Short history of music and concert halls

The composer of symphonic music has lacked a clear impression of the kind of architectural space where his music would be performed since only about 1900. Prior to that, starting in about 1600, music composition in Europe was destined for performance in particular concert halls. That is to say, the music of each stylistic period—Renaissance, Baroque, Classical and Romantic—coincided with a contemporary acoustical environment sympathetic to its performance. But, since the beginning of the twentieth century, with the advent of recordings, digital music and a variety of shapes and sizes of concert halls and opera houses, the composer has had no clear destination for his works.

In the first 150 years after 1600 music was usually performed in the ballrooms of palaces, mostly rectangular in shape, and with surfaces that were usually hard and highly ornamented. In that environment a contrapuntal style of music evolved, usually called Baroque and best exemplified in Europe by Bach, Handel, Corelli and Vivaldi. Bach wrote many of his works for performance in the Thomaskirche in Leipzig, whose acoustics varied from mildly reverberant to quite reverberant depending on the size of the congregation. By the end of this period, concerts began to be offered in small theaters such as the Alte Residenz Theater in Munich, which opened in 1753.

Around 1800 the first halls especially built for concerts appeared. The Altes Gewandhaus in Leipzig built in 1780 and seating about 400 and the King’s Theatre in London dedicated in 1794 and seating 1050 were the beginning. Their construction still mirrored the court ballrooms and when fully occupied, they had reverberation times of 1.3 to 1.5 sec. With these halls and others that soon followed, came the great symphonies and sonatas of Haydn, Mozart and Beethoven—the period of the eighteenth and early nineteenth centuries labeled as Classical.

In 1849 the (old) Liverpool Philharmonic hall seating 2,100 people was built, and in 1863, the Boston Music Hall was opened, seating 2,400 persons and having a reverberation time of 1.8 sec. These halls pointed the way for the next change, the Romantic Period. This period extended through World War I and even later and was characterized by personal and emotional expression of composers starting with Schubert and Brahms and continuing through Prokofiev and Vaughan Williams. Certainly the Boston and Liverpool halls and other halls of their type influenced the design of three of the world’s great concert halls—Grosser Musikvereinssaal in Vienna, Concertgebouw in Amsterdam, and Symphony Hall in Boston. All three opened between 1870 and 1900, and have reverberation times, fully occupied, of 1.9 to 2.0 sec.

All of the halls named above are rectangular in shape. In the post World War II period hundreds of halls have been built, some of which are radically different in shape. These include Royal Festival Hall in London, Philharmonie Hall in Berlin, McDermott Hall in Dallas, Bridgewater Hall in Manchester, Philharmonie Hall in Munich, Kitara Hall in Sapporo, Tokyo Opera City Concert Hall, St. David’s Hall in Cardiff, and Disney Hall in Los Angeles. Certainly music of all periods is performed in these halls, with a growing attention to music of the 20th century such as that by Schoenberg, Berg, Ravel, Ives, Varèse, Bartók, Davies, Adams, Cage, Reich, and Glass.
Sabine’s Monumental Contribution

The first significant contribution to understanding the acoustics of auditoriums was made by a young Harvard assistant professor, Wallace Clement Sabine. At the request of the President of the University he took on the task of correcting the unsatisfactory acoustics of the then new Fogg Art Museum (later renamed Hunt Hall and no longer standing). He modified its excessive reverberation time by bringing into the room various amounts of sound absorbing materials (seat cushions and felt)—as everyone knows, the more material the less the reverberation. He made similar studies in 10 other university halls and came up with the Sabine Reverberation Equation in 1898 which enables the calculation of the reverberation time in an architectural space at each frequency.

![Fig. 1, Reverberation time $T_{60} = R.T.$ as defined in the text.](image)

$$T_{60} = 0.163 \frac{V}{A} \text{ sec}$$

The reverberation time $T_{60}$ is the time in seconds it takes for a loud sound to decay, after cutoff, to inaudibility (technically a decrease of 60 decibels). In the formula, $V$ is the cubic volume of the hall ($m^3$); and $A$ is the total sound absorption at the frequency measured, which is contributed by people, surfaces, sound absorbing materials and objects (dimensionally square meters).

The reverberation in a room influences the sound of the music in several ways. During continuously flowing music, listeners hear the first 10 or so decibels of the sound decay. If this early reverberation time is long enough, each note is prolonged and the music takes on a singing tone. When the music stops abruptly, the listeners hear 35 or more decibels of the decay in the quiet interval. This longer reverberation adds both fullness of tone and loudness and gives the listener a sense of being enveloped by the sound.

