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The Soundscape of Modernity

Architectural Acoustics and the Culture of Listening in America, 1900–1933

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Chapter 2 The Origins of Modern Acoustics

> Symphony Hall, the first auditorium in the world to be built in known conformity with acoustical laws, was designed in accordance with his specifications and mathematical formulae, the fruit of long and arduous research. Through self-effacing devotion to science, he nobly served the art of music. Here stands his monument.
>
> Plaque dedicated to physicist Wallace Sabine
> Located in the lobby of Symphony Hall, Boston

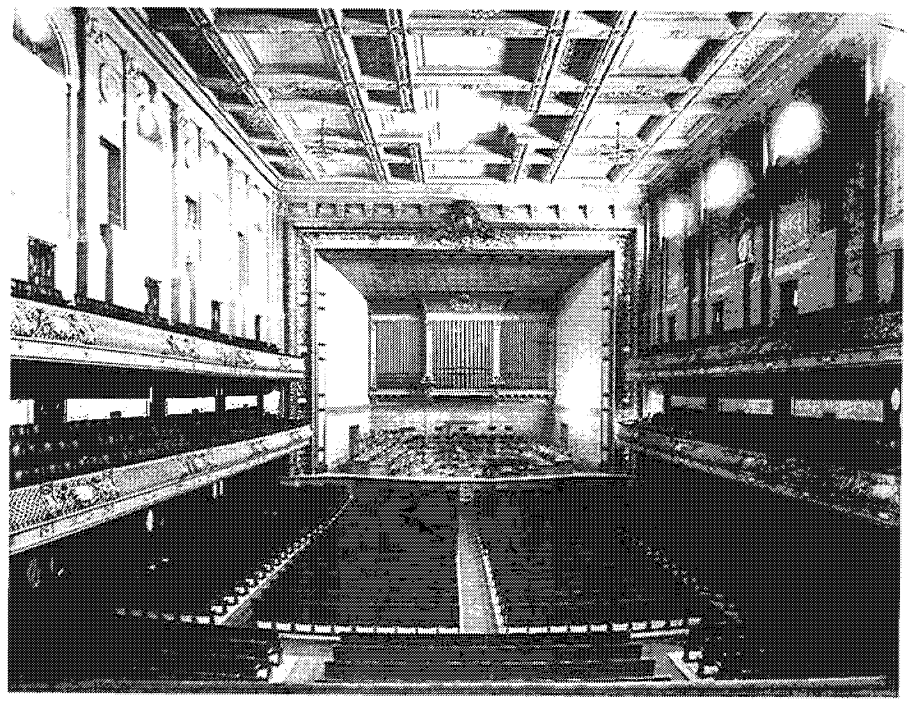
I Introduction: Opening Night at Symphony Hall

On 15 October 1900, the doors of Symphony Hall opened wide, welcoming Boston's music lovers to their new home for orchestral music. (See figures 2.1 and 2.2.) As people entered and took their seats, they noted with approval the tasteful appointments of the interior, but "the question of greatest permanent interest" was that of "the acoustical properties of the new hall."[1] The papers reported that "The great question concerning which not only the thousands in the hall, but tens of thousands not in it, were on the tiptoe of expectation was, 'Is the hall satisfactory acoustically?'"[2] In fact, the question of acoustics had been raised long before opening night; it originated eight years earlier, when the construction of a new auditorium had first been considered.

In 1892, the administrators of the city of Boston announced plans to lay a new road through the downtown site of the city's old Music Hall. While the venerable auditorium had housed a variety of programs over the past forty years, its most noteworthy occupant was the Boston Symphony Orchestra. Wholly owned and controlled by financier and philanthropist Henry Lee Higginson, the orchestra was one of the nation's foremost musical ensembles. Higginson welcomed this opportunity to build a new, exclusive home for his musicians, and he immediately began to raise the funds necessary to construct a new hall. The

2.1
Symphony Hall, Boston (McKim, Mead & White, 1900). Exterior, c. 1900. This new home for the Boston Symphony Orchestra embodied a romantic, even religious dedication to symphonic music that characterized elite culture in turn-of-the-century America. Courtesy Boston Symphony Orchestra Archives.

2.2
Symphony Hall, Boston (McKim, Mead & White, 1900). Interior, c. 1900. To ensure that the auditorium was acoustically worthy of the great music with which it would be filled, architect Charles McKim consulted Harvard University physicist Wallace Sabine on the design of this hall. The gilded crest at the top center of the proscenium is inscribed "Beethoven." Courtesy Boston Symphony Orchestra Archives.

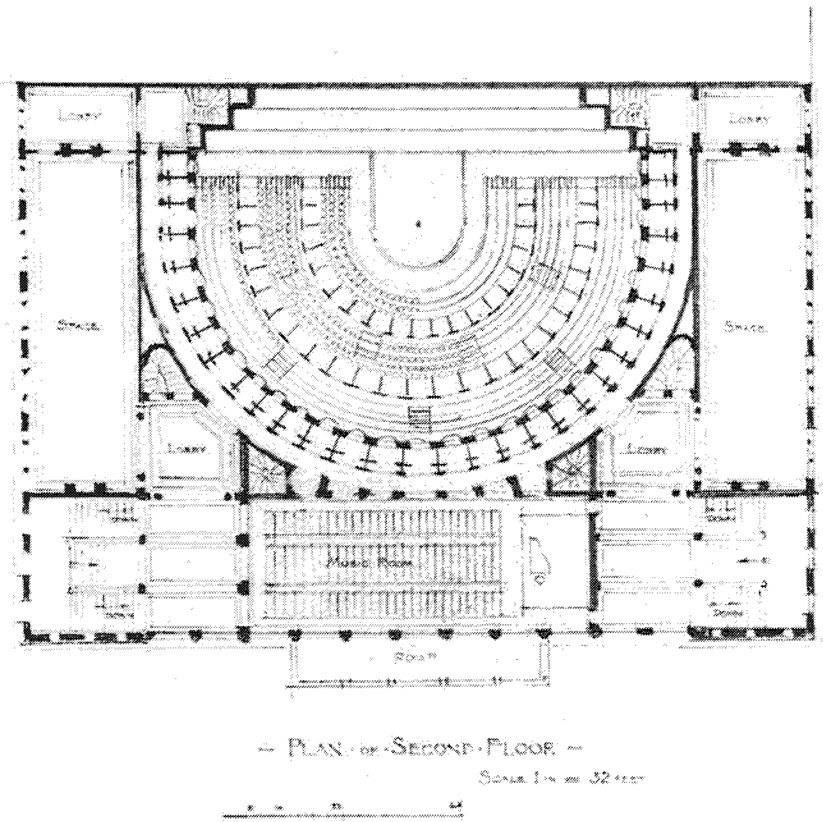


commission went to McKim, Mead & White, a renowned architectural firm then in the midst of building Boston's new public library. Charles McKim took charge of the new project, and Higginson immediately underscored the importance of acoustics. He wanted a hall that would shelter its audience from the "sounds from the world" and do justice to the great music of the past, particularly that of his favorite composer, Ludwig van Beethoven. "Our present hall," he informed McKim, "gives a piano better than a forte, gives an elegant rather than a forcible return of the instruments—noble but weak—I *want* both."[3]

To obtain this effect, Higginson suggested setting the stage in an alcove whose slanted roof would direct the sound of the orchestra out toward the audience. He also identified several European halls well reputed for their sound, and he encouraged McKim to visit and study these halls. McKim contacted John Galen Howard, a former employee then enrolled at the École des Beaux Arts in Paris, and instructed him to inquire into the principles of theater design. Howard spoke with musical and architectural authorities in Europe and worked up three plans, which McKim submitted to Higginson in July of 1893.[4] One plan was rectangular (a form recommended by Charles Lamoureux, director of the Paris Opéra), one was elliptical (the form preferred by Howard's architectural professor, Victor Laloux), and a third—McKim's favorite—was semicircular.

McKim developed his favorite into a more finished design in the style of a Greek theater. (See figure 2.3.) In January 1894, a model was displayed in the newly opened public library, where the patrons "expressed themselves highly pleased with the beauty, simplicity and convenience of the design."[5] Nonetheless, this building was never built, as an economic downturn that spring developed into a severe and ultimately lengthy depression. In April, Higginson informed McKim that the city's "plans of transit" were on hold, thus removing the immediate necessity to build. It was also now difficult to raise funds for a new hall, so the project was temporarily but indefinitely set aside.[6]

By 1898, conditions had improved, the city's roadway proposal reappeared, and Higginson renewed his commitment to build a new hall—but not the one McKim had earlier designed. Higginson informed his architect that, during the hiatus, the board of directors for the new hall had decided that his semicircular design was unacceptable. "While we hanker for the Greek Theatre plan," he explained, "we think the risk too great as regards results, so we have definitely abandoned that idea."[7] The "risk" to which he referred was acoustical; no concert hall had ever been built in the form of a semicircular amphitheater before, and there was no way to know ahead of time how such a hall would sound. The



2.3
Plan for the Boston Music Hall, second floor, drawing by Charles McKim, 1892. This "Greek Theater" design was ultimately rejected by the building committee for the new music hall because its semicircular form was unprecedented in an auditorium intended for symphonic music. © Collection of The New-York Historical Society.

board proposed a rectangular hall, to replicate the form, and, it was hoped, the acoustical success, of the New Gewandhaus in Leipzig.[8]

McKim's own devotion to the Greek theater design had weakened over the years. While traveling in Europe during the project's hiatus, he had discussed auditorium design with a number of eminent musical directors. None could support the unusual form of his amphitheater, and one confessed, "I don't know anything about acoustics, but my first violin tells me we always get the best results in a rectangular hall."[9]

Higginson, however, required something more than a violinist's opinion to ensure that his new hall would be worthy of the great music that he so admired. After all, there were plenty of rectangular concert halls that were not considered acoustical successes. Higginson thus sought the advice of a technical expert, one who could ensure with the perceived authority of scientific laws that his hall would sound as he desired. While he had acknowledged that "musicians must decide the points eventually," Higginson confided to McKim, "I always feel like hearing their opinions most respectfully and then deciding." "Cross' opinions *seem* to me better," he admitted, citing a local scientific authority.[10] In the end, Higginson preferred the counsel of scientists to that of musicians. This preference led him to consult his friend Charles Eliot, the scientifically trained president of Harvard University. Eliot recommended that Higginson contact Wallace Sabine, a young assistant professor of physics at Harvard who had recently worked to improve the acoustics of a university lecture hall.

Wallace Sabine first met Henry Lee Higginson in January 1899. The men carefully studied McKim's plan and Sabine expressed numerous opinions regarding the length of the hall, the number of galleries, the rake of the floor, the shape of the stage, and the system of ventilation. Higginson immediately telegraphed McKim, advising: "It may be wiser to await important letter going tonight before more work on plans."[11] In that lengthy letter, he described Sabine's ideas and made clear that they were to be incorporated into the architect's design: "The room itself I think we can settle between your office, Professor Sabine's office and our office; in fact we shall have to do so." Perhaps fear of offending McKim's sense of authority led Higginson to add a short, hand-written postscript to the typed letter, reassuring the architect that "We will have a perfect hall under your guidance."[12] Any such fear must have been short-lived, however, for upon meeting Sabine, McKim was "much impressed by the force and reasonableness of his arguments, as by the modest manner in which they were presented." He also expressed his confidence that the acoustics of the hall would benefit greatly from Sabine's "counsel and advice."[13]

Sabine and McKim worked together, resolving issues raised by the design and the construction of the hall, throughout 1899 and 1900. On opening night, Higginson highlighted Sabine's contribution in his address to the hall's inaugural audience. "If it is a success," he announced, "the credit and your thanks are due to four men." He acknowledged McKim, the builder Otto Norcross, and the financial manager Charles Cotting, and he also thanked Sabine, adding, "Professor Sabine has studied thoroughly our questions of acoustics, has applied his knowledge to our problem; and I think with success."[14]

Before the nature and extent of Sabine's success can be determined, his work must be examined and contextualized in order to illuminate his accomplishments as well as his audience's expectations. To understand what Sabine accomplished, a brief survey of earlier attempts by both scientists and architects to study and to control sound will first be presented. A detailed examination of Sabine's own investigation will follow, outlining his derivation of a mathematical formula for predicting the acoustical character of rooms. A survey of musical culture in turn-of-the-century America will then consider why the audience at Symphony Hall cared so deeply about what they heard there. Finally, their evaluation of what they heard will be examined. By listening carefully to the creation and critical reception of the acoustics of Symphony Hall, we can begin to comprehend the complex conjunction of science, architecture, and music that constituted this building and this moment in America's cultural history.

II Acoustics and Architecture in the Eighteenth and Nineteenth Centuries

For as long as sound has been reflecting off the surfaces of architectural construction, auditors have reflected upon the subject of architectural acoustics. The ancient Greeks were some of the first to examine the phenomena of sound, considering how it propagated through space and questioning why it behaved differently in different kinds of spaces. In what is considered to be the oldest extant architectural treatise in the Western tradition, the Roman architect Vitruvius articulated ideas about how to control sound in theaters. Philosophers and builders alike, from ancient times through the Middle Ages and into the Renaissance, believed that the phenomena of sound and music were inherently linked to architecture through the underlying harmony of the universe. Simple numeric ratios expressed the order of the cosmos as well as the harmonies of music, and architects—whose goal was to re-create that divine order on a human scale—based their designs on those same proportions.[15]

This belief in the harmony of the universe, a belief that integrated music, architecture, astronomy, and mathematics, was gradually transformed as modern science took shape during the sixteenth and seventeenth centuries. The new science presented an understanding of the world fundamentally different from the divine ratios of the premodern cosmos. As this new way of thinking took hold, science parted ways with both music and architecture.[16]

New theories and experimental techniques enabled scientists to explore more fully the physical dimensions of sound. Mathematicians analyzed the behavior of vibrating strings via the new calculus of Isaac Newton; experimenters like Galileo Galilei and Marin Mersenne examined the motion of vibrating bodies and measured the speed of sound in different media; and countless natural historians collected anecdotes of interesting acoustical phenomena, from unusual echoes to the feats of ventriloquists and talking automata, and recorded them in the pages of new scientific journals.[17]

As modern science took shape, architecture similarly lost its cosmological significance and was recast as a set of techniques that manipulated but no longer transcended the physical world. Alberto Pérez-Gómez has shown that this new kind of architecture, which began to appear in the middle of the seventeenth century, ultimately became "thoroughly specialized, and composed of laws of an exclusively prescriptive character that purposely avoid all reference to philosophy or cosmology."[18] As science and architecture parted ways, the subject of architectural acoustics fell into the gap that opened between them.

