

secularism existed separately from theology, it is possible to observe its unique role in the use and design of spaces. For example, artistic and political forces determined the aural architecture of spaces used for Shakespearean plays and Greek political orations.

Regardless of the motivation for creating or selecting a particular space, whether religious or secular, once a space was used for social activities, the occupants then gained a heightened awareness of its acoustic properties. Just as priests adapted to the acoustics of their churches, so actors adapted to the acoustics of their theaters, musicians to those of their performance spaces, and politicians to those of their meeting halls. In each case, auditory awareness led to a social response, a pattern that has existed since the start of recorded history and probably much earlier.

The Acoustics of Public Spaces in Ancient Greece

Given their strong interest in all forms of aural activities, including music, oration, rhetoric, and religion, the ancient Greeks were likely to have been aware of how these activities were influenced by spatial acoustics. Although acoustical attributes are rarely mentioned in surviving documents, sound was generally viewed as an important social and political resource. Benjamin Jowett (1964), in looking at Plato's dialogue *Laws*, commented that music was viewed as a pragmatic extension of political education and military training. Plato worried that music could make people lethargic, indolent, or irrational because it fed the waters of passion rather than drying them up (Bowman, 1998). Furthermore, in order to preserve the path to truth and goodness, Plato argued that music must be controlled by the state, and should not be left to personal preferences. Sound had power, and spatial acoustics, even if not so recognized, also had power.

The acoustic differences in the spaces of ancient Greece were not subtle. Although only a few buildings from ancient Greece have survived intact, historical records provide commentaries on their design, social use, and in some cases, on the aural experience of their spaces. Two examples will illustrate the role of small and very large acoustic arenas in ancient Greece.

Our first example, the Echo Hall, once stood in the ancient city of Olympia. A long structure measuring some 100 meters by 10 meters (350 feet by 35 feet), it had three enclosed sides and one open side with 44 Doric columns. The renowned traveling geographer Pausanias described how a voice in this hall would echo seven or more times. These strong echoes would have prevented communications over a wide area, creating multiple small acoustic arenas, whose aural privacy would have been ideal for any number of small groups wishing to discuss politics and commerce without fear of being overheard.

In our second example, the Greek amphitheater, poetry, drama, music, dance, and religion fused into a single type of aural experience in a very large public acoustic arena. Greek theater could tolerate neither the excessive reverberation time of large

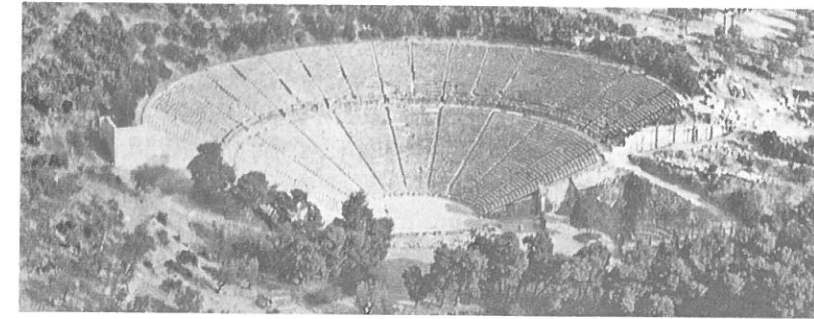


Figure 3.5

Open-air theater in Epidauros. © 1993 Gebrüder Mann Verlag, Berlin.

enclosed spaces nor, with the political need to accommodate large audiences drawn from a democratic society, the limited audience size of smaller enclosures. The open-air amphitheater (figure 3.5) would remain the only means of combining a large audience with oratorical clarity until the advent of electronic broadcasting in the twentieth century, with its widely distributed audiences.

The Greek amphitheater was also the result of geographic and climatic accident. Many major Greek cities were located on rolling hills, which provided ideal acoustic settings for open-air theaters. (In contrast, flat plains, wide valleys, or steep mountains would not have provided good acoustics.) And Greece's mild climate made unsheltered public spaces feasible. Indeed, we might speculate that geography and climate contributed to the success not only of the amphitheaters but also of Greek democracy, which might not have flourished without the frequent, publicly shared experiences these theaters made possible.

