acoustics

Editorial

Acoustics, Soundscapes and Sounds as Intangible Heritage

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Since UNESCO unveiled its declaration for an integrated approach to safeguarding tangible and intangible cultural heritage in 2003 [1], increased emphasis has been placed on the intangible and immaterial components linked to archaeological and historical sites. Their sonic aspects may be regarded as one of these intangible components, as they have played a crucial role in shaping individuals' perceptions about past spaces and buildings and the way people have interacted with such spaces over time [2,3]. Thus, acoustics, soundscapes, and sounds have been embraced as key subjects for a better understanding of our cultural heritage [4].

Adopting the broad definition of the term 'acoustical heritage' proposed by Zhu, Oberman, and Aletta [5], a thorough examination of acoustical heritage should encompass diverse approaches and disciplines. This entails not only delving into the realms of physical acoustics but also exploring the intersections with music, psychoacoustics, history, archaeology, and various other fields. However, there has been a marked emphasis on conducting comprehensive initial acoustic characterizations that have subsequently served as the cornerstone for further multidisciplinary approaches [6–9]. At archaeological and historical sites this type of acoustic research focuses on recovering and analyzing their physical and quantifiable acoustic features. This is carried out through a variety of experimental and simulation techniques, that are mainly based on room acoustics theories and methods [10,11]. Nonetheless, dealing with such sites requires a broad understanding of the term "room", as such spaces often exhibit complex forms and peculiar finishing materials whose acoustic performance is not well known. This is particularly evident in the context of archaeological sites in natural locations, where the morphology is entirely fortuitous and singular. In addition, uncertainties concerning the details of the sound-related events performed in these spaces typically arise due to the scarcity of available evidence.

Therefore, given the inherent complexity of applying standardized methodologies and procedures to archaeological and historical sites, specific considerations are required for a comprehensive analysis of each individual case study. In this regard, Aletta and Kang remarked on the considerable challenges present when dealing with these sites [12]. They emphasized not only the difficulties in conducting standardized impulse response (IR) measurements [13], but also in making plausible acoustic simulations. In this respect, simulating the past acoustics of sites that no longer exist or have undergone significant changes over time is particularly challenging. In such cases, conducting field measurements to follow the recommended validation process for a reliable simulation model is not possible [14]. Moreover, accurately delineating the lost geometry of these sites and realistically estimating the acoustic performance of their finishing materials in the period under study may be difficult or even impossible. In addition, in order to interpret the results, it is essential to take into account the socio-cultural component in which both the sites and the sonic events being investigated are framed.

This dedicated compilation of articles focuses on the acoustical analysis of archaeological and historical sites, placing special emphasis on the methodologies and procedures used. It aims to highlight the necessity of diverse and interdisciplinary approaches to a comprehensive exploration of past sonic experiences. With this purpose, it brings together a collection of original research articles that delve into the acoustics and sonic aspects of a diverse group of sites worldwide. It includes a considerable range of case studies that span various approaches and methodologies, such as acoustic simulations based on finite-difference time-domain (FDTD) methods and geometrical acoustics (GA), as well as spatial IR measurements. The authors have faced and successfully navigated several of the challenges mentioned above, thus contributing to more rigorous and significant research in the field, while thereby expanding our acoustical heritage.

The first article published as part of this Special Issue, *Sound Reflections in Indian Stepwells: Modelling Acoustically Retroreflective Architecture* by Cabrera et al., focuses on the acoustics of two Indian stepwells (or stepped ponds). It analyzes the retroreflective effect—a notable acoustic phenomenon consisting of a multitude of reflections returning to the source, translating into a support for the performer—potentially present in step-based architectures such as the Indian stepwells. The authors used FDTD simulations validated by image source-based calculations to assess the stepped ponds' retroreflective potential and audibility. This assessment depended on the structures' size and geometry, taking into account different positions of the sound source. In addition to introducing a new dimension to the exploration of Indian stepwells, the analysis conducted in these semi-enclosed ancient structures contributes to a deeper understanding of this complex acoustic phenomenon. These structures can be considered an exemplary case study despite not having been initially designed for acoustic purposes but for descending to the pond.