This gap only widened over the eighteenth and nineteenth centuries, as the acoustical interests of scientists continued to diverge from the needs of architects. Mathematical elaborations of the behavior of sound reached their apotheosis in the work of Lord Rayleigh, whose *Theory of Sound* was considered the last word on the subject for many years after its publication in 1877.[19] Experimentalists continued to measure the speed of sound, and to examine vibrating bodies, contriving ingenious ways by which to render visible the minute movements of objects and air. Ernst Chladni, for example, dusted the surfaces of vibrating plates with fine sand that collected at the nodes of those plates, creating geometric patterns beautiful enough to impress an emperor. Upon viewing the phenomenon in 1808, Napoleon offered a prize to whoever could explain fully the formation of the patterns, and this prize was claimed in 1816 by the mathematician Sophie Germain.[20] Rudolph Koenig was awarded a gold medal at the 1862 Crystal Palace Exposition in London for a device that transformed vibrations of sound in air into flickering flames, and he brought this device, along with an impressive set of tuning forks and other acoustical apparatus, to America's Centennial Exposition in Philadelphia in 1876.[21] Other investigators developed means to inscribe the vibrations of sound on various media, attempting to create "sound-writing" instruments that might record sounds in a readable form, and still others continued to attempt to build talking machines.[22]

All these efforts, however, were of little use to architects. Koenig's flames failed to illuminate ideas about how best to control the behavior of sound; the talking machines remained silent on this point; and even Rayleigh's voluminous tome devoted only a few, inscrutably mathematical pages to "aerial vibrations in a rectangular chamber."[23] In 1782, the French architect Pierre Patte had searched in vain for scientific advice on the problem of acoustics, and his colleagues a

2.4
Pierre Patte's 1782 design for a theater whose elliptical shape was intended to reinforce the sound of the performers on stage. Late eighteenth-century European architects like Patte were concerned that the players would be unable to fill such a large space with sound, and they attempted to identify one best form to make the most of the sound. Reproduced here from George Saunders, *A Treatise on Theaters* (London: I. and J. Taylor, 1790), plate IV.

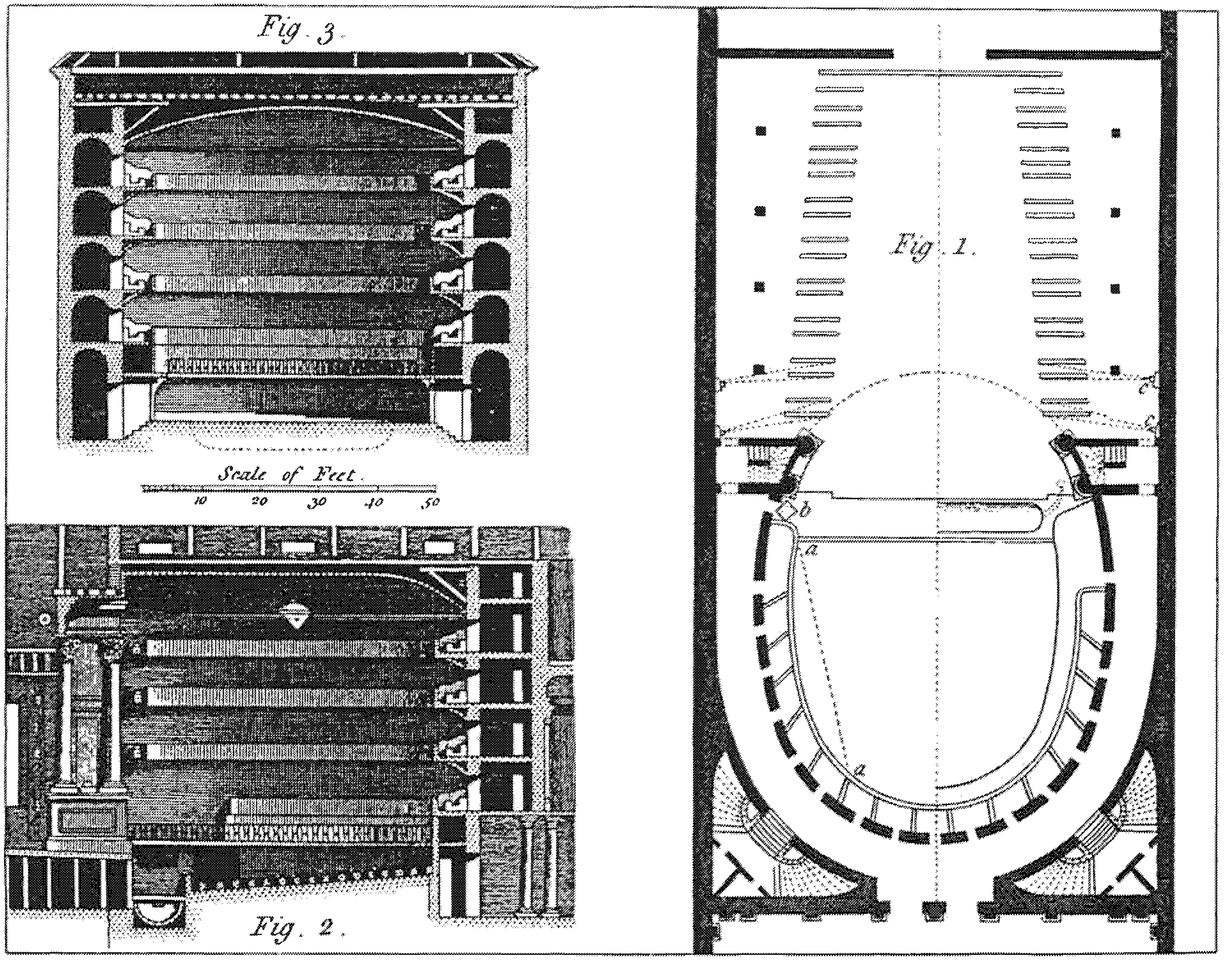
century later were no better off.[24] Left to their own devices, architects like Patte constructed their own creative solutions to the problem of controlling sound.

Pierre Patte's search for scientific advice at the end of the eighteenth century had been compelled by conditions that had recently rendered the need to control sound particularly acute. The commercialization of theater in Europe created new social and acoustical conditions that were perceived to demand expertise not readily available. Theaters built at this time were far larger than their royally sponsored predecessors, and their size presented unprecedented acoustical challenges. Additionally, the commercial nature of the performances taking place within them heightened the importance of delivering good sound, as this accommodation was now considered the right of a public that had paid for admission.[25]

The Margrave's Opera House at Bayreuth exemplified the older, royal tradition in theater design. Built in 1748, its 5,500 cubic meters of space were filled with an audience of just 450 courtly attendants. In contrast, Milan's La Scala, built thirty years later, filled its 11,250 cubic meters with almost 2,300 auditors who gained access not by royal invitation, but by purchasing tickets.[26] The new need for "pecuniary return,"[27] as the architect Benjamin Dean Wyatt put it, led architects to build theaters larger than ever before, but the need to build large had to be limited by the equally important requirement that every member of the audience be able to see and to hear. The goal was thus to identify "the most capacious form which can possibly be constructed, to admit of distinct VISION and SOUND."[28]

Different architects had different ideas about how to identify this form and what it might be. Some turned to analogical thinking, for example, assuming that, because a bell was a sonorous object, a bell-shaped theater would also be sonorous. Others, including the Italian Count Francesco Algarotti, considered these analogies "an absurdity," and promoted instead a more analytical approach that drew on the mathematical certainty of the principles of geometry.[29] Pierre Patte, for example, picked up his compass and rule and applied them to architectural drawings in order to determine which form was best suited to "make the most of" the power of the voice.[30]

Patte evaluated the acoustical properties of differently shaped theaters by analyzing the propagation of sound within them. He drew lines representing rays of sound emanating from a performer on stage, then, following the rule that the angle of incidence is equal to the angle of reflection, he plotted the reflections of those rays off the walls. Patte concluded that an elliptically shaped the-

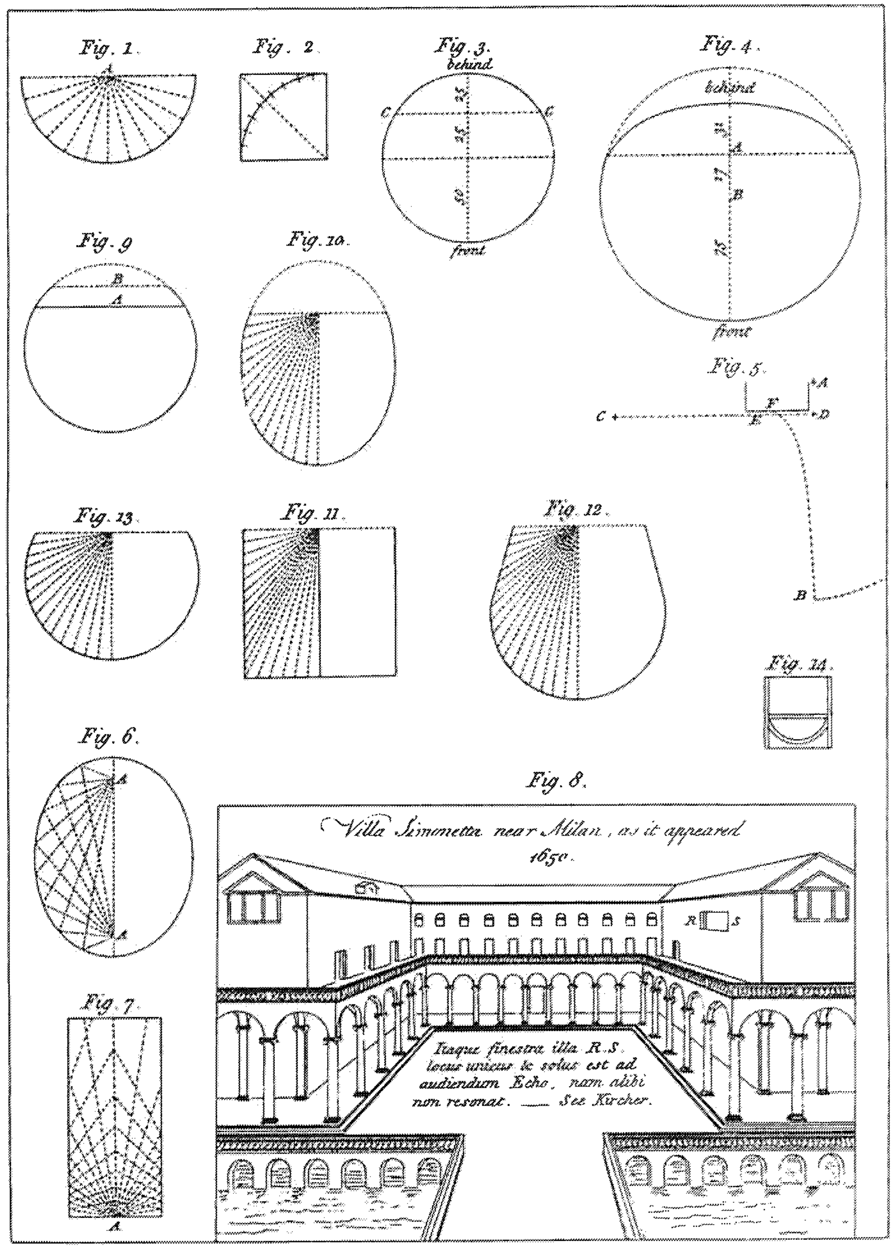


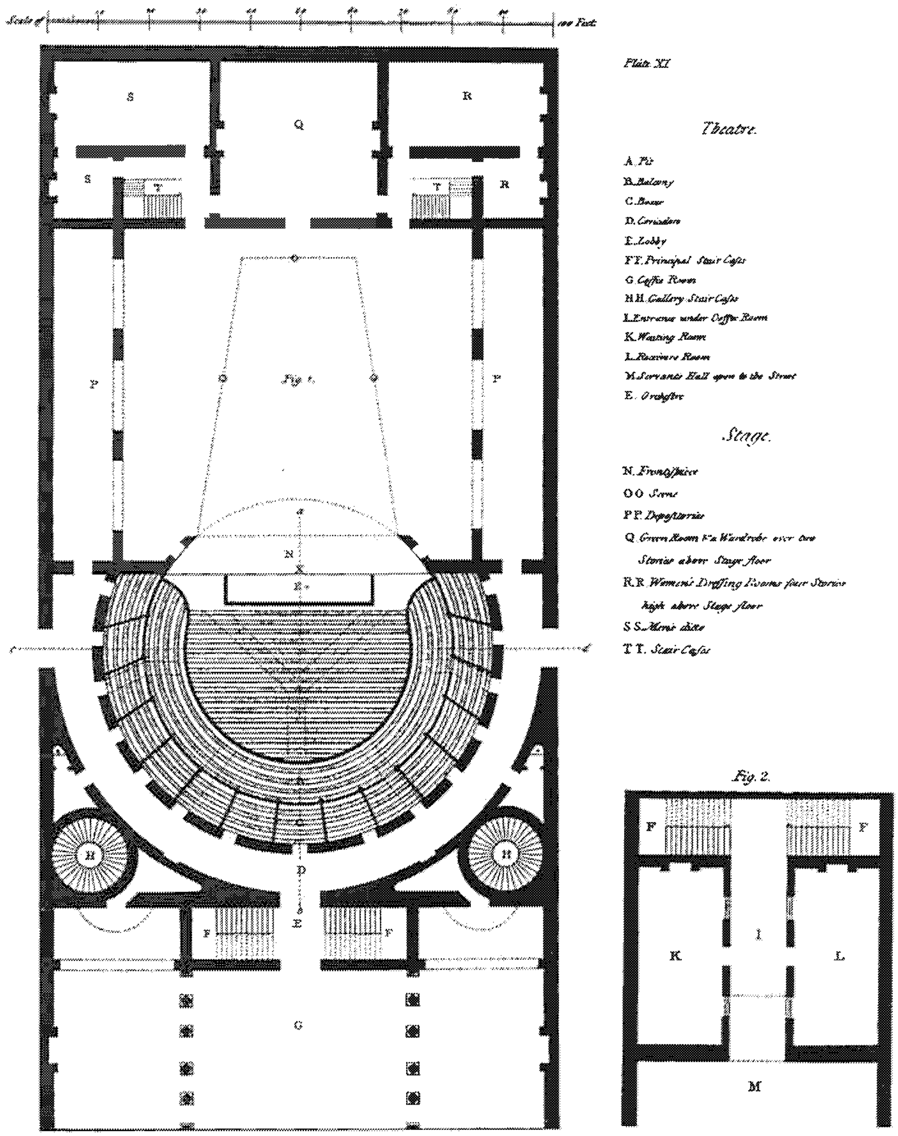
ater would generate the best acoustic effect, believing that its dual foci would actually augment the sound within. According to Patte, the rays of sound emanating from one focus (the performer on stage) would, upon reconvening at the second (in the auditorium), constitute a second source. This would effectively double the sound of the performer, which he feared would be too weak on its own to fill a large theater with sound.[31] (See figure 2.4.)