Theater was an important part of ancient Greek culture, and is still studied in schools across the world. Because of its artistic, social, and political relevance, then and now, there is a large body of information about its theatrical content and its spatial acoustics in surviving historical texts and archaeological evidence. And because Greek theater has broad interest to modern scholars, they study the acoustics of the open-air amphitheaters with the tools of modern science.

Peter Walcot (1976) described the social context of Greek theater as the driving force that defined its art form. Massive audiences attended the Theater of Dionysus in Athens during the festival held in honor of the god to enjoy the plays of Aeschylus, Sophocles, and Euripides. The state sponsored these festivals as part of the annual calendar of religious ceremonies, and the audience was drawn from the general population rather than from a small elite group. As a democratic state, Athens provided theater venues that could seat more than 15,000. The ancient Athenians have been described as a critical and demanding audience, both emotionally and intellectually.

Because plays often had only a single performance, there was intense competition among the resident population of 150,000 for that, relatively speaking, limited seating, with occasional violent confrontations.

From the perspective of satisfying an artistic and political requirement—intelligibility and democracy—Benjamin Hunningher (1956) analyzed the implications of the acoustics on the acting style. Indeed, given the size of the audience, which was seated in a semicircular area set into the rolling hills, acoustics became the central issue. The size of these open-air theaters was immense, even by present-day standards of sporting events. The distance from the performers to the farthest spectator in the fifty-second row was some 80 meters (260 feet). In comparison, a modern opera house, such as the Prinz Regententheater in Munich, has a distance from the curtain line to the farthest seat of less than 30 meters (100 feet). More important, open-air theaters do not add sonic energy from reflecting surfaces the way that enclosed spaces do. Without special design efforts, a large percentage of the audience would not have been able to hear the performance. Regardless of their location, spectators expected intelligibility throughout the seating area.

Applied spatial acoustics was born of the necessity to solve the problems of large-scale spaces. In his treatise on architecture, Vitruvius (30 B.C.) included an extensive discussion on rules for improving theater acoustics. Over the years, many scholars and researchers have tested these rules as well as theories about Greek theater to determine which artistic styles and architectural solutions would have solved the first major problem in spatial acoustics: amplification without electronics. Several ideas have emerged from these studies. First, the large front wall of the skene, positioned behind the performers, would have reflected sound to the audience in much the same way that the front wall of the stagehouse in many sixteenth-century theaters did (and does in some modern theaters as well). Second, increasing the angle of rise in the seating area would have placed the audience closer to the performers. (Amphitheaters with sharper angles of rise do indeed have better acoustics.) Third, the mouth openings of theatrical masks may have functioned as miniature megaphones. Fourth, through special training, performers learned to project their voices for maximum intelligibility. Finally, by singing, performers could project their voices still farther than by simply speaking—much farther, perhaps reaching the most distant seats.

When Robert S. Shankland (1973) correlated the variations in acoustic quality among Greek amphitheaters with their physical parameters, he observed that geometries that optimized sight lines also optimized acoustics because they both follow the same rules. This fortuitous relationship between seeing and hearing, rather than an understanding of acoustic architecture, may have produced the remarkable acoustic clarity of the best Greek amphitheaters, although, even when these theaters are refurbished for contemporary performances, their acoustics are by no means without major problems (Schubert and Tzekakis, 1999).

There is no doubt that Greek performers invented creative ways to compensate for the acoustics of their open-air theaters. J. Michael Walton (1984) argued that their playwrights used "a whole armoury of visual signs and devices to amplify and often to take over from the spoken word." Dance and exaggerated movements do not depend on sound. Even in a society where political influence depended on skilled rhetoric and fixed speech patterns, with appropriately dramatic gestures, the consequence of weak acoustics would not have been severe. This view is consistent with the notion that acoustic limitations forced the performing arts to be multisensory, thereby compensating for reduced sound quality. Greek theater provides the first concrete example of the way in which space controls performers, as well as the art form, and space itself is determined by social, political, and technical forces in the society.

