WORSHIP ACOUSTICS: WHERE ARE WE GOING?

Francesco Martellotta[1], Zühre Sü Gül[2], Chiara Rubino[1], Dario D'Orazio[3]

[1]*Department of Architecture, Construction and Design, Politecnico di Bari, Italy*
[2]*TED University - Department of Architecture, Ankara, Türkiye*
[3]*D'Orazio AEV, Bologna, Italy*

Abstract

Research on the acoustics of worship spaces received significant attention in the early 2000s, with important contributions addressing different religious traditions, architectural typologies, and liturgical practices. This research helped to fill a gap in the scientific literature by combining acoustic measurements in existing buildings, subjective investigations, and the development of design criteria for spaces intended for speech, music, ritual, and communal participation. In recent years, studies on worship acoustics have become more widespread but less systematic. Much recent work has focused on the acoustic characterization of historic buildings, often in relation to documentation, conservation, or restoration. While this has produced valuable knowledge, less attention has been devoted to the changing acoustic needs of contemporary worship spaces, including the use of sound reinforcement, multifunctional layouts, evolving liturgical practices, and the expectations of diverse congregations. This study aims to identify current acoustic design trends in worship buildings, considering both new and existing spaces across different religious rites. The analysis focuses on how design strategies address speech intelligibility, musical quality, ritual atmosphere, flexibility of use, and the preservation of architectural and cultural identity. By examining recent research and design approaches, the study seeks to clarify whether contemporary worship acoustics is converging toward shared design principles or remains primarily shaped by confession-specific requirements.

Keywords: *worship spaces, acoustics, churches, mosques*

Corresponding author: *francesco.martellotta@poliba.it*

1. Introduction

Acoustics of worship spaces has been largely investigated in the last 30 years, as demonstrated by the increasing number of studies that from the seminal studies focused on exploring the acoustics of existing worship spaces in Portugal [1], Switzerland [2,3], Spain [4], Türkiye [5], Serbia [6], Italy [7,8], Germany [9], and Poland [10,11], gradually extended to many other studies, although often characterized by a less systematic approach. To promote easier comparison of data collected among different researchers, Martellotta et al. [12] proposed a set of guidelines for churches. Still, they could easily be extended to other worship spaces by simply taking into account the specific needs of each ritual celebration. Notably, in recent years a significant effort has been made to extend the understanding of acoustic features to diverse worship practices, with several studies dedicated to mosques [13,16], Hindu temples [17], etc. However, despite this large corpus of studies on the acoustics of existing spaces, research exploring the best acoustic conditions suitable for different worship activities, and consequently proposing suitable design criteria, was significantly lower. The general issue is represented by the typically long reverberation time found in such spaces, which directly relates to conveying a "sacred" character to the space and the need for increased speech intelligibility, combined with a significantly variable number of worshippers. Some studies explored, by means of listening tests, the optimal balance between conditions for sacred and liturgical music and speech [18,19]; others based their considerations on more general criteria borrowed from performing spaces [20,21]; and others also tried to include the emotional component in the rating scheme [22,23]. Textbooks were also published providing design criteria specifically for churches [9] or for different worship buildings [24]. Still, the proposed acoustic criteria were often based on a mix between observation of existing buildings (old and new) and adaptation to specific needs of the worship practice, rather than on actual feedback from the audience.

Considering the multiplicity of worship practices, and considering the need to present a concise overview of the state of the art and of the aspects needing further investigation, the subsequent discussion will be circumscribed to Christian worship spaces, subdivided between "reverberant" (Catholic and Orthodox) and "dry" (Reformed) spaces, and Islamic worship spaces. Starting from the specific needs and current design practices, the aspects still needing attention will be identified and briefly discussed. Finally, the role of amplification and electro-acoustics will also be briefly addressed.

2. Acoustic needs of worship practice

2.1 Churches

Catholic, Orthodox, and Reformed churches share long reverberation times from large volumes and reflective surfaces, but their liturgical use of space and voice differs sharply.

In the post-Vatican II Catholic Mass, the celebrant moves among three stations: the altar (*versus populum*), where prayer shifts to a solemn consecratory tone; the chair, seat of presidency and conversational address; and the ambo, reserved for readings and homily in a clear, instructive voice. The congregation responds through song, psalmody, and communal acclamation (*actuosa participatio*), and amplification is now standard at all three stations.

