. Impact of the visual rendering system on subjective auralization assessment in vr. In *No. 10700 (EuroVR 2017) in LNCS*, pages 1–15, 2017.

[18] P. Zahorik. Estimating sound source distance with and without vision. *Optometry and Vision Science J*, 78(5):270–275, 2001.