Size matters: audience size determines aural architecture. The problem is not one of creating a good listening experience for a small number of people located in the "sweet spot," but rather of creating a satisfying experience for an entire audience. Larger audiences create larger problems. For the Greeks, the need for large size was a social consequence of their democracy. For the next two millennia, until technology created the means for listeners to move into a small family room, audience size would be central to aural architecture. But with modern radio broadcasting, millions of families in their parlors could share a listening experience, making the audience profoundly larger than that of a Greek amphitheater. In terms of social function, the aural architecture of Greek open-air theaters is analogous to the aural architecture of modern radio broadcasting. Size matters.

Discussions about Greek aural architecture yet again illustrate the complex interactions among the various social and acoustic issues. Integrating religious spaces into social activities in ancient Greece was similar to doing so in many other cultures, but connecting open-air theaters to social democracy was unique in history. Without the benefit of electroacoustics, Greek amphitheaters were among the world's largest man-made acoustic arenas. They were created to serve a specific need. Yet regardless of how their spaces were used, the relationship between acoustics and social values worked both ways: acoustics responded to social values, and society then responded to the influence of acoustics. Although the specifics vary, the principle remains consistent: culture both filters and reacts to the ways aural architecture is created in any given society.

Shakespearean Theater in Sixteenth-Century England

Whereas the ancient Greeks and Romans established the tradition of large, open-air theaters, the sixteenth-century English emphasized small interior spaces, with improved intelligibility and greater aural intimacy, in their theaters. Given the English climate, enclosing theater spaces was mandatory. And given that theaters served as entertainment, rather than as a political expression of open democracy, they did not

need to be large. English theaters of this period were one of the earliest documented examples of customized aural architecture—acoustic spaces intended for a single use. Eventually, the idea of a reserved space for a specific aural art would be extended to such arts as operas and concerts.

In the late 1960s, working from fragmentary historical records, restorers reconstructed Shakespeare's Globe Theatre in its original form. The current interest in experiencing sixteenth-century theatrical works within their original aural and visual context gives us a unique opportunity to explore historical attitudes toward the aural architecture of theater. Documents give us at least a sense of how participants adapted their acoustic space to dramatic productions, and vice versa. Those who reconstructed the Globe Theatre realized that it was far more than just a place to seat spectators.

Even without any appreciation for acoustics, early theatrical producers overtly recognized that aural architecture was an important part of their arts. In his comprehensive analysis of soundscapes in early England, Bruce R. Smith (1999) argued that the acoustics of theater spaces were recognized as an extension of the human voice. Plays of this period were based largely on verbal rhetoric, a descendant of the Greek tradition of oratory as the highest aural art form. Rather than merely being a place for actors to perform and the audience to listen, the theater was an extension of the actors' mouths, producing, shaping, and propagating their voices. By modern theatrical standards, visual props were sparse and simple. Since oratory was the dominant form of emotional communication, theatrical voices required adequate clarity and loudness to achieve dramatic impact. As discussed in chapter 2, spatial acoustics can provide early sonic reflections, enlarging sonic mass, broadening the acoustic arena, and increasing intelligibility. For all these reasons, sixteenth-century theater spaces were sonic instruments that were extensions of the actors' mouths. Acoustics were an important aural prop, even more important than visual props.

In Shakespeare's time, theaters were generally portable and temporary, installed within such existing spaces as schools, courts, and inns. Moreover, such theaters, each with its own aural personality, were the prized assets of a theater company. Timbers were marked so that they could be dismantled and easily reassembled for the next season or another locale. Early theater spaces were less buildings than portable appurtenances of the company, not unlike stage props. Smith commented that after the theater company at Shoreditch, in Somerset County, had moved to new quarters, they returned two years later to retrieve the theater's wooden framework from their old facilities. Without the old framework, the new space simply did not have the same aural personality as their traditional space. Musicians transported their instruments; acting companies transported their portable theaters. Spatial acoustics had a theatrical personality.

