Acoustical designing for performers

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The normal procedure in acoustical designs usually emphasizes audience acceptance. This approach often results in unfavorable acoustical conditions for performing artists, both instrumental and vocal. The imbalance occurs form neglect of the musicians' need for mutual communication, and too great an emphasis on achieving "optimum" reverberation conditions. There have been notable examples of halls meeting accepted reverberation criteria which have nevertheless proved to be unsatisfactory, and many of these gave trouble because of performance difficulties as transmitted to the audience. Conversely, reverberation conditions can differ considerably from the norm, and still provide a satisfactory hall if the stage is properly designed. Study of a variety of halls strongly suggest that an essential requirement for music is that conditions should be suitable for performers. Architectural designs that provide ample sound reflecting and diffusing structures on stage to enable artists to hear each other well, blend the sound, and achieve favorable "local reverberation" are usually judged to be excellent by both performers and audience. This essential result can be achieved even in rooms which depart appreciably from standard reverberation time criteria.

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I. INTRODUCTION AND EUROPEAN EXAMPLES

In the development of architectural acoustics following the pioneering work of Wallace C. Sabine at the turn of the century, there has been a general awareness of the role of reverberation for the acoustical quality of rooms. As a result there is detailed understanding of the essential factors and a reasonable consensus on the optimum reverberation time characteristics desirable for specific purposes. However, it has become increasingly evident that reverberation time is a necessary but not a sufficient condition for good acoustics. A number of halls have been built whose reverberation time characteristics closely conform to recommended standards, but whose acceptance by both audiences and musicians has not been enthusiastic.

A well-known example of a modern concert hall that has not proved to be as satisfactory as expected is the Royal Festival Hall in London. This hall has had a long history of architectural acoustics, during design, construction, and subsequent alterations. Due to ceiling modifications during construction which were not anticipated in the acoustical design, the reverberation times were initially too short. This condition was corrected to a considerable degree by Parkin[1] with the installation of an "assisted resonance" system, in which sound at selected frequencies is picked up and played back electronically into the hall to produce a lengthened reverberation. This system has accomplished its intended purpose well for the lower and mid-frequencies. However, in spite of this improvement in the reverberation of Royal Festival Hall, it is still far from being completely satisfactory, either for performing artists or audience. This example emphasizes that even with acceptable reverberation times, a hall may still be acoustically unsatisfactory.

It is not difficult to identify the major acoustical defects in Royal Festival Hall. The orchestra has no adequate nearby sound reflecting and sound diffusing surfaces at the sides or at the rear of the stage. Instead, there are several rows of seats for audience behind the orchestra which, when occupied, are effective sound absorbers, and the exposed organ pipes are too distant and too widely separated to be helpful. Flat sound reflecting panels have been installed over the orchestra but these are set at optimum angles to project sound to the audience, and are too high and not sufficiently diffusing to provide adequate scattered sound for the orchestra. Consequently, ensemble playing is difficult and an adequate spectrum of early reflected sounds from orchestra to audience is absent.

Two well-known concert halls in Vienna illustrate a similar situation.[2] The famous Musikvereinsaal has renowned acoustics as judged by both performers and audience. The second hall, the Konzerthaus, has inferior acoustical properties. This is a surprising situation because both halls have the desirable rectangular shape, hard wood floors, excellent reverberation time characteristics, and other architectural features found in first-class concert halls. The reason for their greatly contrasting acoustics is suggested as follows. The stage of Konzerthaus has a concave rear wall having a minimum of architectural detail to scatter sound. From the geometry of this stage, it is evident that the musicians cannot communicate well and in addition, the sound from the various instruments will not be properly blended when projected outward to the audience. (Another extreme example of this defect is in the stage of Orchestra Hall in Chicago.) In contrast, the stage of the Musikvereinsaal is rectangular, not too deep, and has a profusion of architectural detail on all surfaces that insure the ample diffusion of sound. In addition, there are exposed organ pipes behind and above the orchestra (as in the equally famous Boston Symphony Hall) which produce additional sound diffusion. As a result the musicians hear each other well, and the sound is transmitted to the audience thoroughly mixed and blended. There are other architectural details, including less high-frequency ab-

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sorption and a narrower width, that favor the Musikvereinsaal. However, the Konzerthaus has a somewhat longer reverberation time and this factor by accepted standards is more favorable for orchestral music. Comparison of these halls emphasizes two factors. First, an optimum reverberation time characteristic alone does not insure the highest acoustical quality for orchestral music. Of even greater importance, the comparison emphasizes that the stage design and, especially, its sound diffusing character is a vital ingredient for a concert hall.

