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Influence of Hall Geometry on Balance

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ABSTRACT

The balance between the instrument groups of an orchestra is an aspect of concert hall acoustics that is not much addressed in literature or articles. But from a musical point of view orchestral balance is an important factor for the acoustics of a concert hall. This paper gives an overview of recent investigations that have been performed on balance, by means of measurements as well as with 3D raytracing models. In order to focus on the hall and stage geometry (that can be influenced by the acoustician), the investigations have been done with omnidirectional sources. It turns out that several geometrical design aspects can give rise to a quite large Range in perceived loudness differences from different instrument groups at listeners' positions in the audience area as well as at the conductor's position. It is also shown that certain geometry basics are preferred when a most equal balance for omnidirectional sources is aimed for.

A next step will be to include the directional behavior and sound power of instrument groups in order to investigate if certain geometrical design aspects could be beneficial to improve the balance of real orchestra groups in certain hall layouts.

Keywords: Room acoustics, orchestra balance, sound distribution, Strength G, concert hall

1. INTRODUCTION

The orchestral balance, being the sound level differences between the instrument groups at a listeners position, is an aspect of concert hall acoustics that is not much addressed in literature or articles. But from a musical point of view orchestral balance is an important acoustical aspect of a concert hall. Although it is quite clear that the conductor's position is under influence of direct sound and decrease of distance, the information the conductor receives is crucial in order to instruct the different instrument groups to get the best performance in the hall: at the listener positions that usually are under much less influence of the direct sound and decrease with distance.

Of course the directivity of instrument groups and the orchestra seating arrangement have influence on the balance, but the hall geometry is also of great importance, on stage as well as at the listeners positions. The investigation as described in this paper focuses on the influence of the hall geometry on the perceived orchestral balance in the audience area and at the conductor's position.

2. BALANCE IN A SYMPHONIC CONCERT HALL

2.1 The Concept of Balance

The word "balance" in acoustics can have several meanings, for instance: orchestral balance, tonal balance, balance between direct sound, early reflection and late sound.

In this paper, balance is the terminology used for the differences in sound levels and frequency responses from different positions on stage (representing different orchestra instrument groups) as received at the listeners positions in the hall and the conductors position on stage. It may be added that this concept could also be valid for positions at the stage itself. The concept of balance is illustrated in figure 1.

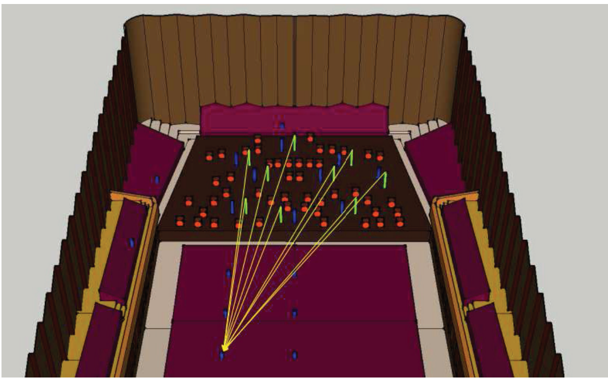

Figure 1 – Concept of balance

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A well known example of an unfavorable orchestra balance is at a seat behind the orchestra, especially behind the horns: every concert will then be perceived as a horn concerto. But there are existing halls with listeners' positions from which you can see a certain instrument group playing, but from where you can't hear them. Or that a soloist player is hidden in the orchestra sound. A perfect musical balance would be the situation in which the audience would perceive the balance between the instrument groups as intended by the conductor, and maybe as intended by the composer but in a lot of the cases that is not easily verified.

There is also the concept of balance in an opera house, in which the balance between soloist singers, choir and orchestra is an important aspect of the performance. This paper is confined to the symphony orchestra in a concert hall.

2.2 Literature and Standards

Beranek [1]: mentions balance: "Some of the ingredients that combine to create good balance are acoustical and others are musical. A performance can lose balance if the stage enclosure or some other surface near the players overemphasizes certain sections of the orchestra or if it fails to support the soloist adequately. Beyond that, balance is in the hands of the musicians, their seating, and the conductor's control of the players."

J. Meyer [2] first recognizes that due to the different distances from the instruments to the conductor, the sound image at the conductor's position will be essentially different than at different places in the audience. Meyer distinguishes three aspects of balance, which should not change to much throughout the audience: Loudness, Timbre and Intelligibility. In Meyer's view, for large halls the assignment is to realize optimum balance with the orchestra arrangement for which the directional behavior in combination with an increasing height of risers best fits to the audience area.

Meyer also describes a test for two different stage layouts and orchestra arrangements in the Stadthalle Braunschweig. The sound level differences from four instrument groups at different positions in the hall are compared to the sound level differences at the conductor's position. The sound level differences significantly reduce with more and higher rises in this case.