As theater increased in popularity, its spaces became permanent. In 1599, the Globe Theatre was large, even by modern theater standards, with a volume of some 10,000

cubic meters (350,000 cubic feet), holding an audience of perhaps 3,000. It was shaped as a twenty-sided cylindrical polygon with a diameter of some 30 meters (100 feet), and had an open-air top. Having a projecting stage and three tiers of raked seating, the Globe was a true theater in the round. The walls and stage canopy provided many surfaces for sound reflection, yet without an enclosing ceiling, the reverberation remained at a modest 1.4 seconds, at least as measured by Russell Richardson and Bridget M. Shield (1999) in the reconstructed version. With ray tracing of sound paths, the researchers demonstrated that the dominant first reflected sounds would have appeared at an optimum delay of about 20 milliseconds, thus fusing with the direct (incident) sounds.

In their analysis of the reconstructed Globe Theatre, Richardson and Shield commented that certain aspects of Shakespeare's plays make more sense when considered in their original setting. Historians believe that sixteenth-century audiences would have been noisy and boisterous, bringing ambient street life into the theater environment. Being on the central stage with a rear canopy as a reflecting surface located actors where their acoustic arena was largest, thereby elevating their voices above this noise. Asides to the audience, which appear superfluous in a modern theater, become meaningful in this context. Although the theater would never be considered as having "great" acoustics, the acting company adapted to the theater space—both theatrically and acoustically—to maximize their impact.

It is tempting to think of these theater companies as being aural architects. In fact, the original design for a circular performance space with three levels of audience galleries was copied from existing bearbaiting and bullbaiting houses. Actors and playwrights then adapted to the acoustics of these replicated structures, and through empirical experimentation, made minor improvements to them. These spaces served their intended purpose: aurally, visually, and socially. Historical records suggest that theater companies acquired increasing awareness of spatial acoustics, rather than beginning with a proactive understanding of acoustic principles.

Builders copied bearbaiting houses when building the Globe Theatre, just as three centuries later, Sabine copied a European concert hall when designing Boston Symphony Hall. In this respect, little changed. In both cases, sponsors evaluated existing choices and then selected the best compromise among competing social, economic, and acoustic requirements. The practice of aural architecture was mainly a process of evaluating existing models and selecting ones for new spaces.

Scholars in sixteenth-century England wrote of a heightened awareness of sound. As the urban soundscape replaced the tranquillity of pastoral life, the utility of manipulating aural space became apparent to the intellectuals of the period, who extended the earlier work of Greek philosophers. As exemplified by Sir Francis Bacon (1626), intellectuals were already espousing the notion that what could be heard could excite passions far beyond what could be seen. Bacon envisioned the creation of new aural

experiences. If nothing else, he recognized the importance of sounds of space being altered, decomposed, recombined, and then broadcast in altered forms, which included synthetic echoes bouncing from virtual surfaces. But with limited technology, his creative inspirations remained only thought experiments. Proactive manipulating of aural experiences—designing a space for a particular aural experience—would have to wait until the twentieth century.

The Advent of Public Performance Spaces

The Renaissance marked a major shift in the character and size of musical spaces, away from religious toward secular, and away from larger toward smaller. Beginning in the fifteenth century, elite institutions that supported cathedrals, palace theaters, and royal ballrooms were no longer the exclusive sponsors of aural architecture. After two thousand years during which Greek and Christian political and religious thought dominated concepts of music and space, the ascending middle class opened musical spaces to broader segments of society.

With their expanding social power and political influence, tavern owners, small shopkeepers, and wealthy merchants determined the acoustic properties of spaces. The Protestant Reformation shifted resources and institutional power away from religious organizations and toward secular ones. Such newly enfranchised groups had their own ideas about artistic sponsorship, and organized religion was no longer the only viable social structure. Princes, parliaments, municipalities, craft guilds, and enterprising merchants took over many of the functions that had been controlled by the church; economic resources and political powers were now shared. And that sharing allowed music and musical spaces to be more than religious.