In the Byzantine Orthodox Divine Liturgy, the priest stands before the iconostasis's Holy Doors, facing the altar as mediator between congregation and sanctuary, emerging periodically through the Royal Doors for blessings and readings. Choir and assembly answer with sung refrains and acclamations, creating a continuous antiphonal dialogue between hidden and visible space.

In Reformed worship, theology centers on the proclaimed Word rather than sacrifice. The elevated, central pulpit lets the minister address the congregation directly in sustained, persuasive speech, while the lower communion table hosts plain, occasional words of institution. Hymn-singing, unison prayer, and creeds form the congregation's substantial, intelligibility-focused participation, producing a soundscape built for comprehension rather than chant.

2.2 Mosques

In Islamic congregational worship, the imam occupies a defined spatial position facing the mihrab, a niche indicating the direction of Mecca (*qibla*), with his back to the congregation rather than facing them directly. This orientation reflects a shared axis of prayer: imam and worshippers face the same direction as equals before God, unlike the frontal confrontation typical of Protestant preaching. The call to prayer (*adhan*), traditionally delivered from the minaret, constitutes the first major sonic signal, historically projected by the unaided human voice and today frequently amplified through loudspeakers to reach the surrounding neighborhood. Within the prayer hall, the imam's recitation of Qur'anic verses in classical Arabic, often performed in a melodic, cantillated style (*tajwid*), is now commonly reinforced by microphones and internal sound systems, especially in larger mosques. The congregation's contribution is primarily unison rather than antiphonal.

In summary, mosque acoustics must satisfy three distinct acoustical requirements that relate both to speech intelligibility and to the spiritual experience of sound:

- the audibility of the Imam's recitation and prayer guidance during the congregational prayer (*namaz*),
- the intelligibility of the sermon (*khutbah*) delivered from the minbar (or, where applicable, the pulpit), and
- the clarity and envelopment of Qur'anic recitation, enabling both attentive listening and congregational participation.

3. Acoustic design practice

3.1 Churches

Collecting data on existing historical spaces distributed across different countries and including Catholic [1,4,8], Orthodox [6,11], and Reformed [3,9] churches showed (Fig. 1) that the overall acoustic behavior did not show a "specific" worship-dependent trend. Conversely, some interesting differences in average reverberation time appeared depending on material use. Starting from the Italian set of Catholic churches, three different sub-sets were identified based on the more or less reverberant nature of the space, largely associated with the use of hard reflecting finishes or more absorbing materials, like wood or soft (porous) stone. Reverberation time in Portuguese or German Catholic churches showed a similar spread. Even German Reformed churches, although remaining closer to the "intermediate" Italian churches, showed very long reverberation in a couple of cases. The latter case is particularly surprising considering that many Reformed churches were adapted to speech-centered worship, but the

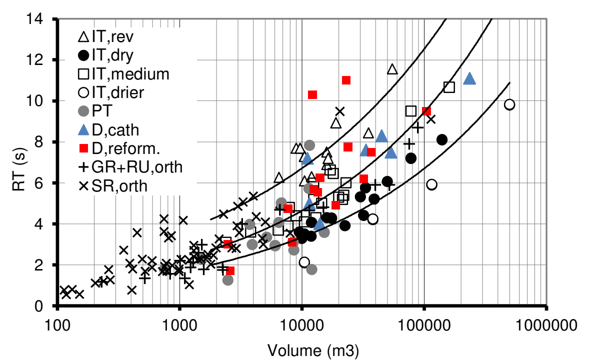

Figure 1. Measured mid-frequency reverberation time (unoccupied) as a function of volume in European churches for Catholic, Reformed, and Orthodox worship. Regression curves correspond to the subsets of reverberant, medium, and dry Italian churches.

