How Room Acoustics Design of Worship Spaces Is Shaped by Worship Styles and Priorities

David W. Kahn

Introduction

The room acoustics design of concert halls is a topic much written about in the acoustics literature (Kierkegaard and Gulsrud, 2011; Hochgraf, 2019). Not only is concert hall design of great interest to many acoustics professionals but it also rightfully garners the attention of musicians, other design professionals such as architects, and the music-loving public. Articles on the room acoustics design of concert halls often appear not only in professional journals such as *The Journal of the Acoustical Society of America* (e.g., Beranek, 2016; Lokki et al., 2020) but also in the popular media (e.g., Wagner, 2019).

In contrast, the acoustical design of worship spaces receives little attention in professional acoustics journals, and it is possible that there have never been any articles published on the topic geared toward the general public (but see Bradley et al., 2016 for a popular treatment). This is curious given how many more worship spaces than concert halls there are and that most members of the general public spend more time in worship spaces than in concert halls. Certainly, the acoustics of worship spaces has as much of an impact, if not more, on the experience of worshippers during a service as does the impact of performance space acoustics on the experience of those same people in a concert hall.

There are many religions, each of which has unique ways of worshipping. This article addresses only those with which I am professionally familiar, which are primarily Christian and Jewish worship services.

Design Considerations

From the viewpoint of an acoustics designer of worship spaces, the acoustics design of concert halls is simple. The nature of the sound sources is well-known, and the nature of the sounds emitted by those sources (usually an orchestra) is fairly consistent. In addition, there are only rare occasions where some of the sound sources are placed "off stage" in a very limited number of works. Furthermore, the audience experience is not participatory; attendees simply listen to the sound being emitted from the performance platform.

Contrast that to a worship space, where the situation is quite different. First, congregations often participate in worship; they are not always just listening. Their audible experience of hearing themselves and others in the congregation is a key element of the worship experience.

Second, although much of the activity in a worship service takes place on a platform at the front of the sanctuary similar to the stage at the front of a concert hall, many worship spaces have musicians' areas (e.g., instruments, singers) that are not integrated into this area but are elsewhere. One example is the Church of the Resurrection in New Albany, Ohio, where the musicians are off to the left of the sanctuary (**Figure 1**). Pipe organs are often integrated into worship spaces, but unlike concert halls where the pipe organ is located on the upstage wall, pipe organs in churches are often also located elsewhere in the space.

Third, in a concert hall, the acoustics designer focuses on the quality of music and is much less concerned about the quality or intelligibility of the *spoken* word because this is rarely a key component of an event in a concert hall. In contrast, in a worship space, the acoustical quality and intelligibility of the spoken word is almost always of importance. Consequently, one important distinction between worship spaces and concert halls is that the former must support both music and the spoken word equally well.

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Figure 1. *Musicians play from a position off the central axis of the sanctuary (**left**) at the Church of the Resurrection in New Albany, Ohio.*

Continuing with our comparison of worship spaces and concert halls, a fourth point is that the style of music can vary dramatically from one worship space to the next. Concert halls host a wide range of musical styles also, but the range is generally not as dramatic as is found in worship spaces. Some worship services use rock bands to lead music; this is most prevalent in some of the more seeker-targeted, nondenominational Christian ministries. Some Baptist churches as well as churches of other denominations have large orchestras on most Sundays that are more like those in concert halls. Of course, many Christian services have choirs, and many Christian worship spaces also include organs. Jewish worship spaces can have a fairly broad range of music included in their services; however, although the range is generally not as wide as with Christian worship spaces, some less traditional Jewish synagogues that include organs and choirs are not unusual, at least for some services.

If a worship space has a consistent worship style from week to week, one can develop an acoustical design to suit that particular music style, but, to complicate matters, some worship spaces have multiple services. It is not uncommon for one church to have both a "traditional" worship service that features primarily choral and organ music in addition to a "contemporary" service that features an amplified rhythm section similar to the instrumentation of a typical rock band.

Concert halls also support diverse programming that may range from chamber music to full orchestra to a "pops" concert that includes some amplification. That is why some concert halls, and particularly halls designed in the last few decades, include adjustable acoustics design elements. Incorporating adjustable acoustics design elements into a worship space, however, is less common, even though there is often an even greater programmatic need for acoustical adjustability.