In a concert hall, the reverberation time is nearly the same at all seats. But, it is generally longer at low frequencies and is always shorter at high frequencies because sound is as it travels through the air. Further, over half of the sound absorption $A$ is due to the audience and orchestra, since the walls and ceiling are generally too hard and thick for much energy to be absorbed in each square meter of surface.

Now, let us come back to Sabine and a new hall. The old Music Hall in Boston was well liked, but the City of Boston threatened to destroy the hall to make way for a new
elevated train system. The owner of the Boston Symphony Orchestra, Henry Lee Higginson, stirred up a group of citizens to buy the land and to provide the money to build a new hall. He engaged Charles McKim of New York as the architect.

Sabine’s success in correcting the acoustics of the Fogg Art Museum by introducing the right amount of felt blankets came to the attention of Higginson and he asked Sabine to apply his findings to the acoustics of the new hall. We know today that this hall is a great success, but how was it possible for Wallace Sabine, with only a formula in his toolbox, to come forth with such a success? Actually, the hall’s excellent acoustics are the confluence of good decisions by four parties, the building committee, Higginson, the architect, and Sabine.

From the beginning, Higginson mandated an audience of 2,600, and, for visual reasons, a width of not more than 76 feet (23 m). This is an ideal width for acoustics, resulting in a hall with intimate sound. Higginson and the architect agreed that the best hall to serve as a model for the new hall was the Gewandhaus in Leipzig (destroyed in WWII) which had a shoebox shape now known to be an ideal configuration acoustically. But the Gewandhaus had a seating capacity 67% of the 2600 that Higginson wanted. To overcome this need for more seats, McKim simply multiplied all dimensions of the Gewandhaus by a factor of 1.3 (1.3 squared is an increase of 69%) to accommodate the 67% increase in audience area. McKim’s design called for one balcony (sides and rear), and the orchestra seated on a stage located at one end of the shoebox.

Before giving any advice, Sabine asked for drawings for the old Boston and Leipzig halls. He also measured the sound-absorbing powers of an audience in a large lecture hall in the Jefferson Physical Laboratory at Harvard. In a reverberation chamber at Harvard he determined the sound absorption by plaster surfaces, carpet, lighting fixtures, etc. When Sabine used his formula to calculate the reverberation time in the old Boston and Leipzig halls he found it nearly the same (ca. 2.0 sec) in both. But McKim’s design would not result in that reverberation time as Sabine’s new formula showed. For an increase of 30% in all dimensions, the area A (1.3²) increases 1.69 times, but the volume V (1.3³) increases 2.2 times, giving for V/A in the formula an increase of 1.3, meaning a reverberation time of 2.6 sec instead of the desired 2 sec. To reduce the reverberation, the volume V needed to be reduced—mostly by lowering the ceiling height. But, there was another problem. McKim’s new design was much longer than either the Boston or Leipzig Halls. Higginson and Sabine both thought this length might result in a “tunnel” sound. Sabine, suggested that the two-balcony design of the Boston Music Hall be copied and that the orchestra be placed outside the shoebox in a stage house at one end. Higginson reduced the row-to-row spacing of the seats, and the combination of these three changes resulted in Boston Symphony Hall as built.

But, there were other decisions that created the good acoustics. The building committee decided that the hall should be fireproof. Thus all surfaces are either plaster on concrete block, or, in the upper parts of the walls and the ceiling, thick plaster. This decision resulted in the preservation of the bass sounds (by contrast, thin wood absorbs bass sounds). And, further preserving the bass, the committee chose seats that are not heavily upholstered. Finally, the architect’s design called for niche’s in the side walls for statues and for coffers in the ceiling to hide the ventilation grilles. Such irregularities result in a pleasant reverberation sound. Sabin’s stage design, for which he had no previous experience, has also been a great success.

With this highly successful hall, why not copy it everywhere? Architects are not like designers of violins who copy the Stradivarius model. Architects, and actually building owners, usually want their new structure to make a statement—to be unique and inspiring visually.
The Next Half Century In Acoustics

From 1898 to 1960 there were hardly any additions to the science or understanding of the acoustics of concert halls. In 1932, Paul E. Sabine, after studying several large concert halls, including New York’s Carnegie Hall, wrote, “All of which serves to emphasize the point [that he had] originally made, that the acoustical side of the designer’s problem consists more in avoiding sources of difficulty than in producing positive virtues.”