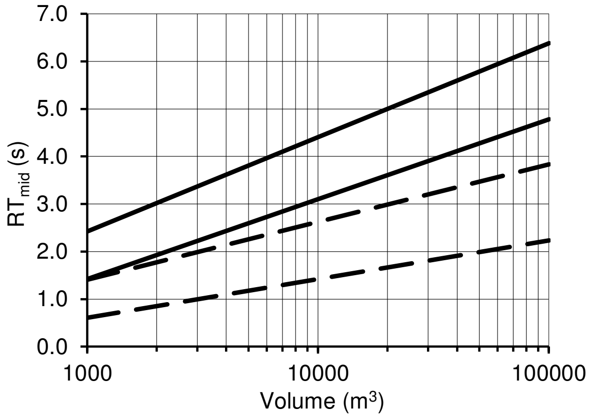

Figure 2. Optimal mid-frequency reverberation time as a function of volume for unoccupied (-) and occupied (- - -) churches.

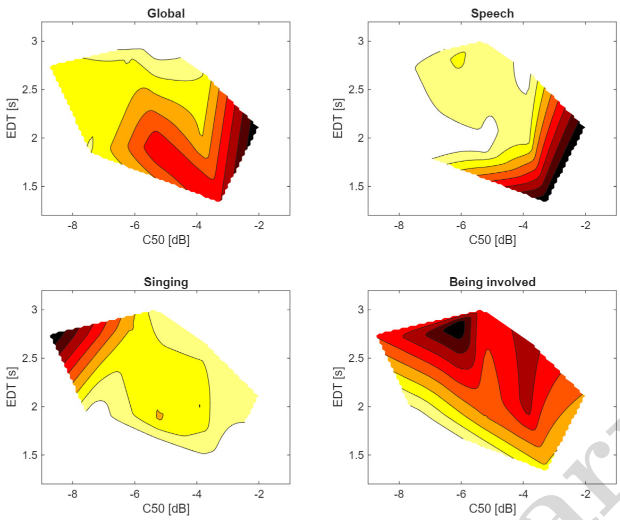

Figure 3. Map of subjective preference (darker=higher) as a function of EDT and C50 with reference to global rating, speech, singing, and involvement ratings.

combination of materials and dimensions clearly prevented dramatic changes.

As for Orthodox churches, data collected by Greek, Russian, and Serbian researchers showed a significantly reduced room volume and reverberation times that tended to be closer to the dry set of Italian churches. However, some more reverberant spaces were also accounted for. The use of unoccupied RT influenced the spread in observed values, which can certainly be reduced when the effect of occupancy is included [25].

Taking advantage of measurements in a subset of occupied spaces [25] and using acoustic simulations including the effect of occupancy [26], it was possible to extrapolate from the previous dataset, considering in particular the dry sub-set, a range of RT as a function of volume that may lead to suitable acoustical conditions when occupied (Fig. 2). However, such data are based on acoustic conditions of existing spaces, where the fully occupied conditions (for which RT is varying around 2 s, depending on room volume) are often hard to be achieved, particularly in recent times in which secularization is reducing attendance. Thus, a partly occupied church is likely to work most of the time under much more reverberant conditions. This is one important criterion that, in the design of new churches, is leading to an increase in sound absorption in unoccupied conditions, so that reverberation time is more stable and acoustical conditions can be better controlled.

In fact, in terms of subjective preference, listeners seem to prefer [18] a mid-frequency early decay time (EDT) around 2 s for choral and organ music. In contrast, longer EDT values, up to 4 s, are preferred only for Gregorian chants. However, in worship practice, the spoken word plays an essential part. A subjective study based on listening tests designed to evaluate the optimal balance between reverberance and clarity in Catholic churches [19], explored different combinations of mid-frequency early decay time and speech clarity (C50) by playing back auralized material including liturgical singing and speech, and asking the subjects to rate which combinations emphasized speech intelligibility, choral singing, the sense of involvement in the celebration and a global rating. Results showed (Fig. 3) that while the sensation of involvement was maximized by long reverberation, for singing a maximum EDT of 2.5 s was preferred, with low clarity. It was interesting to observe that preferred conditions for speech included the highest clarity (-2 dB in this study) and an EDT between 1.5 and 2 s, and were well correlated with the global rating, which maximized when reverberation was around 2 s, and clarity was at -2 dB. Although this study did not cover a wide range of acoustical parameters it nonetheless showed the complexity of the problem as each particular aspect apparently required a specific acoustics, but also suggested that aiming for occupied conditions with an EDT around 2 s (with some volume dependent variability as shown in Fig. 2) and C50>-2dB (that can be achieved by properly controlling early reflections and source directivity) can represent the best balance in a worship space to keep all the aspects satisfied.