Background/History

Unlike concert halls, worship spaces have their roots in prehistory, whereas the concert hall as a dedicated building is a product of the eighteenth century, during which (at least in the West and, more specifically, in England) the live performance of commissioned music morphed from an affair by invitation in private music rooms for small audiences into events for the paying public in larger quarters (e.g., Forsyth, 1985).

Yet music itself is older than either concert halls or houses of worship. Music came before buildings of any kind, and the point of intersection between music and architecture is when we first see music in worship spaces.

Because only much later did music come to be performed indoors for its own sake outside the context of worship, it is not a stretch to say that for most of music history, composers wrote music primarily to be played outside or in buildings not explicitly designed for music performance.

Today, a rich and extremely varied repertoire of sacred and liturgical music exists and it continues to evolve, but it is important to remember that almost none of this repertoire was written to be performed in the spaces where it is performed today. An acoustics designer of worship spaces must be knowledgeable about this repertoire, its history, and its variety, because they relate to the faiths and denominations with which the designer is working. An acoustician must also be capable of designing a worship space to accommodate the full breadth of activity and worship styles that may occur within any given space.

Perhaps the most significant modern development affecting the acoustics of worship spaces and, indeed, nearly all gathering spaces is the advent of electronic sound reinforcement systems. Yet their adoption has not been

Table 1. *Worship priorities*

	Acoustical Characteristics	Architectural Elements Needed To Create This
Traditional music with orchestra and choir	Balance of early-arriving sound reflections and late-arriving reverberant energy, resulting in high levels of clarity and long reverberation times (1.8–2.2 s)	Generally rectangular in plan Compact/efficient seating layout with shallow floor slope Sound-reflecting surfaces located close to congregation and platform: balconies, soffits, ceiling elements
Contemporary music (amplified)	Low levels of reverberation (<1.2 s typical) Minimize discrete echoes from loudspeakers back to platform	Minimized room volume Low ceiling Sound-absorbing wall and ceiling treatments Wall shaping to avoid echoes and late-arriving sound energy
Preaching	High speech intelligibility Acoustic feedback from the room/congregation Acoustic and visual intimacy between preacher and congregation	Minimized footprint Sound-reflecting surfaces located close to the congregation including balconies, soffits, and ceiling elements that direct sound back to the platform
Congregational participation	Early sound reflections between members of the congregation	Minimized footprint Sound-reflecting surfaces located close to the congregation including balconies, soffits, and ceiling elements that direct sound back to the congregation
Thin apace (high aesthetic)	Cathedral-like sound Highly reverberant (>3 s) Poor speech intelligibility	Large acoustic volume Tall ceilings Sound-reflecting materials (wood, stone, concrete, glass)

universal; even today, Orthodox Jewish congregations do not use sound reinforcement systems for their services.

Priorities

When a space is used for multiple activities and if those multiple activities do not all have the same acoustical requirements, the acoustics designer must choose which activity to design for. In our work, we like to engage the owner in this process. Ideally, the owner will provide not only a list of the anticipated activities that take place in that space but will also prioritize those uses. This is a great benefit to the acoustics designer and can help to determine, for example, the need for adjustable acoustics finishes or the need for a supplementary electronic sound system to provide for a way to adjust the acoustical environment to better support a wider range of uses.

The balance in importance between the spoken word and music varies from ministry to ministry. Similarly, the importance of congregational participation varies. For example, in some ministries, the role of the congregation in the worship service is as important as the clergy's role. In others with a far more presentational worship style, the importance of congregational participation is quite low. The nature of the worship service and the prioritization of the typical elements of a worship service can have a profound impact on the acoustical design strategy. **Table 1** lists the typical elements of a worship service and the acoustics and architectural design considerations associated with each.

