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ECHOES IN IBERIAN BULLRINGS

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ABSTRACT

The presence of echoes in an acoustic event can ruin the capture of a spoken message and the perception of a piece of music. Likewise, in the performers' area, clear hearing of one's own voice or instrument and that of the rest of the performers is essential for the coordination and execution of the ensemble. Bullrings are buildings with a circular plan in which echo-encouraging focalizations can occur. Since bullrings lack a roof, the density of reflections is lower than that in a closed area and therefore strong isolated reflections perceived by the audience as an echo can be created. In this work, the echo parameter (Echo Criterion EC) is studied, together with an inspection of the impulse responses and the energy decay curves in the audience zones and in the arena area where the EC parameter exceeds the thresholds: in 4 bullrings highly emblematic of the Iberian Peninsula, one of which has a mobile roof. The results indicate, according to the EC parameter, that there is no echo for the music in the audience zone of the venues, and that the most critical area is where the source and receiver are both in the ring.

Keywords: *acoustics of bullrings, disturbing echo, strong reflection, heritage acoustics.*

1. INTRODUCTION

The transmission of sound between two points in a room is formally represented by the impulse response of the transmission path. This impulse response is composed of direct sound and the numerous repetitions of the original sound impulse caused by reflections of the sound signal at the boundaries of the room. Each of these reflections is specified by its level and its time delay, both of which with respect to the direct sound. This description must be completed by indicating the direction from which each reflection reaches the receiving point.

Under certain conditions said reflection can become an "echo" that is heard as a signal repeated over time that appears to come, subjectively, from a place other than where the source is located. This phenomenon can frequently be observed outdoors; in enclosed spaces these experiences are less common, since echoes are fortunately usually masked by the reverberation of the room. Whether a reflection will become an echo or not depends on its delay with respect to the direct sound, its relative level, the nature of the sound signal, and the presence of other reflections that eventually mask the reflection in question [1].

Early reflections are useful as long as their delay and relative strength remain within certain limits, since they support the sound source. Reflections that reach the listener with a longer delay are perceived as echoes in unfavorable cases; in favorable cases, they contribute to the reverberation of the room. In principle, any reverberation harms the intelligibility of speech because it blurs its temporal structure and mixes the spectral characteristics of successive phonemes or syllables. From the results by Haas [2] it can be concluded that the critical delay time separating useful reflections from harmful reflections is in the range of 50 to 100 ms. To perceive such an echo, the total distance traveled by the reflected sound must be at least 17 m. It is very unlikely that an echo will occur in a closed room, with a greater probability in positions far from the source (lower direct sound) and close to a reflective surface, as verified by Vera-Guarinos *et al.* [3] by using simulation tools.

This risk of echo increases when focalization occurs, such as concave curved surfaces with cylindrical geometry, as appear in bullrings. Likewise, in an architectural space

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without a roof, the density of reflections is lower and Rindel [4] points out that the existence of echoes is more likely under these conditions.

Based on the findings of Haas, Bolt and Doak [5] proposed a criterion represented by constant percentage disturbance contours of the amplitude of reflections as a function of delay time relative to the direct sound. Dietsch and Kraak [6] have also proposed an echo detection criterion based on the time of the center of gravity of the impulse response. The criteria have been investigated for both speech and music. The center of gravity time of an impulse response (p(t)) normalized to its total energy is:

$$t_S(\tau) = \frac{\int_0^\tau t p^n(t) dt}{\int_0^\tau p^n(t) dt} \text{ (ms)} \quad (1)$$

with $n = 2$ for the traditional center-time formula, and $\tau = \infty$ in the upper limit of the integral. For this criterion, a suitable value of n was found to be $n = 2/3$ for speech and $n = 1$ for music.

Lastly, the echo criterion (Echo criterion EC) is expressed by the relationship:

$$\Delta t_S = t_S(\tau) - t_S(\tau - \Delta\tau) \quad (2)$$

$$EC = máx \frac{\Delta t_S}{\Delta\tau} \quad (3)$$

For speech n=2/3, and $\Delta\tau$= 9 ms. For music n=1, and $\Delta\tau$= 14 ms.

If EC exceeds 1 at a time delay s > 50 ms, there is a 50% chance that a listener will detect a disturbing echo for speech. The maximum value of EC(s) after 50 ms is the Dietsch echo parameter. Tab. 1 summarizes all the information presented.