The British architect George Saunders carried out his own investigation and arrived at results different from those of Patte. Saunders was concerned with the extension, rather than reflection, of the voice. "In designing a theatre," he argued, "the first question that naturally arises is, In what form does the voice

2.5
George Saunders's analyses of the propagation of sound. His figure 6 illustrates the focusing property of ellipses that was the basis for Patte's design. Figure 4 shows the results of Saunders's own experiments on the extension of the voice, illustrating the maximum range of audibility for a listener encircling a speaker located at point "A". George Saunders, *A Treatise on Theaters* (London: I. and J. Taylor, 1790), plate I.

Plate I.





2.6
George Saunders's design for a theater, based on the results of his experiments on the extension of the voice. Both the size and the shape of his design were determined by the dimensions he had measured in his experiments. George Saunders, *A Treatise on Theaters* (London: I. and J. Taylor, 1790), plate XI.

expand?"[32] To answer this question, he placed a speaker at a fixed location outdoors in open space, then had an auditor encircle the speaker, listening as he traveled in front of, around, and behind the speaker. The listener determined the most distant point from which he could hear as he encircled the speaker, thus marking out the extent of the voice in all directions. Saunders then used this figure as the basis for his design. (See figures 2.5 and 2.6.)

Algarotti promoted a semicircular theater, and Wyatt a variant of the form proposed by Saunders, but while each writer on acoustics recommended a different form, all agreed that form was the key to good sound. They shared their concern that too little sound would be generated by the performers, and they all identified as their goal the encouragement, even amplification, of the voices on stage. They also uniformly warned against the use of absorbent materials, as absorption would only impede the accomplishment of this goal.[33] Their shared geometrical approach took advantage of skills they already possessed, and was additionally reinforced by a neoclassical aesthetic that promoted the beauty of an architecture based on simple geometrical forms.[34]

The arguments of these authors, however, ultimately represent theories that thrived in books but not in buildings. Algarotti's treatise offered no specific plans for construction, while Saunders and Patte presented plans that were never built. Wyatt's ideas were realized in his Drury Lane Theatre in London; however, Drury Lane had to be completely remodeled not long after its completion, because of problems with sight and sound.[35] In fact, the acoustical realities of modern buildings were quite different from the problems that these men theorized, and the means to control those realities would ultimately prove equally different.

The American architect Benjamin Latrobe initially shared many ideas about sound with his European contemporaries, even though he was not familiar with their works. Upon engaging directly with the acoustics of an actual building, however, Latrobe reevaluated those ideas. Asked by a friend in 1803 to offer advice on the design for a Quaker meeting house, Latrobe turned to geometry to discover the best form for sound. Seeking to maximize the effect of the voice, he determined that a sphere constituted the best acoustical form, for "a ring of first echo perfectly coincident will be produced, and rings of reechoes, *ad infinitum*, many of them nearly coincident would follow." Recognizing that the sphere was not a particularly practical architectural form, Latrobe suggested, "In proportion as a room approaches this form, it approaches perfection."[36]

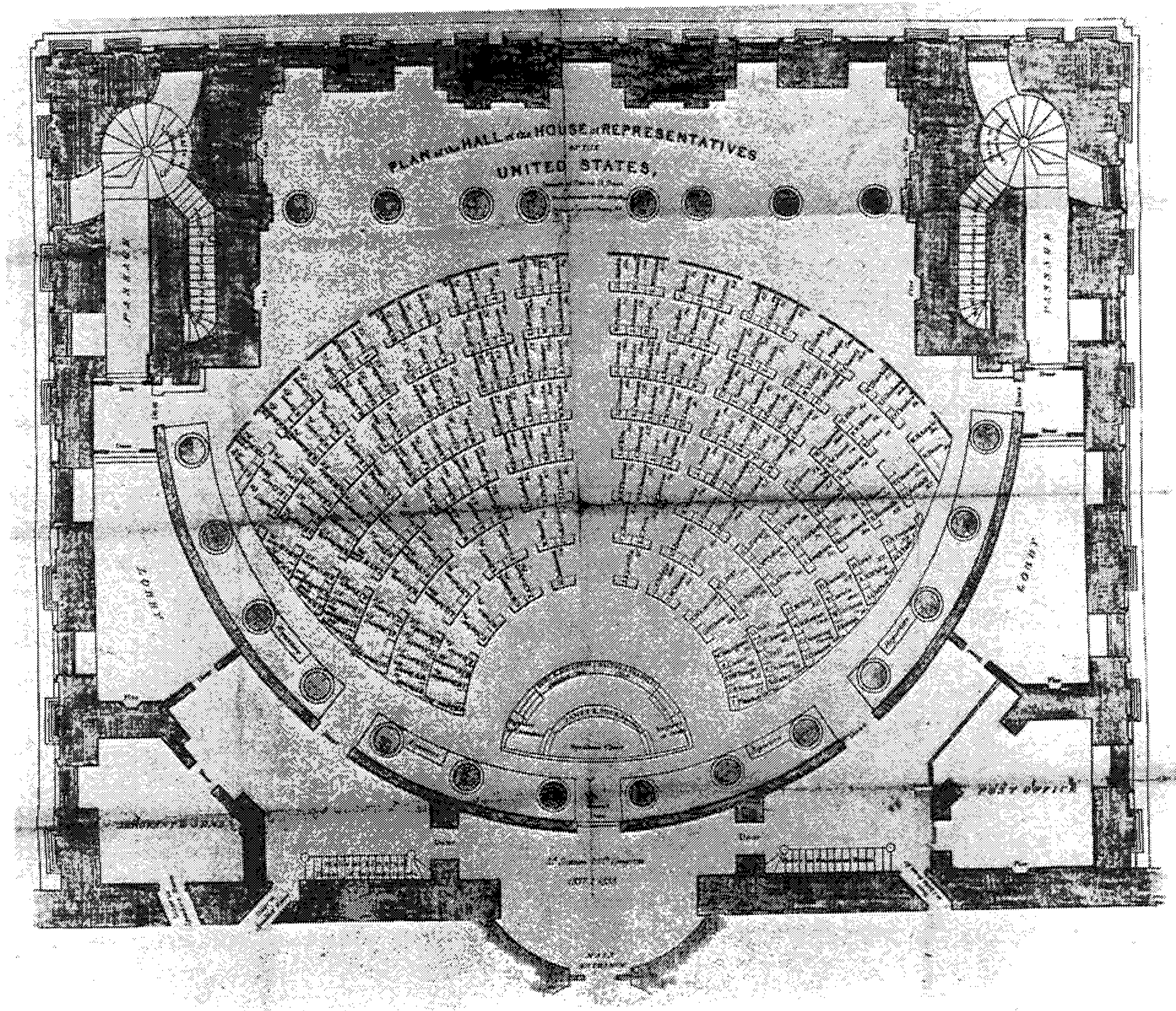
A few years later, as surveyor of public buildings for the United States, Latrobe supervised the construction of the Capitol Building in Washington. Shortly after its 1807 opening, the newspapers reported upon "a very material defect in the hall of the house of Representatives. The voice of the speakers is completely lost in echo, before it reaches the ear. Nothing distinctly can be heard from the chair or the members."[37] Latrobe discovered that not all echoes were beneficial, and he now sought to eliminate them. Curtains were hung, "tastefully and usefully," between the columns of the hall, and the architect reported that "though there is less sound, there is much more heard."[38] The realization that less is more came as a surprise to Latrobe, and he now emphasized that it was "the duty of the architect to suppress or exclude the echoes that would confuse the distinctness of the species of sound which it is the object of the edifice to exhibit."[39]

While Latrobe believed that his efforts to improve the acoustics of the hall had met with the "fullest success,"[40] the Congress and the press continued to complain. The troublesome echoes were eliminated temporarily in 1815 when British troops burned the Capitol to the ground during their invasion of Washington, but when the building was rebuilt in 1819, the new hall proved as unsatisfactory as its predecessor. Over the next few decades, Congress regularly solicited and received advice on how to improve the acoustics of the Hall, but to little avail.[41] One creative suggestion, actually acted upon in 1837, was to reverse the seating arrangement of the Representatives. (See figure 2.7.) The result was not considered an acoustical improvement, however, and before long Congress was back to facing forward.[42]

By mid-century the House had outgrown its still ill-sounding chamber. Plans were drawn up for the expansion of the Capitol and the construction project was assigned to the Army Corps of Engineers under the direction of Captain Montgomery Meigs. In 1853, Meigs was ordered by his commander, Secretary of War Jefferson Davis:

> You will examine the arrangements for warming, ventilation, speaking and hearing. The great object of the extension of the Capitol is to provide rooms suitable for the meeting of the two houses of Congress—rooms in which no vitiated air shall injure the health of the legislators, and in which the voice from each member's desk shall be made easily audible in all parts of the room. These problems are of difficult solution, and will require your careful study.[43]

"By direction of the President, who is desirous of obtaining the best scientific authority within reach upon this subject,"[44] Meigs invited Joseph Henry, secretary of the Smithsonian Institution, to review his ideas on sound as they applied to the new Hall of the House of Representatives. Henry, along with his scientific colleague Alexander Dallas Bache, subsequently reported to Davis that "the principles presented to them by Captain Meigs are correct, and that they are judiciously applied."[45] Nonetheless, when the new hall was finished and put to use it was found to be no better than its predecessor.



Joseph Henry's experience with the new hall may have emphasized to him that attention to form was insufficient to ensure good sound.[46] Others were certainly questioning the old approach, complaining that "form is the only point that architects seem to consider of importance."[47] While the role of materials in controlling sound had been previously acknowledged, architects seeking that control could only conclude that "the different degrees in which substances derived from the mineral, vegetable and animal kingdoms are favourable to the transmission of sound, appear to be regulated by laws not easily demonstrable."[48]

2.7
Seating Plan, United States House of Representatives, 1837–1838. This plan shows a reverse seating arrangement that was recommended by the architect Robert Mills. By having the members "speak to the curve" of the chamber's rear wall, Mills believed that the sound of the hall would be improved. The experiment was unsuccessful and the desks were returned to their normal positions in the subsequent session of Congress. Plan of the Hall of the House of Representatives 1837 & 1838, 2nd Session of the 25th Congress, drawn by David H. Burr. Architect of the Capitol.

Attempts to identify these laws were generally unconvincing,[49] but new ideas about the physical nature of sound would begin to provide a new means by which to understand the action of materials, and Henry himself would help formulate those ideas.

Shortly after his consultation on the House Chamber, Joseph Henry undertook a series of experiments to investigate the effect of materials upon sound. He sounded a tuning fork, placed the stem of the fork against the material to be tested, then measured how long the fork continued to vibrate. Believing his eyes to be more sensitive than his ears, Henry marked the cessation of vibration at the moment when he could no longer visually perceive the movement of the fork. This measure of time represented the sound-absorbing property of the different materials he tested, including cork, rubber, wood, and stone. Unlike eighteenth-century neoclassical architects, Joseph Henry had no interest in representing sound as geometric rays. As a mid-nineteenth-century physicist, he was instead committed to exploring the new idea of the conservation of energy and this energetic conception of sound was at the heart of his investigation.

According to this new way of thinking, the moving fork, the emitted sound, and the material with which the fork was in contact all contained a given amount of energy. While this energy could manifest itself in different ways, it could not be destroyed.