Another example of the importance of favorable acoustical conditions for performance is illustrated by St. Margaret's Church at Westminster in London. The church has excellent acoustics with reverberation conditions considered optimum for a concert hall; being approximately two seconds with an essentially flat characteristic.[3] Large areas of wood, including the ceiling, the pews, and a floor with air space below, provide an exceptionally fine auditorium for music. The rectangular shape is also excellent. We attended two concerts by a chamber music group in this church. In both events the musicians were located near the junction of the choir and nave. In discussions with the performers, we learned that in their judgment the acoustical conditions during the two concerts were very different. In the first concert there were no sound reflecting or sound diffusing surfaces near the players since all permanent ceiling, side and rear walls were too distant to provide communication between musicians or blending of sound. At the second concert, this defect was remedied to a considerable degree by placing movable wood structures on both the sides and behind the performers. The second concert as judged by both musicians and audience, was superior to the first. With the wood panels in place, the performers were delighted with their ability to hear each other and the sound for the audience was greatly improved. These concerts provided a controlled comparison of the beneficial effects of sound diffusing and sound reflecting surfaces placed near performers.

II. EXAMPLES IN THE UNITED STATES

There are interesting examples of concert halls in this country which also illustrate the thesis of this discussion, namely, that a hall must be satisfactory for the musicians or it will not, in general, be acceptable. The concert hall in the Toledo Museum of Art, known as the Peristyle, is a circular room with a low concave acoustic plaster ceiling. There is a curved promenade around the periphery which required the installation of numerous large sound absorbing panels to suppress echoing. These features produce too short a reverberation time as judged by usual standards. Originally an unsatisfactory stage "shell" was employed, constructed of one quarter inch flat plywood panels with no details. About fifteen years ago it was decided to install an adequate stage shell and oak floor for orchestral music. The new shell, designed by the writer, was constructed of heavy oak with side and rear wall and ceiling panels that are highly effective to both scatter and reflect sound. Musicians can now communicate with each other well and the sound projected to the audience is excellent. Dr. George Szell conducted the first Cleveland Orchestra concert with the new shell having had several earlier experiences with the original stage furnishings. He was most enthusiastic about the improved acoustics which were also judged excellent by orchestra and audience. The conclusion from this experience is that the increased effectiveness of the new shell, for player communication, mixing and blending of sound, and a somewhat lengthened "stage reverberation,"[4] all now combine to make this hall effective for orchestral music, in spite of the fact that both the geometry of the auditorium itself and the short reverberation times are, in themselves, unfavorable.

Another example is the new Gartner Auditorium in the Cleveland Museum of Art. This auditorium was originally intended primarily for organ music, having a large Holtkamp organ mounted high above the stage. At the urging of the late Walter Blodgett the acoustical characteristics were changed after completion of the hall, to lengthen the reverberation time for the organ and to increase the bass response. This was accomplished by closing off the openings in the acoustical slat-structure with heavy plywood at the rear of the balcony and on three-fifths of the wall areas to reduce the loss of low-frequency sound by diffusion. However, in addition to organ music, the hall is used for chamber music, small orchestral groups, and choral works. As originally constructed, the rear wall of the stage immediately below the organ was a flat wood surface. Choral groups and musicians on stage could not hear themselves or communicate properly, and the sound reaching the audience was not blended but accented individual instruments whose loudness varied greatly from seat to seat. To correct this condition, as shown in Fig. 1, the rear wall of the stage was completely redesigned, following general suggestions by the writer for introducing sound diffusion at many frequencies and incorporated in drawings

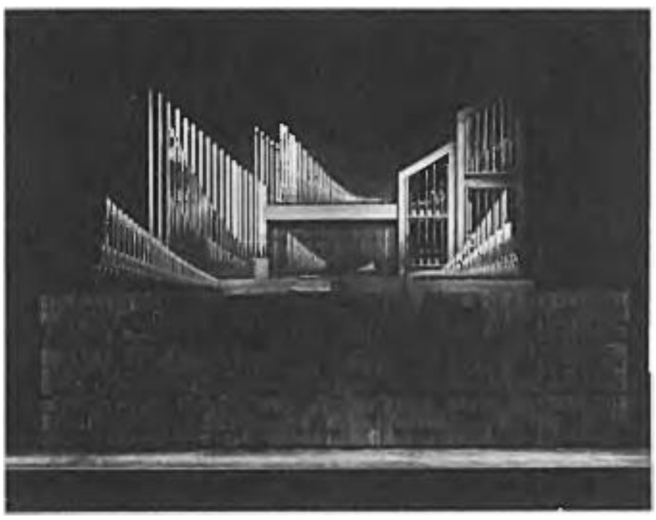

FIG. 1. Rebuilt rear stage wall below the organ in Gartner Auditorium at the Cleveland Musuem of Art. Marcel Breuer and Hamilton Smith, architects. (Cleveland Museum of Art photograph).

