Soundscape approach applied to a heritage open-air concert hall: The case of the Corral del Carbón in Granada

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Soundscape approach applied to a heritage open-air concert hall: The case of the Corral del Carbón in Granada

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ABSTRACT

Finding a metric to evaluate the sound quality of a given product is a challenging task. It depends on multiple criteria and dimensions. This study proposes a soundscape approach to assess the pleasantness of the acoustic environment in an open-air heritage site, the Corral del Carbón in Granada as a complementary tool for selecting concert venues in addition to environmental and room acoustics criteria. Acoustic measurements and surveys were conducted at two locations: the patio of the building and the adjacent street. The methodology involved soundwalks with participants who provided subjective assessments, complemented by objective acoustic indicators and psychoacoustic parameters. The results reveal a significantly more pleasant acoustic environment inside the patio than the street. This kind of comparisons between sites provide information on which is a more suitable setting for concerts. Soundscape approach offers a practical tool for selecting concert venues in heritage contexts by emphasizing the importance of the perceptual experience of the audience, thereby enhancing the decision-making process for concert programmers and acousticians.

Keywords: Soundscape, Heritage buildings, Concert, Sound Quality.

1. INTRODUCTION

Historical sites can enhance the concert experience for attendees from an emotional perspective, as Smith claimed for museums[1]. Hyde demonstrated that, for concert halls, visual input affects the aural experience[2]. The visual aspect is crucial when listening to music, especially during live concerts. This article is part of a broader study on the Methodology for the assessment of heritage sites as sound venues from an acoustic perspective, which includes aesthetic, environmental[3], and room acoustics[4] criteria. In this context, the current article focuses only on the aesthetic criterion.

Hosting concerts in heritage buildings that were not originally designed as concert venues is a common practice. Especially in warmer climates, it is typical to use open-air heritage sites for concerts. The acoustics of concert halls have been widely studied[5–7], but various results indicate that classical room acoustics criteria are not suitable for heritage sites. For example, Paini et al. demonstrated that the reverberation time is not suitable for large unroofed auditoriums[8], and Almagro et al. reported that the Palace of Charles V has low intimacy, clarity, and envelopment, despite the audience's positive reception of its acoustics[4].

Soundscape research examines how humans perceive acoustic environments. Originally an area of concern for environmental psychology, it now intersects with fields such as architecture, physics, and health. This interdisciplinary nature necessitates an integrated approach. Soundscape was pioneered by Schafer[9] and has been applied in architecture by Blesser and Salter[10], among others. While Carpenter and McLuhan[11] point out that sound reveals the physical structure and dynamics of the environment in which it is created, Blesser and Salter[10] go deeper by suggesting that, although we usually think of a soundscape as a collection of sonic events, it also includes the aural architecture of the environment. On one hand, just as light sources are required to illuminate visual architecture, sound sources (sonic events) are required to "illuminate" aural architecture to make it aurally perceptible. On the other hand, aural architecture modifies our experience of sonic events, such as when the reverberation of a concert hall elongates musical notes. Soundscapes consist of sonic events and aural architecture[10], but they also need a listener to complete the experience. Truax[12] calls this the "triadic communication model." Without the human element, a soundscape is merely sound intensity, sound spectrum, and temporal behavior, it lacks meaning. Some emotions a soundscape can evoke include intimacy, privacy, security, warmth, and socialization. In fact, soundscape, as defined by ISO 12913-1[13], is the acoustic environment as perceived and/or understood by a person or people, in context. Currently, knowledge of soundscapes in concert venues remains insufficient.

In general, the selection of concert venues does not consciously account for acoustics. Complaints from neighbors may lead to the avoidance of certain sites or the implementation of measures or emission limits to prevent nuisance. Similarly, venues with poor room acoustics may be penalized by box office performance. While some musicians refuse to perform outside traditional auditoriums, programmers often prioritize other factors, such as ease of stage setup, electrical installations, or lighting, over acoustics. Environmental and room acoustics criteria are needed; however, it is essential to introduce a criterion that considers the audience's perceptions, where the soundscape approach becomes particularly relevant. Although this approach is novel in this specific field, it has already been extensively discussed in urban planning contexts, as highlighted by Brooks in the summary of Chapter 4 by Schulte-Fortkamp et al.[14]. Previous works have shown that desirable ambient noise, such as the sound of flowing water, can reduce unwanted noise, such as traffic or machinery[15–19]. In conclusion, the main contribution of the soundscape concept is that sound can be a resource in heritage venues.

This article aims to serve as a guide for concert programmers, musicologists, sound engineers, or acousticians in evaluating a heritage space for use as a concert hall using a sound aesthetics criterion. It compares a heritage place used as a venue and an adjacent street as an example. This first comparison shows important differences in the perceived and measured acoustics of the courtyard. Further comparisons are required to draw comprehensive conclusions.

The remainder of the introduction provides a comprehensive review of the current state of research on soundscape, sound quality, and the physical parameters associated with soundscape studies. The Materials and Methods section details the surveys and measurements conducted, the sites of interest, and reviews the soundscape indices used. The Results and Discussion section presents the findings, highlighting both objective and subjective differences. Finally, the Conclusions outline the contributions of this paper, with a focus on future work aimed at improving acoustic and aesthetic criteria for selecting heritage venues. The annexes include a glossary to clarify terminology and a portion of the questionnaire used in the study.

1.1. Soundscape Approach and the importance of context

Conventional noise control measures prioritize minimizing noise levels. In contrast, the soundscape approach considers the qualitative aspects of sound, acknowledging that certain sounds, even if loud, may contribute positively to the overall auditory experience. Kang et al.[20] discuss how this shift in perspective has led to the development of innovative methodologies for assessing and evaluating soundscapes, including subjective surveys and sonic mapping techniques. By recognizing the value of sound in shaping our environment, the soundscape paradigm offers new insights for urban planning and architectural design, encouraging a more nuanced approach to managing sound that encompasses both the physical and perceptual dimensions of our acoustic surroundings[14,21]. Soundscape approach underscores the importance of understanding how sounds influence our perception of space and how such perceptions impact our well-being and quality of life[22].

The need for standardisation in soundscape science has resulted in ISO 12913 in four parts: ISO 12913-1[13] defines fundamental terms and concepts related to the soundscape, providing a conceptual framework for its study. ISO 12913-2[23] focuses on methods for assessing the soundscape, detailing techniques and tools used to measure and evaluate the sound quality of a given environment. ISO 12913-3[24] addresses subjective evaluation of the soundscape, including the subjective perception and assessment of environmental sounds by individuals or communities. ISO 12913-4[25] (under development) concentrates on sound mapping techniques to graphically represent the spatial distribution of sounds in a given area.

Given the definition of Soundscape of 12913-1, the context includes the interrelationships between person and activity and place, in space and time[13]. The context may influence soundscape through the auditory sensation, the interpretation of auditory sensation, and the responses to the acoustic environment. Context has a strong influence in the perceptual construct of soundscape. Within the scope of this paper, the context will be a built environment, of heritage significance, and assessed to use for music concerts.