Recent examples of acoustically designed worship spaces [27,28,29] confirm this approach, relying on the substantial support of the PA system. Similar recommendations are found for worship spaces where liturgical music is mostly non-amplified [21], while in Protestant churches, where speech and amplified music play a central role in the celebration, shorter reverberation times are often preferred [21,29]. In these spaces, particularly in modern and contemporary buildings, an auditorium-like approach is followed in the architectural design and, consequently, in the acoustics, so it is not surprising to find a mid-frequency reverberation time below 1.5 s also in very large venues.

3.2 Mosques

Before the introduction of electronic public address systems, mosques relied entirely on the unaided human voice for speech communication. During the Friday sermon (*khutbah*), the imam traditionally preached from the minbar. Although the elevated position improved audibility throughout the congregation, the use of the minbar was primarily a liturgical tradition rather than an acoustic adaptation. This practice continues today, even in mosques equipped with modern sound reinforcement systems. During the five daily prayers, however, the imam leads the congregation from the mihrab. In large historical mosques, one or more müezzins, positioned on the müezzin mahfili, repeated the imam's *takbirs* and other prayer cues so that worshippers throughout the mosque could follow the prayer. In the largest Ottoman imperial mosques, multiple müezzins assisted in relaying the imam's voice across the vast interior, creating a distributed human sound reinforcement system long before the advent of electronic amplification. Thus, rather than relying solely on the acoustics of the building, historical congregational mosques combined architectural acoustics with a carefully developed liturgical practice to ensure the effective transmission of speech throughout the worship space.

In contemporary mosque design, although several traditional architectural elements continue to be preserved as symbolic features, the imam's unamplified voice is no longer the primary consideration. Instead, designing a space that provides optimal conditions for public address (PA) systems has become increasingly important. This is particularly true for modern mosques [29,30] accommodating large congregations—often exceeding 5,000 worshippers—and especially for those that reinterpret the spatial characteristics of classical Ottoman mosques with similarly vast interior volumes. Compared with spaces intended primarily for unamplified speech, the acoustic requirements of electronically reinforced sound are considerably more demanding. Consequently, the acoustical design philosophy of contemporary mosques generally aims to achieve shorter reverberation times than those found in historical examples to improve speech intelligibility through PA systems. To illustrate this evolution, Fig. 4 compares three historical Ottoman mosques from the fifteenth and sixteenth centuries with two contemporary mosques constructed during the last two decades.

Süleymaniye Mosque and Rüstem Paşa Mosque were both designed by the renowned Ottoman architect Mimar Sinan. Although Üç Şerefeli Mosque [31] predates Sinan's works, all three mosques share a similar material tradition, characterized by painted brick domes adorned with gold-foiled pen paintings, limestone and marble wall surfaces, and carpeted floors. In Rüstem Paşa Mosque [14], the extensive use of İznik tiles further enhances the reflective properties of the wall surfaces (while providing scattering at high frequencies). Together, these materials create highly reflective interiors, with the carpet serving as the principal absorptive surface.

Among the historical examples, Süleymaniye Mosque [16] has the largest interior volume; all of the cases have reverberation times (T30) exceeding 6 s at low frequencies. In contrast, the contemporary examples

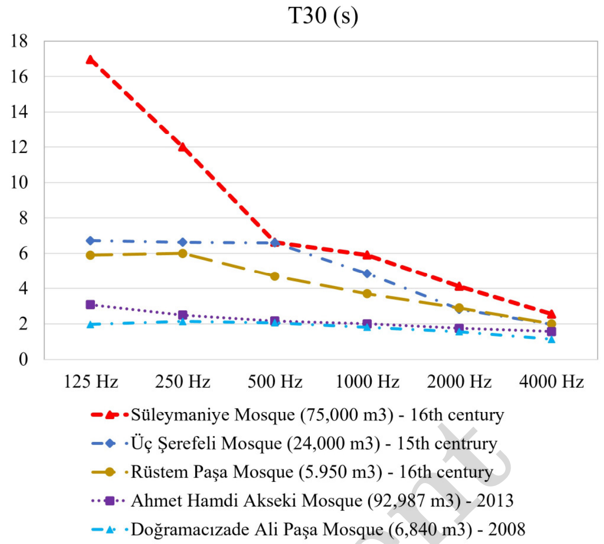

Figure 4. Comparison of reverberation time (T30) over octave bands for historical Ottoman and contemporary mosques in İstanbul, Edirne, and Ankara, Türkiye.