Acoustical Design Strategies

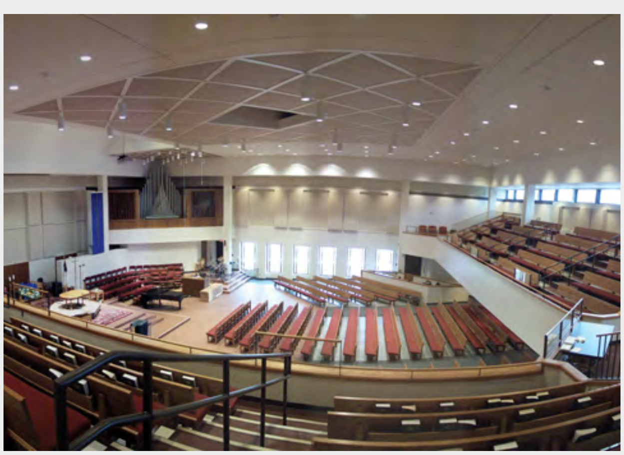
Adjustable Reverberation Time

In a traditional room acoustics design context, the challenge of balancing support for the spoken word versus music is one of choosing the appropriate compromise between a room whose reverberation time is too long for good speech intelligibility and a room whose reverberation time is too short to enhance the music. Some modern concert halls have adjustable acoustics curtains, banners, or panels that allow the reverberation time to be adjusted depending on the music to be played at that performance.

However, even if these elements were to be incorporated into a worship space, it is not practical to adjust them during the worship service, for example, extending curtains for the sermon and retracting them for the music. There are some worship spaces, however, that do incorporate adjustable acoustics curtains and panels. One example is the Roseville Lutheran Church in Roseville, Minnesota (**Figure 2**). Adjustable elements were incorporated because this church has both traditional (choir and pipe organ) worship services as well as a contemporary worship service with a "praise band."

This church knew from experience, before embarking on the design of a new worship space, that there were some very significant challenges involved in supporting both a traditional service with choir and organ and a contemporary service with an amplified praise band with keyboards, electric guitars, amplified vocalists, and more. My acoustics consulting firm, Acoustic Distinctions, worked collaboratively with the architects from the outset to develop a new worship space design that incorporated adjustable acoustics elements, including hinged panels that could easily be opened or closed between services and a large volume above the ceiling and below the roof with a large opening over the location occupied by the pipe organ and the choir. There are large, motorized curtains in this volume that can be extended or retracted.

Figure 2. *The Roseville Lutheran Church in Roseville, Minnesota, is an example of the rare worship space with adjustable acoustics. Acoustic panels behind the platform and seating areas are shown in the open (absorptive) position.*



Use of Partially Coupled Reverberation Chambers

A partially coupled reverberation chamber is a large, very reverberant space (a space with all very reflective finishes, such as a shower stall) that is physically connected to another large space (typically, the seating area of a concert hall, theater, or worship space). The concept of the partially coupled reverberation chamber is to efficiently increase the reverberation time of the primary space. For example, rather than increase the ceiling height within a space to get more volume (volume is directly correlated with reverberation time), acoustically coupling the space to an adjacent volume (perhaps above the ceiling) and using that additional volume as a reverberation chamber can increase the reverberation time of the primary space with less total volume than would be required using just a single architectural volume. The effect of these reverberation chambers can be minimized by providing adjustable sound absorption in the chamber. A coupled reverberation chamber is a cost-effective way to achieve an acoustic goal that might otherwise be impossible because there are usually limits to the size a building can be made due to budgetary or other constraints.

The use of partially coupled reverberation chambers is an acoustical design technique pioneered to a large extent by Russell Johnson (see bit.ly/3cE2Ir3). This technique was first developed to solve the acoustical design challenge of multipurpose halls used both as theaters and concert halls. The volume of the stagehouse below the proscenium opening but outside the orchestra shell was developed into a partially coupled reverberation chamber to enhance reverberation for music when these theaters were used as concert halls.

The acoustical design concept is to have a relatively short reverberation time to support clarity but a long audible reverberant tail that is most audible after a terminal chord is released. Reverberation time is defined as the time for sound to decay by 60 dB. In the coupled situation, greater time elapses before the sound decays to that degree, but the initial constant decay is maintained.

Partially coupled reverberation chambers have been incorporated into the acoustical design of some churches where, in general, the reverberation chamber is created by the space between the ceiling and the roof, such as in the Roseville Lutheran Church (**Figure 2**). The acoustical benefits of this design approach as it relates to worship spaces is that the room's natural acoustics provide for better clarity and therefore better natural support of the spoken word. They also allow the efficient development of a very long reverberation time to support choral and organ music (longer reverberation times can be achieved with less overall volume).

One of the challenges of a reverberation chamber is making sure that enough sound energy gets into the chamber to have an audible impact. When the reverberation chamber is formed by the lower section of the stage house in a multipurpose auditorium, it is easy to get enough energy into that chamber due to its proximity to the performance platform. Similarly, at the Roseville Lutheran Church, the pipe organ and choral loft were located directly below a large opening into the reverberation chamber.