Henry observed that, while a vibrating fork suspended in air from a thread continued in motion for 252 seconds, the same fork vibrated for only ten seconds when placed in contact with a large thin board of pine. The board increased the volume of sound, and Henry explained that "the shortness of duration was compensated for by the greater intensity of effect produced."[50] When the fork was placed in contact with a piece of India rubber, the sound remained very feeble, yet it quickly died away. Where was the compensating effect here? Henry proved that the energy was converted to heat rather than sound, by measuring an increase in the temperature of the rubber as it absorbed the vibrations of the tuning fork.[51]

Joseph Henry's experiments constituted an innovative attempt to analyze and to quantify the sound-absorbing properties of materials, and this attempt was a direct result of a new energetic way of understanding the physical properties of sound. It is not apparent, however, that he applied his results to the design of any structure. Even though these experiments were conducted by Henry to evaluate the design of a lecture hall for his own Smithsonian Institution, Henry's practical contributions to that project focused strictly on its form. In his experiments on materials, he was ultimately more interested in tracking the conservation of energy than with generating knowledge of practical use to architects.[52]

Although Joseph Henry did not apply his new knowledge about materials directly to design of the Smithsonian lecture hall, he did use the publication of those results as an opportunity to speak out against the architecture that housed that hall. American architecture at mid-century was characterized by a historically inspired eclecticism in which virtually any style—from Gothic to Egyptian—was appropriate, as long as it was from the past. Henry disliked this approach, and he particularly disliked the crenellated castle that James Renwick had designed to house the Smithsonian Institution. As head of that organization, Henry worked and lived within its Romanesque towers, but not without complaint. "Every vestige of ancient architecture," he explained, "which now remains on the face of the earth should be preserved with religious care; but to servilely copy these, and to attempt to apply them to the uses of our day, is as preposterous as to endeavor to harmonize the refinement and civilization of the present age with the superstition and barbarity of the times of the Pharaohs." "It is only when a building expresses the dominant sentiment of an age," he continued, "when a perfect adaptation to its use is joined to harmony of proportions and an outward expression of its character, that it is entitled to our admiration."[53]

Henry's opinions about architecture were not widely shared by architects, and the historicism that he decried would become even more prevalent in the years to come.[54] Just as the geometry of neoclassicism had provided architects with a means to attempt to control sound, so, too, did the historical eclecticism of the nineteenth century offer its own approach. Practitioners of an aesthetic of imitation, not surprisingly, turned to imitation as they attempted to solve their problems of acoustical design.

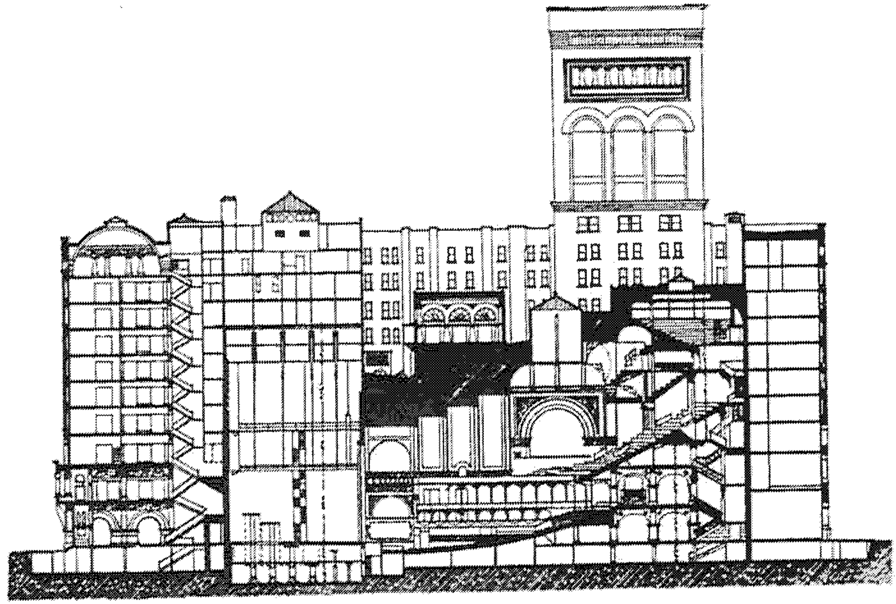
At mid-century the cities of New York, Boston, and Philadelphia were all engaged in the construction of new music halls and opera houses, and in each case the architects drew on the form of an extant European theater in an attempt to re-create the acoustical qualities of that theater in their own design. The New York Academy of Music was patterned after the Berlin Opera House; the Boston Theatre after the theater at Bordeaux; and the Philadelphia Academy of Music after La Scala in Milan.[55] In no case was the attempt at imitation complete, nor were the acoustical re-creations that the architects accomplished. While these projects were more fortunate than many others in being judged acoustically successful, the method of replication was not considered a definitive approach to acoustical design. The architects of the Philadelphia Academy admitted that popular understanding of acoustics among architects was "very vague and indistinct." While they asserted that an architect who had "properly applied himself to this branch of his profession" could "certainly do a great deal toward the accomplishment of his object, especially if his study is founded upon practical experience, combined with the observations and results deducted from other buildings of a similar nature," they had to admit that "there always remains something left to chance."[56]

Almost fifty years later, Henry Higginson and Charles McKim would find few options beyond this method of replication when they sought to ensure good sound in their own music hall. This approach led Higginson to reject McKim's Greek theater plan, as it was unprecedented in housing a modern concert hall, and it drove their decision to build a rectangular hall, in imitation of the old Music Hall in Boston and the Leipzig Gewandhaus. Another precedent that Higginson surprisingly rejected was Carnegie Hall in New York. His orchestra had performed there numerous times since its opening in 1891, and he reported to McKim, "our people all think Carnegie Hall horrible." "Very noisy music produces considerable effect," he explained, "but the moment an orchestra plays the older music and relies on delicate effect, everything is gone. I have always disliked the hall very much, and I expected to like it very much before trying it."[57] Higginson's critique may have been idiosyncratic, for even if Carnegie Hall had not yet acquired the reputation it would later enjoy, the hall's acoustics were the accomplishment of an architect who, alone among his peers, was considered a master of sound.

Dankmar Adler learned his craft while rebuilding Chicago after the great fire of 1871. He established an independent practice in 1879 and received his first theater commission that same year. Adler soon promoted his talented associate Louis Sullivan to partnership, and Adler & Sullivan executed a dozen more theater and auditorium commissions over the next decade.[58] These projects were uniformly judged acoustical successes, and Adler became known as an expert on sound, serving "at various times as a consultant on acoustics."[59] One such project was William Burnet Tuthill's design for Carnegie Hall in New York.[60] His most famous accomplishment, however, was the partnership's own Auditorium Building in Chicago, which was completed in 1890.

As architects, Adler & Sullivan stood out from their colleagues by echoing Joseph Henry's earlier frustrations with the historicist tendencies of their field. Adler castigated nineteenth-century theater design for its reverence for the "his-

2.8
Auditorium Building and Theater, Chicago (Adler & Sullivan, 1889). The movable partitions that could block off the two uppermost balconies are indicated here, in both open and closed positions, with dotted lines. Dankmar Adler, "Theater-Building for American Cities," *Engineering Magazine* 7 (August 1894): 723.

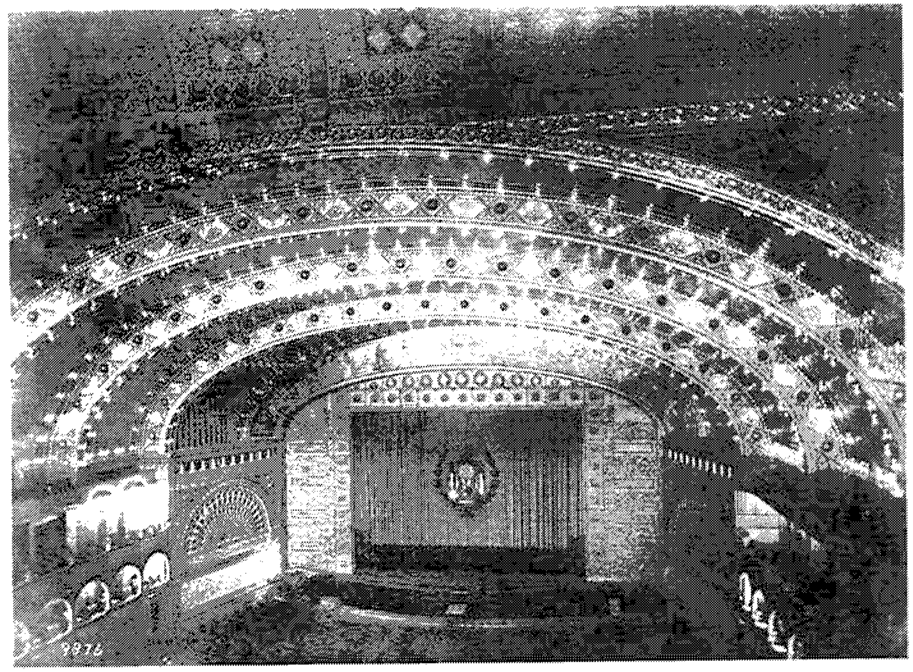


torically transmitted type," a reverence that was "the result of a mental attitude which sees in a brilliant and admirable achievement of the past, not a legitimate evolution from the conditions of its own environment, but a creation standing out for all ages to be blindly idolized and imitated."[61] The Auditorium, in sharp contrast, was a complete expression of the needs of its own environment—the excitement and energy of late nineteenth-century Chicago. It was a ballroom, a convention hall, and an auditorium for a rapidly growing city. The theater held over four thousand people, and Adler incorporated movable ceiling panels that could be pulled down to block off the two uppermost galleries and reduce the capacity when a smaller space was more appropriate. (See figure 2.8.) Adler & Sullivan surrounded the theater with a hotel and offices to render the building financially self-sustaining. Sullivan designed a simple granite facade that heightened the effect of the ornament within. The theater glittered with gilded moldings and ornate grillwork. Murals and a stained-glass skylight added color, while the whole was illuminated by a "tiara" of electric lights embedded in the ceiling.[62] (See figures 2.9 and 2.10.)

Opening ceremonies were held on 9 December 1889. President Benjamin Harrison was a special guest of honor, and a musical program was presented by Adelina Patti, opera's reigning diva. Patti pronounced, "The Auditorium is perfect. The acoustics are simply perfect," and everyone agreed.[63] Architectural

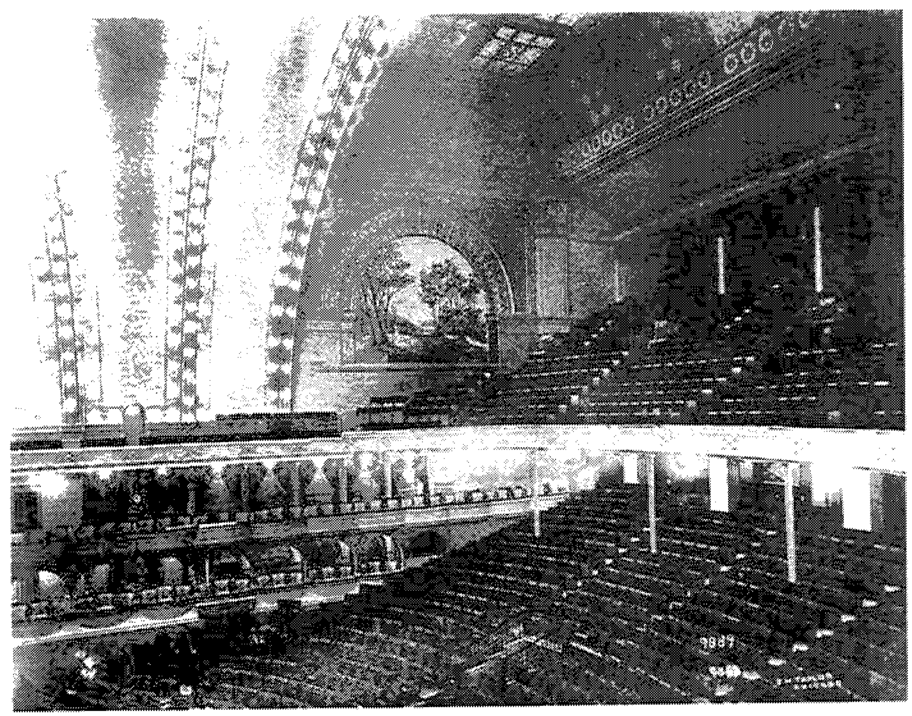
2.9

Auditorium Theater, Chicago (Adler & Sullivan, 1889). Interior, looking toward the stage. The Auditorium Theater was renowned for its excellent acoustics. Architect Dankmar Adler contested his reputation as an expert in acoustics and was ultimately unable to explain why his buildings sounded so good. *Auditorium Building* (Chicago: J.W. Taylor, c. 1890). p. 15. Courtesy Marquand Library of Art and Archaeology, Princeton University.



2.10

Auditorium Theater, Chicago (Adler & Sullivan, 1889), looking toward the rear balconies. In this photograph, the two uppermost balconies have been blocked off by movable partitions (the upper one curved, the lower one flat), thereby reducing the capacity of the hall from over 4,000 to about 2,500. *Auditorium Building* (Chicago: J.W. Taylor, c. 1890), p. 17. Courtesy Marquand Library of Art and Archaeology, Princeton University.



critic Montgomery Schuyler wrote, "It is pleasant to know that in this instance the science of acoustics, which so many architects deny to be for their purpose a science at all has been vindicated, and that the auditorium is in fact an excellent place in which to hear."[64]

Adler articulated his ideas on theater acoustics in a paper that he read to the American Institute of Architects in 1887. He offered advice on situation, construction, fireproofing, lighting, and ventilation, and concluded with the caveat that "all of these will be as naught unless the acoustic properties are such as to permit the easy and distinct transmission of articulated sound to its remotest parts."[65] In order to secure this effect, Adler proposed that the architect should avoid hard, smooth surfaces, and instead design well-broken walls and ceilings arranged to direct the sound toward the audience. The proscenium should be low, with the width and height of the hall increasing toward the rear, to promote the passage of sound.