1.2. Sound Quality approach and its attributes

Sound Quality has both, auditory and non-auditory attributes. While non-auditory aspects of sound quality fall outside the scope of this article, it is crucial for those assessing the suitability of heritage sites for concert use to take these factors into account. Kang et al.[26] list the non-auditory factors observed for site selection of soundscape research in two categories. Physical-contextual (visual, environmental, and visual meaning) and Social-contextual factors (socio-economic and demographic, pre-conception and personal preference, and intention). ISO WG68 is working in a standard about Non acoustic factors influencing the perception, interpretation and response to environmental sounds[27], so these categories may need to be revised.

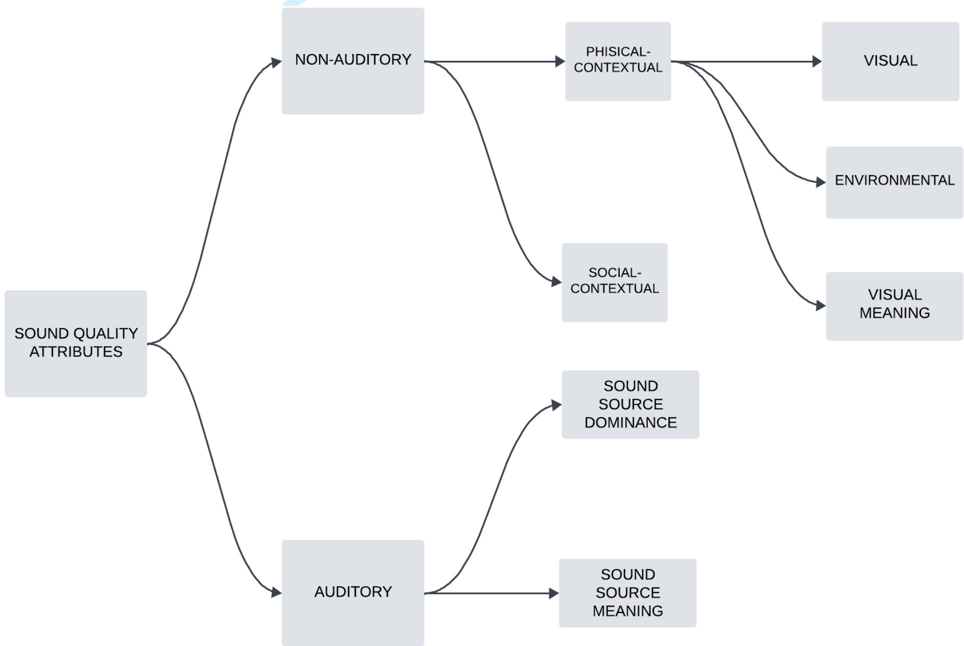

Figure 1 Soundscape Sound Quality attributes

"Visual attributes" are closely tied to the aesthetics of a space, and heritage buildings should possess distinctive architectural and aesthetic qualities that can enrich the concert experience. The decision to host a concert in such a venue is predicated on the belief that the visual and historical significance of the building will contribute positively to the event. The heritage status of the venue is intended to complement and enhance the concert, offering a unique and immersive environment that is difficult to replicate in more contemporary settings. Beyond aesthetics, the concept of "visual meaning" plays a vital role in this alignment. Aesthetics should not be judged simply as good or bad; the appropriateness of the space for a particular event is equally important. This appropriateness concept is what Blauert[28] refers as "eignung" in Product Sound Quality. For instance, Canon Law 1210[29] states that "Only those things which serve the exercise or promotion of worship, piety, or religion are permitted in a sacred place; anything not consonant with the holiness of the place is forbidden." This underscores that certain musical genres may be inappropriate for performance in a Catholic church, where tradition and customary practices must be respected. Environmental factors, such as light, temperature, and humidity must also be considered. For example, it would be impractical to hold a concert in an open-air auditorium during cold and rainy seasons. Social-contextual factors should favour the use of a heritage site for hosting a concert. The beauty of the location, coupled with the event to be held, should influence the behaviour of the audience and align with socio-economic, demographic, and personal preferences of the attendees. Furthermore, the musical genres programmed must complement the heritage space to achieve synergy and enhance the concert experience.

Physical attributes of sound are not enough to assess sound pleasantness or sound quality. According to Zwicker[30], in addition to acoustic features of sounds in particular aesthetic and/or cognitive effects may play an essential part. Also according to Herranz-Pascual et al.[31] the best way to perform an accurate evaluation of pleasantness in the acoustic environment of an existing place is to ask the users of that place about the pleasantness which they feel in the existing soundscape. That is a time-consuming task and a simpler way is needed to quickly assess how good a heritage place is to host a concert in terms of sound quality. The subjective relationship of the listener to the sound is important. Auditory attributes of sound quality include the "sound source dominance" and the "sound source meaning". The meaning (Semiotics) or the context where the sound is heard are important.

1.3. Physical magnitudes related to soundscape

According to Fiebig et al.[32], the most used indicators and parameters for soundscape are Loudness (N), Sound pressure Level (L), Sharpness (S), Roughness (R), Fluctuation Strength (F), and Tonality (T). The ISO Standard [23] explains the indicators to be measured and how they have to be calculated, avoiding prior bias. L_{Aeq}, L_{Ceq}, L_{AF5}, L_{AF95} according to ISO 1996[33]. In case of Psychoacoustic parameters, Loudness is calculated according to ISO 532-1[34]. For all other psychoacoustic parameters, the method of calculation must be reported. A complete review of the descriptors for soundscape assessment are included in "A systematic review of prediction models for the experience of urban soundscapes"[35]. Fiebig's review of the use of psychoacoustic parameters on soundscape studies[32] shows the lack of comparability due to different or non-specified computation methods of the parameters used. So one of the aims of this paper is to use indices that can be calculated easily and with a clear methodology.

2. MATERIALS AND METHODS

2.1. Survey and measurements

It is common practice in soundscape research to perform soundwalks. Participants fill out a questionnaire at every stop and a series of measurements and/or recordings are made to correlate with their answers. Following the Soundscape Indices (SSID) Protocol[36], 360 video and first-order Ambisonics (O1A) audio were recorded to enable recreating the conditions in the laboratory. The measurement setup consisted of a GoPro 360 Max, a Zoom F8 recorder, a Rode NT-SF1, and a PCB 378B02 microphone connected via an NTi ICP ASD Adapter. A Brüel & Kjaer 4231 calibrator was used to record a 94 dB signal at the beginning and end of each session. The omnidirectional microphone measurements enable the calculation of typical acoustic indicators or psychoacoustic parameters through post-processing. Recreating soundscapes in a laboratory setting is challenging. While level calibration is effective for 1 kHz, Ambisonics recordings must be equalized because neither the microphones nor the transcoding algorithms to binaural are flat. Additionally, O1A does not meet the spatial resolution required for high-quality playback as human HRTF are complex, but this can be improved by upsampling to higher-order Ambisonics, for example, using Harpex plugins by Berge and Barrett[37] or SIRR by Pulki[38]. The recordings, analyses, and questionnaires also follow the Soundscape Indices (SSID) Protocol[36] which is also compatible with the ISO 12913-2[23]. Binaural recordings were not made. HEAD acoustics ArtemiS and HBK BK Connect have been used to calculate the parameters. Proprietary algorithms of both brands have been avoided and it has been ensured that both software analysers give the same result. Section 2.4 reviews the most used indices used for soundscape. Some terms may have different meanings in especific areas, so it has been felt necessary to clarify the use of some terms in this context in a simple way (see ANNEX A: TERMINOLOGY AND CALCULATION OF THE SOUNDSCAPE INDICES).