Fasold [3] refers to a paper of Tennhardt [4] from which he concludes that "not only the total orchestra loudness is of importance, but also the balance of loudness from separate instrument groups (...)." In the quoted article, Tennhardt describes that the "optimal balance" was established by schooled test persons at a listening position at 30m from stage at the first balcony in a concert hall in Sofia, Bulgaria [5,6]. The optimal sound level difference for optimal balance ΔL_{B0} in dB(A) (AI) with respect to the woodwind (63 dB(A)(AI)), would then be +4,2 for the strings, +2,0 for Brass and + 7,5 for bass instruments. In this optimal balance the original sound power level and directional behavior of the instrument groups are taken into account. As objective criterion for balance investigation Tennhardt defines the "Registerbalancemaß BR", which is the ratio of loudness, measured as A-weighted sound energy densities w_{500}, between instrument groups, relative to the optimum balance at the reference point. From [5,6] Tennhardt deduces that the optimum balance is realized at a BR_{xy} (between instrument groups x and y) between -4 and +4 dB(A) for slight correlated signals at the ears and between -6 and +6 dB(A) for strongly correlated signals at the ear.

Jaffe [7] lays a lot of weight on "the source area" (the instruments on stage), balance is in his opinion, next to on-stage hearing, one of the most important factors. He states that the higher powered brass and percussion instruments are located at the rear of the orchestra platform in order to provide the conductor with reasonable balance between the power levels of the the various sections. But in many halls, the reinforcement from the rear wall, given to the brass and percussion sections can overwhelm the lower-powered string and woodwind instruments. Listeners would be more aware of imbalances than the conductor, who is very close to the strings and the woodwinds.

Notwithstanding the above mentioned literature, the balance of a concert hall is for sure not standardized as a quality parameter of a concert hall: there is not any parameter nor a guideline how (or not) to incorporate the concept of balance in the design of a concert hall, nor to check the hall quality with a measurement procedure or otherwise.

2.3 Acoustics, Music or Architecture?

Orchestral balance in a concert hall is clearly the result of different influences:

- on a macro scale: the shape of the hall and arrangement of the audience area.
- on an intermediate level: the stage sizes and enclosure, the stage design: flat, shape and height of platforms or risers and in case of risers: the choice for the adjustable height
- on a musical level: the orchestra size and arrangement, the influence of the conductor, the ability of the musicians to increase or decrease their loudness: either on instigation of the conductor,

but also through the feedback they perceive from the acoustics of the hall

- on a micro scale: the directional behavior and sound power of the musical instruments.

All these factors are related to each other and influence each other. It is quite difficult to analytically separate them in order to change the balance if that should be desired. Often it is the conductor who takes the blame if the balance is perceived as incorrect. But although he has influence on the balance by means of instructing the musicians, choice of orchestra arrangement and in some cases the height of the risers, his influence is not limitless. It is also not always easy for a conductor during a rehearsal to listen at several positions, due to a limited rehearsal time and/or the fact that it can be quite difficult to go to a balcony or at different vineyard terraces.

For sure, the stage design including the stage enclosure (if there is any) is of influence on the balance. But how, in the design of a concert hall, the resulting stage and stage enclosure comes to be can be quite surprising. To give a few examples:

- in a recent concert hall tender for the acoustic consultant the client (local government) made it very clear that the stage design of the winning architect should not be changed, at all.
- in an existing hall the conductor at the time was given all freedom for the stage design, a 312m² large stage was realized so he was sure that every possible orchestra instrumentation would be possible, like Messian and new, modern compositions. The result is a stage on which the musicians repeatedly complain about not hearing themselves or the others.
- often architects draw stage layouts in order to show that their stage design is a proper choice, but not all of them are aware of orchestra arrangements and it has even occurred that an architect in the drawing downsized the musicians by a certain percentage in order to make them fit.

Also the orchestra arrangement is of influence on the balance, but when you ask an orchestra why they are seated the way they are, they often refer to the orchestra staff who is responsible for the orchestra furniture and scores. The staff usually has their own preferences regarding for the stage setup regarding time and effort, but they are also influenced by the musicians higher in hierarchy. In a lot of cases, these underlying choices have nothing to do with either acoustics or music.

3. MOTIVATION AND STARTING POINTS OF THIS INVESTIGATION

3.1 Inducement for and Goal of this Investigation

The inducement for this investigation are several occasions in which the conductor asked for a change in balance. The two main occasions are mentioned:

- after a question from the conductor of the Netherlands Philharmonic Orchestra a test was setup with a 20 cm elevation of the woodwind section in order to change the balance in favor of the woodwind. The result was overwhelming: the difference was almost too large, at least in the audience area, the conductor was much satisfied. But there were also some severe complaints from musicians that the elevation of the woodwinds resulted in a much higher sound level on stage, mainly from the brass. Which was an unexpected side effect, as the brass platform had not changed.
- the conductor of the Dresdner Philharmonic asked if the balance at his position could be slightly altered to be more in line with the listening positions in the Kulturpalast. See paragraph 4.2.

