INTERNATIONAL SYMPOSIUM on MUSICAL and ROOM ACOUSTICS

ISMRA 2016

September 11-13, 2016

La Plata, Buenos Aires, Argentina

Measurement of Concert Halls / Opera Houses: Paper ISMRA2016-56

Stage and pit acoustics in opera houses

Martijn Vercammen [(a)], Margriet Lautenbach [(b)]

[(a)] Peutz, Mook, Netherlands, m.vercammen@peutz.nl
[(b)] Peutz, Zoetermeer, Netherlands, m.lautenbach@peutz.nl

Abstract

Musicians and singers in opera houses work together in an extremely difficult acoustical environment. Due to the acoustic and visual aspects, the orchestra is traditionally situated in a pit before or partly below the stage. This lowering and partly covering the orchestra works positively on the balance between singers and orchestra. The partly covering is especially positive for large opera's; it enables a full symphony orchestra sound without losing the balance to the lower power of the singers. Bayreuth is an extreme example of such an orchestra pit that significantly reduces the loudness of the orchestra. However, the working environment for musicians and singers is a real challenge. As they usually can't see each other, they both heavily depend on the conductor, in the pit the loudness is high and the singers often stand between absorbing decorative elements and curtains.

Although there are not much reflection paths left between musicians and singers, the few remaining possibilities for early energy sound transmission paths can cause large differences between opera houses. The differences are clearly noticeable in the acoustical interaction between musicians and singers as well as in the balance between the two at the listeners' positions. Measurements made in the Staatsoper Berlin, Festspielhaus Bayreuth, Oper Cologne and Komische Oper Berlin are used to analyze the differences, which can be used for the design of new opera houses as well as improvements for renovations.

Keywords: opera house, stage acoustics

Stage and pit acoustics in opera houses

1 Introduction

Musicians and singers in opera houses work under acoustic difficult circumstances. Due to acoustic and scenic reasons, mainly with respect to sound development and balance between orchestra and singers, the orchestra pit is a traditional and logical part of an opera house. The "underground" working place in the orchestra pit is especially beneficial for the balance between the singers and the orchestra. Especially for the grand opera's the orchestra pit enables the sound and timbre of a full orchestra (about 100 musicians) without acoustically losing the singers completely. This can mainly be achieved by an orchestra pit which is just partly open to the hall, with Bayreuth as an extreme example.

For musicians it is a challenge to work and to work together under these conditions: the musicians and the singers do usually not see the other, in the orchestra pit it is often quite to very loud and the singers are often surrounded by absorptive scenery and curtains. What transmission paths are still available for the musicians and how can they be evaluated acoustically?

2 Measurements in four opera halls

To investigate the transmission paths for the musicians and singers room acoustic measurements are performed in four halls. This is an extension of the work presented in [1]. Three of these halls where measured as part of consultancy work to improve the acoustics. The measured transmission paths are:

- Between a source and receivers on stage;
- Between a source and receivers in the orchestra pit;
- Between a source on stage and receivers in the orchestra pit and vice versa.

In addition to the transmission paths, the resulting balance in the public area between a source on stage and a source in the orchestra pit is compared.

The measurements are performed according to ISO 3382 [2]. The measurement results were evaluated based on the Strength G for the balance in the hall and Early support ST_{Early} , and the Early Strength G_{80}, for the conditions for the musicians. In the Early Strength the influence of the hall is "excluded" and is calculated for individual positions by relating the direct sound and reflections up to 80 ms after the direct sound to the free field "outside" sound level at 10 m distance from the source:

$$G_{80} = 10\lg \frac{\int_0^{80} p^2(t)dt}{\int p_{10}{}^2(t)dt} \tag{1}$$

Contrary to concert halls, in opera houses there is no direct line of sight, so no direct sound path between the rear positions in the pit and the positions on stage. In concert halls it was found that especially the early reflected energy (so without direct sound) from 5 to 80 ms gives good correlation to musicians opinion ([3],[4]), while in opera houses the direct sound has to be incorporated and for some positions without direct sight it is difficult to distinguish between "direct" sound and the very early reflections.