Table 1. Echo thresholds for EC by Dietsch and Kraak.

Signal	n	$\Delta\tau$ (ms)	$EC_{10\%}$	$EC_{50\%}$	Bandwidth (Hz)
Speech	2/3	9	0.9	1.0	700-1400
Music	1	14	1.5	1.8	700-2800

In this study, the EC parameter is studied in the receivers in the audience area in a set of bullrings, since these roofless spaces present the possibility of the presence of echoes [4]. Another important aspect of the problem related to echo involves the experience of the interpreters themselves. For an orchestra to collaborate successfully, musicians need to hear themselves and their colleagues clearly. Accordingly, this study has also considered positions in which both the source and the receiver are in the ring. In particular, this acoustic phenomenon has been studied in a covered bullring, since several authors pointed out a case in a covered bullring in Spain where a flutter echo clearly appears in the ring [3, 7].

2. EXPERIMENTAL PROCEDURE

Measurements were carried out without an audience and following the recommendations of the ISO 3382 standard [8, 9], thereby ensuring maintenance of required background noise levels and signal-to-noise ratio (SNR). There was no wind during the measurement times (air speed less than 0.5 m/s) and environmental conditions were monitored by measuring temperature with a precision of ± 1ºC and a relative humidity precision of ± 5%. To carry out in-situ measurements, the following equipment was used:

The signal generation, acquisition, and analysis process was carried out with the IRIS v. 1.2 software package [10], and through the MOTU 4PRE HYBRID sound card. The excitation signal was a sweep of sinusoidal signals with a duration of 30 seconds and a frequency range of 20 Hz to 20,000 Hz. This excitation signal was reproduced in the space using a DD5 García Calderón ultralight dodecahedral omnidirectional source located at 1.50 m above the ground, previously amplified with a B&K-2734-type power amplifier. The impulse responses (IRs) were captured with the Core Sound TetraMic microphone array pointing in the same direction as the source, which enabled the incorporation of temporal and spatial (3D) information.

In all cases studied, the microphone was placed 1.20 m from the ground, except in the receivers in the passageway located 1.60 m from the ground [11, 12]. The EC echo parameters have been obtained through the wav signals of the bullrings loaded into the EASERA software, since the IRIS platform does not provide this parameter.

3. SPACES STUDIED

This section briefly describes the spaces studied, namely three open bullrings (Real Maestranza de Caballería de Ronda (RMCR), Real Maestranza de Caballería de Sevilla (RMCS), and Las Ventas de Madrid) all located in Spain, and a fourth, Campo Pequeno de Lisboa, Portugal, measured with its closed roof and with a segment of the roof open. The multi-source nature in which the bullfighting spectacle takes place requires a good number of source-receiver combinations to understand its sound field. The spaces are described in the same order in which the acoustic measurements were carried out and, in all cases, the choice of the source and receiver positions has followed the recommendations published by the authors to characterize the acoustic environment of bullrings [11, 12].

3.1 Real Maestranza de Caballería de Ronda

The Royal Maestranza de Caballería de Ronda, created in the 16th century, is today a non-profit charitable entity, dedicated to the conservation, dissemination, and research of its historical and documentary heritage, cultural promotion, and the teaching of horse riding. [13]. This bullring, located within the historical center of Ronda, is one of the oldest in Spain and was declared as an Asset of Cultural Interest, in the monument category in 1993.
This bullring, the first built in stone and with the largest arena in the world at 66 meters, began its work in 1769. It was officially inaugurated in 1785 and, in 1788, the main façade in the Classicist Baroque style was completed. In the 20th century, various interventions were carried out.
Its interior façade has a double floor with continuous galleries. The double gallery of arcades, with 136 columns forms 68 frontal segmental arches supported by Tuscan columns. The capacity is for 4890 spectators. The grandstands are distributed across both galleries with five rows of stands each.
In this bullring, 48 source-receiver combinations have been recorded corresponding to 4 source positions and 12 positions of signal reception (Fig. 1).