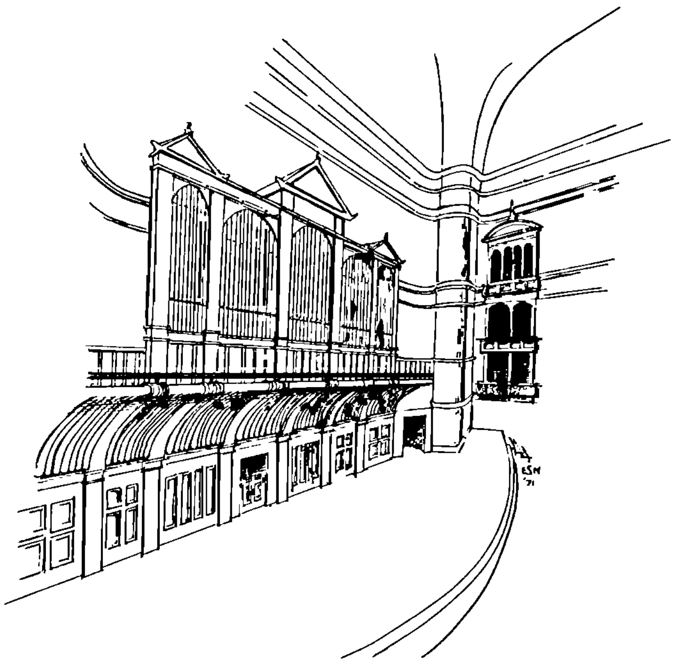

FIG. 2. Stage of Concert Hall at Troy, New York, showing acoustical features of stage favorable to the orchestra. Charles Post, architect.

by Eleanor N. Shankland. These changes were discussed in detail with Marcel Breuer and Hamilton Smith, the architects, by A. Beverly Barksdale, and the writer. When the need for ample sound diffusion on the stage was explained to the architects, they readily agreed and prepared detailed designs for a highly effective sound diffusing and sound reflecting wood structure with a random pattern both in depth and breadth. Because of the organ, it was impractical to install sound diffusing elements above the performers, but the top section of the new rear wall is hinged and can be tipped forward and be more effective. Plans were also made to provide similar structures for the sides of the stage, but the changes in the rear wall proved to be so effective that these have not been necessary. When the positioning of the players is optimum (not too near the wall or to the front of the stage), both performers and audience agree that the Gartner Hall acoustics are now greatly improved for string quartets and orchestral and choral groups.

Perhaps the earliest American example of excellent stage design for performers is in the concert hall at Troy, New York. As evident in Fig. 2, the stage geometry of this hall emphasizes the theme of this discussion, namely, the rear stage wall is close to the musicians and has ample architectural detail to provide diffusion for both low-frequency and high-frequency sounds. In addition, the nearby exposed organ pipes above the stage and the adjacent boxes contribute additional sound diffusion. The acoustics of the Troy Hall have been acclaimed for over a century, and it has other desirable acoustical features in addition to the stage. However, we believe that the stage design is an essential factor for its success.

Additional examples are provided by two halls used regularly by the Cleveland Orchestra. The present stage shell at Severance Hall was installed in 1958, at the urging of the late George Szell, with the architectural design made by the late Cleveland architect, Mr. Edward A. Flynn in consultation with the writer. The heavy wood shell with large convex cylinder elements, as shown in Fig. 3, provides an environment where the orchestra can clearly hear each other and where an ample spectrum of early reflected sound is projected to the audience. This shell has greatly improved the sound in Severance Hall, especially on the main floor where the absence of sound reflecting side walls is a serious defect. An additional change made in 1958 was the removal of all carpet from the auditorium and its replacement with vinyl tile to lengthen the reverberation time, so not all the improvement can be ascribed to the orchestra shell. The experience of two decades has shown that several acoustical features of the shell could now be improved upon. First, while the large convex wooden cylinders of the shell walls and ceiling provide adequate diffusion for low-frequency sounds, there are no small scale architectural details to scatter the high frequencies, which are critically important for communication between musicians. Another problem with the shell is that it is too deep for optimum effectiveness, in contrast, for example, to the stage geometry at Troy, New York. The deep shell at Severance is needed to accommodate the Cleveland Orchestra Chorus that frequently sings with the orchestra. In orchestra concerts without the chorus, sounds reflected from the rear of the shell are overly delayed and unless the players, especially brass and percussion, are skillfully placed on the stage (which was a prime concern of Dr. Szell) difficulties are experienced. Furthermore, to smoothly join with the auditorium of Severance Hall, the ceiling of the stage shell is necessarily too high to give useful reflected sounds for the orchestra itself, especially for strings and woodwinds near the front center of the stage. However, in general, the stage shell at Severance Hall is highly satisfactory when skillfully used.