In many publications the acoustics is evaluated in terms of clarity C_{80} and definition D_{50}. (e.g. [11],[12]). These data are not presented here, since loudness or strength seems to be the primary perception parameter.

The source used is a point source that is sufficiently omnidirectional, also at short distance [5]. The source is calibrated with the sound level at 1 m from the source.

The measurements are performed in unoccupied halls with orchestra furniture in the pit.

The scenery was depending on the opera playing. The acoustic relevant aspects of the scenery are described in the next paragraphs, combined with some data of the halls itself.

Figure 1 gives an overview of the measurement positions, in this case for the opera house of Cologne, but the positions are systematically equal for the other opera houses. In this paper we will concentrate on the transmissions mentioned above.

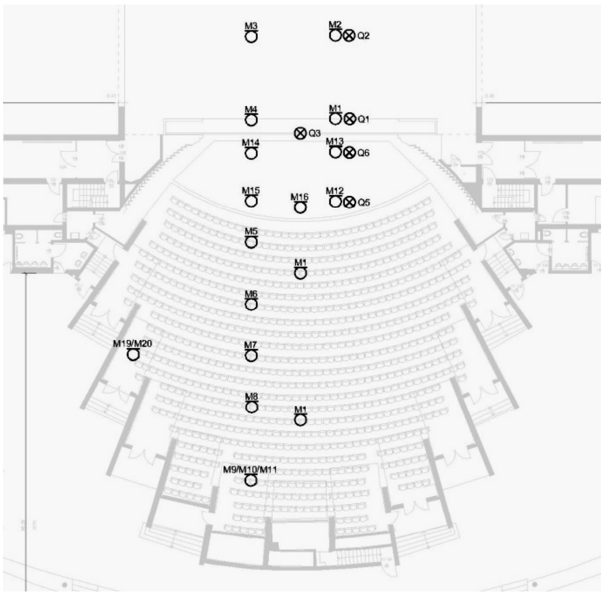

Figure 1. Measurement positions in the opera house of Cologne.

Qx are source positions, Mxx are microphone positions.

2.1 Opera House Bühnen Köln

The opera house of the Bühnen Köln (“Cologne Stages”) has a public capacity of 1346 within a room volume of 10000 m^3 (hall without fly tower). The reverberation time of the unseated situation is 1.4 s, with audience the reverberation time is 1.2 s, both without the influence of the fly tower (iron curtain down). This was before the renovation that is ongoing at this moment. The response measurements were performed with iron curtain open, the scenery existed of a reflective rear wall, and on the sides curtains were present.

2.2 Deutsche Staatsoper “Unter den Linden”, Berlin

The Deutsche Staatsoper “Unter den Linden” in Berlin (DSO) has a public capacity of 1350 within a room volume of 6,500 m^3 (hall without fly tower). This was before the renovation that started in 2010 (and is not finished at this moment). The reverberation time of the situation without audience was 1.3 s, with audience the reverberation time was 1.1 s (with iron curtain closed). The scenery during measurement was completely absorptive; all around stage was some kind of carpet with a layer of foam (scenery of Macbeth).

2.3 Festspielhaus Bayreuth

The Festspielhaus in Bayreuth has a public capacity of 1800 within a room volume of 10,800 m^3 (hall without fly tower). The reverberation time of the unseated situation is 2.4 s, with audience the reverberation time is 1.6 s, both without the influence of the fly tower. In both cases the stage opening is closed with a (metal) fire curtain. The reverberation time without audience is from our own measurements (confirmed in [7]), with audience is from literature [6]. The (famous) orchestra pit in Bayreuth is quite large, therefore the number of measurements is larger than in the other opera houses. Figure 2 also shows a section of the stepwise sunken pit. The curved shell has an angled reflector, the horizontal covering is absorptive, but the rear ceiling is reflective. Hall and pit are described in many publications (e.g. see references mentioned in [7],[8],[9]). The intention of Wagner was to have no distracting light from the pit and create a far away sound, as from a mystical abyss [8].