Participants were volunteers who were already aware of the project or tourists who agreed to participate in the survey. An explanation of the history of the building was offered to them in exchange. There were only two stops in this short soundwalk: The patio of the building and Puente del Carbón street, located outside the building next to Reyes Católicos street, which has road traffic (see Figure 2). There was not a predefined order, and the questionnaires were filled for each point.

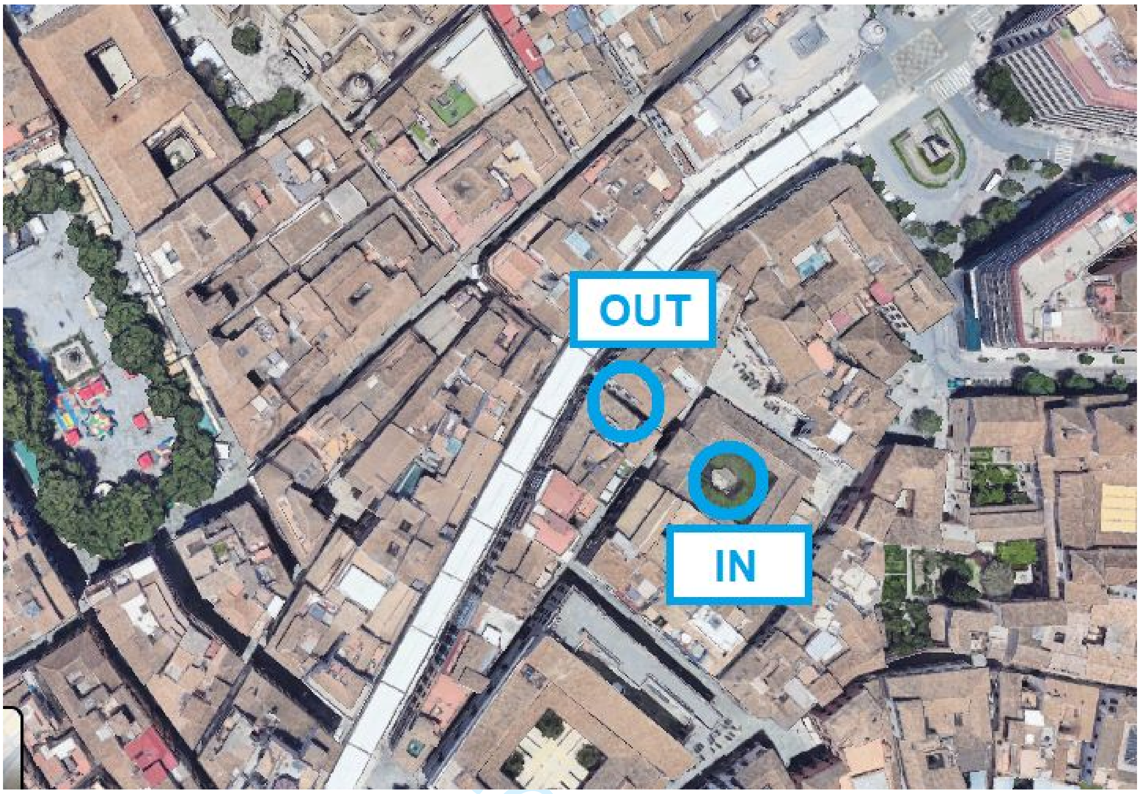

Figure 2 Measurement points. Corral del Carbón (In) and Puente del Carbón (Out). Granada City Centre

The participants were briefed on the sound walk's main characteristics and methodology at the beginning of each session, emphasizing five key instructions: Remain in silence for a minimum of five minutes at the assessment site concentrating on the sound. Answer the questionnaire without rushing or overthinking. Complete all questions on the questionnaire. Proceed to the next assessment point and repeat the task.

2.2. Corral del Carbón

The Corral del Carbón building was built in the 14th century as a Fundaq (or alhóndiga), a place where corn was sold and stored. It also served as a resting place for merchants Over the centuries, it has served as an open-air theatre (corral de comedias), a coal warehouse, and a tenement house until 1928, when it was purchased with public funds raised through ticket sales at the Alhambra. Three restoration actions were made since then and currently holds the offices of the International Festival of Music and Dance of Granada, the Andalusí Legacy Foundation and the City of Granada Orchestra.

The gate is elaborately decorated, especially for its humble original use It consists of a sharp, brick horseshoe arch, with scalloped archway decorations made of carved plaster known as ataurique. Above the horizontal molding that limits the alfiz runs a strip horizontal plaster, with an inscription in large kufic letters which translated says: "He is Allah, [Who is] One, Allah, the Eternal Refuge. He neither begets nor is born, Nor is there to Him any equivalent" (surah 112 from the Quran), it is known from Almagro[39] that some inscriptions have disappeared. Above the gate is a geminated window formed by two arches separated by a column. The window has lattices, which served to watch from inside without being seen. There is a hallway across the gate with two stone benches at both sides. Plasterwork decoration creates fully ornamented arches. Again, there is a geminated window over a smaller gate that gives access to the courtyard. The hallway is richly adorned for such a humble building.

The building has three floors with porticoed galleries oriented to this courtyard (see Figure 3). The courtyard floor is covered by cobblestones and in the center there is a watering place with a square stone basin in the middle and two lateral pipes, each of which receives water from ditches coming from the two rivers of Granada (Darro and Genil) respectively according to Torres-Balbás[40]. It may be a legend given the complex engineering works needed but

Torres-Balbás is known for his serious and rigorous work. Vines climb up the columns to provide shade in the summer and some plants grow from pits and pots. Traffic noise is masked by the subtle noise of vegetation and birds. The sound of water has the same effect, but it is stopped before and during the concerts.

Previous papers researched about the building. Reinoso[41] provides a very good architectonical description focusing on surveying and modeling to aid conservation of heritage buildings and García-Quesada and Almagro[42] inferred some acoustical properties but further research and analysis was needed.

Figure 3 Patio of Corral del Carbón

The building also hosts some concerts of the Music Festival (see Figure 4) [43]. Quoting Jolente de Maeyer "Playing in a historical site like tonight will be very inspiring because while we are playing we can see this beautiful place and I think at audience also always inspires us as well to feel the energy of so many people sitting there" [44].

Figure 4 Corral del Carbón concert layout during measurements

2.3. Street Puente del Carbón

The street is called Puente del Carbón (Coal Bridge) because historically it was a bridge that crossed the Darro River. The bridge, depicted in many engravings, was buried between 1873 and 1884 to help the city grow. Nowadays it is a narrow alleyway that links the main façade of the Corral del Carbón with the bustling street Calle Reyes Católicos (see Figure 5). The area is typically busy with pedestrians but traffic noise is dominant. While Puente del Carbón is influenced by traffic noise, it is quieter than the nearby main road. Additionally, it offers views of several heritage buildings, adding cultural relevance to the site. Crucially, this location allows us to survey the same participants in both settings, inside the courtyard and in the street, minimizing auditory memory bias and enabling a more accurate comparison of the two sound environments.