These two cases in which smaller changes had a large impact on the balance lead to the goal of this investigation: The goal of this investigation is to search for the influences that an acoustician has, either in the design phase, or if a conductor or an orchestra asks for help, to change the orchestral balance in the hall or on stage. It is also a search for a way to characterize or review the balance.

3.2 General Principals of this Investigation

In order to focus on the influence of the hall geometry solely, the concept of balance for this article is investigated by means of measurements and calculations with omnidirectional sources in real halls (with orchestra furniture on stage, unoccupied) as well as in 3D raytracing models of the same halls and alterations thereof. Sources and receivers are placed at the middle positions of the most important instrument groups of an American Arrangement (V1, V2, AV, Ce, Ba, Wood, Brass, Percussion and Conductor/Soloist). From these 9 source positions on stage the impulse responses are measured / calculated to 9 receiver positions on stage as well as 18 receiver positions in the audience areas.

The measurements have been performed in the main hall of Musis Arnhem and Kulturpalast Dresden, both of them being dedicated classical concert halls with a volume of 16.000 and 20.500 m³. Both halls are very homogenous in sound field and calculations with raytracing show good agreement with the measurements, in general and when it comes to balance.

4. MEASURED BALANCE IN REAL HALLS

4.1 Concert hall example I: Parkzaal Musis Arnhem - the Netherlands

The Parkzaal of Musis in Arnhem is a recently opened concert hall (2017). It is a classical rectangular hall for a full symphony orchestra, "Het Gelders Orkest" which also resides here and has their rehearsals in the new hall. The hall holds a 1000 audience capacity, within a volume of 16.000m³.

The Parkzaal has almost flat stalls and one balcony level that surrounds the hall. There is no 2nd balcony but a technical floor provides downward reflections as a 2nd balcony would.

After a few months of rehearsing and trial concerts, a full measurement program has been carried out in the Parkzaal, from which the Balance (in Strength G) has been derived. Figure 2 gives an overview of the measurement positions on stage as well as in the audience area.

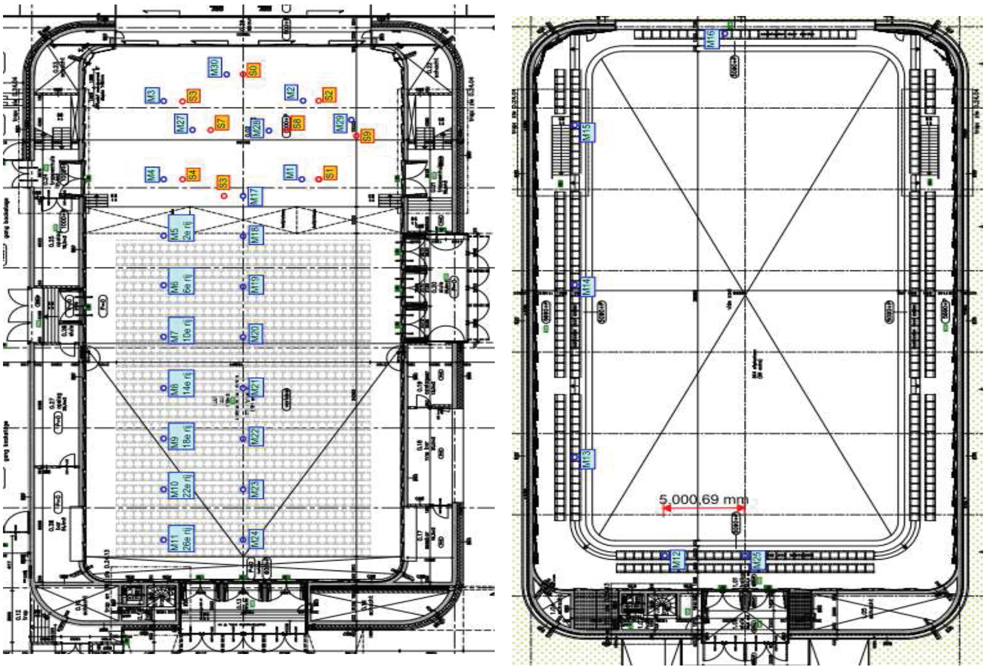

Figure 2 – Measurement positions in Musis, on ground level (left) and balcony (right)
Red (oRange) are the source positions on stage, the soloist and the middle of the instrument groups
Blue are the receiver positions on stage and in the audience

Annex 1 gives an overview of the measured Balance (in Strength G) at all receiver positions which are schematically positioned in the same layout as the real measurement positions. At every receiver position the G is measured for all different sources on stage. Each source has its own color, source "0" being percussion is always represented by the red line for instance. The G is given in the octave bands 250 to 4kHz, therefore not only the balance from the sources is given, but also the tonal balance as influenced by the hall.

From the graphs in Annex 1 a lot of information can be gathered, but for a good look zooming in the digital pdf document is useful to read the information. From the graphs it can be seen that at the receiver positions on stage the G from the different sources varies quite a lot, this is due to the dominating direct sound and the relative large differences in distances. Measured G's that strongly stand out above the other ones are always due to a very short distance between source and receiver. At the conductor position for instance a relative high G has been measured for sources 1 (celli) and 4 (1st violins), but these sources are very close to him. This means that if the celli and 1st violins would be omnidirectional and equally loud to all other instrument groups, the conductor would perceive them about 2 dB louder than any other group.