exhibit a different reverberation profile across the octave bands. This difference primarily reflects deliberate acoustical interventions introduced to improve speech intelligibility while maintaining the characteristic ambiance of mosque interiors.

In Ahmet Hamdi Akseki Mosque [30], the principal acoustical treatment is integrated into the dome, which is clad with perforated gypsum board backed by mineral wool behind the dome lattice. Additional absorption is provided through the partial application of micro-perforated wooden panels on selected wall surfaces. The smaller Doğramacızade Ali Paşa Mosque [20] adopts a different approach with its glass dome. Here, the mid-frequency response is optimized by applying perforated wooden panels with an air cavity and mineral wool backing to the inclined pendentive surfaces. In contrast, the remaining interior surfaces consist of travertine and solid (imperforate) maple panels. The stone wall surfaces are sandblasted to increase sound scattering and promote a more uniform sound field. Despite the substantially larger volume of Ahmet Hamdi Akseki Mosque compared with Doğramacızade Ali Paşa Mosque, both achieve remarkably similar reverberation times of approximately 2 s at mid frequencies. Although these values remain higher than those typically targeted in contemporary speech-oriented spaces, they represent a careful compromise. Even in the presence of modern public address (PA) systems, preserving a reverberant sound field that supports the spiritual atmosphere of the mosque remains a primary design objective.

4. The role of PA systems

During the last two decades, the design philosophy of sound reinforcement systems for worship spaces has undergone a significant transformation. Traditional distributed public-address systems based on multiple conventional line arrays are being replaced by coherent

waveguide-based sources capable of maintaining controlled directivity over longer distances. This transition is particularly relevant for worship spaces, where the interaction between electroacoustic systems and room acoustics is crucial for speech intelligibility.
For conventional line arrays at sufficiently high frequencies, the array behaves as a cylindrical source rather than a spherical one. This behavior provides two important advantages for speech reproduction. First, the increased directivity factor enhances the direct-to-reverberant ratio, increasing the relative contribution of the direct sound field. Second, the direct level decreases more gradually.
However, the same physical principles introduce significant limitations in large reverberant spaces. The high vertical directivity substantially reduces the amount of early reflected energy reaching the audience. Consequently, the room impulse response tends to consist of a dominant direct sound followed, after a characteristic build-up period, by the diffuse reverberant field. The duration of this transition depends primarily on room volume and reverberation time: large and reverberant churches require a longer time for the diffuse field to become fully established.
To compensate for this behavior, conventional church sound systems frequently rely on multiple distributed arrays covering different portions of the audience. Each loudspeaker effectively operates on a sort of local acoustic subspace, shortening propagation distances.
Such distributed configurations inevitably require accurate temporal alignment. Digital delay processing allows listeners to localize the celebrant correctly despite the presence of multiple loudspeakers distributed throughout the space. Nevertheless, identifying an optimal delay reference is often challenging because the alignment can only be perfect within a limited listening region. Away from this point, different loudspeakers become partially decorrelated, producing perceptible localization errors [32].
For these reasons, current research and industrial development are increasingly directed towards reducing the number of acoustic sources while preserving adequate sound coverage over long distances. Conventional line arrays, however, may exhibit intrinsic limitations that can be tackled by waveguide-loaded coherent sources. The concept, first introduced commercially by Christian Heil for L-Acoustics in the early 1990s, employs compression drivers coupled to specifically designed waveguides [33].
Initially developed for large outdoor reinforcement systems, waveguide technology is increasingly adopted in worship spaces with audience distances of 30–40 m. Modern compact waveguides operate from crossover frequencies around 800–1000 Hz upwards, allowing the high-frequency section to maintain coherent radiation over the entire listening area. Below this crossover frequency, radiation is generally provided by a limited number of larger transducers.
From the perspective of room acoustics, the most significant consequence is that a single main source (or, at most, a stereo pair) can effectively cover the entire audience. At the same time, small conventional loudspeakers are used only as localized fillers for acoustically shadowed regions. This architecture substantially reduces the need for delay alignment, minimizing interactions between multiple coherent sources. In practice, the narrow vertical beam substantially reduces the acoustic energy radiated towards domes, vaults, barrel ceilings and other highly reflective overhead surfaces, thereby limiting late reflections, focusing effects and long-delay echoes. Conversely, the wide horizontal coverage allows for a controlled excitation of the lateral boundaries, generating early lateral reflections that reinforce the useful sound field over a broad listening area.