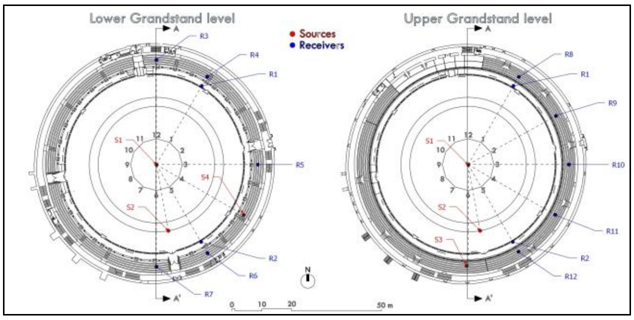

Figure 1. Floor plans of the bullring of Ronda showing the 4 sources (S) and the 12 receiver positions (R).

3.2 Real Maestranza de Caballería de Sevilla

The building of this bullring describes, both externally and internally, the shape of an irregular polygon, consisting of 30 unequal sides. The external appearance is in the Late-Baroque style pointing to Neoclassicism, in which the Puerta del Príncipe predominates, flanked by two towers, in contrast to the rest of the façade, which is mostly whitewashed. The ovoid-shaped arena, a product of the multiple historical vicissitudes suffered by the architectural complex, stands out for its vast surface, with diameters ranging between 63.2 and 57.9 meters: its arena is not flat, but slightly conical.
The bullring of the Real Maestranza de Caballería of Seville stands out precisely for not being perfectly circular, since, during its prolonged construction from 1740 to 1881, it was forced to adjust to the surrounding dwellings and resembles a large house where the bullring is the central courtyard. The public is accommodated in two areas: 12 segments of stalls and grandstands with a capacity of 11,500 seats. Above this seating area there is an archway with an irregular layout, like the arena, with marble columns, protected with gabled Arabic tile roofs [14]. These are made up of 117 numbered arches, plus the richly ornamented Prince's box.
As for the construction materials that the bullring shows today, with the exception of the stone of the façade, the ornamental details and columns of the main boxes are these common to Sevillian architecture: brick, Arab tiles, and wooden beams. In the most recent interventions, steel and reinforced concrete have also been incorporated [14].
In this bullring, 75 source-receiver combinations have been recorded corresponding to 5 positions of the source and 15 receivers (Fig. 2).

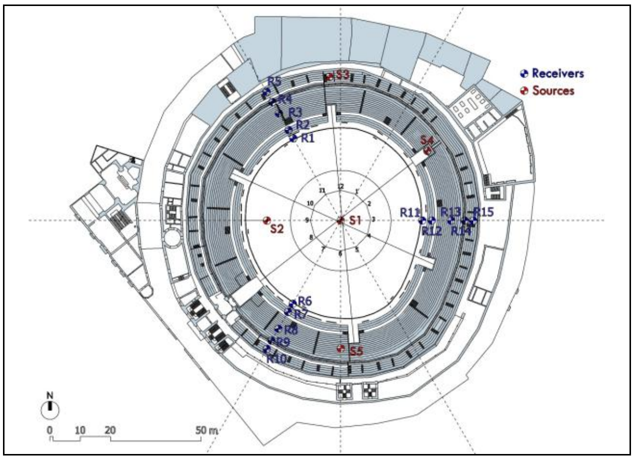

Figure 2. Floor plan of the bullring of Seville showing the 5 source positions (S) and the 15 receivers (R).

3.3 Las Ventas bullring in Madrid

This bullring was designed with the intention of building a monument on the scale of the city, since the volume, the façade and the anteroom of the bullring take on really important dimensions [15]. Construction begins in 1919 (architect José Espelius Anduaga) and concludes in 1931 (architect Manuel Muñoz Monasterio). It is the largest bullring in Spain, built in the neo-Mudejar style. With a capacity for 23,798 spectators, it is the third largest bullring in the world, after those in Mexico City (CDMX, Mexico) and Valencia (Carabobo, Venezuela). It is also the second largest in terms of the diameter of the arena, at 61.5 m, after the Ronda bullring (Málaga, Spain) [16]. It has four floors of circular galleries and five projecting turrets on its exterior façade (Fig3).