The Perimeter Church north of Atlanta, Georgia, is another example of a worship space where the void between the ceiling and the roof was utilized as a reverberation chamber (**Figure 3**). Unlike most churches, the Perimeter Church built a theater with a fully rigged stage house to support their large-scale dramatic productions; therefore, there is not much, if any, acoustical connection between the stage, where the sound originates, and the ceiling void over the audience seating area. The ceiling has discrete openings that allow the reverberant energy in this void/reverberation chamber to add to the audible reverberant tail as heard by the congregation, similar to the effect that reverberation chambers have in multipurpose performance spaces and concert halls. The challenge at the Perimeter Church was to get sufficient sound energy from the stage up into this void, which was solved with a simple sound reinforcement system. Microphones placed over the musicians amplify their signal, which is then played into a series of loudspeakers located above the ceiling void.

Figure 3. *Recesses in the ceiling of the Perimeter Church north of Atlanta, Georgia, are actually "windows" coupling the main sanctuary volume with a reverberation chamber between the ceiling and the roof.*

Sound Reinforcement Systems

The advent of electronic sound reinforcement systems has helped to increase intelligibility of the spoken word, particularly in larger and more reverberant spaces. Large cathedrals are spaces where, historically, the spoken word was not intelligible other than to perhaps a small congregation located close to the pastor. Understanding the spoken word has generally become a higher priority in both Christian services and Jewish services. Furthermore, sermons have grown in significance and have become a more important, if not *the* most important, element of a service.

Most of these large cathedrals, many of which were constructed several hundred years ago, have added sound reinforcement systems in more recent years; Notre Dame in Paris, France, is one example. This has allowed larger congregations who may gather in these spaces for special events to all hear and understand the spoken word.

Before the development of electronic sound reinforcement systems, attempts were made to improve the intelligibility of the spoken word through the use of sound-absorbing finishes. There are many examples

Figure 4. *The vaulted ceiling surfaces at the Riverside Church in New York City are Guastavino tile that required sealing after sound reinforcement was added to the sanctuary.*

of churches in the United States that incorporated Guastavino tile in the form of Akoustolith (a product developed in the early 1900s expressly for the purpose of limiting undesirable reflections in spaces with vaulted ceilings), usually in the ceiling, to reduce the reverberation time. But these finishes improved one acoustic parameter at the expense of another; the acoustical quality of the spaces where they were installed declined for music and, in particular, choral and organ music, both of which are typically the primary, and sometimes only, source of music in these spaces. One example is the Riverside Church in New York City (**Figure 4**).

As the quality of sound reinforcement systems increased, many of the churches that incorporated Guastavino tile, including the Riverside Church, have decided to go back and use multiple coats of special clear sealants to *increase* the reverberation to provide better acoustical support of music. However, one challenge with sound reinforcement systems is that they can increase loudness but not necessarily speech intelligibility.

In order to increase intelligibility, these systems must provide a significant increase in the loudness of the *direct* sound (the sound that travels to a congregant's ears directly from the loudspeaker), with a smaller increase in the loudness of the reverberation. One way to do this is to provide small loudspeakers close to the congregants. These systems are known as pew-back systems. If the speaker is close to the congregant, it is easier to improve the loudness of the direct sound compared with the loudness of the reverberant sound. Still, pew-back systems are expensive and tend to sound unnatural, but as electronic sound reinforcement technology improves, it is becoming more possible to attain the elusive combination of natural sound, lower cost, and better speech intelligibility.

As sound reinforcement systems developed, many churches suspended large speakers or arrays of speakers over the platform or otherwise mounted them at a distance from the congregants. These systems often increased the level of reverberation as much as the level of direct sound; as a result, many of these attempts were not successful.

One of the most significant advances in the design of loudspeakers that is continuing to improve to this day is better directional control over a wider frequency bandwidth. This allows a loudspeaker to aim a larger percentage of sound energy into the sound-absorptive seating area, with a smaller percentage of sound energy going into the

Figure 5. *Steerable arrays in the ceiling permit a minimal suspended speaker array system at the Church of the Resurrection in Leawood, Kansas, to serve a large congregation, aiming sound toward the absorptive seating areas and away from the reflective surfaces.*

sound-reflecting wall, floor and ceiling surfaces. This provides a greater increase in the loudness at the listener's ears between the direct sound from the speaker and loudspeakers relative to the loudness of reverberant sound in the room. As this technology improves, it becomes possible to suspend a smaller number of speakers over the performance platform to enhance the intelligibility of the spoken word to larger congregations.