In 1958, P. H. Parkin and H. R. Humphreys of England concluded, “The present state of knowledge about the acoustics of rooms for music is such that major faults (such as echoes) can be avoided in design [and] nearly all the advice that can be given is qualitative only, at this stage of knowledge. The one important exception is the reverberation time which can be specified [calculated,] and …measured objectively…”

The Principal Acoustical Attributes of a Concert Hall.

After about 1960, funds became available for extensive studies of the acoustics of concert halls and opera houses in many countries. Leading contributors to the science of room acoustics since then have been, Schroeder, Cremer, Blauert, Kuttruff, Winkler, and Mueller in Germany, Hidaka, Ando, Nagata, and Morimoto in Japan, Barron, Parkin and Allen in England, Lamoral, Vian and Tissaye in France, Gade in Denmark, Bradley in Canada, Marshall in New Zealand, Kosten and de Lange in Netherlands, and Beranek, Harris, Johnson, Kirkegaard, Jaffe, Siebein and Cavanaugh in the United States. From their experiments and experience, the following physical quantities have evolved.

General

The physical quantities that are presented below are usually measured at low frequencies, middle frequencies and high frequencies. Generally, the most meaningful data are at middle frequencies. Acoustical data are usually taken at a number of locations in a hall and are presented as the average of the data at those seats. Those customs are followed in this paper.

Reverberation Time

Unquestionably, the reverberation time in a hall is of primary importance. For the modern symphonic repertoire, the optimum time, with full audience and at mid-frequencies, is 1.9 to 2.1 sec. Chamber music fares better in a hall with an RT of 1.6 to 1.8 sec, while opera is best performed in a house with an RT of 1.4 to 1.6 sec.

Early Sound Reflections

Early sound reflections are those that arrive at a listener’s position in the first 80 to 100 milliseconds after the arrival of the direct sound. In Fig. 2, the direct sound and four typical sound reflections are shown that arrive from the side walls, ceiling and rear of stage. Sound is radiated by the instruments in all directions and is partially absorbed by the attendees (and, as shown in Fig. 2, the portion of the sound that strikes a listener and is not absorbed is radiated out into the hall to again be reflected around the hall, striking the listener repeatedly).
Fig. 2. Sequence of sound reflections as heard by a listener when a quick note is sounded on the stage.

At a listener’s position, these reflections occur in the time sequence shown in Fig. 3. First, the direct sound is heard, then the first reflection $R_1$, followed by the reflections from the other surfaces, $R_2$, $R_3$, $R_4$, etc.

Fig. 3. Sequence of sound reflections heard by the listener of Fig. 2.

The separation between the arrival of the direct sound and that of the first reflection is called “initial-time-delay gap (ITDG).”

Fig. 4. The Initial-Time-Delay Gap equals the time $t_{R1} - t_D$, measured in milliseconds. As seen in Fig. 4, the ITDG is determined by the difference between the time it took for the first reflection to travel from the source to the listener, $t_{R1}$, minus the time it took for the direct sound to make the trip, $t_D$. In the best halls, at the center of the main-floor audience area, the ITDG is less than 20 ms. Values greater than 30 ms are found in lesser halls.

**Binaural Quality Index (BQI)**
It has been found in the best halls, that a significant amount of the energy in the early reflections should come to a listener’s ears from lateral directions. This means that the reflections $R_1$ and $R_2$, in Fig. 1 are more important than $R_3$ and $R_4$, etc. Also, the music sounds better if it is not identical at the two ears. The BQI is a measure of these two factors, first, the degree to which the energy comes from the lateral reflections and to the degree which the sound differs at the two ears. In the best halls, BQI is measured to be between 0.6 and 0.7 at middle frequencies and between 0.8 and 0.9 at low frequencies.

**Strength of the sound, $G$**

The strength of the sound is largely dependent on the size of the audience. It is obvious that an orchestra can give out only so much sound energy. This energy is distributed over the audience, and the amount for each listener depends on how many listeners there are. Of course, part of the energy might be absorbed by carpets, draperies and thin wood. In the best halls, these items are used only sparingly. Thickly upholstered seats also absorb more bass and some sound is absorbed by a pipe organ. At mid-frequencies, in the best halls, $G$ measures between 2 and 5 decibels at mid-frequencies.