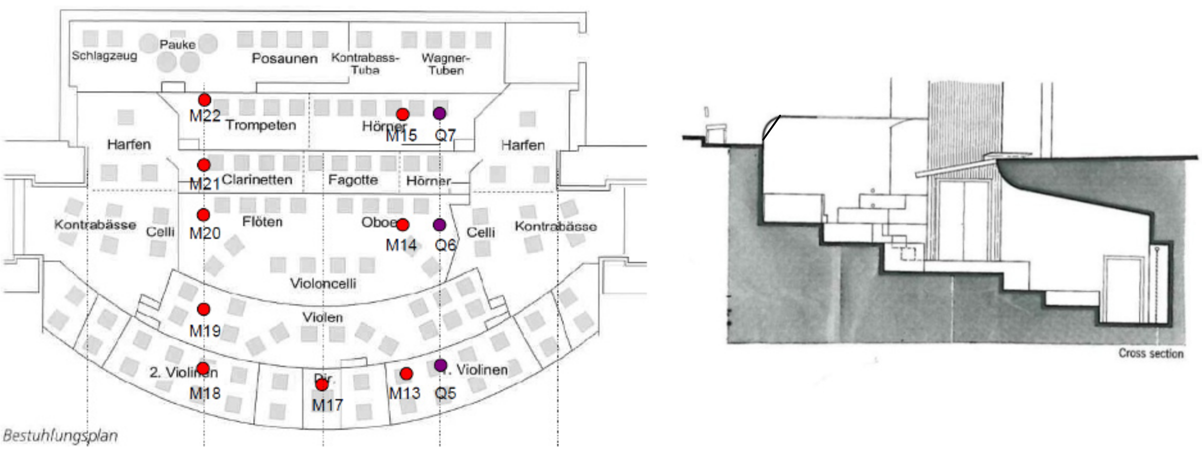

Figure 2. Festspielhaus Bayreuth: Plan and section of the pit. Measurement positions in the orchestra pit. Q5 to Q7 are source positions, M13 to M22 are microphone positions.

See figure 2 for an overview of the source and receiver positions in the pit. There was no scenery present, there was a curtain hanging in front of the rear wall, the side walls have reflecting panels under an angle of about 45 degrees, aimed at the hall.

2.4 Komische Oper, Berlin

The Komische Oper in Berlin (KOB) has a public capacity of 1205 within a room volume of about 7000 m^3 (hall without fly tower). The reported measurements were taken after renovation of the orchestra pit in 2015. The reverberation time without audience was 1.5 s (with iron curtain closed). The scenery during measurement was partly absorptive, partly reflective, with a scenery with some curtains in low positions. With iron curtain open the reverberation time was reduced to 1,4 s.

3 Comparisons between the opera houses

3.1 Support

The table below gives an overview over the measured ST_{Early} [dB] in the four opera houses.

	Opera Cologne	Staatsoper Unter den Linden, Berlin	Festspielhaus Bayreuth	Komische Oper Berlin
Stage: S1(front of stage)	-15.2	-12.5	-14.8	-12.3
S2 (rear of stage)	-14.8	-19.5	-17.9	
Pit: S5 (front of pit)	-11.3		-9.5	-9.2
S6 (rear of pit)	-9.1	-9.4	-5.3 -4.4	-7.2

The results show that the support at the rear of the stage is clearly lower in some situations (e.g. DSO with very absorbing scenery). The support in the pit is higher than on stage. At the rear of the pit, in the covered area, it is even higher. Despite of the sound absorbing covering of part of the pit, the support is extremely high in Bayreuth. This was measured without musicians. It can be expected that when the pit is full with musicians the levels in the covered areas will be somewhat lower.

3.2 Balance in the hall

The balance in the hall between sources on stage and in the pit are shown in figure 3. The strength is shown as a function of distance of source S1 (front of stage), which means that for each receiver position in the hall, the different soucres are shown for the same distance (the actual distance is different).