5. Conclusions

Based on the above discussion of the current acoustic design trends for worship spaces, it is possible to identify some general trends that span across different religious traditions. First of all, worship spaces share an inherent multi-functionality due to the liturgical and ritual needs that involve both the celebrant and the congregation in an interplay where spoken (or cantillated) word is alternated with congregation responses or singing, possibly supported by musical instruments. Within this framework, room acoustics must provide a suitable balance among the need for the community to aurally perceive the sacrality of the space as well as to emphasize the sensation of being part of a congregation, with the more pragmatic need to understand the spoken word during the readings and preachings. The latter aspect is usually solved by means of electro-acoustic support, but even the most recent systems do not work well when room acoustics changes. Thus, to limit such variations and provide a better support to electro acoustic devices, following a combination of principles inherited from concert-hall design and some dedicated subjective studies, the current trend in the acoustic design of newly built worship spaces is aiming for a mid-frequency revebreration time (or EDT) around 2 s, with variations depending on room volume, with further reductions in those spaces that are traditionally inspired by auditoria (mostly protestant churches). In this way, changes due to variable attendance can be minimized while preserving a reverberant response of the space that conveys a sense of sacredness. In addition, proper control of early reflections may significantly support clarity (in combination with PA system design) and community response.
In existing buildings, the role of PA systems becomes essential to overcome the acoustic limitations of the space. Control of reverberation time and reflections is generally impossible as these buildings are listed and no, or very limited, changes are possible, circumscribing the possible actions to the addition of removable elements like curtains or tapestries.

References

[1] A.P.O. Carvalho, “Objective acoustical analysis of room acoustic measurements in Portuguese Catholic churches”. *Proc. Noise-Con 94*, Ft. Lauderdale, Florida, 805-810 (1994).

[2] V. Desarnaulds, S. Bossoney, K. Eggenschwiler, “Studie zur Raumakustik von Schweizer Kirchen”. *In Proc. Akustik–DAGA 98*, Zürich, 710-711 (1998).

[3] V. Desarnaulds, *De l’acoustique des églises en Suisse - Une approche pluridisciplinaire*. Doctoral Thesis, Ecole Polytechnique Fédérale de Lausanne. (2002)

[4] M. Galindo, T. Zamarreño, S. Giron. “Clarity and Definition in Mudejar-Gothic Churches”. *Build. Acoust.* 6, 1-16 (1999).

[5] Z. Karabiber, Z., “A new approach to an ancient subject: CAHRISMA project”, *Proceedings of the 7th ICSV Conference*. (2000)

[6] M. Mijic. “Serbian Orthodox Church – An Acoustical View”. *Proc. 17th ICA*, Rome, 2001.

[7] E. Cirillo and F. Martellotta. “Sound propagation and energy relations in churches”, *J. Acoust. Soc. Am.* 118(1), 232-248 (2005).

[8] E. Cirillo and F. Martellotta, *Worship, acoustics, and architecture*, Multi-science publishing, Brentwood (2006).

[9] J. Meyer, *Kirchenakustik*. Verlag Erwin Bochinsky, Frankfurt am Main (2003).

