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THE SIMPLE DESIGN OF SHOEBOX CONCERT HALLS AND THEIR SHORTCOMINGS

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1. INTRODUCTION

In recent years, there has been a tendency to only build rectangular shoebox-shaped concert halls. There are some important reasons why it is desirable to have such widespread use of rectangular halls: since many famous orchestras, as well as conductors, travel a lot and present their repertoire in many different places, it is a big advantage if they always find similar room acoustical conditions, so they are not forced to adjust their presentation - tempi and balance - to different room acoustics. For critics it is also easier to judge performances played under similar room acoustical conditions. They judge the quality of a presentation not only by their own imagination but also by comparing it with the numerous experiences they have had before. It is difficult for them to decide which part of a presentation in a new hall is influenced by the hall and which by the artists. So if they are rattled by a new listening experience, they tend to quote it bad. There is one striking case which demonstrates that even with a rectangular hall, but a very large one, at the time it opened: today's highly reputated Boston Symphony Hall. It received terrible reviews after opening. One critic wrote: "... and to conclude with, 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 degrees of violence" (1). Since that time, nothing has been changed in the hall, but now it is quoted as one of the best in the world.

2. SIMILARITIES OF WELL-KNOWN RECTANGULAR HALLS

There are some prototypes of rectangular halls such as the Musikvereinssaal Vienna, opened in 1870, the Concertgebouw Amsterdam, opened in 1888 and the Boston Symphony Hall opened in 1900. Since physics shows that there will be similar acoustical conditions in halls with similar shape and the same materials, the rules for designing a rectangular hall can be easily deducted from famous examples.

Table 1 shows a comparison of data of the three mentioned well-known concert halls: Capacity up to 2,600 persons, orchestra pit 20 m wide and 10 m deep, 1 m above floor level, hall dimensions 40 to 50 m long, approx. 20 - 23 m wide and 18 m high. Inclination of the ground floor between 0 and 1.5 m. Depending on the number of seats, one or two horseshoe-shaped balconies with a depth at the sides of approx. 3 m (2 to 3 rows) and of approx. 7 m at the rear. The balconies in a height of approx. 5 and 10 m above floor level. All inner surfaces having ornamentations with profiles, lesenes, caryatides, columns, statues etc. The materials of the surfaces are wood on concrete for the floor and wood on wooden risers for the podium. The stage walls are either plaster or 12 to 24 mm wood, the walls at the audience area are plaster on brick walls, the ceilings are covered with plaster on a wooden supporting structure.

Table 1: Data of three well-known rectangular concert halls (2) (3) (4)

	Musikvereinssaal Vienna	Concertgebouw Amsterdam	Boston Symphony Hall
seat capacity	2,000*)	2,000	2,600
volume (m^3)	15,000	18,000	19,000
orchestra area (m^2)	20 x 10 = 200	21 x 13 = 270	17 x 10 = 170
podium height (m)	1,10 - 1,35	1,10 - 1,25	0,90 - 1,10
length (stall area) (m)	40	45	48
width (m)	20	28	23
height (m)	18	17	18
distance between rows (m)	0,75 - 0,85	0,75	0,75 - 0,85
inclination stalls (m)	0	0	1,5 starts with the 10th row
reverberation time 500/1,000 Hz occupied (s)	1,9 - 2,1	2,0	1,8 - 1,9

*) including 320 standies

It can clearly be seen, these halls are very similar as far as the basic shape is concerned. In contradiction to what many musicians say, these halls have no or only a small wooden lining. All you have to know in order to copy an old-fashioned shoebox-shaped concert hall are the dimensions and informations about the materials. Fig. 1 gives the basic dimensions.