Figure 5 Calle Puente del Carbón

2.4. A review of the most used soundscape indices

This section will list the most commonly used indices in soundscape research, ordered by their complexity and within two categories. Those which need only indicators for its calculation and those which need psychoacoustic parameters. Table 7 (ANNEX A: TERMINOLOGY AND CALCULATION OF THE SOUNDSCAPE INDICES) reviews the calculation formulas for the indices.

Having the typical indicators measured with a sound level meter, such as LAeq, LCeq and percentiles according to ISO 1996-1[45]. The higher channel value will be selected in case a binaural recording is used. The following indices can be calculated: The Harmonica Index was developed for the Harmonica Project[46] and was implemented in the Dynamap Project[47]. It quantifies noise perception hourly on a linear scale from 0 to 10. It is defined by the sum of two components, one related to the background noise and the other to the events. Ricciardi et al. propose the Soundscape Quality[48] index as an indicator of urban sound quality. The model is based on linear regressions with perceptive variables. A large number of questionnaires were filled together with mobile phone measurements.

The tranquillity prediction tool (TRAPT)[49] can be calculated by including visual aspects. It evaluates the tranquillity based on audio-visual parameters. The visual attributes are described by the "percentage of natural features (excluding sky) present within the scene" (NF), which was later improved to the "Natural and Contextual Features" (NCF) present within the visual scene. This is the percentage of natural sources, such as vegetation, and listed buildings as religious and historic buildings, monuments and man-made elements in keeping with the surrounding environment. As explained in section 1.1, the visual aspects of a heritage building must be synergistic to its sound quality as a venue. Therefore, NCF is expected to be 100%. Lavandier et al.[50] define Pleasantness (SoP) for the first time. It was later revised by Lavandier et al.[51] using the L_{day} descriptor. It was revised again by Aumond et al.[52] using an indicator specifically designed. Both revised indices are considered difficult to obtain in the context of this article.

Typical psychoacoustic parameters include Loudness, Roughness, Sharpness or Tonality. Engel et al. [32] shows the lack of comparability due to different or non-specified computation methods of the parameters used. So one the targets of this paper is to use indicators that can be easily calculated and the method must be clear. Loudness and Fluctuation Strength were calculated using ISO 532-1 [18] for free-field conditions. Sharpness was calculated according DIN 45692 [53]. Roughness and Tonality were calculated according ECMA 418-2[54] and ECMA 74[55].

Sound Quality Index (SQI), as defined by Çakir et al.[56] is among the indices including psychoacoustic parameters. It was estimated using a multiple variable regression using loudness, roughness and sharpness: Sensory Pleasantness (P) is modelled ignoring this subjective non acoustic information. A good review is written on chapter 9 of Fastl and Zwicker[30]. Then, Relative Sensory Pleasantness (PA) is formulated as a combination of sharpness, roughness, tonality and loudness. Also, Fastl and Zwicker[30] define Psychoacoustic Annoyance (Nuisance) using Loudness, Roughness, and Sharpness. The PA model was revised and improved for tonal sounds by Guo-qing et al.[57] as Improved Psychoacoustic Annoyance (PA+) which can be very useful to evaluate the annoyance of environmental background noise for concerts.

3. RESULTS AND DISCUSSION

In this section, the results of the measurements and surveys are presented, followed by a discussion of their implications. The findings are analyzed in relation to the soundscape indicators and psychoacoustic parameters, with conclusions drawn regarding the suitability of the Corral del Carbón as a concert venue based on these results. All the indicators and parameters were calculated using ArtemiS, BK Connect showed little to none differences except for percentiles. BK Connect current version does not allow to calculate level percentiles but they can be extracted from level versus time. Table 1 shows the results of the acoustic indicators measured during the four sessions and the averaged results. The analysed time corresponds to the five-minute period of silent listening. The results show consistent differences in Sound Pressure Level (SPL) between the two measurement points. (in and out, see Figure 6 and Figure 7). BK Connect showed little to none differences in every parameter.Table 2 shows the calculated psychoacoustic parameters.

Table 1 Acoustic indicators

Session	L_{A5}	L_{A10}	L_{A50}	L_{A90}	L_{A95}	L_{Aeq}
	dBA	dBA	dBA	dBA	dBA	dBA
1 out	76	74	65	59	58	70
1 in	51	50	46	45	45	48
2 out	74	73	66	61	60	69
2 in	57	55	49	42	41	51
3 out	69	68	63	58	57	65
3 in	57	55	47	44	43	51
4 out	71	69	62	58	57	66
4 in	51	49	44	40	39	46

NCF was calculated using ImageJ software. In case of the patio, a 100% is considered as NCF. On street Puente del Carbón, a 360 frame of the video was taken, a +/-20º segment was selected, and the area of the sky was excluded from the calculations and the NCF was found to be 33.13%. It is arguable which parts are NCF and which are not. Our criterium was that all the historical façades are NCF unless they look altered, for example as shop windows.