The research presented by Weber et al. delves into another complex acoustic phenomenon analyzed by applying a methodological approach based on the FDTD method. On this occasion, the FDTD simulation is used to investigate the *Sound Scattering by Gothic Piers and Columns of the Cathedrale Notre-Dame de Paris* (France). The simulation is validated through a meticulous comparison of the simulation results with experimental measurements taken on scale models of seven piers and columns of different designs, and analytical models. The simulated scattered fields are analyzed in terms of sound propagation and the results are discussed in terms of audibility under different listening scenarios. With this case study, the authors not only add new knowledge to the acoustics of the emblematic Gothic Cathedral of Notre-Dame de Paris, but also offer new insights into the diffraction and higher-order propagation effects caused by these architectural elements, typically present in other cathedrals and historical buildings.

Computation based on FDTD is also used by Martellotta et al. in their article entitled *Low-Frequency Response of a Rupestrian Church by Means of FDTD Simulation*. An FDTD modeling is chosen to simulate the low-frequency behavior of the 11th-century Rupestrian Church Saints Andrew and Procopius, in Monopoli (Apulia, Italy). They first analyze the acoustics of the church remains using information derived from a set of IRs measured on-site, focusing on the results of several room acoustical parameters, spectrograms, and modal reverberation time. These data also serve to calibrate the simulation model of the church in its current conservation state, whose finishing was reconstructed by adding plaster and frescoes in the late medieval period. In order to accurately define the model's boundary conditions, the authors consider it essential to characterize the acoustic performance of the tuffaceous surfaces of the church using an impedance tube. Seating audience is also incorporated in the reconstructed model to investigate whether the strong modal behavior caused by the morphology of the space may have impacted the liturgical celebrations held in the church during that period.

In their *Investigation of a Tuff Stone Church in Cappadocia* via *Acoustical Reconstruction*, Adeeb et al. use room acoustic simulations based on ray tracing and image source methods to acoustically reconstruct the Bell Church, a partially demolished Middle-Byzantine masonry church in Cappadocia (Turkey). Since acoustic measurements cannot be performed in the church in its current condition, the simulation models are tuned taken as a reference a set of acoustic measurements previously conducted in two structures in the nearby region built with similar materials. Material tests are again necessary during the modelling for determining the sound absorption characteristics of tuff rocks [15]. This acoustic study assesses the evolution of the acoustical performance of the church over time based on three different acoustic models of the space: Phase I (without frescoes), Phase I (with frescoes), and Phase II (with frescoes and narthex), in an attempt to understand the context of the use of a Middle-Byzantine church for different cultural practices.

An Acoustic Reconstruction of the House of Commons, c. 1820 and 1834 is presented by Foteinou et al. In this article, room acoustic simulations based on ray tracing and image source methods serve to evaluate how the lost Commons chamber (Palace of Westminster, London, UK) might have shaped political speeches and discussions during the period under investigation. Because the calibration of the acoustic model by means of IR measurements is deemed not to be possible, several versions of the model are assessed in order to ensure a feasible representation of its boundary conditions. The authors opt for a validation approach similar to that mentioned by Adeeb and Sü Gül [16]. Such an approach uses on-site measurements previously conducted in five spaces sharing geographical location, historical uses and/or architectural characteristics with the House of Commons, as a reference to support the modeling decisions made. The simulated IRs are used not only to describe the acoustics of the space through acoustic parameters but also to conduct historically-informedauralizations.