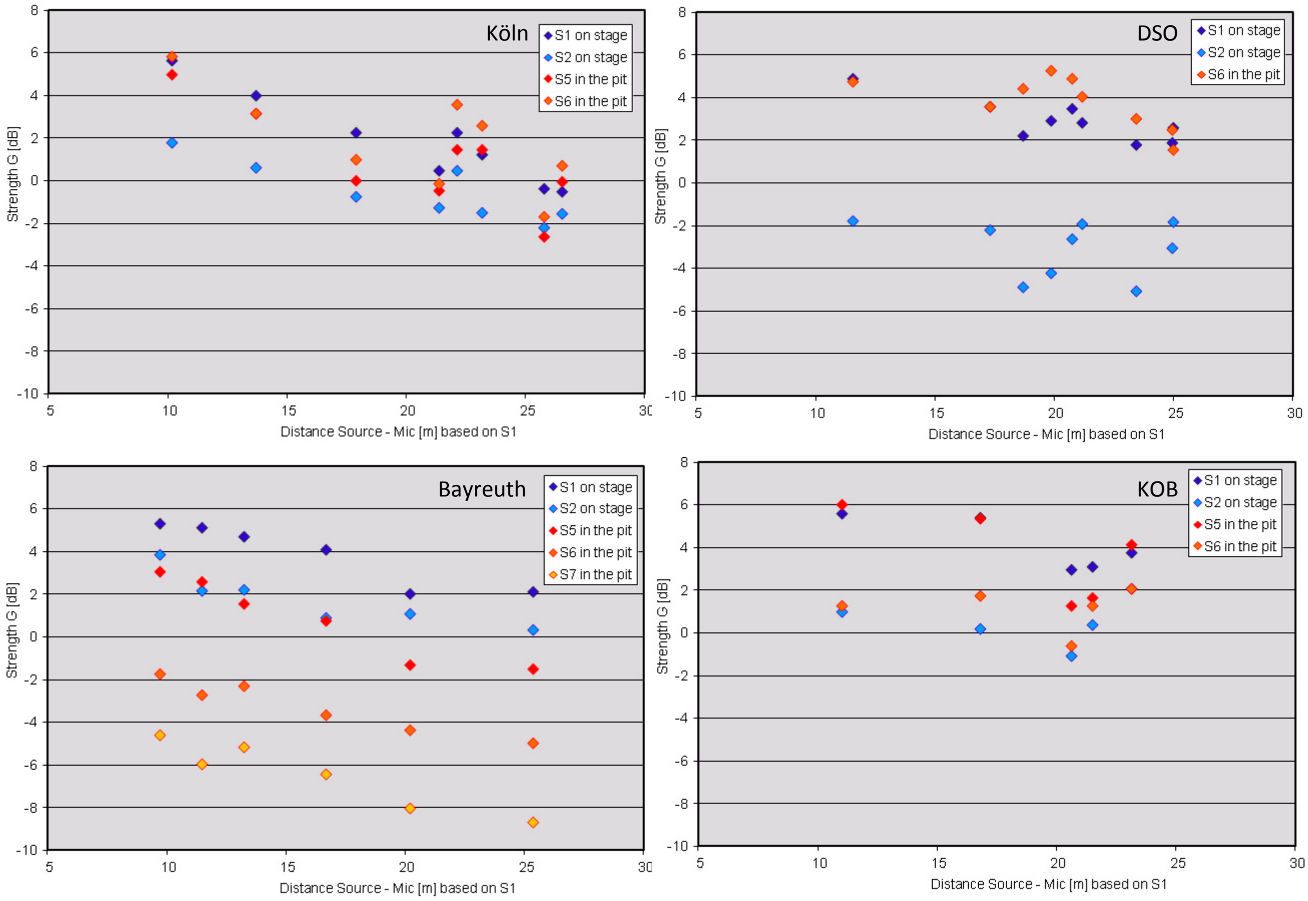

Figure 3. Measured Strength *G* in the hall as a function of the distance from S1, for different positions of the source: blue: source on stage (S1,S2): red/orange: source in the pit (S5,S6).