Adler later justified these recommendations with explanations that drew upon the scientific language of the conservation of energy, but it is not apparent that the science of energy actually helped him to generate his designs. According to Sullivan, Adler's success in architectural acoustics was intuitive. "It was not a matter of mathematics, nor a matter of science," he explained. "There is a feeling, perception, instinct, and that Mr. Adler had. Mr. Adler had a grasp of the subject of acoustics which he could not have gained from study, for it was not in books. He must have gotten it by feeling."[66]

Adler himself described his technique, not as an instinctive one as Sullivan portrayed it, but as a simple program of independent thought and action. In 1894, he warned his fellow architects that he would not provide "a repository of historical information about the theaters of the past, nor a description or critical disquisition upon the theaters of the present day, nor yet a compendium of scientific formulae for solving the various problems of theater design." "With a view to stimulating original and independent thought and action," he explained, "I shall call attention to certain facts and conclusions, the recognition and formulation of which are within the reach of every intelligent observer and of every industrious student of objects and events."[67] To Adler, the theater was an "organic whole," and he took issue with those who would design a structure "in strict accordance with the tenets of any 'style,'" then leave the resolution of practical problems to "engineers and 'specialists.'"[68] He even contested his own reputation as an "alleged expert," and proposed that anyone capable of clear and incisive thought could join the ranks of such experts.[69]

But here, too, Adler's ideas were not widely shared by his colleagues. As early as 1811, Benjamin Latrobe had called for "a system by which an architect could be guided in his design,"[70] and throughout the century, architects had echoed this plea for experts to provide them with a set of "fixed rules."[71] Most shared the willingness of architect Rudolph Markgraf "to buy any books, articles, pamphlets or liter[a]ture setting force [sic] a practical method whereby to make sure of the successful properties of an Auditorium, or to employ the service of experts, if there are such experts, and if the services of such experts or specialists, can be secured at a reasonable fee and with an assurance on their part of satisfactory results."[72]

Adler's assertion that every architect could be his own acoustical expert fell on deaf ears, and Adler's success in this field remained uniquely his own. While he used the language of science to describe his approach to the problem of acoustics, he failed to provide a scientifically based system of design, and there was no means by which he could share his success with others. Adler passed away in 1900, and his acoustical expertise died with him. At the time of his death, however, architects were suddenly presented with a new means by which to achieve that success for themselves. Just a few pages away from Adler's obituary in the *American Architect and Building News*, American architects would encounter the first of a series of papers on acoustics by Wallace Sabine. Like Adler's intuitive approach, the system that Sabine outlined would consistently produce acoustically successful structures. But Sabine would additionally succeed where Adler had failed, by offering architects a compendium of scientific formulae that he, as a specialist, could simply and easily apply to their designs.

III Wallace Sabine and the Reverberation Formula

Wallace Sabine was born in 1868 in Richwood, Ohio. He was an intelligent child with an ambitious mother who apparently demonstrated an "abnormal conscientiousness in the exercise of her maternal duties."[73] Mrs. Sabine was certainly intent upon providing Wallace with every opportunity to develop his abilities. She enrolled her young son at Ohio State University, where he studied physics with Thomas Corwin Mendenhall and graduated in 1886 at the age of eighteen. Mrs. Sabine then left her less ambitious husband behind and moved with her son and daughter to Boston so that both could continue their studies, Wallace at Harvard University and his sister Ann at the Massachusetts Institute of Technology.[74]

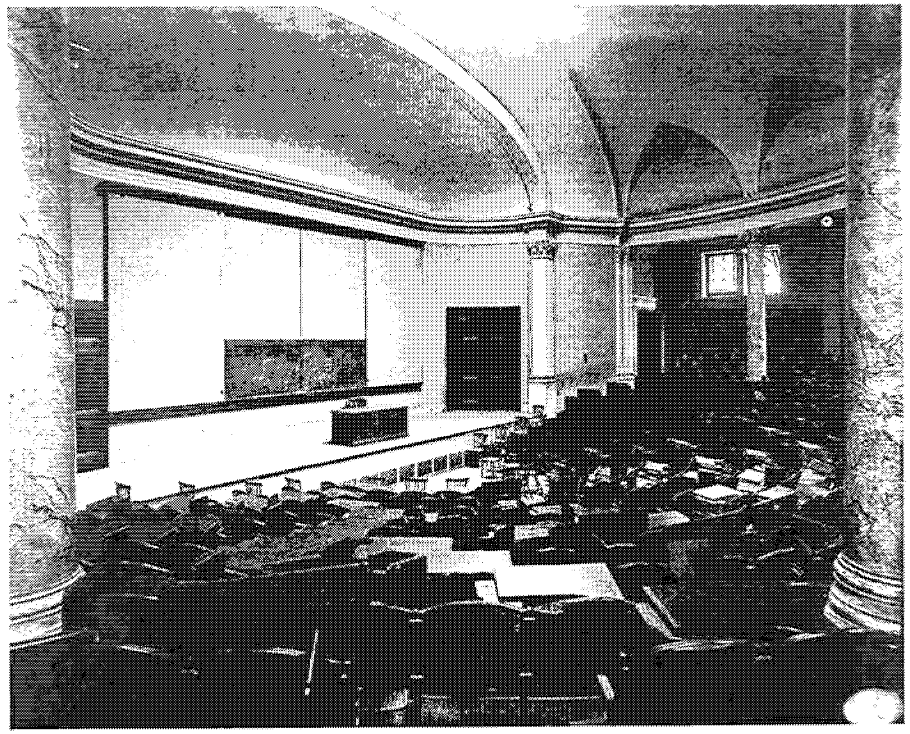
Sabine received his M.A. from the Department of Physics at Harvard in 1888, and he subsequently collaborated with his senior colleague John Trowbridge on a series of studies exploring different aspects of electricity.[75] One investigation followed the research of Heinrich Hertz, who had recently produced the first evidence for the existence of electromagnetic waves. Hertz's work had drawn upon analogies to sound, and Trowbridge and Sabine followed suit when they concluded that Hertz's equations did not fully represent the behavior of electrical oscillations in air:

> Since the latter writer has taken the term *resonance* from the subject of acoustics, and has given it a new significance in relation to electrical waves, we are tempted to draw also an analogy from the subject of sound. Laplace showed that the discrepancy between the value for the velocity of sound in air calculated from the theoretical equation, and that obtained by experiment, was due to a transformation of energy in heating and cooling the air during the passage of the sound wave. Our experiments on the transmission of electrical waves through the air show also that the values calculated from the theoretical equation do not agree with the experimental values. The discrepancy, we believe, can be explained also by a consideration of the transformation of energy in the dielectric.[76]

Almost fifty years earlier, Joseph Henry's exploration of the acoustical properties of materials had constituted an early foray into the new energetic physics. Now, physicists like Sabine thought nothing of drawing upon the properties and principles of energy to connect phenomena as diverse as light, heat, electricity, and sound. Sabine was studying electricity, however, not sound, and this analogical thinking was about as close as he came at this time to the science of acoustics.[77] When he turned to acoustics just a few years later, however, and initiated what would become a lifelong investigation of the behavior of sound, this energetic framework would prove crucial in shaping his work.

In 1895, Sabine was asked by President Eliot to improve the faulty acoustics of a university lecture hall in Harvard's new Fogg Art Museum. The room was too reverberant, generating such a prolonged echoing of sound that a speaker's voice was unintelligible to the listeners who gathered there to hear it. (See figure 2.11.) Disappointed with this loss of valuable teaching space, Eliot asked Sabine to find a way to reduce the reverberation in the room. He suggested that Sabine develop a quantitative measure of acoustical quality, in order to compare the faulty room with Harvard's acoustically superb Sanders Theatre. Eliot hoped that the new hall could then be altered to match the acoustics of the theater.[78]

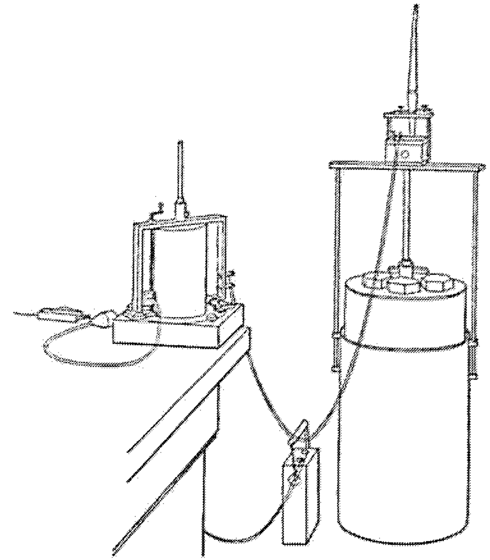
2.11
Lecture Hall, Fogg Art Museum, 1895 (since demolished). Harvard's president Charles Eliot assigned the task of improving the acoustics of this excessively reverberant room to Wallace Sabine, a young assistant professor of physics at the university. Courtesy of the Harvard University Art Museums, © President and Fellows of Harvard College.



It was not obvious to Sabine what that measure should be, as the measurement of sound was a problem that had long challenged acoustical experimenters. Throughout the past century, scientists had approached this problem primarily by attempting to render visible acoustical phenomena. Sabine initially adopted this strategy and employed a variant of Rudolph Koenig's "dancing flame" device to study the sound in the Fogg Lecture Room, but there was no useful way to interpret the results. Sabine thus abandoned all attempts to look at sound, and instead chose the seemingly obvious, but long neglected, alternative of listening to it. He discovered that "the ear itself, aided by a suitable electrical chronograph," gave "a surprisingly sensitive and accurate method of measurement."[79] What Sabine chose to measure was the time of reverberation: the duration of audibility of residual sound as it echoed through the room and slowly died away.

Sabine's technique consisted of sounding a source, an organ pipe with a pitch of 512 cycles per second (cps), until a steady volume of sound was achieved in the room. He then shut off the source of sound and listened to the residual sound, or

2.12
Experimental apparatus employed by Wallace Sabine in his investigation of reverberation. The large tank of compressed air was used to sound the organ pipe mounted on top of it. Sabine then shut off the air supply and listened to the continuation of sound, or reverberation, until it was no longer audible. The chronograph on the table recorded the interval, or reverberation time. Wallace Sabine, *Collected Papers on Acoustics* (Cambridge, Mass.: Harvard University Press, 1922), p. 15.



reverberation, until it was no longer audible. A torsion pendulum silently recorded the duration of audibility to hundredths of a second. (See figure 2.12.)

Sabine carefully measured the reverberation times of the Fogg Lecture Room and Sanders Theatre, and he studied numerous other rooms throughout the Harvard campus, as well as in Cambridge and Boston. In order to minimize the disturbing effects of streetcars, students, and other sources of noise, he conducted all of his research late at night.[80] Sabine emphasized to his undergraduate students the importance of experimental precision and accuracy, and he clearly practiced what he preached. He once threw out over three thousand measurements, representing several months' work, after determining that the clothing worn by the observer (himself) had a small but measurable effect upon the outcome of his experiments. Subsequently, he always wore the same outfit ("blue winter coat and vest, winter trousers, thin underwear, high shoes") when experimenting.[81]

Sabine measured the reverberation times of rooms as he found them, and he additionally manipulated those reverberation times by introducing different quantities of sound-absorbing materials. The removable seat cushions from Sanders Theatre proved conveniently portable and standardized absorbers of sound, and Sabine could be glimpsed on any given night (if one happened to be out between midnight and four o'clock in the morning) lugging heavy stacks of cushions across the dark campus in order to make his measurements.

Sabine's experimental method derived from his earlier collaborations with John Trowbridge, and was based on his fundamental assumption that sound, like virtually all other physical phenomena, was best defined as a body of energy. When Sabine studied electrical phenomena, he had focused on transformations of electrical energy in the material through which it passed. Having now turned to acoustical phenomena, Sabine retained that focus and based his examination on the transformation of sound energy in a room into heat and motion by the architectural materials of which the room was constituted. It is not evident that Sabine knew of Joseph Henry's earlier studies, but he shared Henry's emphasis on energy and materials. Sabine's work differed, however, in that the practical application of his results was always foremost in his mind.

Sabine's energetic treatment of sound was nonetheless insufficient to generate the quantitative understanding that he sought. Indeed, for a long time he was not sure what to do with his measurements, except to keep making more of them. After several years of experimentation and thousands of hours devoted to the painstaking collection of data, he was still unable to derive a fundamental mathematical relationship between the architectural properties of a room and its reverberation time. Until he had achieved that understanding, Sabine would not consider his work complete. Meanwhile, the Fogg Lecture Room remained unusable and unused.

By 1897, President Eliot had run out of patience. When he prompted the young professor for a progress report, Sabine responded, "I certainly hope to bring it to success in time, but only after a variety of experiments and a training of my hearing which will require several years, and the working of some rather remote side issues."[82] Eliot's own response was now unequivocal: "You have made sufficient progress to be able to prescribe for the Fogg Lecture Room, and you are going to make that prescription."[83] Thus forced, Sabine had panels of sound-absorbing felt hung on various wall surfaces in the lecture room, and the auditorium was finally usable, although far from the acoustical equivalent of Sanders Theatre.

The conclusion of this episode might have signaled the end of Wallace Sabine's work on acoustics.[84] It was at this time, however, that Henry Higginson approached Charles Eliot to solicit scientific advice on his new concert hall, and Eliot passed Higginson's request on to Sabine. Knowing the limitations of his understanding of sound, Sabine was initially reluctant to undertake this important new assignment. According to his biographer, he went home that evening and "devoted himself feverishly to a perusal of his notes, representing the labors of the preceding three years. Then, suddenly, at a moment when his mother was watching him anxiously, he turned to her, his face lighted with gratified satisfaction, and announced quietly, 'I have found it at last!'"[85]

What Sabine found was that when he plotted the quantity of Sanders Theatre seat cushions (x) versus the corresponding reverberation time for a room (y), the resulting graph was a rectangular hyperbola, a standard mathematical curve characterized by the equation:

$$x\,y = k,$$

where k is a constant. Sabine had graphed his data before,[86] but this time, by extrapolating beyond the points representing data that he had collected, he was able to see his experimentally derived fragment as part of a larger curve, a hyperbola. (See figure 2.13.) Sabine's earlier preoccupation with the precision and accuracy of his data points had prevented him from seeing this curve. Only after he had been forced to stop experimenting was he able to consider the data at hand without thinking about how to improve it or to collect more of it. Only then did he discover the hyperbolic relationship.

Sabine realized that his discovery was a breakthrough for his understanding of reverberation. Now eager to assume responsibility for the acoustics of Higginson's new music hall, he immediately wrote to President Eliot:

2.13
Wallace Sabine's plots of reverberation time versus the amount of sound-absorbing material in a room, 1900. The first graph shows his experimentally derived data. The second graph shows how he extrapolated this curve to discover the hyperbolic relationship between the two quantities. Wallace Sabine, *Collected Papers on Acoustics* (Cambridge, Mass.: Harvard University Press, 1922), pp. 21, 22.