**Clarity (Definition)**

Clarity or definition usually refers to the degree to which sounds that follow one another stand apart. Clarity decreases as the reverberation time increases and as the loudness of the reverberant sound compared to that of the early sound increases. The physical measure is $C_{80}$, the ratio of the strength of the early sound to that of the reverberant sound—the dividing time is 80 msec—expressed in decibels. A decibel designation means that if the strength of the early sound equals that of the late sound, $C_{80}$ equals zero decibels. A positive value for $C_{80}$ means the early sound is stronger and a negative value means that the reverberant sound is stronger. In the best concert halls, $C_{80}$ at middle frequencies lies between -1.0 and -5.0 decibels, meaning that the reverberant sound is stronger than the early sound.

**Surface Diffusivity**

It is well known that irregularities in the surfaces of a concert hall—side walls and ceiling—improve the quality of the reverberant sound. Only a few halls have ever been built with smooth side walls and in those the sound had a disturbing “brittle” or “glarey” or “glassy” sound. There is no physical measure of diffusivity that would permit one to determine an optimum amount, but, at the moment, the more irregularities the better.

**The Famous Older Halls**

*Vienna’s Grosser Musikvereinssaal*, seating 1680 and rectangular in shape, is shown in Fig. 5. Over 85% of its surfaces are plaster, or brick, or, in the ceiling, plaster on wood lathes. The seats are lightly upholstered—some are not upholstered. There is no orchestra enclosure and a few audience seats are located at the left and right rear parts of the stage. Everywhere there is ornamentation and statues. The mid-frequency reverberation time RT, fully occupied, is 2.0 sec and the mid-frequency Binaural Quality Index BQI is 0.64. The clarity factor $C_{80}$ is -2.8.
Amsterdam’s Concertgebouw, seating 2,037 at regular concerts. The hall is rectangular in shape, as shown in Fig. 6, and there are irregularities on all surfaces which are of plaster. The stage is unique among concert halls. Half is steeply raked and 20% of the audience is seated on either side. The main floor is flat and the stage is higher than in other halls to make the orchestra visible at the rear. The hall is unusually wide, 27.7 m, compared to 19.8 for Vienna and 22.9 for Boston. The RT is 2.0 see, the BQI is 0.51, and C₈₀ is -3.3.
**Boston’s Symphony Hall**, seating 2,625 at regular concerts and 2,369 at “Pops” concerts is shown in Fig. 7. It is rectangular in shape, and to accommodate this many seats there are two balconies. The orchestra is seated in a separate stage house. The main floor is flat and for “Pops” concerts, tables are located throughout. For regular symphonic concerts, a wooden floor is added, raked at the rear half to make viewing better. There are irregularities on all surfaces, which are of plaster or plaster on concrete block. To preserve bass, the seats are lightly upholstered. The sound is clear, live, warm, brilliant and loud, without being overly loud. The RT is 1.9 sec, the BQI is 0.64, and $C_{80} = -2.8$.

![Symphony Hall in Boston, Massachusetts, USA](image)

**London, Royal Festival Hall**, seating NEW, WITH MATERIAL FROM KIRKEGAARD

**Berlin, Philharmonie**, seating 2,212, with 250 behind orchestra and about 300 on each side, “vineyard” style, surround seating, is shown in Fig. 9. It was opened in 1963. The audience is broken into blocks, and many seats in them receive early lateral reflections from the side walls that surround them and from the wall behind. The fronts of the terraced (vineyard) blocks provide early reflections both for the musicians and the audience seated in the middle of the hall. Additional early reflections are provided to the orchestra and the audience by ten large suspended panels hung above the stage. Some seats in the upper blocks receive early reflections from the convex, tent-shaped ceiling. In the seats in front of the orchestra the sound is clear, balanced, and with a liveness that completely surrounds one. Those seated to the rear, or near rear, of the stage hear a different sound: the trumpets and trombones radiate forward, and the French horns backward. In the rear, the sounds from piano and soprano singers are unnatural because the middle and high-frequency sounds are projected forward. This hall is considered one of the most successful of the surround type built since 1960. The RT = 1.9 sec, the BQI is 0.46 and $C_{80} = -0.60$.