These measurements show significant differences in sound transmission within opera houses and between opera houses. A singer from the rear source position (S2: about the middle of the stage house) can hardly be heard in case of sound absorbing scenery. The results for the DSO, with this particular scenery are rather extreme, but also the measurements in Cologne show this. With a partly covered pit, the rear positions in the pit (typicaly brass) still have a rather good transmission to the hall, especially for the balcony measurement positions where there is a direct line of sight (Cologne, DSO). For these balcony reciever positions, the sources in the pit have higher G than sources on stage, the screening by the sunken orchestra pit only works at stalls level.

Bayreuth is special, sound from the pit is hardly capable of reaching the public, especially from the rear of the sunken and covered pit. At all listener positions there is a clear balance in favour of the singers on stage.

3.3 Transmission on stage and in the pit

Figures 4 gives an overview of the measured Early Strength on stage and in the pit. Also shown is the theoretical decrease of the direct sound in free field conditions. On stage (figure 4a) all measurements show a clear distance dependancy. The absorptive stage scenery at the DSO accounts for a large decrease of strength with distance, the levels are hardly higher than to be expected in free field conditions.

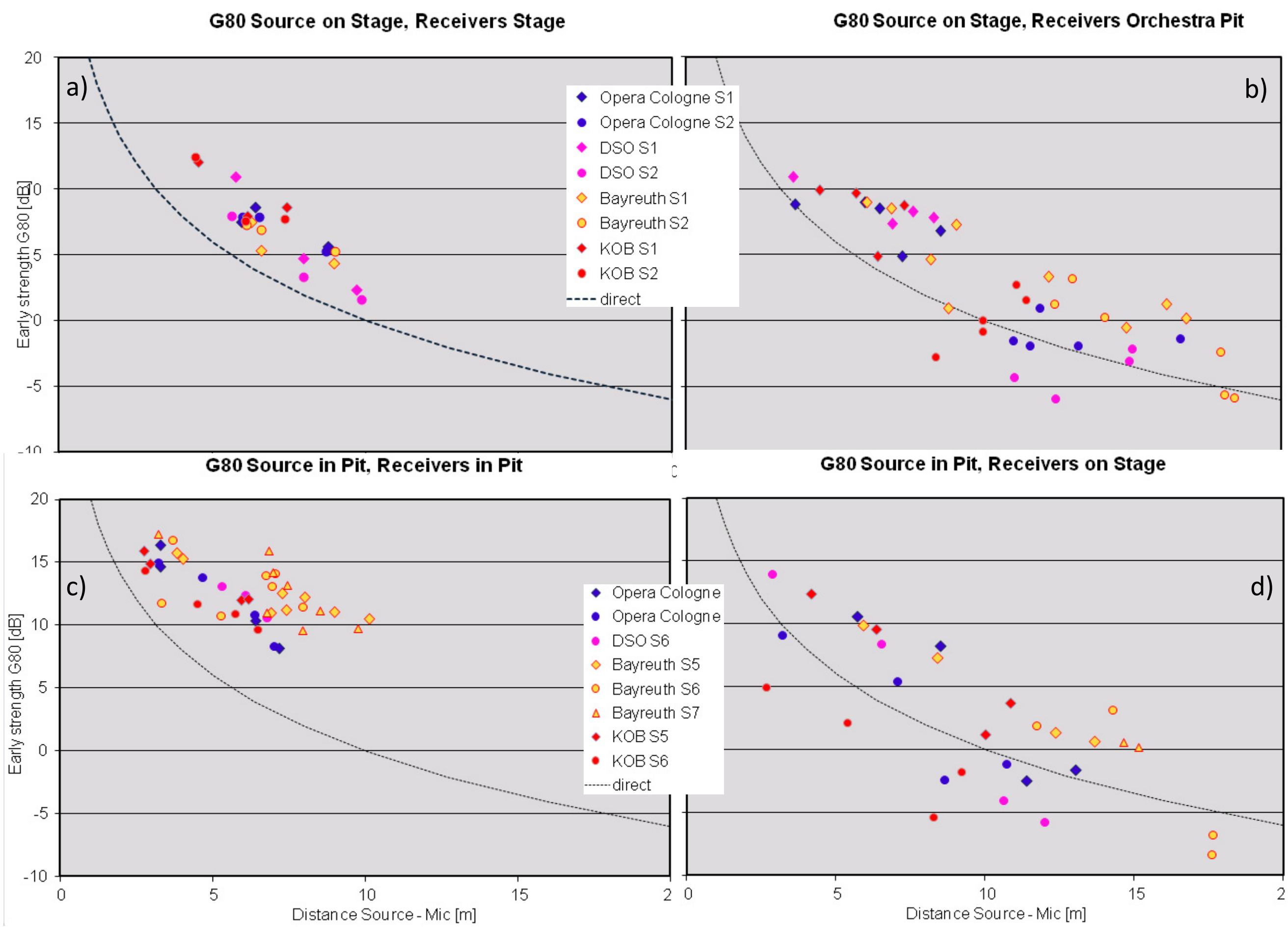

Figure 4. Measured Early Strength (G80) from the sources on stages and in the pit to the receivers on stage and in the pit.

As for transmission from stage to pit (4b), this seems to be better from the frontal position S1 to the frontal, visible positions in the pit, probably due to the reflecting walls in the pit. For positions further on stage and further in the pit, the Strength drops to hardly audible levels, especially considering the masking from other instruments in the pit (4c). For some positions without direct line of sight, the Strength is lower than would be expected from direct sound in free field conditions.

The Strength levels in the pit (4c) are between 9 and 16 dB, which is very loud, roughly 6 dB louder than for stage positions in concert halls [13]. However it has to be considered that the measurements are taken with orchestra furniture only, without musicians. The presence of the musicians will increase absorption and reduce sound levels in the pit. Because of the smaller volume these effects will be more significant for an orchestra pit than for the stage in a full size concert hall, reducing the actual difference between pit and stage a bit. The closed pit in Bayreuth shows a significantly higher sound level than the three other, more open pits.