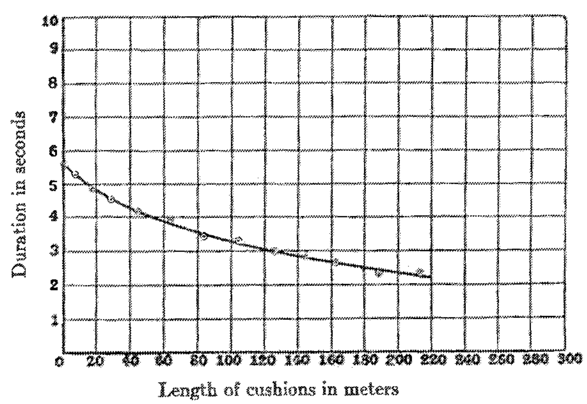


Fig. 5. Curve showing the relation of the duration of the residual sound to the added absorbing material.

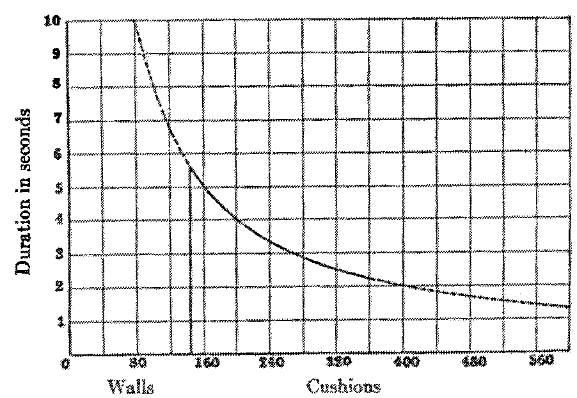


Fig. 6. Curve 5 plotted as part of its corresponding rectangular hyperbola. The solid part was determined experimentally; the displacement of this to the right measures the absorbing power of the walls of the room.

> When you spoke to me on Friday in regard to a Music Hall I met the suggestion with a hesitancy the impression of which I now desire to correct. At this time, I was floundering in a confusion of observations and results which last night resolved themselves in the clearest manner. You may be interested to know that the curve, in which the duration of the residual sound is plotted against the absorbing material, is a rectangular hyperbola with displaced origin; that the displacement of the origin is the absorbing power of the walls of the room; and that the parameter of the hyperbola is very nearly a linear function of the volume of the room. This opens up a wide field.[87]

Ever the experimenter, he added, "It is only necessary to collect further data in order to predict the character of any room that may be planned, at least as respects reverberation."[88]

Sabine's development of this wide field resulted, by 1900, in a comprehensive and quantitative analysis of reverberation.[89] He initially represented his hyperbola with the equation:

$$(a + x)\, t = k,$$

where

a = absorbing power of room (walls, ceiling, etc.),
x = absorbing power of materials added to the room,
t = reverberation time, and
k = the hyperbolic constant.

In this form, Sabine's equation differentiated the absorbing power of the room itself (a) from the absorbing power of the materials added to it (x). This distinction reflected his experimental practice, in which he first measured the reverberation time in a room, then introduced additional sound-absorbing objects to alter that reverberation time. As his focus moved away from experimentation and toward a fuller understanding of the mathematical relationship itself, the distinction between these different types of absorbing factors would become less significant.

Sabine initially expressed the total absorbing power of each room in terms of its equivalent in Sanders Theatre seat cushions. While this unit of absorption was convenient for Sabine himself, it was clearly problematic as a more general scientific standard, and Sabine replaced it with a new "open-window unit" of absorption. This unit was equivalent to the complete absorption of sound energy provided by an open window one square meter in area. Since all energy impinging on such an opening would escape to the space beyond, with no reflection back into the room, the unit represented one square meter of a perfectly absorbent material. "Hereafter," Sabine reported, "all results, though ordinarily obtained by means of cushions, will be expressed in terms of the absorbing power of open windows—a unit as permanent, universally accessible, and as nearly absolute as possible."[90]

Sabine next broke down the total absorbing power of a room into its individual components, including such items as plaster walls, wooden floors, rugs, and curtains. He expressed the absorbing power of each component with the quantity:

$$a_n \, s_n,$$

where

a_n = "coefficient of absorption," or absorbing power per unit area of material n, and

s_n = total surface area of material n in the room (in square meters).

Now, the total absorbing power of any room could be represented by the quantity:

$$(a_1 s_1 + a_2 s_2 + \ldots + a_n s_n).$$

For any given room, Sabine could experimentally derive the value of this sum by measuring its equivalent in Sanders Theatre seat cushions. He also knew, after making some measurements, the surface area of each different material in the room. His task was thus to determine the absorption coefficients of all those different materials. To accomplish this, Sabine set up systems of equations representing different rooms, each of which contained a different proportion of a range of materials. When he had as many equations as he had unknown coefficients, Sabine was able to solve the equations and determine the values of the different absorption coefficients. Once determined, the coefficient for a given material was available for any future calculation, and Sabine published tables of these coefficients for others to use.[91] Sample values included:

Open window	1.000
Wood-sheathing (hard pine)	.061
Plaster on wood lath	.034
Plaster on wire lath	.033
Glass, single thickness	.027
Plaster on tile	.025
Brick set in Portland cement	.025

These numbers may generally be interpreted as indicating the percentage of energy absorbed by each type of surface when it is exposed to sound. In other words, every time a body of sound energy encounters a surface of plaster on tile, 2.5 percent of that energy will be absorbed by the material, and 97.5 percent of the energy will be reflected off that surface back into the room. The complete absorption of an open window was represented by a coefficient of 1.00, or 100 percent.

Sabine's next task was to determine the value of the hyperbolic constant, k, for each room. By comparing hyperbolae for different rooms, he determined that the constant was directly proportional to the volume of the room. Before this proportion could be satisfactorily derived, however, Sabine had to deal with a difficult complication. His hyperbolae varied slightly from pure form in a systematic manner, and he attributed this variation to the lack of a constant initial intensity of sound in his experiments. "Each succeeding value of the duration of the residual sound was less as more and more absorbing material was brought into the room," Sabine explained, "not merely because the rate of decay was greater, but also because the initial intensity was less."[92] The lack of a suitable source, one that could generate sound of a constant intensity no matter what the condition of the room, led Sabine into a complicated side-investigation to correct for the variations that he could not eliminate or control.[93] He ultimately determined that the hyperbolic parameter k was proportional to the volume of a room according to the equation:

$$k = .164\ V.$$

Sabine's equation could now be written in the form:

$$t = \frac{.164\ V}{\sum (a_n\ s_n)},$$

where:

t = reverberation time (in seconds),
V = volume of room (in cubic meters),
a_n = absorption coefficient of material n, and
s_n = surface area of material n (in square meters).

This formula could now be used to predict the reverberatory quality of a room in advance of its construction, a privilege long sought, but never before enjoyed, by architects or their clients. The absorption coefficients of commonly employed building materials were already determined and tabulated, and values for V and s_n could be calculated off blueprints or other scaled drawings. With these known quantities in hand, the equation could generate the unknown quantity t, the reverberation time of the proposed room.

If the reverberation time that resulted from such a calculation were deemed unsatisfactory, an architect needed only to modify his design—changing the overall volume of the room, or the type or proportion of materials employed within it—until a satisfactory result was achieved. With this equation, Sabine had finally achieved the fundamental, quantitative understanding of reverberation that he had long sought, and he now welcomed the opportunity to work with Charles McKim on the design for Henry Higginson's new music hall.

When Sabine first met with Higginson in January 1899, to review McKim's design, he was unable to estimate on the spot its prospective reverberation time, as it took some time to calculate the volume of the room and the different surface areas of materials from the drawings. He nonetheless offered a number of preliminary suggestions. Most significantly, as Higginson reported to McKim, "Professor Sabine thinks the hall altogether too long. How long it should be he does not venture to say, considering that partly a matter of experiment and partly a matter of calculation, which he has not yet reached, but he is very much afraid of the long tunnel which we have laid out."[94]

While the reverberation time that Sabine later calculated from this design is not recorded, it appears not to have been in line with Higginson's acoustical criteria as embodied in the old Music Hall and the Leipzig Gewandhaus. In March, McKim informed Higginson that he would revise his design, following Sabine's suggestions. "It will be no improvement to the proportion of the large hall to cut down its length," the architect admitted, "but if, acoustically, you consider that you have reason to believe that it will be better, we shall not oppose."[95] The result was to reduce the overall volume of the hall, and thus also its reverberation. In order to maintain the original seating capacity, McKim followed Sabine's suggestion to add a second gallery to the one he had originally specified.

In his published account of the derivation of his reverberation equation and its application to the design of Boston's new music hall, Sabine outlined how he verified that this new plan would achieve the desired acoustical result.[96] He obtained scaled drawings of Boston's old Music Hall and the Leipzig Gewandhaus and he calculated their reverberation times from the data that he read off these drawings; 2.30 seconds for the former, and 2.44 seconds for the latter. (See figure 2.14.) He then turned to McKim's revised plans for the new hall, calculating its overall volume, as well as the total surface area of each of the

2.14
Architectural sections of the Leipzig Gewandhaus, the Old Boston Music Hall, and the New Boston Music Hall (Symphony Hall). The two older structures served as acoustical models for Symphony Hall. Sabine analyzed their designs and used his reverberation formula to ensure that the new hall would possess the same amount of reverberation as the models. Wallace Sabine, *Collected Papers on Acoustics* (Cambridge, Mass.: Harvard University Press, 1922), p. 66.

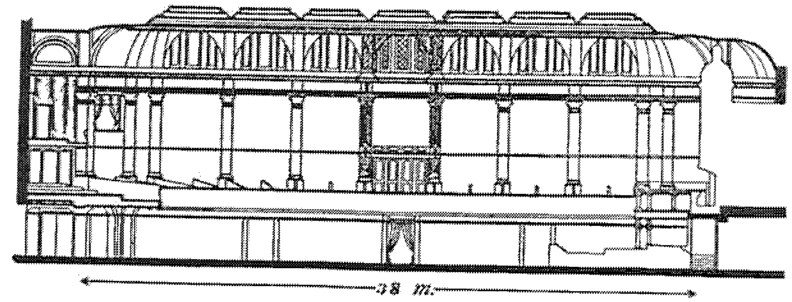


Fig. 20. The Leipzig Gewandhaus.

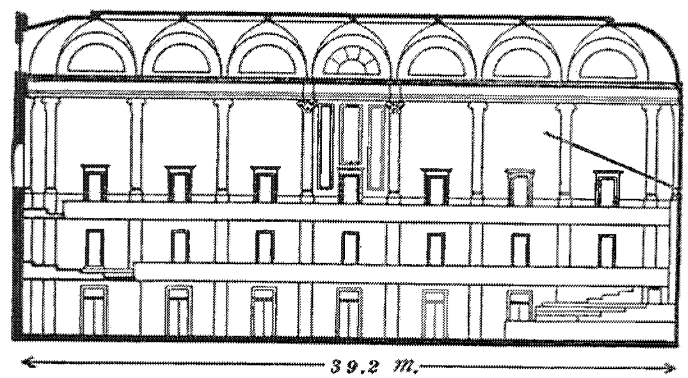


Fig. 21. The Old Boston Music Hall.

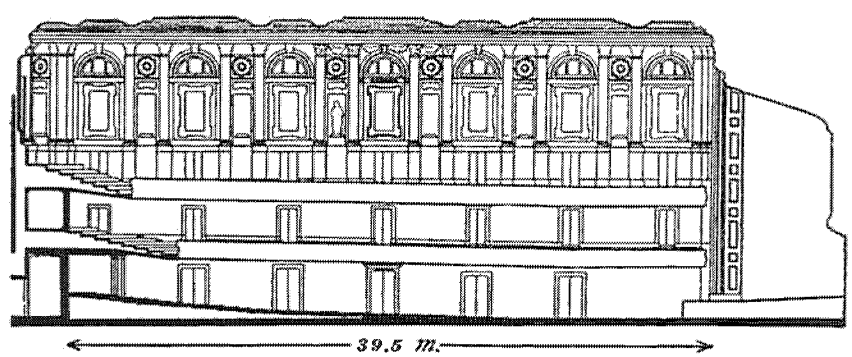


Fig. 22. The New Boston Music Hall.

different materials out of which it was constructed, including plaster on lath, plaster on tile, glass, wood, and draperies. He also factored in the highly absorbent surface that the audience and orchestra members would constitute when the house was filled to capacity. Plugging all these data into his equation, he determined that McKim's hall would have a reverberation time of 2.31 seconds. The closeness of this value to those of the other halls ensured that the new hall would faithfully reproduce the amount of reverberation present in those acoustical exemplars. Sabine's technique enabled McKim to re-create the sound of past structures without having to re-create the structures themselves, and Sabine highlighted this fact when he emphasized that "neither hall served as a model architecturally."[97]

Sabine, McKim, and Higginson were in constant contact over the course of 1899 and 1900, working out the details of design and addressing new issues that arose during the construction of the hall. Sabine advised on questions ranging from where to place the organ pipes to what kind of seats should be installed.[98] Many of the questions that he addressed could not be answered simply by churning out another reverberation calculation, and he clearly drew on a more general knowledge of sound that he had gained during his years of research. Sabine even recognized the role of audience psychology in affecting judgments about the acoustical quality of the hall. When asked if a wood lining should be applied to the stage area, he informed Higginson that the small quantity of wood in question would not significantly affect the acoustics one way or another. He noted, however, that, "subjectively even this small display of wood will increase the acceptability of the hall to the public by gratifying a long established—and not wholly unreasonable—prejudice."[99]

Sabine's mathematically quantified understanding of the behavior of sound provided the basis of expertise that accredited all his suggestions, even those for which the reverberation equation itself did not provide a direct answer. It also inspired the confidence with which he rendered his advice. That advice was attractive to McKim not only because it was perceived to be scientifically authoritative, but also because it did not significantly constrain the architect's creative freedom. Sabine did not dictate one best form; his technique was applicable to any form or style of building. Although based on the manipulation of building materials, here, too, his technique laid out no strict prescriptions or proscriptions. With Sabine's technique, any desired acoustical end could be achieved through an endless variety of architectural means. If an architect were committed to one particular aspect of his design, he could simultaneously ensure the desired acoustical result by manipulating other aspects of it. This enabled Sabine to work easily with Charles McKim, as well as with many other architects who would subsequently seek his advice.