It can also be seen that the receiver positions in the audience close to stage (M5, M18, M14 and M15) are still under influence of differences in distances, but for all other receiver positions in the hall, the Balance in Strength G is quite even. No matter where the source positions on stage is, the loudness at the receiver position is quite similar within a narrow bandwidth of 1 to 2 dB. We could call this a quite homogenous hall in that respect.

There is only one instrument that at some positions somewhat stands out: source 0, being percussion in the rear in the middle of the stage is 1 to 2 dB louder at the rear of the stalls.

4.2 Concert hall example II: Balance adjustments in the Kulturpalast Dresden - Germany

The Kulturpalast Dresden, opened in April 2017, was very well received [8]. After a few months of rehearsals and concerts, the conductor asked if it would be possible to alter the balance at his position. Investigation showed that the balance in the hall in general was really good, comparable to the Concertgebouw and Musis (Annex 1), but there was a slight unbalance at listeners positions on the middle axis of the hall: the sources on the middle at the rear of the stage were 2 to 3 dB more enhanced than the other sources.

It appeared that the problem could for a part be reproduced with the 3D raytracing model, though with a shift in position. See figure 3a. But the influence of several solutions could at least be studied first with the 3D model. From there measurements were carried out in the hall with temporary alterations which included:

1. the already installed "variable" absorption for fine scale adjustment in the ceiling [8] was partly set to absorbing;
2. a flat rear stage wall (instead of the angle in the middle that might focuses on the middle axis);
3. absorption on parts of the white band of the rear stage wall;
4. an enlarged stage at the soloist position (this was an explicit wish of the orchestra).

From the measurements a combination of 1. and 3. turned out to be very effective, especially if considered how small the changes are with respect to the acoustical result.

After realization of the measures the measurements were performed again. The result prior to and after installation of the measures is given in figure 3b.

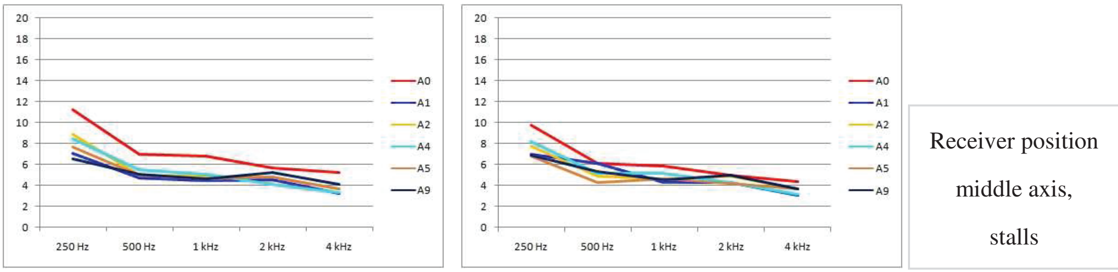

Figure 3a – Balance in Strength G, Kulturpalast calculated

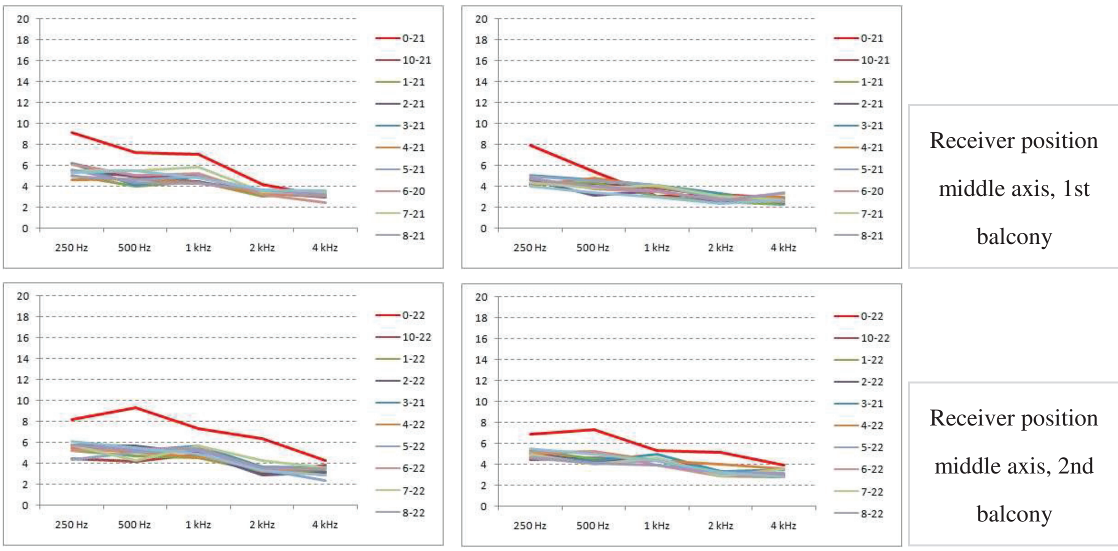

Figure 3b – Balance in Strength G, Kulturpalast, measured
Left prior to the described measures, right after installation of measures.