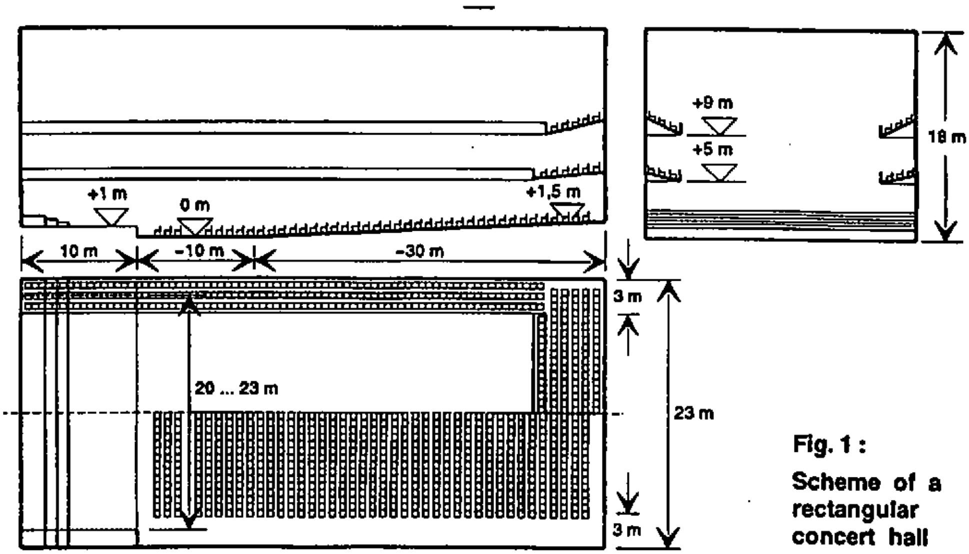

Fig. 1 : Scheme of a rectangular concert hall

3. SOME TECHNICAL REASONS FOR THE GOOD ACOUSTICS OF OLD SHOEBOX-SHAPED HALLS

Let's start with the size of the orchestra podium: A podium of 200 m^2 is large enough to house even the largest symphony orchestra but it forces the musicians to sit close together. This improves the acoustical contact between the musicians. Furthermore, the reflecting side and front walls are close together and therefore more effective: The reflections are stronger and arrive earlier than in modern halls with their enormous podiums which are intended for all sorts of performances such as ballet, TV entertainment, etc. This limited size of the orchestra podium is an acoustical advantage because it improves the acoustical contact within the orchestra.

The next very important item is related to the size of the chairs and the chair arrangement: The narrower the chairs and the smaller the distance between rows the smaller the sound absorption of the audience area. Since the absorption coefficient of the occupied area is nearly independent of the number of seats, the absorption per person becomes lower if more persons are sitting in a given area. For example, the uncomfortable row distance of approx. 75 cm in the old halls provides space for nearly 50 % more listeners in the same area than the very comfortable seats with a row distance of 1.1 m as chosen for modern halls. From the room acoustical point of view, the sound absorption per person in the case of 75 cm row distance is approx. 30 % less than with a row distance of 1.1 m. The width of the orchestra pit of around 20 m determines the width of the hall. Assuming a width of the chair of approx. 55 cm allows space for approx. 30 persons in one row. A maximum length of the audience area of 38 to 48 m allows 1,200 to 1,500 persons at maximum in the stalls. Including the aisles, there is a maximum distance from the orchestra pit to the last row of less than 40 to 50 m. This concentration of the audience is a big advantage compared to modern halls, where the same number of listeners need a much lager area.

For placing additional audience, side balconies are used. Given a total length of the room including orchestra podium of approx. 50 m and 2 to 3 rows of seats, 300 to 500 persons can be seated in this area. One or two rear balconies with a depth of approx. 8 m provide space for additional 300 to 500 persons.

The reverberation time as defined by W. C. Sabine in a concert hall depends only on the sound absorption of the surfaces and the volume. As the sound absorption is proportional to the number of seats, there is a rule of thumb for determining the necessary total volume of a hall with a reverberation time of approx. 2 s. For a modern hall it says that 8 to 10 m^3/person are necessary. As you can see from table 1 for the halls listed, a volume of 7.5 m^3/person was sufficient. The reason for this is the "highly packed" audience.

The audience area is very absorbing for sound of gracing incidence. So it is useful to place the orchestra on a podium of at least 1 m height as it is done in old-fashioned halls. In addition, it is effective to incline the rear seats of the stalls as it is done in the Boston Symphony Hall. Since the angle of gracing incidence should not be below 5 degrees, an inclined floor has to start in a distance of approx. 10 m from the podium and reach a height of approx. 1.50 at the last row. However, in halls with flat stalls there is an unpleasant, indistinct sound in the rear.

An advantage of the parallel sidewalls: Due to the sound reflections, which are improved by the side balconies, the source is perceived as being extended, especially with increasing loudness (see Fig. 2). Since the stereophonic recording was introduced, this is a highly appreciated effect of fashion but of course also hinders the localization of the sound sources.