The article entitled *The Bacinete Main Shelter: A Prehistoric Theatre?* by Alvarez-Morales et al. assesses the potential influence of acoustics on the sociocultural practices of prehistoric societies in two shelters at the Bacinete rock art complex (Cádiz, Spain). The selection of these shelters is guided by both their spatial configuration and the presence of rock art, rendering plausible the hypothesis that they could have functioned as "performance" spaces. The archaeoacoustic study is based on the analysis of a comprehensive set of spatial IRs measured on-site using Ambisonics techniques. The authors examine the acoustic properties of the shelters under different usage hypotheses. These hypotheses are designed to partially compensate for the uncertainties related to, firstly, the lack of evidence regarding the particular sound events undertaken by post-Paleolithic hunter-gatherer societies and, secondly, the potential alterations in the site due to prolonged exposure to weathering agents. Additionally, Alvarez-Morales and her colleagues delve into considerations regarding the applicability and limitations of standardized protocols described in the ISO 3382-1 [13] for characterizing the acoustics of open-air spaces.

The Renaissance palace of Charles V, built inside the fortification of the Islamic Alhambra Palace (Granada, Spain), is the research object of *The Acoustics of the Palace of Charles V as a Cultural Heritage Concert Hall* by Almagro-Pastor et al. Despite its original design not catering for acoustic purposes, since 1883 this heritage site has been used as an unroofed concert hall. This motivated the authors to examine the acoustics of the venue on the basis of data derived from experimental measurements taken on-site. The methodology employed involves a substantial number of source and receiver positions designed to explore the impact of the palace's geometry on the acoustics experienced by the performers and audience. The acoustic parameters derived from the collected IRs and the spatial distribution of reflections are analyzed. The authors explain that an additional set of Impulse Responses (IRs) was recorded using a studio monitor as a sound source. This was intended for auralization purposes with the view of minimizing the impact of both the frequency response and the directivity of the dodecahedral source.

In their article *Measuring the Acoustical Properties of the BBC Maida Vale Recording Studios for Virtual Reality*, Kearney et al. implement a detailed and time-consuming optimized protocol for registering spatial IR sets for virtual reality (VR) applications at heritage sites. The proposed protocol requires a proper definition of the characterized location grid to ensure sufficient IRs for real-time interpolation. It involves different types of loudspeakers and microphones to enable reconstruction from the perspective of both the performers (3DoF) and the audience (6DoF). Moreover, multiple spatial IR measurements at each characterized location considering different loudspeaker rotations are included in order to achieve a realistic representation of the directional properties of the sound source. The proposed workflow is then applied in four iconic studio spaces at the British Broadcasting Corporation (BBC) Maida Vale studios (London, UK), which vary in size, geometry, and purpose. A crucial aspect of this analysis is the open accessibility of the captured impulse response database, making it available to a global audience.

Last but not least, this Special Issue also features an insightful review on the *Intangible Mosaic of Sacred Soundscapes in Medieval Serbia* by Đorđević et al. The initial part of this work provides an overview of previously published research concerning the indoor acoustics of medieval churches in Serbia. The surveyed works predominantly used IR measurements and virtual models to characterize their acoustic features, with a particular emphasis on their impact on speech and singing in medieval religious practices. The subsequent section delves into the limited body of literature addressing open-air soundscapes associated with religious activities in the area. Following a sociocultural analysis of the significance of outdoor soundscapes in Orthodox Christian practices during this historical period, the authors advocate the inclusion of significant sound-related elements such as the use of the semantra and bells, the sonic events integral to litany processions, and the state and church assemblies held in the immediate proximity of churches and monasteries. These, together with an examination of indoor church acoustics should be part of future archaeoacoustic enquiries. In their view, this holistic approach is essential for a comprehensive understanding of the aural environment of sacred soundscapes in medieval Serbia.

To conclude, we would like to highlight the richness of this Special Issue by acknowledging both the broad range of methodologies used and approaches taken by the authors, as well as the chronological and cultural diversity represented by the investigated case studies. We hope this Special Issue, in conjunction with the enduring topic collection on 'Historical Acoustics', will contribute to enriching the academic discourse on the world's acoustical heritage by fostering the latest and innovative research in the field. Finally, and equally important, we hope it will serve to reinforce the need for a multidisciplinary approach that encompasses acoustics, soundscapes, and sounds as integral components of our intangible heritage.

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