At the same time, his method clearly assigned responsibility for the final acoustical result to the consulting scientist, not the architect. Whereas Dankmar Adler had encouraged architects to take responsibility for the acoustical consequences of their designs, few shared his point of view. What architects wanted was a means by which to delegate this responsibility to an outside authority, and this was exactly what Sabine offered. Sabine's expertise was thus attractive to architects like McKim not simply because he provided an answer to long-standing questions of acoustical design, but also because his particular answer was one that architects were happy to hear.

Sabine's method not only satisfied McKim's desire to design good sound for Symphony Hall, it also served the needs of the audience who came to hear that sound. Why were the acoustics of Symphony Hall so important to those who gathered there on opening night? The development of musical culture over the past century had rendered the act of listening increasingly important, and this new culture of listening culminated in America just as Symphony Hall opened its doors to receive its audience.

IV Music and the Culture of Listening in Turn-of-the-Century America

During the eighteenth and early nineteenth centuries, music in America was performed primarily by amateurs who made music for their own enjoyment.[100] By around 1850 this local fare was regularly supplemented by the occasional performances of professional musicians—primarily visitors from Europe—who were now touring the larger cities of the United States. In 1843 the Philadelphia diarist Sidney George Fisher noted, "A love of music has grown up in this country within the last few years, and the artists of Europe find it a profitable field of operations."[101]

American-born artists as well as traveling Europeans began to profit by performing before growing audiences of eager listeners. Louis Moreau Gottschalk, perhaps the nation's first internationally recognized virtuoso, not only played in big cities like New York and Boston, but also carried his music to the hinterlands. "What singular audiences I meet with!" he proclaimed. "You can imagine what the population must be in little towns that, founded only seven or eight years ago, nevertheless give receipts of three or four hundred dollars, and sometimes more. The other evening before the concert, an honest farmer, pointing to my piano, asked me what that 'big accordion was.' He had seen square pianos and upright pianos, but the tail bothered him."[102]

While a grand piano was a novelty to the farmers of Indianapolis, in the larger cities the instruments were now commonplace. In fact, musical offerings had proliferated in American cities to the point where demand for concert space often surpassed the available supply. In Philadelphia, the 1852 charter for the new Academy of Music stated that "it cannot have escaped the observation of the merely casual observer, that the taste for and cultivation of music have rapidly increased among us within the last ten years, and we believe such an establishment as we are now laboring to obtain, would do more than anything else in guiding, fostering and sustaining a love for the most refining and humanizing of all the arts."[103] The charter also referred to the advantages "in the way of business as well as of pleasure" that the opera house would secure for the city. The population of Philadelphia then stood at half a million, and it was hoped that "all of these persons, whether possessed of a taste for music or not, would resort to a place of cheap and elegant amusement."[104] The project was as much a commercial venture as a cultural one, and openly so. The merchants who had incorporated to finance the new construction were not wealthy enough to make good any deficits that might result from poor attendance, and they were willing to accommodate any kind of performance that promised to sell tickets. At the same time, however, romantic notions of the ennobling nature of music were beginning to be heard, and these new ideas would increasingly be attached to both the performance and audition of music.

The phenomenon had already been under way for over a century in Europe. When Count Francesco Algarotti had petitioned for an acoustically controlled architecture in 1762, he pleaded as vehemently for a new attitude toward listening to accompany the sound. Algarotti longed for a rationally designed theater that would no longer constitute "a place destined for the reception of a tumultuous assembly, but as the meeting of a solemn audience."[105] His desire to control sound was paired with an equally strong desire to control the behavior of the audience. Algarotti himself already constituted such a concerted listener, and he sought an architectural means to engender this attentive way of listening in all concertgoers.

Over the course of the next century, the transformation that Algarotti longed for would indeed occur. This change was the result of complicated social and cultural forces that have been richly explored by Richard Sennett and James Johnson.[106] Urbanization, the decline of the aristocracy, the rise of the middle class, the romantic movement in arts and letters, and the development of symphonic music are just some of the factors that contributed to the gradual transformation of "the perpetual chattering of the company, in visits being made from one box to another, in supping therein, and . . . gaming"[107] into a rapt preoccupation with what was taking place on stage. In America, as Lawrence Levine has shown, these phenomena came fully into play in the nineteenth century, and resulted, by the end of that century, in a musical culture that was religious in its intensity. Listening now became a way to worship at the temple of great art.[108]

This new way of thinking about music was first and most voluably heard in Boston. At mid-century, John Sullivan Dwight began to use his *Journal of Music* "to articulate tirelessly the conception of a sacralized art: an art that makes no compromises with the 'temporal' world; an art that remains spiritually pure and never becomes secondary to the performer or to the audience; an art that is uncompromising in its devotion to cultural perfection."[109] When Boston's Music Hall opened in 1852, *Dwight's Journal* sang its praises:

> Oh fair retreat, where even now
> Art's consecrating footprints shine,
> Where Song, with her imperial brow,
> Shall hold her sway by right divine!

The commemorative poem ended several stanzas later, with "all earth's people" "kneeling near the shrine of Song."[110] But Dwight's lofty ideals for music were not yet a reality in America. Indeed, when the Music Hall was nostalgically described many years later, it was hardly remembered as a cultural shrine:

> What a versatile place was the old Music Hall,
> With its concerts and sermons and dances and all!
> Wendell Phillips has lectured there, Patti has sung,
> While the Warren Street Chapel shows captured the young.
> Crowds were drawn here by Theodore Parker, but some
> Were attracted by Mr. and Mrs. Tom Thumb.
> For a function, a fight, and a fireman's ball
> Might occur the same week in the old Music Hall.[111]

The concert halls and opera houses built in America at mid-century pointed toward a new cultural ideal but did not yet attain it. Audiences still chatted during concerts, or even whistled along (to show that they knew the tune, Gottschalk claimed), and the distinction between professional and amateur was not always clear. A rich furrier might rent out the New York Academy of Music and stage his own production of *La Traviata*, or a local shoemaker might choose to accompany a visiting virtuoso on his flute.[112] During the latter half of the century, however, musicians and music lovers like John Sullivan Dwight undertook a campaign to educate Americans to appreciate great music, and to approach it with an attitude of humility and respect.

When the French conductor Louis Antoine Jullien toured America in 1853 and 1854, he attracted large crowds by convening massive choruses and staging musical novelties like the *Fireman's Quadrille*, "which included fireworks and a simulated fire so realistic that it induced hysterical screaming and fainting spells among some in the audience."[113] When it came time to perform the music of Beethoven, however, Jullien demonstrated his reverence by donning white gloves and a special jeweled baton, and he encouraged his audiences to treat the music that his baton brought forth with equal respect.

Jullien's violinist Theodore Thomas disliked such gimmicks, and when he began touring with his own orchestra in the 1860s, he worked to develop in American audiences an appreciation for good music free of such spectacular trappings. When Thomas was appointed head of the new Chicago Symphony Orchestra in 1889, he was finally in a position to develop a relationship with a permanent ensemble of musicians as well as with a permanent audience, and he undertook to train both with equal vigor. In Boston, too, after years of pleading by John Sullivan Dwight, a permanent symphony orchestra was finally established under Higginson's sponsorship, and a series of stern German conductors similarly demanded as much of their audiences as they did of their musicians.

By 1900, these efforts had born fruit and Dwight himself, not to mention Count Algarotti, would have been pleased with the decorum and the concentrated attention to listening that now characterized the behavior of concertgoers in America. The concert hall became a solemn place, and listening became serious business. Applause was now restricted to specific places in the program, and spontaneous outbursts were discouraged. Conductors were even known to stop in the middle of a piece and reprimand audiences that talked or made other distracting noises during a performance.[114] At the 1891 opening of Carnegie Hall in New York, "a poor little girl who chanced to sneeze was regarded as a fiend incarnate."[115] A reporter for the *New York Herald* noted that the audience was "most interesting as a study of music lovers not under the pressure or mandates of fashion. The women in the boxes were in evening dress, and many were the same who nightly ornamented the *loges* of the Metropolitan Opera House, yet there was a decided change in demeanor. There was no idea of chatter or conversation."[116]

On opening night at Symphony Hall, "an inspired Harvard student" startled the audience by leaping up from his seat and calling for a volley of cheers for Henry Higginson. The audience chose not to respond, so the young man cheered alone then returned to his seat, where he sat quietly for the remainder of the program.[117] Control was the key; it was not meant to be fun. Theodore Thomas considered concertgoing "an elevating mental recreation which is not an amusement,"[118] and the *Boston Evening Transcript* editorialized proudly that "Boston does not take her music frivolously, but as a service, an education."[119]

Even in the realm of domestic music making, this sober new attitude toward music prevailed. Children were given music lessons in order to instill character and discipline, not to inspire creativity and joy; and the young women who performed in the parlors of Victorian America similarly demonstrated virtue more than virtuosity.[120] When the phonograph began to make itself heard, John Philip Sousa feared that "no one will be ready to submit himself to the ennobling discipline of learning music," and all that would be left was "the mechanical device and the professional executant."[121] But domestic music making was already on the decline, part of a larger phenomenon referred to as "The Decline of the Amateur." In 1894, the *Atlantic* magazine recalled that the adjective "amateur" had formerly signified "respect, dignity and worth." But now, "amateur has collided with professional, and the former term has gradually but steadily declined in favor; in fact, it has become almost a term of opprobrium. The work of an amateur, the touch of the amateur, a mere amateur, amateurish, amateurishness,—these are different current expressions which all mean the same thing, bad work."[122]

As amateurs gradually abandoned their own music making and listened increasingly to professional musicians, a wide chasm opened between the two groups. Amateurs who continued to make music at home found it difficult to imitate the pyrotechnic performances of turn-of-the-century virtuosi like Ignacy Jan Paderewski and Fritz Kreisler. Sheet music publishers did their best to bridge the gap, by offering "Brilliant but not Difficult"[123] versions of the most popular showpieces, but the effect of the discrepancy was gradually but effectively to silence many amateur performers of music. By the end of the century, countless parlor pianos had been replaced by automatic "reproducing" pianos or other mechanical devices that recreated the performances of great concert pianists.[124] The phonograph, too, as Sousa had feared, was now replacing self-made music with recordings by professional executants. The result of these trends was a new dissatisfaction with amateur music and, perhaps more significantly, a heightened engagement by amateurs with the experience of listening to professionals.

In 1910, for example, the social reformer Jane Addams noted a generational difference between her mother, who believed herself to have possessed musical talent but lacked opportunity to develop it, and Addams herself, who, in spite of all advantages in her youth to develop such a talent, knew herself to be lacking it. "I might believe I had unusual talent," she wistfully acknowledged, "if I did not know what good music was."[125] Concurrent with Jane Addams's youth, Edward Bellamy's best-selling novel *Looking Backward* fictionalized the same phenomenon. Bellamy told the story of Julian West, a wealthy young Bostonian who fell into a hypnotic sleep one evening in 1888 and awoke one hundred years later to find himself in the social utopia of late-twentieth-century America. West was offered music by his hostess, Miss Edith Leete:

> "Nothing would delight me so much as to listen to you," [he] said.
>
> "To me!" she exclaimed, laughing. "Did you think that I was going to play or sing to you? . . . Of course, we all sing nowadays as a matter of course in the training of the voice, and some learn to play instruments for their private amusement; but the professional music is so much grander and more perfect than any performance of ours, and so easily commanded when we wish to hear it, that we don't think of calling our singing or playing music at all."[126]

The music that Edith offered to Julian was a telephonic transmission of a performance that took place in one of the city's many music rooms, each "perfectly adapted acoustically to the different sorts of music."[127] Music performed by professionals in acoustically designed rooms represented the ideal for Bellamy, and for many others, in late-nineteenth-century America. The role of nonprofessionals, like Edith and Julian and the millions of Americans who read about them, was to listen intently and appreciate fully the sounds that they were privileged to hear.

Henry Higginson himself had gone to Europe as a young man hoping to become an accomplished musician. What he learned there was that he "had no talent."[128] Higginson subsequently fulfilled his love of music by sponsoring musicians more talented than himself, by listening carefully and critically to their performances, and by building a hall that would draw on scientific expertise in order to provide the best possible environment in which to listen. The two thousand others who gathered with Higginson on opening night shared his love of listening, as well as his concern over the quality of the sound that they heard.