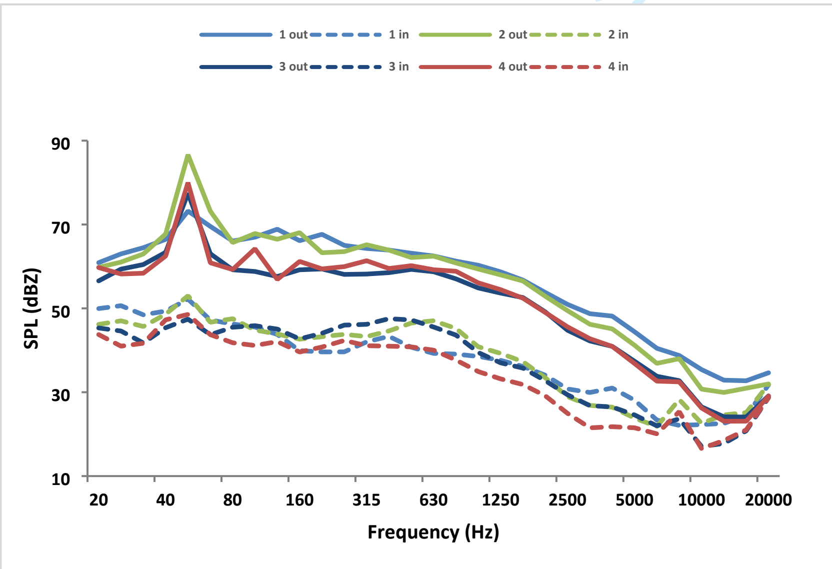

Figure 6 Level vs frequency (1/3 octave) of the measurements

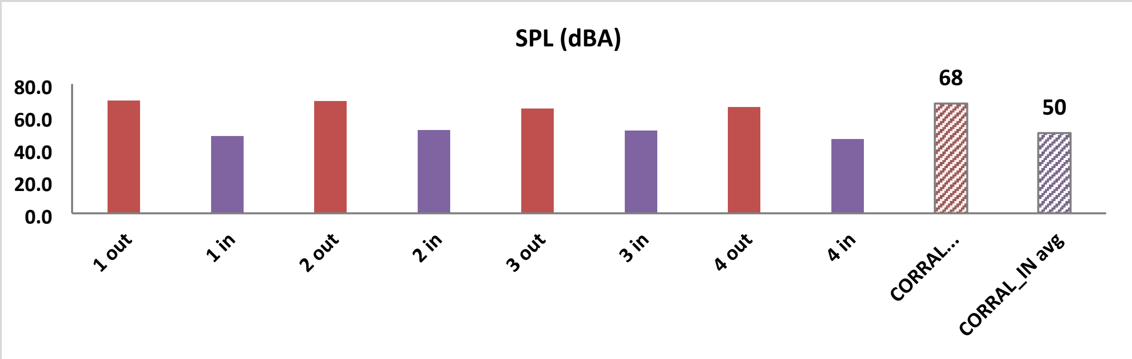

Figure 7 A-Weighted global values of the measurements

Table 2 Psychoacoustic parameters

Session	F	N_5	N_{50}	N_{95}	N	R	S	T
	vacil	sone	sone	sone	sone	asper	acum	Real
1 out	1.25	37.97	17.42	11.32	26.60	1.96	1.23	0.08
1 in	0.79	7.16	5.40	4.66	6.22	1.77	1.38	0.09
2 out	1.19	35.89	21.34	15.17	27.27	2.10	1.09	0.16
2 in	1.03	8.98	5.40	3.46	7.12	1.70	1.28	0.14
3 out	1.20	23.84	15.85	10.54	18.88	1.83	1.17	0.13
3 in	0.95	8.78	5.07	3.81	6.93	1.75	1.18	0.15
4 out	1.24	26.63	15.31	11.51	20.22	2.35	1.12	0.14
4 in	0.86	6.22	3.97	2.74	4.96	1.80	1.29	0.13

Table 3 shows the calculated indices from the acoustic indicators and Table 4 shows the calculated indices from the psychoacoustic parameters.

Table 3 Calculated indices from acoustic indicators

Session	HI	SQ	TR	SoP
1 out	8.51	5.90	0.87	6.90
1 in	3.72	9.99	6.80	9.88
2 out	8.31	5.79	0.92	6.68
2 in	4.77	9.10	6.28	9.28
3 out	7.34	6.53	1.60	7.19
3 in	4.63	9.44	6.32	9.61
4 out	7.59	6.71	1.43	7.43
4 in	3.50	10.18	7.09	10.08
Avg out	8.05	6.14	1.13	7.00
Avg in	4.27	9.59	6.54	9.67

Tranquillity (TR, TRAPT): The TRAPT index, which considers both audio and visual factors, revealed a much higher tranquillity score for the patio. The patio's 100% NCF (Natural and Contextual Features) played a significant role in this, suggesting that the venue's serene visual and acoustic environment makes it an ideal setting for concerts. TRAPT is the simplest index to calculate, and the only one implemented in a legal regulation (UK).

Soundscape Quality (SQ): The SQ index also showed higher values for the patio, reinforcing its overall acoustic pleasantness and appropriateness for musical performances. This suggests that the Corral del Carbón offers a more engaging and enjoyable sound environment compared to the noisy and chaotic street nearby.

Table 4 Calculated indices from the psychoacoustic parameters

Session	SQI	P	PA	PA+
1 out	4.05	0.0050	70.31	70.46
1 in	5.20	0.0203	16.96	17.06
2 out	4.07	0.0077	68.29	68.80
2 in	5.25	0.0272	20.60	20.90
3 out	4.59	0.0133	46.90	47.21
3 in	5.32	0.0297	20.23	20.54
4 out	4.36	0.0089	56.40	56.70
4 in	5.33	0.0272	15.51	15.73
Avg out	4.27	0.0087	60.48	60.79
Avg in	5.27	0.0261	18.32	18.56

Psychoacoustic Annoyance (PA+): The PA+ values were notably lower inside the patio compared to the street, indicating a less annoying and more comfortable acoustic environment. This index's sensitivity to tonal noises, such as those from electrical equipment, underscores the patio's suitability by highlighting the minimal presence of such disturbances. The differences between PA and PA+ are quite small in this case.

Soundscape data analysis is covered by the ISO 12913-3[24]. Its Annex A provides a comprehensive guide to the questionnaire-based soundscape assessment (method A). The most common form of representation is a two-dimensional model of perceptual attributes (circumplex)[58]. Pleasantness is represented on the X axis while Eventfulness is represented on the Y axis. Mitchell et al.[59] propose a more holistic and effective method of analysing and representing the data as a probabilistic distribution of perceptions within the circumplex model. Table 5 shows the English and Spanish translation of the perceptual attributes[60]. Table 6 shows the results (mean, median, standard deviation, and standard error of the mean) with regard to their question numbers.

Table 5 Perceptual attributes used in the questionnaires

dimension	ISO 12913-2: 2018	Spanish - Word 1	Spanish - Word 2
1 – p	pleasant	agradable	*placentero*
2 – ch	chaotic	caótico	*confuso*
3 – v	vibrant	estimulante	*vibrante*
4 – u	uneventful	sin actividad	*estático*
5 – ca	calm	calmado	*tranquilo*
6 – a	annoying	desagradable	*molesto*
7 – e	eventful	con actividad	*dinámico*
8 – m	monotonous	monótono	*aburrido*

Table 6 Results from the questionnaires

	p Q2.1	ch Q2.2	v Q2.3	u Q2.4	ca Q2.5	a Q2.6	e Q2.7	m Q2.8
(MEAN) In	4.58	1.58	4.47	2.21	4.32	2	3.21	2.32
(MEAN) Out	2.21	3.37	3.26	1.89	2.37	3.74	4.47	3.16
(MEDIAN) In	5	1	5	2	5	1	2	2
(MEDIAN) Out	2	4	3	1	2	4	5	3
(SDEV) In	0.748	0.936	0.678	1,104	1,079	1,298	1,321	0.976
(SDEV) Out	1,321	1,692	1,445	1,165	1,422	1,163	0.678	1,182

(SEM) In	0.172	0.215	0.156	0.253	0.247	0.298	0.303	0.224
(SEM) Out	0.303	0.388	0.332	0.267	0.326	0.267	0.156	0.271

The results from the surveys consistently indicated a more favourable acoustic environment within the patio. Participants rated the patio higher in terms of pleasantness and calmness, while the street was perceived as more chaotic and annoying, which aligns with the results of the indices.