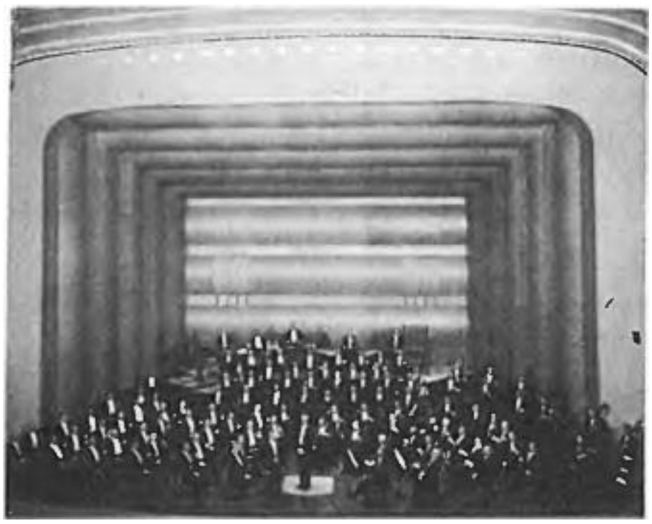

FIG. 3. Orchestra shell in Severance Hall, Cleveland, Ohio. Edward A. Flynn, architect.

FIG. 4. Drawing of Blossom Music Center with side of pavilion roof omitted to show orchestra shell. Peter van Dijk, architect.

When a stage shell (Fig. 4) was designed for the new Blossom Music Center near Cleveland, important features suggested by Dr. Szell from the experience at Severance Hall were incorporated by Christopher Jaffe and the architect, Peter van Dijk. The modifications were primarily directed to provide numerous heavy sound reflecting wood panels to give many early reflected sounds for the audience, and also for communication between the musicians. The shell ceiling at Blossom is nearly horizontal and therefore projects but little sound to the audience, but does help the musicians communicate, especially those near the center of the stage. The directivity of orchestral instruments is also a consideration. However, for frequencies below 1500 Hz, most instruments are sufficiently isotropic radiators of sound, so that this factor is only important for player communication at higher frequencies.

The absence of early reflected sound from orchestra to audience due to the open sides of the Blossom Pavilion is a serious acoustical defect. However, this is in large part compensated by reflections to the audience from the numerous panels of the stage shell.

The Cleveland Orchestra Chorus also participates in concerts at Blossom, so the rear wall of the shell is again too deep for optimum conditions for regular orchestral concerts. This defect can be mitigated by covering the rear wall with a sound absorbing drape. This added absorption is by no means ideal, but does eliminate troublesome delayed reflections from the rear wall of the shell.

As final examples, we cite two recently constructed concert halls in Ohio. These are the E. J. Thomas Hall for the Performing Arts in Akron, and the Umstaddt Hall in Canton. An unusual opportunity to compare the acoustics of these halls was afforded when Mr. Louis Lane conducted Mahler's Sixth Symphony in them with the combined Akron and Canton orchestras on the nights of 21 and 22 February 1977. After the second concert there was an opportunity to discuss the acoustics with Mr. Lane, who was highly pleased with the acoustics of the Canton Hall as compared with the Akron Hall for the following reasons.

Both halls have reverberation time characteristics generally considered satisfactory for orchestral music. Although the Canton Hall has somewhat longer reverberation times this factor alone is not the main reason for favoring its acoustics. A major merit of the Canton Hall for orchestral concerts is in the stage arrangements Specially designed portable sound reflecting and sound diffusing structures of heavy wood are placed as close as possible at both sides and behind the orchestra. There are also overhead panels which reflect sound to both the musicians and the audience. In contrast, at Akron, the original stage had few sound diffusing surfaces. The stage walls are flat angled sound reflecting surfaces and their primary function is to project sound from orchestra to audience; and do not provide adequate communication between performers. Furthermore, the stage ceiling at Akron is so high (to join smoothly with the complex movable ceiling of the hall) that it provides but little help in permitting members of the orchestra to hear each other. A modification at Akron recommended by the writer was to employ a structure at the rear of the stage having efficient sound diffusing and sound reflecting properties. This helps the musicians at the rear of the stage a great deal. It is planned to provide similar structures of the sides of the stage. Comparison of these two halls emphasizes the fact that even with acceptable reverberation time characteristics, the acoustical acceptance of a hall may nevertheless depend critically on stage design.