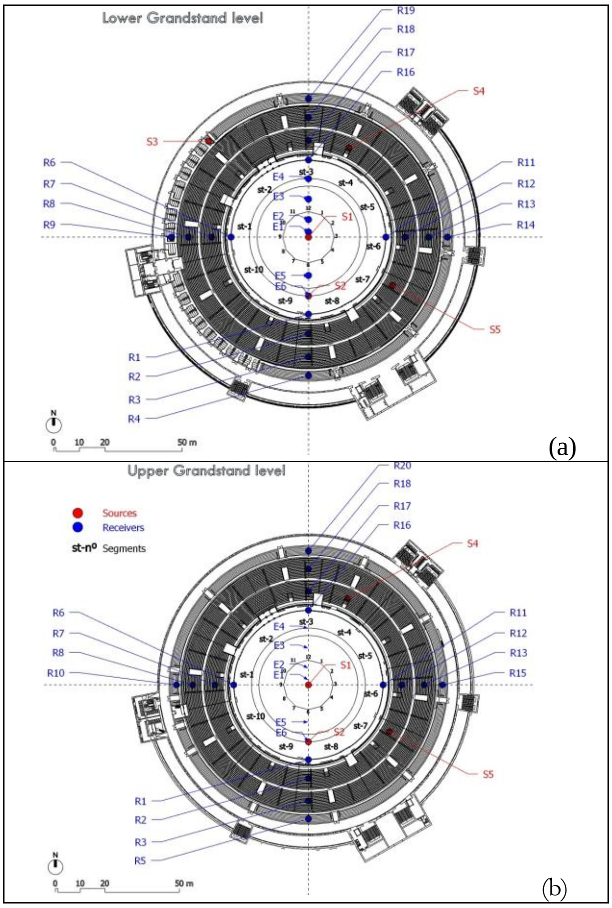

Figure 3. Locations of the 5 sound sources (S) and 20 receivers (R) in the bullring of Las Ventas de Madrid: (a) in the ring, stalls, boxes and lower grandstands; (b) in the upper grandstands.

This bullring is distributed into ten segments (four shade segments, numbered 1, 2, 9, and 10; two sun and shade segments, numbered 3 and 8; and four sun segments, numbered 4, 5, 6, and 7). The presidential boxes, for the Royal Family and other authorities, are located to the east, in a central place in the shade area. In turn, the segments are divided by height into stalls, boxes, lower grandstands and upper grandstands (Fig. 3).

In this bullring, 71 source-receiver combinations have been recorded, all of which have direct sound corresponding to 5 positions of the source and 20 receivers (in certain sources, not all the receivers have provided measurements), and 6 more combinations with source and receivers in the ring (Fig 3).

3.4 Campo Pequeno bullring in Lisbon

The Campo Pequeno bullring in Lisbon began its construction in 1889, designed in the neo-Mudejar style by the Portuguese architect António José Dias da Silva and was completed in 1892. It had a capacity of 8,500 people before the 2000 reform. It was inspired by the old bullring (now demolished) in Madrid built by Emilio Rodríguez Ayuso.

Campo Pequeno was originally built of solid red facing brick, and underwent a thorough remodeling in 2000, whereby the brick was replaced with reinforced concrete. A commercial gallery was created in the basement and other similar spaces at street level (José Bruchy, Pedro Fidalgo, Filomena Vicente, and Lourenço Vicente).

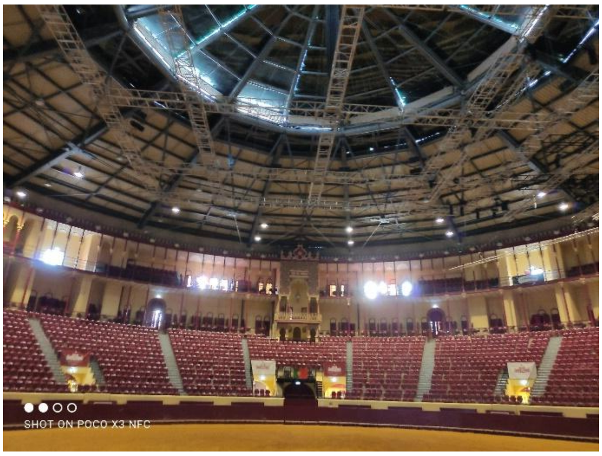

Figure 4. Interior view of the bullring of Campo Pequeno, showing the mobile roof, the presidential box, Sector 2, Sector 1 even and odd, and Sector 7. (Source: The authors).

The most significant change has been the installation of a mobile roof (João Goes Ferreira) that enables the building to be used for various activities throughout the year (Fig. 4). The diameter of its arena is 36.4 m and the stalls are distributed into 7 sectors: the North half (1 even, 7, 6, and 5) and the South half (1 odd, 2, 3, 4 odd, and 4 even). Its capacity is of 6,698 seated spectators. The plaza is distributed from bottom to top into stalls, boxes and galleries (Fig. 4).