From the graphs on the left side it can be derived that source "0", being percussion on the middle of the stage (red line), was 2 to 3 dB more amplified by the hall than other instruments. The amplification of the percussion was audible, but to a limited extend, there were no remarks from the audience on this point, only the conductor and musicians from the orchestra had noticed it. After realization of the measures this amplification has been strongly reduced, but still visible in the graphs at the 2nd terrace. This investigation shows that the balance can be altered by small changes in hall geometry. The interventions in the hall were relatively small. It was also interesting that the 2 to 3 dB decrease was audible, but mainly for trained ears.

5. INFLUENCE OF HALL GEOMETRY ON BALANCE

5.1 Investigations with raytracing

During the investigations for the Kulturpalast, it turned out that results from raytracing calculations are in quite good agreement with measurements results. This may lead to the observation that at least a part of balance differences can be attributed to the geometrically reflected energy within the hall. This means, that large-scale alterations of hall geometry can be investigated by means of raytracing to gain insight in what might have impact on balance.

So with the 3D model from the Parkzaal Musis as a starting point of being a hall with very good acoustic properties to realize a homogenous sound field, several geometrical design aspects have been altered in order to investigate their influence on balance. Therefore the hall layout and measurement positions as shown in figure 4 are the starting point for the calculations. The position of the sources and receivers is never changed, unless the height of stage risers and stage enclosure (including listening areas) is changed. These height changes have a small influence on the distances between source and receiver. But apart from that, the source and receiver positions are always exactly comparable between the different configurations that have been investigated.

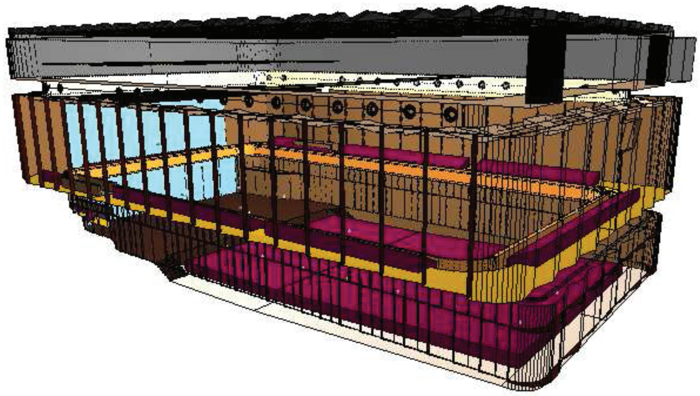

Figure 4 – 3D calculation model of the Parkzaal

It might be clear that the amount of data in such an investigation is enormous. An overview of the graphs of all receiver positions as in Annex 1 is very helpful to comprehend the results. But apart from that it would be very helpful to have a single-number parameter that could give a clue about the quality of balance. When small or even non-existing differences in Strength G between instrument groups would be considered as the preferred quality (ie. all omnidirectional sources are perceived equally loud) than the Range of G (the spread between the minimum and the maximum) could be a good indication for the quality of balance. The smaller the Range at a certain position, the better. This can be presented in two ways:

-the average Range per position: first the Range per position is calculated, and from that the average over all positions is taken

-the maximum Range that occurs in a certain configuration at a certain position .

For the conductor's position, the same can apply. In the ideal situation the conductor would be as close to the musicians as possible to account for perfect timing and very exact hearing and steering, but at the same time he would like to be in the middle of the audience to hear how the orchestral music is perceived. So it might be assumed that a small Range at the conductor's position is the preferred situation. An example is given in the next paragraph.

It is the case that several configurations do not only alter the balance in the audience area and the conductor's position, but also on stage. It is still under investigation what would be a good parameter to describe the balance on stage. For sure, positions on stage might be too close to the walls of a stage enclosure to give accurate results from raytracing. Interference and diffraction of close by reflective surfaces might be of influence which is not accurate in raytracing procedures. Run to run variations (same configuration calculated again) also show that parameters with a time frame for early reflections (like ST_{Early}, $G_{5\text{-}80}$) are not stable in calculation results. Therefore the focus in this article lies on the balance in Strength G in the audience area and the conductor's position.