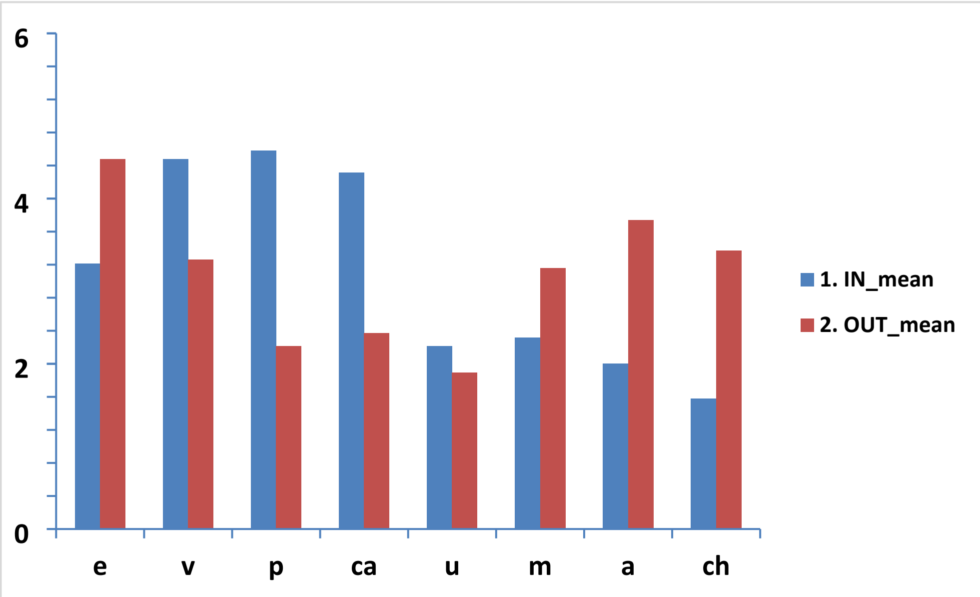

Figure 8 Graphical results of Table 6

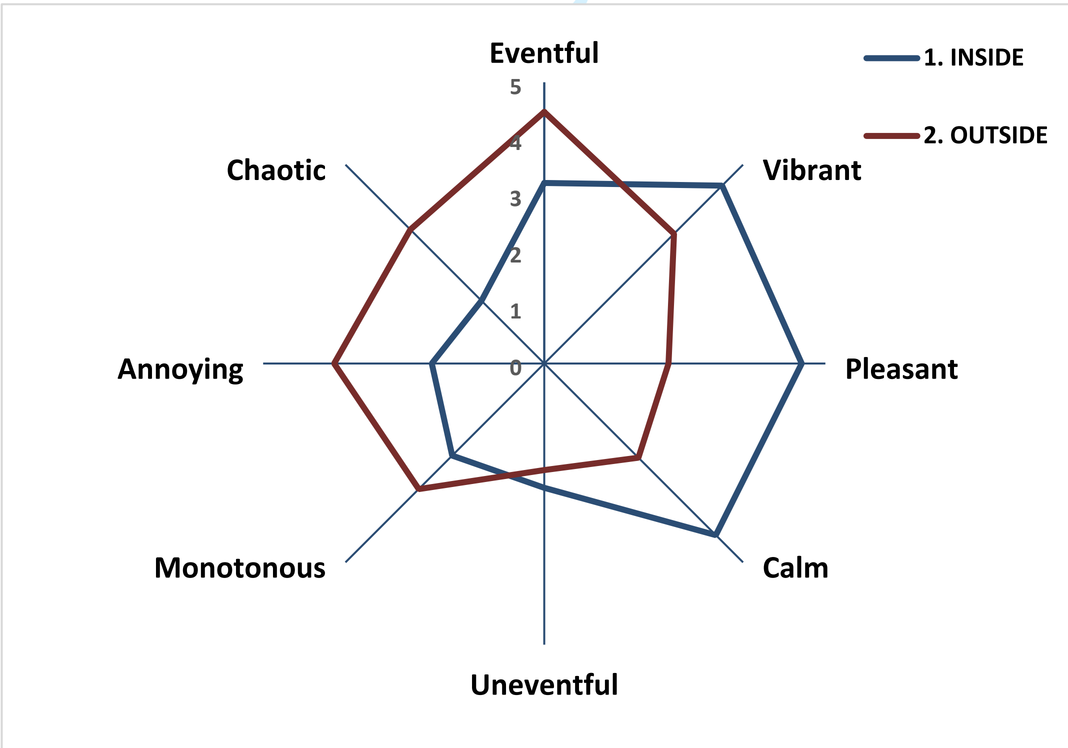

Figure 9 Circumplex diagram

The findings of this study underscore the significant difference in acoustic environments between the patio of the Corral del Carbón and the adjacent street, Puente del Carbón. The results indicate that the patio offers a more pleasant soundscape. Although the sound levels inside the patio remain high, they are dominated by natural sources such as water, birds, and the rustling of vegetation, which mask the external traffic noise and enhance the subjective experience, in conjunction with the visual aesthetics of the place[1,15–19]. This is particularly noteworthy, given the cultural and historical significance of the Corral del Carbón, a heritage site that has been used as a concert venue. This study has limitations that should be addressed in future research. The scope of the study was limited to two locations within a single heritage site, and the sample size of participants was relatively small. Additionally, the study did not stablish a criterion to evaluate which index is more appropriate for the assessment.

4. CONCLUSIONS

One of the key contributions of this paper is the application of the soundscape approach, traditionally used in urban planning, to the evaluation of heritage concert venues. By integrating subjective assessments with objective acoustic measurements, this study provides a comprehensive methodological framework for evaluating the suitability of heritage sites for musical performances. The use of psychoacoustic parameters alongside traditional acoustic indicators to calculate typical descriptors offers a nuanced understanding of the sound environment, bridging the gap between measurable acoustic properties and human perception. This approach not only enhances the selection process for concert venues but also offers insights into how different acoustic environments within the same site can impact the overall experience. The findings suggest that heritage sites like the Corral del Carbón can provide a more immersive and pleasant acoustic experience, which is crucial for ensuring the success of musical performances in such venues.

This study contributes to the field by demonstrating the value of the soundscape approach in assessing the acoustic environments of heritage concert venues. The innovative integration of psychoacoustic parameters with traditional acoustic indicators offers a perceptual-based understanding sound in heritage contexts. This approach can be particularly useful for concert programmers, acousticians, and cultural heritage managers when selecting and preparing venues for musical performances.

While the findings are promising, certain limitations must be acknowledged, mainly on the amount of venues and participants. Future research could build on this work by expanding the scope to include multiple heritage sites and a larger, more diverse sample of participants. This approach must also be integrated with environmental and room acoustics criteria to develop a more robust framework for evaluating concert venues. Furthermore, longitudinal studies that assess the impact of different scenarios on the soundscape of heritage sites and traditional concert halls could provide valuable insights for enhancing the acoustic quality of these venues.

In conclusion, this study offers a novel contribution to the field by applying the soundscape approach to the evaluation of heritage concert venues, providing a valuable tool for venue selection that considers both objective and subjective factors. Future research should continue to refine this approach and explore its application in a broader range of contexts.

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ANNEX A: TERMINOLOGY AND CALCULATION OF THE SOUNDSCAPE INDICES

This article is intended as a guide for concert programmers, musicologists, sound engineers or acousticians when evaluating a heritage space for use as a concert hall. Aspects related to environmental acoustics, soundscape and sound quality will be evaluated. Some terms may have different meanings in these areas, so it has been felt necessary to clarify the use of some terms in this context in a simple way.

Ambisonics: Surround sound technique that captures, processes, and reproduces sound from all directions around a listening point. Ambisonics is based on the idea of representing a sound field as a mathematical construct, allowing for the manipulation of sound in three-dimensional space. It is usually encoded in A or B formats and orders. Higher orders provide better space resolution.

Descriptors: measure how people perceive the soundscape, and are calculated from indicators and parameters. Descriptors and indices are synonymous in this context.