These social changes accelerated the shift away from the acoustic extremes of high reverberance in cathedrals and low reverberance in open-air theaters. In varying degrees, spaces now had modest reverberance, and concomitantly, aural clarity and intimacy. As music chambers, concert halls, opera houses, and theaters proliferated; they became the dominant manifestation of artistic spaces. Not only artistic sensibility, but also social forces drove this transformation, thereby creating a new generation of aural architects.

The Reformation signaled the end of Roman Catholic dominance of the aural architecture of public gathering spaces. For the newly formed Protestant sects, churches were more a utilitarian place for sharing religion than a vision of a heavenly home. The service was led by a minister whose liturgy focused on words, ideas, and reasoning. In support of these theological changes, a new generation of church builders began to emphasize acoustic clarity and spatial intimacy through lower ceilings and smaller room size. Automatically, with smaller spatial volume and denser congregations, the new architecture produced shorter reverberation time. Unobstructed sight lines and

increased intelligibility became a requirement for the new architecture, which better suited the spoken sermon.

The larger Dominican and Augustinian churches in Germany, for example, were renovated with the addition of galleries, tribunes, and private boxes, changes that increased sound absorption and decreased reverberation time (Bagenal, 1951). The original Thomaskirche in Leipzig, the space for which Bach wrote the Saint Matthew Passion and Easter Mass, was acoustically more like a small concert hall than a grand cathedral. Leo Beranek (1962) estimates that, when full, the Thomaskirche had a reverberation time of no more than 1.6 seconds, which supported the delicacy of stringed instruments, and a more rapid ebb and flow of musical tempos. Bach and other composers adapted to these acoustic changes by altering their phrasing and inventing new musical forms.

Just as the aural architecture of Reformation churches encouraged new styles in religious music, so small taverns in the century to follow would encourage secular music by hosting public concerts (Elkin, 1955). In a room specially set aside for performance, musicians would sit on a raised podium where they would entertain the drinking guests. Investing in the new musical spaces, proprietors would provide comfortable furnishings for patrons who paid admission fees or purchased food and drink. Listeners would give tips to musicians. The earliest historical record of such musical taverns dates from the mid-seventeenth century. Some music houses published schedules, similar to the marketing and advertising of a modern concert series. Music, as consumable entertainment, became a public business, and every business needed its space. Aural architecture was now an investment based on economic yield.

Music houses brought together individuals who shared an interest in music. Enterprising leaders created amateur music clubs, whose members were from all social levels, including the working class. Members had access to instruments, scores, and a place for informal performances. Handel, during his first visit to London, attended one such club, as did poets, painters, and nobility. The Music Club of the late seventeenth century, run by Thomas Britton, the proprietor of a small coal delivery business, was so famous that the B.B.C. recently did a special program of a concert performed in that space. To have a place to practice their art and earn a living, professional musicians built concert rooms in various fashionable residences. Newspapers routinely printed advertisements for locally organized concerts. Music developed a passionate following among amateurs and professionals alike. Sponsorship of music and performance spaces moved away from prevailing organized institutions, with their theological and philosophical rules. The aural properties of space were now controlled by other ideas.

The ingenuity, creativity, and resourcefulness of these seventeenth-century individuals pursuing music were an extension of a pattern that predates written history: music

as entertainment. Throughout history, troubadours, entertainers, and wandering minstrels traveled from town to town and from festival to festival. Because they would play their music wherever crowds gathered, their performance spaces had unpredictable acoustics. Being sensitive to the effect of their music on the audience, these performers, no doubt, selected their music, tempo, instruments, and playing style to match the immediate acoustics as best they could.

In contrast, many of the social changes in the seventeenth century raised the importance of dedicated spaces for musical performances. Audiences went to hear musicians in these spaces, each with unique, stable, and predictable, which is not to say good, acoustics. Ordinary living spaces were transformed, at least in name, into "music rooms." A wealthy merchant might organize a music night in his elegant parlor. Listeners and performers now had the opportunity of experiencing the effects of space on music. Some spaces were more ideal for certain types of music, while others degraded the listening experience. With this diversity of music and spaces, auditory spatial awareness expanded.