[10] Z. Engel, K. Kosala, “Acoustic properties of selected churches in Poland”, *Mechanics* 24(3),173-181 (2005)

[11] P. Malecki, J. Wiciak, D. Nowak, “Acoustics of Orthodox Churches in Poland”, *Archives of Acoustics* 42(4):579-590, 2017

[12] F. Martellotta, E. Cirillo, A. Carbonari, P. Ricciardi, “Guidelines for acoustical measurements in churches”, *Appl. Acoust.* 70, pp. 378-388, (2009)

[13] A.A. Abdou, “Measurement of acoustical characteristics of mosques in Saudi Arabia”. *J. Acoust. Soc. Am.* 113, 1505–1517 (2003)

[14] L. Topaktaş, *Acoustical properties of classical Ottoman mosques, simulation and measurements*. Master’s Thesis, Middle East Technical Univ.(METU), Ankara, Turkey, 2003.

[15] D.J. Oldham, A. Elkhateeb, “The architectural development of the historic Masjids in Cairo and its acoustical impact”, *Build. Acoust.*, 15 (3) (Sep. 2008), pp. 197-229,

[16] Z. Sü Gül, M. Çalışkan, and A. Tavukçuoğlu, “On the acoustics of Süleymaniye Mosque: From past to present.” *Megaron*, 9(3), 201-216, 2014.

[17] S. Aswathanarayana, B. Boren; “Acoustic analysis of two Hindu temples in Southern India” *JASA-EL.* 1 March 5 (3): 031601. (2025)

[18] F. Martellotta, “Subjective study of preferred listening conditions in Italian Catholic churches”, *J. Sound Vib.* 317(1-2), 378-399 (2008)

[19] F. Martellotta, “La ricerca dell’equilibrio fra chiarezza e riverberazione nella progettazione acustica delle chiese”, *41° Convegno Nazionale AIA*, Pisa 17-19 giugno 2014.

[20] Z. Sü Gül, M. Çalışkan, “Impact of design decisions on acoustical comfort parameters: case study of Doğramacızade Ali Paşa Mosque”, *Appl. Acoust.*, 74 (6), pp. 834-844 (2013)

[21] D.W. Kahn, “How room acoustics design of worship spaces is shaped by worship styles and priorities,” *Acoust. Today* 17(3), 31–39 (2021)

[22] A. Algargoosh, “The link between the acoustic characteristics of worship spaces and their emotional impact,” *J. Acoust. Soc. Am.* 155(5), pp. 3027–3036, 2024

[23] M. A. P. S. Tavares, et al., “Acoustic Characterization of worship ambiance – Old Goa’s Capela do Monte, a comprehensive example,” *Proc. of 37th Internoise 2008*, Shanghai, in08_0526, (2008).

[24] M. Kleiner, D.L. Klepper, R. Torres, *Worship space acoustics*, J. Ross Publishing, 2010.

[25] V. Desarnaulds, A.P.O. Carvalho, G. Monay. “Church acoustics and the influence of occupancy”. *Build Acoust* 2002; 9(1): 29–47

[26] L. Alvarez-Morales, F. Martellotta, “A geometrical acoustic simulation of the effect of occupancy and source position in historical churches”, *Appl. Acoust.* 91, 47–58, 2015

[27] G. Fratoni, D. D’Orazio, L. Barbaresi, “Acoustic Comfort in a Worship Space Made of Cross-Laminated Timber”. *Build. Acoust.*, 26, 121–138 (2019).

[28] N. Prodi, G. La Porta, “Il caso del Complesso Parrocchiale “Sacro Cuore di Gesù” a Baragalla”, in *Proc. of the Conference “Organi a canne e acustica nelle chiese”,* Genoa, June 9-11 2025.

[29] D.T. Bradley, E.E. Ryherd, L.M. Ronsse, *Worship space acoustics*, Springer New York, NY, 2016

[30] Z. Sü Gül and M. Çalışkan, “Acoustical design of Turkish Religious Affairs Mosque.” In *Proc. ICA 2013*, Montreal, Canada. POMA, 19, 015083 (2013).

[31] Z. Sü Gül, “Acoustical features of the Üç Şerefeli Mosque (the mosque with three balconies)” In Proc. *11th Forum Acusticum - Euronoise 2025*, Malaga, Spain, (2025).

[32] M.S. Ureda, “Analysis of loudspeaker line arrays,” *J. Audio Eng. Soc.*, 52(5), pp. 467–495, 2004.

[33] M. Urban, C. Heil, and P. Bauman, “Wavefront Sculpture Technology,” *J. Audio Eng. Soc.*, 51(10), pp 912–932, (2003).