In this bullring, 108 source-receiver combinations have been recorded corresponding to 4 positions of the source and 18 receivers with the roof oculus closed and 2 positions of the source and 18 receivers with the roof oculus open. Of these measured combinations, 24 correspond to both the source and receiver located in the ring (Fig. 5).

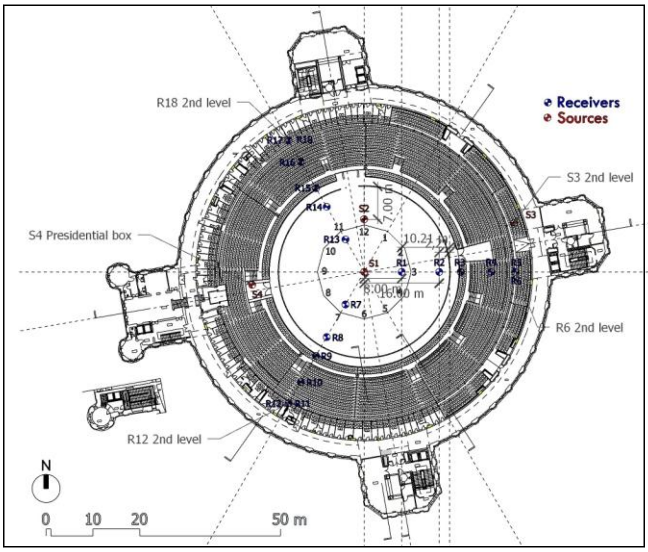

Figure 5. Locations of the 4 sources (S) and the 18 receivers (R) in the ring, stalls, boxes, and grandstands in the bullring of Campo Pequeno.

4. RESULTS AND DISCUSSION

Explanations are now given regarding the receivers at which EC exceeds or coincides with the values of 1 and 1.8 for speech and music respectively, according to Tab. 1. The tables below show these values for each space studied and the time in ms of the reflection of the impulse response that gives rise to this EC value. In all cases, in the following tables, T_{SPEECH} and T_{MUSIC} are relative to the time of emission of the source. Likewise, due to a lack of space, the results of the source where musical sources are located in the bullrings (music band, bugle and timpani, and trumpets) are omitted if, at the corresponding reception points, there is no risk of a disturbing echo for music and these receivers provoke no comments.

4.1 Results in the bullring of Ronda

In accordance with these general considerations in the Ronda bullring, Tab. 2, of the 48 combinations measured, in only 2 combinations is there a risk of echo exclusively for speech: for source S4 in receivers R3 and R5 in the public area (Fig. 1).

Table 2. Echo parameters and source-receiver distance in the bullring of Ronda.

S4 Lower Gstand (Public)	EC Speech	EC Music	T_{SPEECH} (ms)	T_{MUSIC} (ms)	d_{s-r} (m)
R3	1.01	0.94	3580	216.3	57.9
R5	1	0.64	3400	3410	17.3

Consequently, an echo is produced only for speech in two positions of the first-floor stands, with the source in the public area and in the first-floor stands, although R3·is at a much greater distance than R5, see Fig. 1. This bullring is therefore known to be free of echoes although it has only been measured in half of the bullring.

4.2 Results in the bullring of Seville

According to the general comments in the Seville bullring of the 75 combinations studied in Tab. 3 it can be observed that there is a risk of echo for speech in 5 combinations in S2 R1, R2, and R10 and in S5 in R8 and R13, all in the public area.

Table 3. Echo parameters and source-receiver distance in the bullring of Seville.

S2 Ring side	EC Speech	EC Music	T_{SPEECH} (ms)	T_{MUSIC} (ms)	d_{s-r} (m)
R1	1.07	1.07	2910	2910	29.3
R2	1.19	1.27	2760	2760	31.3
R10	1.05	1.02	2050	2050	41.3
S5 (Public)					
R8	1.00	0.92	1760	1770	20.0
R13	1.21	1.53	167.6	172.6	55.5

According to Fig. 2, there is a risk of echo in symmetrical radii regarding S2, although R1 and R2 are in the passageway and lower grandstand respectively, and R10 is in the covered gallery.
As for source S5, R8 and R13 are in the same row with respect to the ring, although R13 is at a much greater distance than R8.
In the two bullrings shown below, the risk of echo in the audience area for a bullfight has been studied, and also when the source and receiver are both in the arena, which is of interest in the case of theatrical and musical performances where both the sound source for speech or music and the audience are located therein.