By the eighteenth century, music rooms had grown in size, proliferating throughout London, which was the musical capital of the world. The popularity of music, combined with the attractiveness of commercialized entertainment, created pressure to seat larger audiences and orchestras. Music rooms became concert halls. This in turn spurred the invention of new forms of music, such as the concerto. Larger spaces required instruments that had a brighter and more powerful tonal color, as exemplified by the violin replacing the viol. Virtuoso musicians adjusted their style so that those seated in the last row could hear the delicacy of their interpretation. In recognition of spatial acoustics, for example, the celebrated flutist of early eighteenth century Johann Joachim Quantz (1696) taught musicians to be aware of, and to incorporate, the effects of acoustic space on their performances. The need for adjusting to a space was now an accepted fact.³

Musicians' appreciation of spatial reverberation, especially when performing nineteenth-century music in nineteenth-century concert halls, is abundantly clear in the many quotations collected by Beranek (1996a). The renowned violinist Isaac Stern said that "as the [violinist] goes from one note to another the previous note perseveres, and he has the feeling that each note is surrounded by strength. When that happens, the violinist does not feel that his playing is bare or 'naked'—there is a friendly aura surrounding each note. . . . The effect is very flattering. It is like walking with jet-assisted take-off" (Beranek, 1996a). Reverberation is even more critical to organ music, which, because an organ pipe's valve is an on-off device with no intermediate intensity, sounds dreadful without it. Unlike pianists, organists cannot produce gradual changes in loudness by varying the velocity or pressure on the keys, and they have no equivalent of the sustain pedal. They must therefore rely on reverberation to produce smooth decay and mixing. The famous organist E. Power Biggs, wrote that "an organist will

take all the reverberation time that he is given, and then ask for a bit more, for ample reverberation is part of organ music itself. . . . Certain French music depends so completely on long periods of reverberation that, no matter how well played, in acoustically dead surroundings it falls apart into disconnected fragments" (Beranek, 1996a).

During the prolific period of classical music compositions, spatial acoustics, from the perspective of the composer, became a recognized extension of music, and from the perspective of the performers, spatial acoustics became an extension of their instruments. Musical compositions explicitly specified the instruments' voices, and implicitly specified spatial acoustics. Both music and space were dynamically responding and adapting to each other in a mutually beneficial embrace, a marriage without any means for an amicable divorce.

The seeds of future discontent were sown with the rapid proliferation of concert halls. If they were to accommodate the passions of musical purists and idealists, future aural architects would need to design a musical space for each genre of music from each historic period: anything else would be an "unacceptable" compromise. But, constructed at great cost and effort, concert halls become as inflexible as natural caverns, flattering some genres and disparaging others. Although conductors and musicians do their best to adapt to spatial acoustics, adaptation has its limits.

As we will see shortly, the implications of music tightly integrated with spatial acoustics would haunt the twentieth-century arts. Social changes unrelated either to music or to acoustics would alter aural architecture in a way that inadvertently damaged the legacy of classical music. And then, still later, with the development of inexpensive artificial reverberators, each musical genre could indeed have its own ideal spatial acoustics. Thus technology first undermined and then supported the marriage between music and space.

Industrialization Creates New Aural Attitudes

As noisy machines and devices permeated society during the nineteenth century, the bucolic soundscape was replaced by an industrial one. Machines of this period produced noises at intensities well beyond that of hand tools, making our modern urban environment appear quiet by comparison. This industrial soundscape modified the way people experienced sound and space. Unintended and unplanned reactions to this new environment changed the concepts of music, musical space, acoustic arenas, and aural architecture. Public acoustic arenas, which had served the traditional role of facilitating social cohesion, shrank as noise overpowered this common resource. Private acoustic arenas became an important alternative to public ones. Sound became something that could be owned and controlled.

At the same time that society was losing the use of public acoustic arenas and focusing on creating private ones, post-Edison technology also created a new form of