V Conclusion: The Critics Speak

Did Symphony Hall provide the acoustical environment so eagerly sought by the people who gathered there and listened so intently? The answer to this question was not immediately obvious to all who were present on opening night. William Foster Apthorp, music critic for the *Boston Evening Transcript*, dryly characterized the new building as "one of the prime fixed conditions of our hearing the larger forms of orchestral and choral music for the rest of our lives." He took very seriously his role as an arbiter of the acoustical quality of this fixed condition; so seriously, in fact, that he declined to discuss the sound of the opening night concert. Apthorp referred to McKim's and Sabine's "singleness of purpose," by which "their calculations kept but one object constantly in view: to adapting the hall to the use of the Symphony Orchestra, and to nothing else." He deferred judgment because oratorio, not symphonic music, had been performed. "I await the first symphony concert with impatience," he proclaimed, "for that will be the only real test."[129]

Apthorp's decision to withhold judgment also took into account the fact that the opening night concert had used an unusual arrangement of musicians on stage. To accommodate the large chorus required for Beethoven's *Missa Solemnis*, the first five rows of seats had been removed so that the stage floor could be extended out beyond the proscenium into the auditorium. In spite of the unusual arrangement, most critics were willing to submit their opinions of the acoustics of the hall, and their reviews were generally positive. The *Boston Herald* declared that "Symphony Hall's acoustic properties are all right. Hear, Hear!" and the out-of-town papers agreed. New York's *Evening Post* heralded the hall as "what very few concert halls are—a success acoustically," and suggested that, if an old myth that halls improved and mellowed with age proved true, it would not be surprising if "mellowing time made it a Stradivarius among halls."[130]

Henry Krehbiel, music critic for the *New-York Daily Tribune*, devoted considerable space to Sabine's work in his opening night review. "Hundreds of ears," he reported, were "alert this evening to learn whether the greatest of the problems that the construction of a music hall involves had been solved in this instance." Sabine's confidence in the result of his calculations struck Krehbiel as daring, but he concluded that it was both "justified and rewarded," for "the effects were most gratifying, and it can safely be said that for its purposes Boston has the most beautiful, appropriate and admirable hall in the United States."[131] Yet, Krehbiel suggested that until Sabine conducted a "scientific investigation after the fact," and made a precise measurement of the reverberation time in the hall, "the sceptic may not yet feel confounded." Sabine apparently never made this measurement, responding personally to Krehbiel that the only meaningful test of his work would come with the actual use of the hall.[132]

A few nights later, the first concert of the regular season was heard. The stage was restored to its normal configuration, and the orchestra was led by Wilhelm Gericke in a performance of standard works, including one of Higginson's favorites, Beethoven's Fifth Symphony. After this concert, Higginson wrote to Sabine, "Just a word to thank you for your pains and success in the Hall. Of both no doubt exists. I have never heard the music as now. You have proved here that the Science of Acoustics certainly exists in a definite form. You have done a great part of the Hall, and every one thanks you."[133]

The papers generally shared Higginson's sentiments. Philip Hale, of the *Boston Sunday Journal,* concluded that "doubt as to the acoustic properties of the hall were dispelled. Solo instruments were heard with delightful distinctness; the bite of the strings was more decided than in the old hall, and the ensemble was effective without muddiness or echo."[134] The *Sunday Herald* declared the hall "A Complete Success," noting that "The wholly favorable impression made by the acoustic qualities of the hall on the opening night was re-enforced last evening. Everything is heard with the most perfect distinctness, the contrasting timbres of the different instruments stand out clearly, and at no time, even in the heaviest fortissimos, is there any cloudiness of tone."[135] The *Herald* celebrated Sabine's work as "A Feat in Acoustics," and quoted extensively from his published article on reverberation in order to describe his work to its readers.

A new note of uncertainty was introduced, however, by other papers in response to this concert. The *Boston Post* reported that, while there was no difficulty in hearing throughout the hall, there seemed to be "less body" to the sound than had been the case in the old Music Hall. The reviewer suggested, however, that this might be due to the selections performed rather than to the hall itself.[136] William Apthorp, now finally prepared to pass judgment on the new hall, also measured its acoustical merits with ambivalence. Apthorp first noted the familiarity of the pieces on the program, "so one could give almost undivided attention to the effect of the music in the hall." As he listened to the opening number, Weber's overture to *Euryanthe*, he found the effect of the music disappointing: "Everything was clean-cut and distinct, the tone was beautifully smooth, and, so to speak, highly polished; but it had no life, there was nothing commanding and compelling about it." In contrast, the Handel Concerto for Organ that followed almost convinced him that the acoustics of the hall were "superb." But Beethoven's Fifth Symphony confirmed his initial reaction, and he reported that, while there was a "great distinctness of definition," the tone had "no body, no fulness; it is not searching; it is thin and ineffectual. Moreover, the hall itself seems perfectly dead to it, it does not awake to the orchestra's call and vibrate with it. Things that should sound heroic and awakening, seem merely polite and irreproachable."[137]

Apthorp suggested that Beethoven sounded as if he had appeared in "impeccable evening dress," freshly coiffed by the court hairdresser, the very picture of a "Brumellianly elegant" dandy, and it was obvious that the critic preferred his romantics unkempt and unruly. Still, Apthorp took pains to discount these early impressions. He emphasized that they were, above all, a reaction to the newness and unfamiliarity of the sound of the orchestra in the new hall. He confessed that he felt disoriented, seemingly in "some new musical country, never visited before, where old habits of listening needed reforming."[138] Apthorp noted that his tentative and preliminary judgments would be subject to future revision, and in his review of the next evening's concert of the Handel and Haydn Society, he did in fact revise those opinions. Now, he concluded that the effect of the music "left nothing to be desired."[139] But over time, Apthorp's fluctuating opinion of the acoustics of the hall stabilized into a decidedly critical viewpoint, and that criticism began to echo in the columns of other papers.

The *Musical Courier*, a national paper published in New York, came out strongly against the sound of the new building. Citing praise by the Boston press of Sabine's work, the *Courier* begged to differ: "We do not accept all that is said . . . as the acoustics on Saturday night were by no means satisfactory." The *Courier's* criticism, however, was leveled not so much against the sound itself, but more philosophically against the idea that "science" could ever master anything as beautiful and ephemeral as great music:

> Sound is not music, but is merely one of music's utilizations. A voice or tone may sound scientifically correct at a given time in a given hall and may be measured and its formula fixed and established chronometrically or chronographically or in any

> chronoform, but that sound or combination of sounds is not music. Music does not repeat itself; music is the moment, because music is art and art cannot be measured beforehand. . . . From the days of Pythagoras all kinds of experiments in acoustics have been facing the physicists and agitated the laboratories, but no clew has been discovered for such a science as can foretell with usual and necessary scientific accuracy how music will sound, and why not? Because if music could always sound as we before its issue could predict by formula $X + N = Y$, why then it would no longer be music.[140]

Apthorp had resisted the controlled character of the sound of Symphony Hall most strongly when it was applied to the impassioned strains of Beethoven. The reviewer for the *Courier* similarly, if more fundamentally, resisted the very idea of a scientifically controlled sound, as it contradicted his own romantic conception of the unpredictable nature of all music.

The criticism of the *Courier* represented an extreme, if revealing, reaction to the sound of Symphony Hall. Nonetheless, as time passed, a rising chorus of criticism could be heard. In March 1901, Apthorp noted, "there was much in the solo part that I could not hear well. Maybe the hall was again at fault; it is certainly not a brilliant hall,"[141] and papers that had initially approved of the sound of the hall now reported negatively. The same *Herald* that had pronounced the hall "A Complete Success" now referred to "the unfortunate acoustics of Symphony Hall,"[142] and the *Journal*, too, changed its opinion: "The acoustical properties, in spite of Mr. Sabine's brave pamphlet illustrated with diagrams and figures, are by no means satisfactory to either musicians or hearers."[143]

In May 1902, Henry Higginson received an unsolicited letter from a man named Edmund Spear, who offered his services "as an acoustician in aiding you with the remodeling of Symphony Hall which I understand has been undertaken."[144] Later that year, the writer Frank Waldo published a glowing account of Sabine's work on Symphony Hall. The *Boston Evening Transcript* excerpted Waldo's piece, and Apthorp amended a scathing postscript, condemning Sabine with perhaps the ultimate insult. He deemed "Mr. Sabine" incompetent "to express a musical opinion of any weight whatsoever," as Sabine came musically from "the amateur class." Apthorp continued, "We have not yet met the musician who did not call Symphony Hall a bad hall for music. Expert condemnations of the hall differ, as far as we have been able to discover, only in degree of violence."[145]

What did Sabine make of this expanding wave of criticism? Little evidence exists, but in a letter to Charles McKim written in May 1901, Sabine indicated that his first intimation of criticism had come just two weeks earlier, and he expressed surprise at the fact that initially positive reviews had now given way to criticism. He also took issue more specifically with what some listeners had identified as the cause of the worsening acoustics. Apparently, people were blaming the now-bad sound on the installation of statues into niches in the walls high above the second balcony. (See again figure 2.2.) The statues, which were cast plaster replicas of famous artifacts from antiquity, had been called for in McKim's original plans, but a lack of funds had prevented their procurement and installation in time for the hall's opening. They were gradually obtained and installed in the months after opening night, until this acoustical controversy brought the installations to a halt.[146] Sabine explained to McKim that the statues were part of the original plan "not only artistically in your scheme but acoustically," and he adamantly asserted, "The statues will not in the least affect the reverberation in the hall."[147]

Sabine also emphasized that he had not been the source of any musical judgment associated with the acoustical design of the hall. Reverberation, he acknowledged, was "a matter of taste." "Recognizing this," he explained to McKim,

> I sought the opinion of Mr. Gericke, and the Committee in regard to what halls were satisfactory in this respect and accepted this as the best available definition of the desired result. Then I made a special study that this above all things might be quantitative, investigated these halls, was struck by the nice agreement of the opinions expressed, and reproduced the condition in the present hall. On the certainty of my work in this respect I shall not yield."[148]

Wallace Sabine ultimately dealt with the highly subjective opinions of the critics and the public in the only way he could; he attempted to objectify them. In 1902, he embarked upon a study of "The Accuracy of Musical Taste in Regard to Architectural Acoustics," declaring this problem fundamental to any future work, "for unless musical taste is precise, the problem, at least as far as it concerns the design of the auditorium for musical purposes, is indeterminate."[149] Sabine divided the subject of architectural acoustics into two distinct lines of investigation. The first was based on the physical phenomena, and the second on their musical effect. "One is a purely physical investigation," Sabine elaborated, "and its conclusions should be based and should be disputed only on scientific grounds; the other is a matter of judgement and taste, and its conclusions are weighty in proportion to the weight and unanimity of the authority in which they find their source."[150]

To investigate the latter, Sabine had a committee of faculty members from the New England Conservatory of Music listen to piano music in five different rooms in the conservatory. He altered the reverberation time of each room by introducing varying amounts of sound-absorbing materials (the ever-useful Sanders Theatre seat cushions), and each committee member indicated when they felt each room sounded best. Sabine then evaluated the consistency of opinion expressed: the average optimal reverberation time for the five rooms was 1.08 seconds, and the average departure from this value was just 0.05 seconds. Sabine indicated that he found this high degree of accuracy in musical taste "surprising."[151]

By the time of this investigation, however, it appears that the general sentiment regarding the acoustics of Symphony Hall, if not that of William Foster Apthorp, had begun to return to a more favorable consensus. In February 1902, the chair of the statuary committee, Mary Elliot, wrote to McKim expressing her desire to resume installation of the statues in the hall. "A freind [sic] of ours," she informed the architect, "who is a Musician told me the other day that Gericke & the Musicians generally, are feeling very differently about the Acoustics of the Symphony Hall this winter, the Music sounds beautifully & they think that the general drying out of the Materials has made a great difference in the resonance."[152] It is unlikely that the drying or aging of the walls of the hall had any significant effect upon the sound. More likely, the musicians simply required time to become used to playing in the new hall. As they grew familiar with the sound of the space, they learned to adjust their technique in order to fill the space with the sound that they desired.[153]

In 1903, Theodore Thomas moved his Chicago Symphony Orchestra from Adler & Sullivan's Auditorium into the new Orchestra Hall designed by architect Daniel Burnham.[154] Thomas made clear that he would require a period of experimentation with his musicians in the new hall before he would be able to produce the sound he desired.[155] In Chicago, where the dominant personality was the conductor, the building was treated like a new instrument that Thomas had to learn to play. In Boston, in contrast, it was the owner Higginson, not any particular conductor, who defined the orchestra in the public mind.[156] Wilhelm Gericke's contribution was little acknowledged in early discussions of the acoustics of Symphony Hall, and the music that he created there was considered separately from the sound of the building itself.[157] Perhaps this distinction was a result of the fanfare over Sabine's work that had preceded the opening of the hall. It was a novelty for a scientist to be so involved in the creation of a new auditorium. How to distinguish the contribution of that scientist from all the other factors and players was an interesting new problem that appears to have been ignored.

It is also possible that the initial rejection and gradual acceptance of the sound of Symphony Hall was due to the fact that the audience required time to become used to that new sound. Apthorp had certainly acknowledged the discomfort of unfamiliarity in his early reflections upon the experience of listening in the new hall, and others may have shared his distress, perhaps without being fully aware of the reason for it. For whatever reason, as the sound of Symphony Hall grew familiar, listeners' displeasure did indeed dissipate.

While it is difficult to determine exactly when the criticism of Symphony Hall's sound was silenced once and for all, indirect evidence suggests that the hall's reputation was restored within just a few years of its opening. Sabine, for example, was soon in great demand as an acoustical consultant for architects from all over the country, and this would hardly have been the case if his work on Symphony Hall were considered a failure. McKim, Mead & White apparently never lost faith in his contribution to their work, and they were reenlisting his services as early as 1901.

At the time of his death in 1919, Sabine's eulogist could claim that the acoustics of Symphony Hall "have now been approved by the audiences of many years,"[158] and the reputation of the hall has only improved over the subsequent decades. In the 1950s, a plaque commemorating Sabine was installed in the foyer of the hall. The memorial calls attention to the building's historic status as "the first auditorium in the world to be built in known conformity with acoustical laws," but the hall itself offers its own testimony whenever music is performed within it, for Symphony Hall is considered today to be one of the best places in the world for listening to music.

The acoustical reputation of Symphony Hall is only one measure of Wallace Sabine's success, however, and for the story that follows, it is not necessarily the most important. Sabine's work succeeded in many different ways, for many different groups of people. For architects, he provided the "fixed rule" and the scientific expertise that they had long sought to guide and inform their acoustical designs. For audiences, his work endowed the spaces in which they gathered to listen with what most listeners considered to be a satisfying sense of control. And, for scientists like himself, Sabine opened up a wide new field of opportunity. His method established a research agenda and it identified new problems that now required solution. A new community of acoustical researchers would confront these problems, and would soon provide an even greater and more powerful range of solutions.