5.2 Theoretical Extremes for Balance

To provide an indication of the Range per position, calculations are also made for:

- a theoretical free field situation, in which only the distance determines the SPL and the G

- a theoretical diffuse field according to (1), in which the distance plays the prominent role within the critical distance, but outside the critical distance the influence of the distance decreases severely.

$$Lp = L_w + 10\lg\left(\frac{Q}{4\pi r^2} + \frac{4}{A}\right) \qquad (1)$$

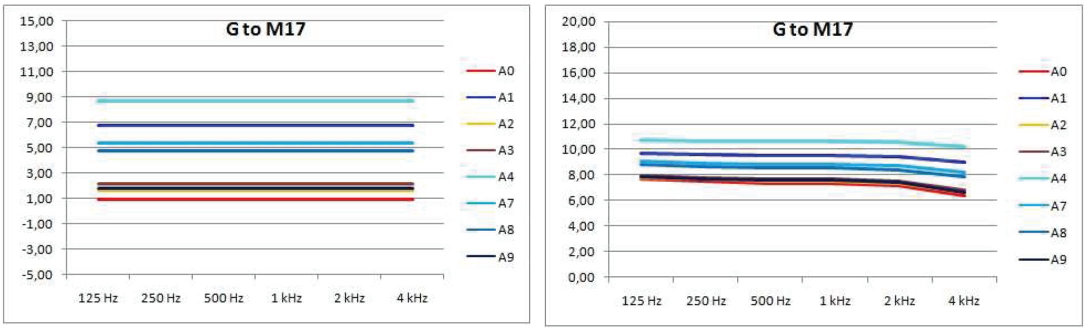

Figure 5 – Balance in Strength G at the conductors position. Left: in a theoretical free field
Right: in a theoretical diffuse field (same scale, different range)

In these two theoretical extremes, the balance could be summarized as follows:

Table 1 – Calculated balance in Strength G, 500-1000 Hz, [dB]

Configuration	Range at conductor	Average Range per position in the audience area	Maximum Range at a certain position in the audience area
Free Field	7.7	4.3	7.4
Diffuse Field	3.3	0.5	1.9

Thus, in theory: the possible extremes in balance could be audible and therefore significant.

5.3 Agreement between measurement and 3D model

First of all, the table below gives an overview between the Balance in G from the measurements and calculations of the Parkzaal Musis:

Table 2 – Measured and calculated Balance in Strength G, 500-1000 Hz, [dB]

Configuration	Range at conductor	Average Range per position in the audience area	Maximum Range at a certain position in the audience area
Parkzaal measured	3.6	1.5	2.8
Parkzaal 3D model	4.0	1.5	2.7

5.4 Investigation of stage geometry configurations

Through the 3D model a lot of different elements variations are checked, separately and in different combinations: stage walls, stage reflector, shape of the stage (rectangular, trapezium), flat stage, risers (straight and circular) and diffusion (geometrically modeled as well as numerical).

The starting point for the stage size is 18 x 12 m at average (width x depth).

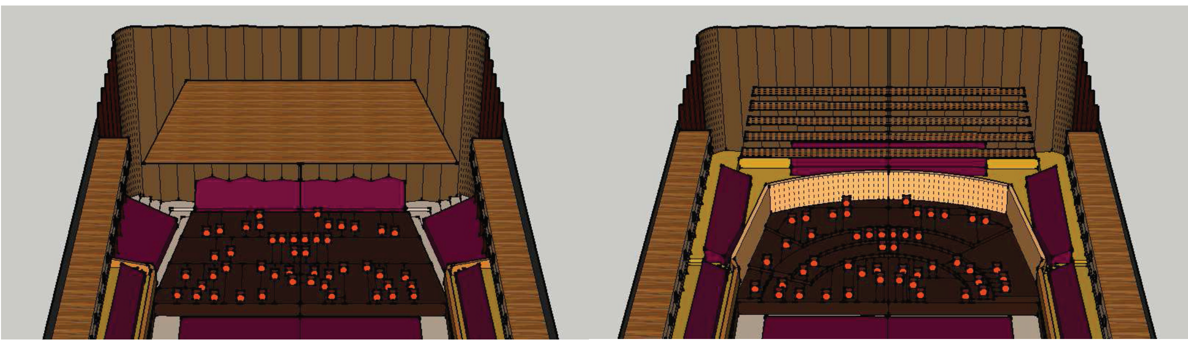

Figure 6 – Overviews of the 3D model. Left without stage enclosure and 100% reflector, flat stage.
Right trapezium10 with curved stage rear wall, 50% reflector and curved risers

First of all, the 3D model is cleared of the stage enclosure and reflectors. The stage is surrounded by audience and therefore without early reflections.

Table 3 – Calculated Balance in Strength G, 500-1000 Hz, [dB]

Configuration **starting without stage enclosure**	Range at conductor	Average Range per position in the audience area	Maximum Range at a certain position in the audience area
No reflector, flat	5.0	2.3	5.9
50% reflector, flat	4.6	2.3	5.9
100% reflector, flat	4.4	2.4	5.9
Stage side walls, 50% reflector, risers	4.4	2.1	6.0
Stage rear wall, no reflector, flat	5.2	1.8	3.4
Stage rear wall, **50% reflector**, flat	4.5	1.9	3.4

It turns out that in the configurations without stage enclosure the balance in the audience area shows a much larger Range than the Parkzaal in the existing situation. Adding a reflector (50% or 100% stage coverage), stage side walls or risers do not have a significant positive effect on the balance. Only when a rear wall is added, a clear effect is to be seen in the audience area, though it seems to increase the Range in Strength G at the conductors position. But this might be reduced by means of a reflector with a 50% coverage. It is noted that without stage enclosure all parameters for early reflections are (very) low but with a small range.