Indices: See descriptors

Indicators: (or acoustic indicators) are the traditional acoustic quantities that can be measured with a sound level meter (L_{Aeq}, L_{A90}, L_{A50}, etc.).

Metrics: Within sound quality the term metrics [61] is widely used, which would be analogous to descriptors.

NCF (Natural and Contextual Features): The percentage of natural sources, such as vegetation, and listed buildings as religious and historic buildings, monuments and man-made elements in keeping with the surrounding environment

Parameters: (or psychoacoustic parameters) are measurable quantities that are somewhat more complex to obtain and relate to the way sound is perceived by the human ear. The parameters used in this paper are Loudness (N), Roughness (R), Sharpness (S), Fluctuation Strenght (F), and Tonality (T)).

Table 7 Summary of the Soundscape Quality Indices used

INDEX	CALCULATION	REFERENCE
Harmonica Index	$HI = 0.2(L_{A95} - 30) + 0.25(L_{Aeq} - L_{A95})$	Ribeiro et al. [46]
Soundscape Quality	$SoundQuality = 19.08 - 0.19L_{A50} - 0.06(L_{A10} - L_{A90})$	Ricciardi et al. [48]
Tranquility	$TR = 9.68 - 0.146LAeq + 0.041NCF$	Pheasant et al. [49]
Sound Pleasantness	$SoP = 16.92 - 0.15LA50 - 0{,}06\ (LA50 - LA90)$	Lavandier et al. [50]
Sound Quality Index	$SQI = 7.2935 - 0.05851N - 0.3723R - 0.7792S$	Çakir et al. [56]
Sensory Pleasantness	$P = e^{-0.7R} \cdot e^{-1.08S} \cdot (1.24 - e^{-2.43T}) \cdot e^{-(2.43T)^2}$	Zwicker, Fastl [30]
Psychoacoustic Annoyance (PA)	$PA = N_5\left(1 + \sqrt{w_S{}^2 + w_{F,R}{}^2}\right)$ Where: $w_S = [(S - 1.75)0.25log(N_5 + 10)]^2\ \ for\ S > 1.75\ acum$ $w_{FR} = \frac{2.18}{N_5{}^{0.4}}(0.4F + 0.6R)$	Zwicker, Fastl [30]
Psychoacoustic Annoyance (PA+)	$PA = N_5\left(1 + \sqrt{w_S{}^2 + w_{F,R}{}^2 + w_T{}^2}\right)$ Where: $w_T = \frac{6.41}{N_5{}^{0.52}}$T	Guo-Qing et al. [57]

ANNEX B: QUESTIONNAIRE

The questionnaire could be filled either on paper or online. The questionnaire was extensive, including questions outside the scope of this research.

4(Q3) Overall, how would you describe the present surrounding sound environment?

- ◯ Very good
- ◯ Good
- ◯ Neither bad nor good
- ◯ Bad
- ◯ Very bad

Figure 10 shows the questions of interest in Spanish.

3(Q2) For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is... (please, answer the 8 scales)

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Pleasant	◯	◯	◯	◯	◯
Chaotic	◯	◯	◯	◯	◯
Vibrant	◯	◯	◯	◯	◯
Uneventful	◯	◯	◯	◯	◯
Calm	◯	◯	◯	◯	◯
Annoying	◯	◯	◯	◯	◯
Eventful	◯	◯	◯	◯	◯
Monotonous	◯	◯	◯	◯	◯

4(Q3) Overall, how would you describe the present surrounding sound environment?

- ◯ Very good
- ◯ Good
- ◯ Neither bad nor good
- ◯ Bad
- ◯ Very bad

Figure 10 Soundscape questionnaire

REFERENCES

1. Smith, L. T. A.-T. T.-. *Emotional heritage : visitor engagement at museums and heritage sites LK - https://tamulibraries.on.worldcat.org/oclc/1154133804*. (Routledge. London, England, 2021).

2. HYDE, J. Acoustical Intimacy in Concert Halls: Does Visual Input Affect the Aural Experience? (2024) doi:10.25144/18319.

3. Almagro-Pastor, J. A., García-Quesada, R., Ramallo, S., Martínez-Irureta, F. J. & Ramos-Ridao, Á. F. Assessing environmental noise impact of PA systems with the swept-sine method. A case study in the heritage site of the Alhambra. *Appl. Acoust.* **176**, (2021).

4. Almagro-Pastor, J. A., García-Quesada, R., Vida-Manzano, J., Martínez-Irureta, F. J. & Ramos-Ridao, Á. F. The Acoustics of the Palace of Charles V as a Cultural Heritage Concert Hall. *Acoustics* **4**, 800–820 (2022).

5. Astolfi, A., Bo, E., Aletta, F. & Shtrepi, L. Measurements of acoustical parameters in the ancient open-air theatre of tyndaris (Sicily, Italy). *Appl. Sci.* **10**, (2020).

6. Bevilacqua, A., Amadasi, G., Iannace, G. & Trematerra, A. Acoustic Simulations Applied to the Garden of Rufolo's Villa in Ravello: Comparison between Different Scenarios. *Appl. Sci.* **14**, (2024).

7. Alonso, A., Sendra, J. J., Suárez, R. & Zamarreño, T. Acoustic evaluation of the cathedral of Seville as a concert hall and proposals for improving the acoustic quality perceived by listeners. *J. Build. Perform. Simul.* **7**, 360–378 (2014).

8. Paini, D., Gade, A. C. & Rindel, J. H. Is reverberation time adequate for testing the acoustical quality of unroofed auditoriums? *Inst. Acoust. - 6th Int. Conf. Audit. Acoust. 2006, Copenhagen, Denmark.* **28**, 66–73 (2006).

9. Schafer, R. M. *Our sonic environment and the soundscape the tuning of the world*. *Destiny books* vol. 1 (1977).

10. Blesser, B. & Salter, L.-R. *Spaces Speak, Are You Listening? The MIT Press* (2007). doi:10.1017/CBO9781107415324.004.

11. Carpenter, E. and McLuhan, M. *Acoustic Space. In Explorations in Communication: An Anthology.* (1960).

12. Truax, B. *Acoustic Communication*. (2001).

13. ISO. ISO 12913-1 Acoustics — Soundscape Part 1: Definition and conceptual framework. (2014).

14. Schulte-fortkamp, B., Sisneros, J. A., Popper, A. N. & Editors, R. R. F. *Soundscapes : Humans and Their Acoustic Environment*. (2023).

15. Rådsten Ekman, M. *Unwanted wanted sounds : Perception of sounds from water structures in urban soundscapes*. (2015).

16. Brown, A. L. The acoustic environment as resource, and masking, as key concepts in soundscape discourse and analysis. *8th Eur. Conf. Noise Control 2009, EURONOISE 2009 - Proc. Inst. Acoust.* **31**, (2009).

17. Brown, A. L. & Rutherford, S. Using the Sound of Water in the City. *Landsc. Aust.* **2**, 103–107 (1994).

18. Cerwén, G. Listening to Japanese gardens: An autoethnographic study on the soundscape action design tool. *Int. J. Environ. Res. Public Health* **16**, (2019).

19. Cerwén, G. Listening to Japanese gardens II: expanding the soundscape action design tool. *J. Urban Des.* **25**, 607–628 (2020).