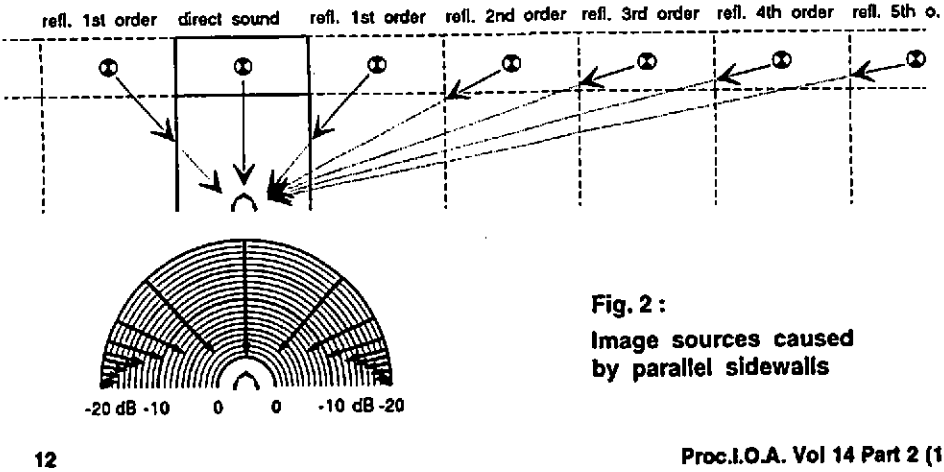

Fig. 2 :
Image sources caused by parallel sidewalls

According to the architectural style of the old halls, the walls and ceilings have been structured by using columns, caryatides, lesenes, niches, profiles etc. which results in an important item for their acoustical characteristics. The more or less irregular surfaces lead to an acoustically useful, so-called diffuse reflection. This means that the sound wave bouncing against the wall is not reflected in a "regular" way but in many different directions. This effect of a certain diffusing element depends on its dimensions measured in wave lengths. So, for a low frequency such as 125 Hz (c) with a wave length of approx. 3 m, the usual profiles of around 0.5 m are too small for creating essential diffuse reflections. But for frequencies around 440 Hz (a'), the profiles and columns start to scatter the sound waves in many directions. If, for example, an instrument radiates only in a certain direction, the sound is not only reflected regularly into a limited area but spread over a large angle. So the disadvantage of the directivity of an instrument is compensated by the room.

Let's take the violin as an example, an instrument similar to the human voice. From 200 Hz to 600 Hz, the violin acts as an omnidirectional sound source but above this frequency range, it starts to radiate with high directivity. Also at these higher frequencies, the profiled surfaces of the old hall start to diffusely reflect the incoming sound waves.

As mentioned before, the materials out of which the surfaces of old halls have been built are wood on concrete for the audience floor at the stalls, plaster on bricks and plaster on wooden substructures at the ceiling. These surfaces are strongly sound- reflecting at medium and high frequencies and moderately sound- absorbing at very low frequencies, so they cause a relatively long reverberation independent of frequency.

The orchestra podium is made out of wood on wooden risers. It still is doubtful whether such a relatively heavy wooden floor radiates considerable sound energy e. g. from cellos which excite the floor via the peg. But it is certain that a normal wooden floor excited by the peg carries out tangible vibrations which the player can sense. For other instruments, not in rigid contact with the plates, but located close to it, the light-weighted wooden linings at the walls act as absorbers. If the orchestra podium is surrounded by wooden plates in front of an air space, these plates absorb low-frequency energy, especially from instruments located close to it like double-bass and kettledrums. By this, these instruments become better balanced without a considerable reduction of the reverberation time of the hall.

Since the reputation of a hall depends strongly on the assessment by the musicians, there is another advantage of the shoebox-shape as mentioned before: a large part of the radiated sound energy is reflected back to the musicians and thus gives them a good feeling. That is stimulating like a sound reflecting bath room. On the other hand, due to the near sound reflecting surfaces, a slightly inexact striking is masked.

If one takes the viewpoints mentioned above into consideration, a copying of the old-fashioned halls is easy. But the number of people who like classical music is steadily increasing. If only rectangular halls similar to the existing ones provide perfect room acoustical conditions, no enlargement of the room would be possible. By changing the size, the reflection pattern at any particular point in the hall will be changed. So in this case the only way of increasing the capacity would be to increase the number of seats within the given audience area. However, the seating comfort in the old halls does not meet today's demands. So in a modern hall 2 600 persons need much more space than in the old Boston Symphony Hall.

4. ACOUSTICS OF SHOEBOX-SHAPED CONCERT HALLS

Asking an audience participant of a symphonic concert about the "acoustics" of a hall, one often gets the answer: "I don't know because I'm not an expert". This implies the question whether acousticians are only working for specialists like musicians and critics. Sometimes one can get this impression.

On the other hand, there are many criteria which are obviously easy for everyone to characterize and which describe the acoustics of a hall. The fist trivial criterion is the absence of a disturbing background noise. Next is the loudness: whether the presentation has sounded strong enough and with sufficient dynamics. Then the question whether the music sounded slightly slurred but not too much merged. Another criterion is whether is is possible to localize the position of the sound sources acoustically or whether the orchestra sources seem to be enlarged by the room. Another important judgement: Does the orchestra sound dark, warm, bright, or sharp. Of course most of these observations may be influenced by the conductor and the musicians. For example, if the conductor prefers the wind, a missing string sound does not mean that the room is responsible for this.

For the musicians, hearing each other is of great importance, as well as whether the room "forgives" inexact playing and whether one gets a feeling of how it sounds to the audience.