Then the shape of the stage is investigated: rectangular or trapezium with opening angels of 5, 10 and 20 degrees. For these cases a stage enclosure is always present by means of 3m high walls at the sides and the rear of the stage. The audience area's around the stage are elevated accordingly. All configurations have a reflector of 50% coverage. In all cases diffusion on the stage walls is present.

Table 4 – Calculated Balance in Strength G, 500-1000 Hz, [dB]

Configuration **with stage enclosure and 50% reflector**	Range at conductor	Average Range per position in the audience area	Maximum Range at a certain position in the audience area
Rectangular, flat	4.4	1.6	3.4
Trapezium 5, flat	4.4	1.8	3.6
Trapezium 10, flat	3.9	1.8	3.3
Trapezium 20, flat	4.5	1.6	3.2
Rectangular, saw tooth side wall diffusion	3.8	1.6	3.1
Trapezium 10, straight risers	4.3	1.9	5.1
Trapezium 10, circular risers	4.3	1.8	4.5

From table 4 it might be concluded that the general stage shape is not of any large influence on balance. In all cases, the 3m high but diffusive stage walls reduce the Range in the audience area when compared to the results in table 3. It appears that risers do not have an significant effect on the average Range, but there is always a position in the audience with a higher maximum Range.

In detail it seems that risers do enhance the instrument groups in the front part of the stage. It might be that this enhancement of risers is beneficial for the balance if the directionality and sound power of the instrument groups are taken into account. This will be investigated in a next step (but not included in this article).

A remarkable result arises from a stage with a different width to depth ratio: 15 x 14m. There are a few concert halls which have a rather narrow stage width equal to these sizes.

Table 5 – Calculated Balance in Strength G, 500-1000 Hz, [dB]

Configuration with stage enclosure and 50% reflector	Range at conductor	Average Range per position in the audience area	Maximum Range at a certain position in the audience area
Trapezium 10, flat, **15 x 14m**	5.6	2.0	5.3

With a relative narrow and deep stage, the Range in Strength G seems to be higher for the audience as well as for the conductor. This result is still present with smaller variations in the stage enclosure.

The most remarkable result comes from a stage enclosure with a curved (focusing) rear stage wall, even though raytracing can only incorporate the geometrical focusing, not the pressure increase caused by equal length of sound paths. This result seems logical, nevertheless there are a lot of concert halls with a curved rear stage wall. A (numerical) high scattering shows a significant reduction of the Range in Strength in the audience area, but the result is still far from the numbers as shown in table 6.

Table 6 – Calculated Balance in Strength G, 500-1000 Hz, [dB]

Configuration with stage enclosure and 50% reflector, **curved rear wall**	Range at conductor	Average Range per position in the audience area	Maximum Range at a certain position in the audience area
Trapezium 10, flat, low scattering	3.8	3.3	9.3
Trapezium 10, flat, low scattering, risers	4.7	3.0	9.2
Trapezium 10, flat, high scattering	3.7	2.6	6.0

From this series, the lowest Range in Strength G at the conductor's position (3.2 dB) occurs at a trapezium10 stage enclosure with an angled rear wall with a 50% reflector, but the difference to other trapezium shapes is very small. The largest Range in Strength G at the conductor's position (5.6 dB) occurs at the stage with the narrow stage enclosure of 15 x 14 m. The pictures and graphs of these two extremes are given in figure 7.

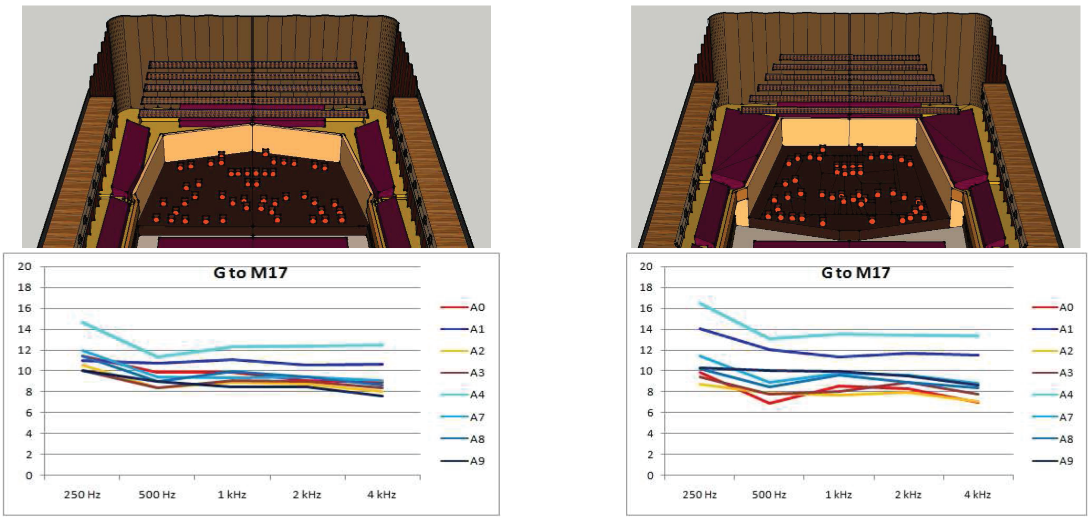

Figure 7. An overview of the conductor's position with the lowest (left) and the highest (right)