From pit to stage (4d) the results correspond roughly to the transmission from stage to pit. Large differences occur, depending on the position in the pit and on stage. Only from front of the pit to front of the stage a sufficient audibility is possible. It is interesting to see that the transmission between stage and pit in Bayreuth seems to be slightly better than in other halls, at least for some positions. This is probably due to the efficiency of the tilted reflector in the shell covering.

4 Conclusions and discussion

The measurements presented here show significant differences in sound transmission, depending on source and receiver position. In general the conclusions are:

- without specific acoustically effective stage scenery the opera stage acts like a theatre stage: absorptive, with low transmission to the rest of the stage and the hall.
- orchestra pits are loud and in many cases the balance is in favour of the orchestra sound from the pit. Only with a partly covered pit the balance changes in favour of the singers, but with the drawback of a higher strength in the pit, with Bayreuth as en extreme example
- audibility between stage and pit, especially for positions not in the front, is poor. Communication between stage and pit can be improved by reflectors at the parapet.
- the balance between singers and orchestra is much better in the stalls than at balcony level. The special very closed pit in Bayreuth favours the singers, but there is also a significant difference for different positions in the pit.

A full symphony orchestra has more sound power than a singer. Brass and woodwind is louder than 100 years ago. In recordings it is the opposite. The loudness of the orchestra is lower compared to the singer, without the frequency effects that would occur in a real situation when trying to do something with the pit. So apart from the artistic quality of the performers (loud singers and not so loud orchestra) it would help if the geometry of the hall would do the opposite and support the sound from the singers more than the sound from the orchestra. But in opera houses the orchestra is positioned between singers and audience. Just this distance effect is already a disadvantage for the singers. The reflective surroundings of the orchestra pit don't help either for this balance. Bad audibility of own instrument and of other instruments will result in playing louder. So optimising playing conditions in the pit can help to restore the balance somehow. This can be done by increasing the depth of the pit, using diffusion on the walls and maybe even by adding a bit of absorption near loud instruments. In many halls reflectors can be seen at the walls and ceiling at forestage, reflecting the sound from orchestra to audience. Much more logical it would be to reflect the sound back to the orchestra. This was applied in the Düsseldorf Opera [14] and turned out to be very effective in increasing the Early Reflection Strength in the pit.