4.3 Results in the bullring of Madrid

In Las Ventas bullring in Madrid, of the 71 combinations registered in the audience area, there is a risk of echo for speech in 5 combinations: S1 R2, R11, R12, and R16 and in S2 R17.

Table 4. Echo parameters and source-receiver distance in the bullring of Madrid in the audience area.

S1 Ring center	EC Speech	EC Music	T_{SPEECH} (ms)	T_{MUSIC} (ms)	d_{s-r} (m)
R2	1.09	1.23	291.50	296.17	38.0
R11	1.07	1.13	266.21	268.98	30.3
R12	1.15	1.28	293.98	297.73	38.1
R16	1.02	0.99	266.27	265.94	29.9
S2 Ring side					
R17	1.11	1.45	399.08	401.58	60.3

Tab. 4 indicates the values of the EC parameters in the audience area. Tab. 5 shows the results when the source and receiver are in the arena.
The source S1 in the center of the ring does not produce an echo pattern in the audience in any of the bullrings studied, except in this bullring in Madrid, in which the seating area reaches great heights. An echo is produced in three radii and when the source is located in the ring on the picadores line S2, an echo is produced only in one receiver at a long distance R17 (Fig. 3).
In the combinations of S1 and 6 reception points in the arena there is a risk of echo, for speech and music in E1 and E2 positions, and only for speech in E3, E4, E5, and E6, that is, in all positions studied there is a risk of echo for speech (Tab. 5). The EC parameter values increase at short distances to the source.

Table 5. Echo parameters and source-receiver distance in the bullring of Madrid when the source and receiver are in the ring.

S1 Ring center	EC Speech	EC Music	T_{SPEECH} (ms)	T_{MUSIC} (ms)	d_{s-r} (m)
E1	2.57	2.10	176.75	181.94	2.0
E2	2.72	2.07	162.17	167.02	6.9
E3	2.17	1.75	138.31	143.10	14.8
E4	1.31	0.98	115.46	120.46	22.8
E5	1.46	1.19	115.17	120.19	15.0
E6	1.65	1.56	136.75	141.75	22.6

As an example, corresponding to S1-E3 of Las Ventas bullring, Fig. 6 shows the energy-time and Schroeder curve.

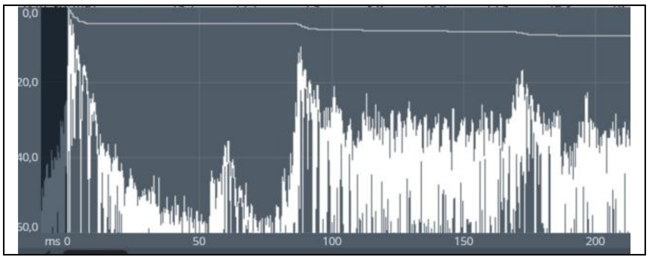

Figure 6. Energy decay curve and Schroeder curve in S1-E3 combination in the bullring of Las Ventas at broadband, from IRIS v.1.2.

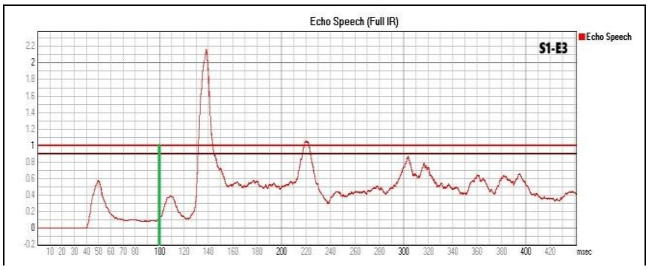

Figure 7. The echo coefficient EC for speech. The vertical green line is the time limit of 50 ms. The horizontal dotted lines represent the probability of detecting a disturbing echo: 10% (violet) and 50% (red).

Fig. 6 shows the significant reflections that give rise to a double echo for speech at approximately 95 ms and 178 ms relative to the direct sound, and the discontinuity of the energy at those moments in the integrated Schroeder curve derived from the impulse response of S1-E3 combination in the bullring of Las Ventas. Fig. 7 shows the EC coefficient by Dietsch and Kraak derived from EASERA software showing the strongest reflection now at 138 ms from the emission of the source.