20. Kang, J. *et al.* Ten questions on the soundscapes of the built environment. *Build. Environ.* **108**, 284–294 (2016).

21. Kang, J. Soundscape in city and built environment: current developments and design potentials. *City Built Environ.* **1**, 1–16 (2023).

22. Aletta, F., Oberman, T. & Kang, J. Associations between Positive Health-Related Effects and Soundscapes

Perceptual Constructs: A Systematic Review. *Int. J. Environ. Res. Public Health* **15**, (2018).

23. ISO. Acoustics - Soundscape - Part 2: Data collection and reporting requirements PD ISO / TS 12913 ‑ 2 : 2018. (2018).

24. ISO. ISO 12913 ‑ 3 : 2019 Acoustics — Soundscape — Part 3: Data analysis. (2019).

25. Iso, D. ISO/TS Draft 12913-4: Acoustics — Soundscape — Part 4: Design and Intervention. (2022).

26. J. Kang *et al.* Towards soundscape indices,. *Proc. Int. Conf. Acoust. ICA 2019, Aachen,* (2019).

27. Iso, P. D. PD ISO / TS 12913 ‑ 2 : 2018 BSI Standards Publication Acoustics — Soundscape. (2018).

28. Blauert, J. *Communication acoustics*. *Communication Acoustics* vol. 91 (2005).

29. Code of Canon Law.

30. Fastl Hugo, E. Z. *Psycho-Acoustics Facts and Models*. (Springer Verlag. New York, USA, 2017).

31. Herranz-Pascual, K., García, I., Diez, I., Santander, A. & Aspuru, I. applied sciences Analysis of Field Data to Describe the Effect of Context (Acoustic and Non-Acoustic Factors) on. 1–18 (2017) doi:10.3390/app7020173.

32. Engel, M. S., Fiebig, A., Pfaffenbach, C. & Fels, J. A Review of the Use of Psychoacoustic Indicators on Soundscape Studies. *Curr. Pollut. Reports* **7**, 359–378 (2021).

33. ISO. ISO 1996-2:2017 Acoustics -- Description, measurement and assessment of environmental noise -- Part 2: Determination of sound pressure levels. (2017).

34. ISO. ISO 532-1 Acoustics — Methods for calculating loudness. (2017).

35. Lionello, M., Aletta, F. & Kang, J. A systematic review of prediction models for the experience of urban soundscapes. *Appl. Acoust.* **170**, (2020).

36. Mitchell, A. *et al.* The Soundscape Indices (SSID) Protocol: A Method for Urban Soundscape Surveys—Questionnaires with Acoustical and Contextual Information. *Appl. Sci.* **10**, 2397 (2020).

37. Berge, S. & Barrett, N. High Angular Resolution Planewave Expansion. *Ambisonics Symp.* 4–9 (2010).

38. Pulkki, V. Spatial Sound Reproduction with Directional Audio Coding. *J. Audio Eng. Soc.* **55**, 503–516 (2007).

39. Almagro Cárdenas, A. Inscripciones Árabes de Granada con un apéndice sobre su Madraza o Universidad Árabe. (1879).

40. Torres Balbás, L. Las alhóndigas hispanomusulmanas y el Corral del Carbón de Granada. (1946).

41. Reinoso-gordo, J. F. Cultural Heritage Conservation and Sustainability Based on Surveying and Modeling : The Case of the 14th Century Building Corral del Carb ó n Carbón using. (2018) doi:10.3390/su10051370.

42. García Quesada, R. & Almagro Pastor, J. A. POSADA AL-FUNDUQ AL-GIDIDA Y ACÚSTICA. 1–9 (2018).

43. Festival de Granada: Corral del Carbón. https://granadafestival.org/escenarios/corral-del-carbon/.

44. Festival Internacional de Música y Danza de Granada. Facebook video. https://www.facebook.com/GranadaFestival/videos/180931563009974/.

45. ISO. ISO 1996-1:2016 Acoustics. Description, measurement and assessment of environmental noise. Basic quantities and assessment procedures. (2016).

46. Ribeiro, C., Anselme, C., Mietlicki, F., Vincent, B. & Da Silva, R. At the heart of harmonica project: The common noise index (CNI). *42nd Int. Congr. Expo. Noise Control Eng. 2013, INTER-NOISE 2013 Noise Control Qual. Life* **6**, 4767–4776 (2013).

47. Bellucci, P., Peruzzi, L., Brambilla, G., Zambon, G. & Bisceglie, A. Implementing the Harmonica index in the dynamap project. *24th Int. Congr. Sound Vib. ICSV 2017* 1–8 (2017).

48. Ricciardi, P., Delaitre, P., Lavandier, C., Torchia, F. & Aumond, P. Sound quality indicators for urban places in Paris cross-validated by Milan data. *J. Acoust. Soc. Am.* **138**, 2337–2348 (2015).

49. Pheasant, R., Horoshenkov, K. V & Watts, G. R. Tranquillity rating prediction tool (TRAPT). (2010).

50. Lavandier, C., Delaitre, P. & Ribeiro, C. Global and local sound quality indicators for urban context based on perceptive and acoustic variables. *Euro Noise* 1471–1476 (2015).

51. Lavandier, C., Aumond, P., Gomez, S. & Domingués, C. Urban soundscape maps modelled with geo-referenced data. *Noise Mapp.* **3**, 278–294 (2016).

52. Aumond, P. *et al.* Modeling soundscape pleasantness using perceptual assessments and acoustic measurements along paths in urban context. *Acta Acust. united with Acust.* **103**, 430–443 (2017).

53. DIN. DIN 45692:2009-08 Measurement technique for the simulation of the auditory sensation of sharpness. 14 (2009) doi:https://dx.doi.org/10.31030/1521326.

54. International, E. Psychoacoustic metrics for ITT equipment-Part 2 (models based on human perception) COPYRIGHT PROTECTED DOCUMENT. **2**, (2009).

55. ISO. ECMA-74 - Acoustics - Measurement of airborne noise emitted by information technology and telecommunications equipment. (2022).

56. Çakir Aydin, D. & Yilmaz, S. Assessment of sound environment pleasantness by sound quality metrics in urban spaces. *A/Z ITU J. Fac. Archit.* **13**, 87–99 (2016).

57. Di, G. Q., Chen, X. W., Song, K., Zhou, B. & Pei, C. M. Improvement of Zwicker's psychoacoustic annoyance model aiming at tonal noises. *Appl. Acoust.* **105**, 164–170 (2016).

58. Axelsson, Ö., Nilsson, M. E. & Berglund, B. A principal components model of soundscape perception. *J. Acoust. Soc. Am.* **128**, 2836–2846 (2010).

59. Mitchell, A., Aletta, F. & Kang, J. How to analyse and represent quantitative soundscape data. *JASA Express Lett.* **2**, 037201 (2022).

60. Vida, J. *et al.* Soundscape attributes in Spanish: A comparison with the English version of the protocol proposed in Method A of the ISO/TS 12913–2. *Appl. Acoust.* **211**, (2023).

61. Fiebig, A. & Kamp, F. Development of metrics for characterizing product sound quality 1 . Introduction to Product Sound Quality. (2019).