calculated Range in Strength G

The lowest maximum Range in the audience area is to be found in any of the trapezium shaped stages or the rectangular shape with saw tooth shaped side walls, all with a 50% reflector. The largest maximum Range in the audience area is to be found for a stage with a curved rear wall. For both the graphs to M20 (middle stalls, middle axis of the hall) the graphs are given in figure 8.

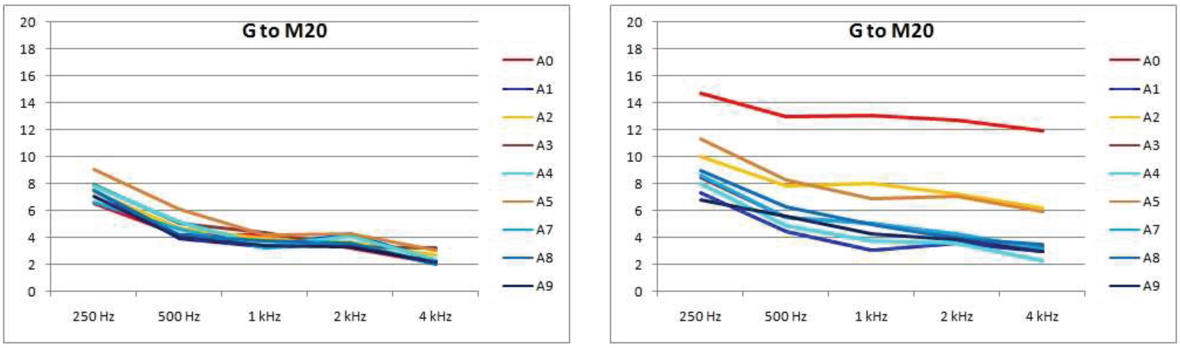

Figure 8. An overview of the largest maximum Range in Strength G (right) at the stage with the curved rear wall at position M20 (middle stalls, on the middle axis of the hall) and the Range at the same position on a stage with the lowest maximum Range (left).

6. CONCLUSIONS AND OUTLOOK

In this paper we have presented the concept of balance: the difference of sound levels from different source positions at receiver positions in the hall. Measurements and calculations have shown that the balance shows certain sensitivity to geometrical changes in the surroundings of the orchestra.

It turned out to be possible to optimize the balance in a concert hall, based on the results from a raytracing model followed by investigating the a most promising measures in the real hall by means of measurements. From there, further investigation has been carried out with the means of raytracing models based on a real hall to investigate the influence of stage geometries. These calculations showed the positive influence of reflective stage walls and orchestra reflector and the negative effects of a narrow and deep stage, as well as a curved rear wall.

The next step will be to take the directionality of the orchestra instrument groups as well as their sound power into account. It will be interesting to investigate what their influences are and how they combine with certain aspects of the stage surrounding. The investigations will continue by means of calculations as well as measurement.

REFERENCES

1. Beranek LL. Concert Halls and Opera Houses, Music, Acoustics and Architecture. 2nd ed. New York, USA: Springer; 1996. p. 32.
2. Meyer J. Akustik und musikalische Aufführungspraxis. Frankfurt am Main, Germany: Verlag das Musikinstrument; 1980.
3. Fasold W. Veres E. Schallschutz und Raumakustik in der Praxis. Berlin, Verlag für Bauwesen. 1998.
4. Tennhardt HP. Modellmeßverfahren für Balanceuntersuchungen Neuen Gewandhaus Leipzig. Acustica 56, 1984.
5. Reichardt W, Ganev S, Kussev A, Balancemessung von Orchestermusik im Konzertsaal. Z. elektr. Informations- und Energietechnik 4, 1974.
6. Reichardt W, Kussev A, Prüfung der Balance in Konzerträumen bei impulsiver Erregung, Acustica 31, 1974.
7. Jaffe JC. The acoustics of performance halls, Spaces for Music from Carnegie Hall to the Hollywood Bowl. 1st ed. New York: W.W. Norton&Company; 2010 p. 38-39.
8. Lautenbach M. Vercammen M. Kulturpalast Dresden, Proceedings of IOA Hamburg, 2018.

Annex 1 – Overview of the measured Balance in G in the Parkzaal:
For all receivers (figure 2) the measured strength G in the 250 to 4000 Hz octave bands is given for all source positions on stage (figure 2), with exception of M8, 19, 10 and 21, they are left out to fit the results on an A4