We believe that acceptable reverberation time limits in a hall for music can be rather wide, provided they do not exceed reasonable tolerances. There are, however, exceptions. It has been found that halls having too prominent a high-frequency reverberation are always judged as being too "harsh." This often occurs in small concert halls for music schools, due to the reduced air absorption of high-frequency sound as compared with a standard size concert hall. For example, in the Cleveland Institute of Music, the Kulas Hall as originally designed, was much too strident due to excessive high-frequency sound. After construction this could only be corrected (without major architectural alterations) by the addition of heavy carpet on all aisles and exposed floor areas. Another serious defect in the reverberation time characteristic is a deficiency of low-frequency sound. However, except for such extreme variations in reverberation time characteristics, reverberation conditions can depart considerably from the accepted norm and still result in a satisfactory concert hall, when the stage is properly designed.

There are other reverberation criteria that may need revision. The long held belief that reverberation times should be longer for larger rooms is not basic for musical requirements. Rather, the desire for a longer reverberation in large halls expresses an indirect requirement for greater total sound energy to produce adequate loudness. Without sound amplification this can only be achieved by reducing the sound absorption, and so producing a longer reverberation.

There has been a long-standing argument as to the optimum reverberation times in churches for organ music; in contrast with generally accepted criteria for speech intelligibility. Here also, we believe that it is the fullness of the organ sound that is desirable and not a long reverberation *per se,* which in itself only harms the clarity of music. For example, St. Margaret's Westminster, discussed above, renowned for its organ music and Bach Cantatas, has a reverberation time of only 2 s, a condition very close to Bach's St. Thomas Church in Leipzig when occupied. We believe that the primary design objective for organ music should be to achieve a "cathedral effect" which results from the sense of space and distance produced in a large church by binaural hearing and not from a long reverberation time alone. Cathedrals famous for their organ music, such as Chartres and King's College Chapel at Cambridge,[5] have relatively short reverberation times. Furthermore, the "cathedral effect" cannot be realized in a small church by a prolonged reverberation, as the sound field is too nearly isotropic.

III. CONCLUSIONS

The examples discussed above all emphasize the fact that an optimum acoustical environment for performers is essential for concert hall acoustics. Thus, a major criterion of architectural and acoustical design should be to provide stage arrangements for this objective. These are first, to provide ample sound diffusing elements on the side and rear walls, and if possible on the ceiling. These elements should be heavy sound reflecting structures; but sound reflection alone, especially by angled flat surfaces, will not produce the desired results; sound diffusion is of even greater importance. Movable flat overhead reflectors are alone not adequate as they are very sensitive to angular adjustment to achieve satisfactory conditions and can seldom serve both musicians and audience. The sound field characteristic that is of greatest importance is the spectrum of early reflected sounds following the direct sound. This discrete spectrum rather than the initial slope of an averaged reverberation decay curve should be a prime objective of acoustical design.

It is readily possible for designs to achieve this objective, but they should be considered by both the architect and acoustical engineer as being of equal importance to planning for the auditorium itself.

ACKNOWLEDGMENTS

I am greatly indebted to Mr. A. Beverly Barksdale for illuminating discussions on the concert halls referred to in this paper, and to Professor Arthur H. Benade for helpful criticisms.

[1]P. H. Parkin, J. Sound Vib. **2**, 74 (1965).

[2]Vern O. Knudsen, *Architectural Acoustics* (Wiley, New York, 1932), pp. 545–546.

[3]Hope Bagenal and Alexander Wood, *Planning for Good Acoustics*, (Methuen, London, 1931), pp. 224–229, and measurements and observations by the writer in 1974.

[4]J. E. West, G. M. Sessler, and J. L. Flanagan, J. Acoust. Soc. Am. **55**, 1022 (1974). The importance of "stage reverberation" has been emphasized by their work at the Philadelphia Academy of Music. This hall has a short reverberation time, but nonetheless, is pleasing to both concert audiences and musicians. However, it was much better before the renovation of 1968 when much carpet was installed.

[5]Arthur H. Benade (Case Western Reserve U.) and Philip Bate of London (personal communication).