One recent example of the successful use of steered arrays is the United Methodist Church of the Resurrection in Leawood, Kansas (**Figure 5**). The loudspeakers allow a great deal of directivity pattern flexibility. As a result, the sound energy emanating from them covers the wide wraparound seating area, with minimal sound spill onto reflective surfaces such as the walls outside the seating area, the platform, and the ceiling.

Natural Enhancement of Speech Intelligibility

The acoustical design of modern Jewish Orthodox synagogues is one unique challenge that deserves its own discussion. One challenge is that some of these spaces are quite large; providing good speech intelligibility to hundreds of people for unamplified speaking is a formidable challenge. Keeping background noise levels very low (e.g., from the building's HVAC systems, outside noise) is one essential design consideration because high speech intelligibility requires a good signal-to-noise ratio. Because the loudness of the signal (unamplified speaking) is limited, with no ability to boost the level with an electronic sound reinforcement system, the "noise" must be as low as possible to increase the signal-to-noise ratio in the worship space.

The room shaping must be designed to reflect the sound of a person speaking into the congregational seating area. The sooner those reflected sounds arrive, the louder they will be. Also, our auditory system integrates reflected sounds arriving soon after the direct sound more effectively than later-arriving reflected sounds to improve speech intelligibility.

An additional complication in an Orthodox synagogue is that there are two different and important locations where speaking or chanting takes place. One is from the center bimah where the speaker faces the front of the room (the Ark) with his back to half the congregation.

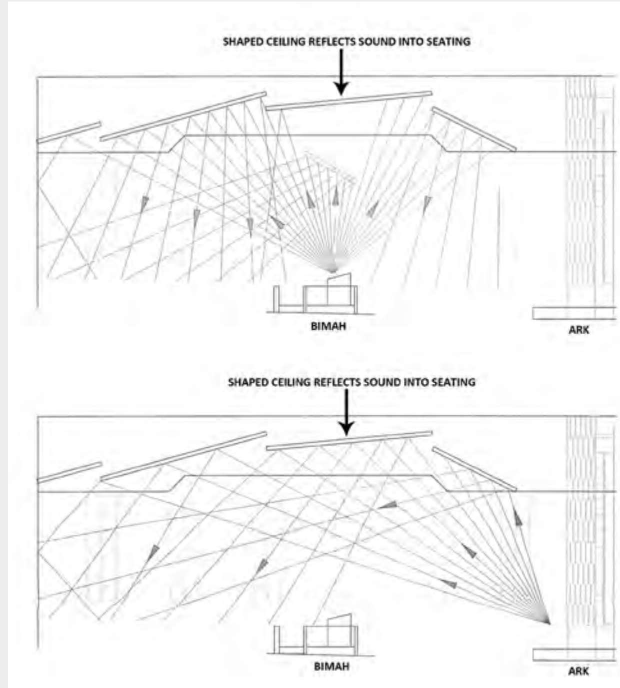


Figure 6. *Reflections for a sound source originating at the central bimah of a synagogue (**top**) and from the Ark (**bottom**).*

Figure 7. *Young Israel of Greater Cleveland Orthodox synagogue in Beachwood, Ohio, features ceiling shaping to support a person speaking at two critical locations.*

The second location is from the Ark facing the congregation; the room shaping must support strong early reflections to the entire congregational seating area for both speaking locations.

One example is Young Israel of Greater Cleveland in Beachwood, Ohio. The seating capacity of this Orthodox synagogue is unusually large. Providing excellent speech intelligibility for such a large congregation without the use of any electronic sound reinforcement was a formidable challenge. As is typical for Orthodox synagogues, there are two sound source locations that require natural reinforcement. The opportunity to improve natural reinforcement of speaking and chanting was limited to the ceiling design. **Figure 6** shows how the proposed ceiling design provides the needed reflections into the seating area from both sound production locations; **Figure 7** shows the built interior of the Young Israel of Greater Cleveland synagogue.