4.4 Results in the bullring of Lisbon

In Campo Pequeno bullring in Lisbon, of the 60 source-receiver combinations in the audience area with the closed oculus (CO), there is a risk of echo for speech in only 1 combination: S2 R9. Of the 24 source-receiver combinations in the audience area with the open oculus (OO), there is a risk of echo for speech in only the same combination as with the closed oculus: S2 R9, located in the passageway at its most distant point from the source that has been measured, see Tab. 6 and Fig. 5.

Table 6. Echo parameters and source-receiver distance in the bullring of Lisbon with the two roof configurations: closed oculus (CO), and open oculus (OO), in the audience zone.

S2 Ring side	EC Speech	EC Music	T_{SPEECH} (ms)	T_{MUSIC} (ms)	d_{s-r} (m)
R9 CO	1.11	1.14	136.12	141.12	30.6
R9 OO	1.00	1.04	135.83	140.98	30.6

In the 12 source-receiver combinations in the arena, with the oculus closed, there is a risk of echo for speech in 8 combinations: S1 R1, R2, R7, R8, and R13; and in S2 R1, R7, and R8. Of the 12 source-receiver combinations in the bullring with the roof oculus open, there is a risk of echo for speech in 7 combinations in S1 R1, R7, R8, and R13; and in S2 R1, R7, and R8, see Tab. 7.

Table 7. Echo parameters and source-receiver distance in the bullring of Lisbon with the two roof configurations, closed oculus (CO), and open oculus (OO), when source and receiver are both in the ring.

S1 Ring center	EC Speech	EC Music	T_{SPEECH} (ms)	T_{MUSIC} (ms)	d_{s-r} (m)
R1 CO	1.32	1.11	89.17	94.17	8.5
R1 OO	1.23	1.07	88.56	93.27	8.7
R2 CO	1.01	1.15	157.77	163.92	15.9
R7 CO	1.66	1.38	92.75	97.77	7.1
R7 OO	1.52	1.27	93.42	98.33	7.0
R8 CO	1.06	1.11	155.54	158.33	15.9
R8 OO	1.05	1.14	157.33	160.55	15.8
R13 CO	1.54	1.31	90.50	95.50	7.7
R13 OO	1.57	1.32	90.65	95.54	7.7
S2 Ring side					
R1 CO	1.03	0.94	82.88	87.54	13.8
R1 OO	1.09	0.99	83.08	87.81	13.9
R7 CO	1.22	1.13	100.31	105.10	17.3
R7 OO	1.24	1.20	100.46	105.27	17.4
R8 CO	1.21	1.29	123.67	128.25	25.9
R8 OO	1.15	1.25	123.46	128.06	25.9

In Campo Pequeno bullring, in the two roof configurations, the patterns of impulse responses and curves of decay are very similar. Small differences are due to the absorption of the textile that makes up the mobile roof and to differences in the sessions of measurement, in both the receivers in the spectator areas and those located in the ring. Likewise, the similarity is observed in the values obtained in the echo parameters (EC) in Tabs. 6 and 7. In this bullring, the risk of echo appears in one more position with the oculus closed and the source in the center of the ring than with the open oculus. With the closed oculus with the source in the center S1, an echo appears in 5 of the 6 possible combinations, while with the open oculus an echo appears in 4 of the same 6 possible combinations. For the source in S2, an echo appears in 3 of the 6 possible ones, with closed oculus and in the same 3 combinations with the oculus open of the 6 possible ones.

4. CONCLUSIONS

Generally speaking, there is no echo for music in the audience area of the bullrings. Several of the source positions analyzed correspond to musical signals. On the other hand, in the receivers where an echo appears, it is for the speech signal, which is why the source-receiver combinations that come from the source in the position of the music band, from bugle calls and timpani, and from trumpet calls have been ignored in the discussion. Likewise, the risk of echo for the spectators in the public area of the bullrings appears only in a very small number of receivers. When the source and receiver are placed in the arena, an echo appears for speech in all the combinations studied in Las Ventas and in almost all combinations in Campo Pequeno bullring with either the roof closed or open. The few positions of the audience at risk of echo could improve with the presence of the public; however, as future work, it will be studied (with IRIS 3D plots of sound intensity vectors) whether the reflections that produce echo in the arena come primarily from the painted wooden barrier that delimits the arena or from the public area.

5. ACKNOWLEDGMENTS

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