As mentioned above, the covered pit in Bayreuth Festspielhaus has quite specific acoustic conditions for quite specific repertoire (Wagner opera's) that is partly written for this situation. So solely for the Wagner operas, opera houses could consider to create the possibility to cover the pit at least partially, to reduce the sound from the orchestra. This covering and sound absorption will not have the same effect on all frequencies and all instruments, and not for all audience positions it will be the same.

Another way to improve the balance between singers and orchestra is to support the singers with sound reflective scenery. Some opera houses do this and it is an efficient measure. But it involves many people in the preparation of the scenery and the argument against it is that it limits the artistic freedom of the designer of the scenery. Awareness regarding these effects in opera houses (directors and designers of scenery) could be increased.

Since the audibility of rear positions in the pit differs from front positions, it could be considered to move around with instrument groups to optimise the sound in the auditorium.

References

[1] M. Lautenbach, M. Vercammen, K.-H. Lorenz-Kierakiewitz, Acoustic Aspects of Stage and Orchestra Pit in Opera Houses, *Proc. of DAGA,* Darmstadt, 2012

[2] EN ISO 3382-1. Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces (ISO 3382-1:2009)

[3] M. Lautenbach, M. Vercammen, Stage Acoustics: Renovation of the concert hall de Doelen, Rotterdam and other stages, *Proc. Int. Symp.on Room Acoustics ISRA* 2010, Melbourne

[4] M. Lautenbach, M. Vercammen, Stage Acoustics, ISO 3382 and beyond, *Int. Symp. on Room Acoustics ISRA*, Toronto, Canada, 2013

[5] K-H. Lorenz-Kierakiewitz, M. Vercammen, Entwicklung eines verbesserten raumakustischen Messlautsprechers für Raumimpulsantwortmessungen, *Daga* 2010, Berlin

[6] Beranek, L.L.: Concert Halls and Opera Houses: Music, Acoustics, and Architecture. *Springer, 2nd edition*, 2004

[7] M. Garai, K.Ito,D.D'Orazio, S. De Cesaris, F. Morandi, The acoustics of the Bayreuth Festspielhaus, *Proc. ICSV22*, 2015

[8] J.D. Polack, M. Retbi, Wagner and the cinema, a cognitive approach to the acoustics of the Bayreuth festival theatre, *Proc. inst. of acoustics, Vol. 33. Pt.2*, 2011

[9] M. Holden, Orchestra Pit Acoustics – From Bayreuth to Broadway, *Proc. acoustical Soc. of Am.* 1998

[10] A. James, Extremes, Flexibility and Authenticity in Orchestra Pit Acoustics, *Proc. Inst. Of acoustics, 19, 3; 137-144*

[11] J.-I. Gustafson, G. Natsiopolos, Stage set and acoustical balance in an auditorium of an opera house*, Proc. ICA*, 2001

[12] T. Hidaka, L. Beranek, Objective and subjective evaluations of twenty-three opera houses in Europe, Japan and the Americas, *J.Acoust.soc.Am.107(1)*, 2000

[13] M. Lautenbach, M. Vercammen, Stage acoustic requirements extended to orchestra rehearsal rooms, *Proc. ISMRA* 2016

[14] K-H. Lorenz-Kierakiewitz, M. Vercammen, H. Kremer, Verbesserung der Akustik im Orchestergraben: Umgestaltung des Proszeniums der Deutschen Oper am Rhein in Düsseldorf, *DAGA*, 2011