Acoustical Support of Congregational Participation in Worship

Some spaces have acoustical environments that encourage congregants to sing and participate in a worship service by reciting responsive prayers or by singing. Although, in general, more reverberant rooms provide better support of congregational participation than less reverberant rooms, the correlation between reverberation time and acoustical support of congregational singing is poor. Reverberation *level* correlates more strongly. The reverberation level is generally higher in smaller rooms than in larger rooms, whereas the reverberation *time* is generally higher in larger rooms than in smaller rooms. Consequently, smaller worship spaces generally provide better acoustical support of congregational participation than larger rooms.

As rooms get larger, the surface closest to the congregation (the floor) becomes the most important sound-reflecting surface to support congregational participation. Choir and music directors know from experience that carpeting is the worst thing to have on the floor to support congregational participation.

Acoustical support of congregational participation is a very dynamic phenomenon based on the known tendency of people to speak or sing more loudly to be heard as others around them do the same. In a worship space, if a congregant hears other congregants singing, he or she will feel comfortable singing more loudly. This encourages fellow congregants, in turn, to sing more loudly. This can result in a swell of energy that meets the goal of supporting congregational participation.

Conversely, in gathering spaces like restaurants, where the goal is to minimize the swell of energy to allow diners to communicate with a minimum of effort, carpeting is essential (see Roy and Siebein, 2019). Restaurants with sound-reflective floors, almost regardless of other wall and ceiling finishes, are often unpleasant spaces in which to have a meal due to the loudness of conversations at other tables. In other words, the acoustical goals for the design of a space to support congregational participation is exactly the opposite of the goal for the acoustical design of a restaurant.

Next to the floor finish, the ceiling is often the next closest surface to the congregation (compared with the walls) for a large majority of congregants. Therefore, in general, when sound absorption is required to control excessive reverberation in a worship space, it is best to incorporate sound absorption on the walls and not on the ceiling.

Some very large worship spaces use electronic enhancement (also called electronic architecture) systems to enhance acoustical support of congregational participation. These systems typically have arrays of ceiling-suspended loudspeakers that electronically add sound energy into the congregational seating area so that congregants hear themselves and other congregants more loudly, which encourages them to participate.

The Stonebriar Community Church north of Dallas, Texas, is one of several examples of churches that incorporated an electronic architecture system. These systems are rarely used in worship spaces but are frequently added to spaces for music performance that have compromised acoustics. Stonebriar's natural acoustics were designed to support their amplified praise band and, as a result, were not ideal for choral and orchestral music, styles used for their traditional services. Furthermore, congregational participation was a high priority for this church. To enhance their traditional service and to improve the acoustical support of congregational singing, Stonebriar added a separate electronic architecture system. In this arrangement, microphones hang both over the musicians' area and the congregation. That signal is processed and played back through an array of speakers that are suspended from the ceiling, pointing down toward the musicians' area and the congregation. The additional reverberant sound energy these speakers provide in the congregational area encourages people to participate in the worship service.

Conclusion

The acoustical design of worship spaces can be a far greater challenge than the acoustical design of a concert hall because the program of use is more varied and complex and there are inherent conflicts between the acoustical needs to support music versus speaking, both of which are fundamental requirements in almost all worship spaces. Furthermore, there are many more worship spaces likely to require acoustics design input than concert halls. My training and acoustics design experience in the design of concert halls was much greater than my design of worship spaces until the mid-1990s. In the last few decades, I have had the unique opportunity to lead the acoustics design of many worship spaces and to apply my experience in the design of concert halls to the design of these worship spaces; multiple examples have been discussed in this article. The examples chosen show the very wide breadth of design solutions, each informed by the unique worship style and prioritized program of use of each ministry.

It is hoped that these examples will serve as inspiration to other acoustics design specialists and their clients for more worship spaces of the future to provide better acoustical support of their unique worship style and, in so doing, enhance the experience of both the congregations and the clergy who lead these services.

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About the Author

David W. Kahn dkahn@ad-ny.com

Acoustic Distinctions
60 East 42nd Street, Suite 2036
New York, New York 10165, USA

David W. Kahn is a specialist in the field of architectural acoustics, with extensive experience shaping the sonic environment of worship spaces, performing arts centers, theaters, and many other places. Since 1983, he has helped architects and clients achieve excellence through the integration of exceptional room acoustics, sound isolation, building noise and vibration control, and appropriate AV systems into the overall design of thousands of projects. David is also an active musician (trumpet) whose ear is attuned to worship spaces and performing arts centers as a performer and participant as well as an acoustician.