In the old rectangular halls sometimes the insulation against outside noise is not sufficient and therefore there is a disturbing background noise. On the other hand, the loudness in these halls is sufficiently high, even when playing a pianissimo. The reverberation is relatively long so that successive notes sound legato and inexact playing is masked. If one closes the eyes one cannot localize the position of the instrument playing. One feels surrounded by music. The music sounds "warm" but not too dark. Even a medium class orchestra sounds acceptable in these halls.

For a long time, scientists have tried to find criteria which describe precisely the observations of the listeners and which can be measured. In Table 2 some of the most important quantities are listed. These criteria and their values for rectangular halls can be quoted as acceptable, so that they are taken for planning new halls.

Of course, the number of criteria is much larger but the mentioned ones describe the important observations and they can be predicted.

Such a prediction is easy for the background noise: It's pure engineering work to protect a hall against outside noise and from the air conditioning system. But how far the influence of the acousticians reaches may be seen from the fact that they even require a certain humidity of the air because dry air leads to a low reverberation at high frequencies and therefore to a loss of "brightness".

The sound transmission achieved from the podium to the audience should be as uniform as possible. This can be achieved by providing a strong direct sound with the help of an inclined auditorium and by compensating the attenuation of the direct sound by directing strong reflections from walls and ceiling against the far distant seats.

The reverberation time is a function of volume and frequency- dependent sound absorption. By choosing a sufficiently large volume and appropriate walls, the required reverberation time can be achieved.

The acoustic "clarity" is determined by the sound energy which reaches the listener, or the musicians, soon after the direct sound.

The criterion "spatial impression", or the ability to identify the location of the sound sources has not yet been sufficiently defined. The cross-correlation index, κ, is a comparison of the signals received by both ears and can be used to describe this spatial impression. $\kappa \geqq 0.7$ means that the source can be acoustically localized, $\kappa \sim 0.2$ makes this impossible: one feels "surrounded" by sound. The lateral efficiency (5) is the ratio between the energy reaching the listener from the sides compared with the total energy. A value of 0.16 measured at some places in the empty Musikvereinssaal (4) corresponds approx. to a $\kappa \sim 0.4$.

The ranges given for reverberation time, clarity index and interaural cross correlation describe roughly the range of preference of different listeners.

Table 2: Some important room acoustical criteria and their meaning

subjective meaning	objective criterion	value for rectangular halls	comment
background noise	A-weighted sound level L_A	$L_A < 25$ dB(A)	disturbing noise inside the hall caused by outside traffic, air conditioning system etc.
sound transmission from the stage to the audience	strength index G	$-30 \geqq G \geqq -40$	The strength index has to be as uniform as possible within the hall
reverberation	reverberation time T	$1.7 \leqq T \leqq 2.2$ s	The reverberation time describes the merging of the playing.
clarity	clarity index C	$-4 < C < +2$	the precision to hear musical phrases
source localization	interaural cross-correlation index κ lateral efficiency, LEF	$0.7 \geqq \kappa \geqq 0.2$ LEF ~ 0.16	How the sound sources can be localized.

5. SHORTCOMINGS OF THE UNIFORMITY OF CONCERT HALLS

Looking back, one may get the impression that copying the of old-fashioned shoebox-shaped concert halls is the best we can do, because these halls are preferred by conductors, musicians and critics and not disliked by audiences. Conductors and musicians can present their repertoire everywhere in the same way; the critics do not have any problems with the judgement of different performances. But whether the paying audience, interested in symphonic music, wants to always hear a uniform performance, is doubtful. Of course the blurred sound is useful for an unprecise playing orchestra but for top musicians, an acoustics which makes audible the precision pleases the audience more. Furthermore, a "stereophonic" sound field in which one cannot localize the sound sources is a fashion caused by the recordings but may be disappointing after a while . Therefore halls with a precise sound field in which playing is more difficult but which makes audible the art of playing presents an exciting experience for the audience and also for top musicians. For example, Beranek (2) reports a comment by Karajan about the Musikvereinssaal: "...One shortcoming is that the technical attack of instruments, bows and lips gets lost. Instruments that do not sound precise in time merge. Also successive notes tend to merge into each other..."

So, since the precision of playing music is steadily increasing, this should be taken into consideration when designing acoustics for a modern room. Furthermore, since acoustics and architecture of a concert hall cannot be separated, it is important that both are coincident. There is one modern hall where this is the case: The Berlin Philharmonie designed by architect H. Scharoun and the acoustician L. Cremer. Although there is an acoustics which is different from that of an old shoebox-shaped hall and although it's not easy to play there, this hall has been fully accepted and loved by the audience after a while.

It would be a pity if expressive, timeless symphonic music were to be buried in the late century architecture of shoebox-shaped concert halls. It would be a great loss, if due to its uniform presentation, young people would not become aware of the beauty and liveness of this music which becomes audible when a new exposure is obtained through different rooms and room acoustics.

6. REFERENCES

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