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Sydney, Australia, Opera House, Concert Hall, seating 2,679, which is shown in Fig. 10, opened in 1973. It is difficult to classify the shape of this hall. It is long and is sort of oval shaped with an overall length of 60 meters, a width at its widest point of 39 meters and a height at its highest of 24 meters. These dimensions are greater than those of nearly any other indoor hall. About 410 of the seats are located behind the orchestra and 158 on each of the two sides of the orchestra. The main audience area is steeply raked from the front of the stage to the rear of the hall. The ceiling is oddly shaped. This combination of unusual features gives a sound to music that is different from that in the three early halls and this difference has made the hall somewhat controversial. The RT = 2.1 sec. No BQI or C₈₀ data available.

Berlin, Konzerthaus (formerly Schauspielhaus), opened in 1986 and seating 1575 is shown in Fig. 11. This hall is rectangular shaped, has two balconies, and a flat seating area and is among the most beautiful halls in the world. There are irregular surfaces everywhere. It
is about the same width as the Vienna hall, but is somewhat shorter. Seated on the main floor, 
the listener is immersed in the reverberant sound. The clarity is about the same as that in 
Vienna and Boston. The acoustics are ideal for music of the Classical and Romantic periods. 
The RT = 2.0 sec, BQI = 0.64, and $C_{80} = -2.8$.

![Image of Konzerthaus](image1)

*Fig. 11. Konzerthaus (Formerly Schauspielhaus), Berlin, Germany*

**Los Angeles, Disney Hall**, opened in 2003, seating 2265, is shown in Fig. 12. Three 
architectural features stand out: the surrounding of the orchestra by the audience, the curved 
surfaces on either side that extend the full length of the hall, and the complex shaped ceiling. 
Great efforts were made to make the various surfaces supply early reflections to as many 
seats as possible. The acoustics are excellent at a significant number of seats, especially 
those in front and not too far back. Seats to the rear of the orchestra, and those farther back 
are not as satisfactory. The RT = 1.85 sec. No BQI or $C_{80}$ data are available.

![Image of Disney Hall](image2)

*Fig. 12. Disney Hall in Los Angeles, California, USA, view looking 
to rear of hall from the stage*

**Tokyo, Japan, Tokyo Opera City Concert Hall** (TOC), seating 1,636 and opened in 
1997, is shown in Fig. 13. This hall is unusual architecturally because it embodies a 
pyramidal ceiling with its apex reaching 28 m above the main floor. It is rectangular below
the ceiling. The hall is narrow, 20 m, and its length is about the same as that of Vienna. The sound is warm, enveloping and reverberant with a strong bass. The RT = 1.96 sec, BQI = 0.72 and C80 = -2.75.

![Image](https://via.placeholder.com/150)

Fig. 13. Tokyo Opera City Concert Hall, Japan, view looking toward stage.

**Lucerne, Switzerland, Culture and Congress Center Concert Hall.** opened in 1999 and seating 1,892, is shown in Fig. 14. The hall is essentially rectangular, and its interior space is augmented by 6,000 m³ of reverberation chamber located on the two sides and front of the hall. The chamber space is made available by opening all or part of 50 curved-front heavy doors spread out on three levels, just behind the seating. A canopy hangs above the stage, having two sections that can be pulled up or down or tilted separately. With the doors open, the RT = 2.1 sec, and when closed the RT = 1.9 sec. Curtains exist which can be pulled in front of the chamber doors. With them, and doors closed, RT = 1.7 sec. No BQI or C80 data are available.

![Image](https://via.placeholder.com/150)

Fig. 14. Culture and Congress Center Concert Hall, **Lucerne, Switzerland,**

**Dallas, Mc Dermott Hall in Meyerson Center,** seating 2,065, sidewalls parallel, rear wall horseshoe shaped, with a large multi-sectioned canopy overhead, is shown in Fig. 15. It was dedicated in 1989. Acoustically, the unusual feature of the Meyerson is the 7,200 m³ of reverberation space wrapped around the perimeter of the hall above the highest audience level and concealed by an open-weave cloth grille. When the separating doors behind the grille are open, the addition of the extra space acts to increase the reverberation time. It is most apparent after stop chords or during slow moving music. The canopy, either in its
entirely or in sections, can lowered for recitals or chamber music concerts. With the chambers open, RT = 2.7 sec—with chambers closed, the estimated RT = 2.1. sec, and $C_{80} = 0.60$. No BQI data available.

Fig. 15, McDermott Concert Hall in Meyerson Symphony Center, Dallas, Texas, USA