La Philharmonie de Paris concert hall competition, part 1 : Acoustic brief

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LA PHILHARMONIE DE PARIS CONCERT HALL COMPETITION, PART 1: ACOUSTIC BRIEF

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ABSTRACT
A new 2'400 seat concert hall is to be constructed in the Parc de la Villette in Paris, next to the existing Cité de la Musique. Kahle Acoustics, in collaboration with Altia Acoustique Paris, has been appointed as the client's acoustician throughout the project. Our first task was to define the acoustic brief for the concert hall competition and to participate in the elaboration of the architectural brief. This paper presents the research undertaken for this project – first questioning and finally confirming the client's brief – and will present the final acoustic brief. As the client's brief requested an innovative acoustical and architectural concept, it was decided to not define any architectural shape, but formulate all acoustic requirements in terms of objective – both acoustic and architectural – criteria.

CLIENT BRIEF AND ACOUSTIC CHALLENGES

For the new Philharmonie de Paris concert hall, the client's brief asked for a 2400-seat concert hall with excellent acoustics for the symphonic repertoire. From an acoustician's point of view, a seat count of 2400 is already the first challenge as the power of individual instruments and the orchestra is not extensible, and acoustical excellence is known to be difficult to achieve above 2000 seats. In addition, the seat count calls for a very large acoustical volume in order to obtain the desired fullness and richness of sound and a reverberation time that also suits organ recitals and symphonies with choir. This leads to the challenge of ensuring sufficient strength, clarity, definition and acoustic presence of the sources in such a huge volume.

The client also asked for an innovative acoustical and architectural concept, breaking with the traditions of 19th century concert halls: the 'shoe box' shape – commonly considered as one of the best acoustical shapes for concert halls, but with severe limitations for seat counts in excess of 2000 seats – was ruled out by the client. A new architectural and acoustical design was the client's stated wish.

The shape of the hall is supposed to be architecturally enveloping, meaning that an important part of the audience is seated behind and to the sides of the orchestra. This is not a new concept: back in 1963 the Berlin Philharmonie was the first hall to propose this new arrangement of seats, creating a new relationship between performers and their audiences. Since then, many other "vineyard" style concert halls have followed this path with various degrees of acoustical success or failure. The enveloping shape actually leads to a new set of acoustic challenges. With the stage being enveloped by absorptive audience and the lateral walls being farther apart, the need for early lateral reflections needs to be fulfilled through other architectural elements than in a narrower room. Obtaining good orchestral balance for all seats is made more difficult by the presence of audience all around the orchestra. The acoustic concept needs to provide an adequate blending of sound so that a homogeneous sound distribution is achieved for all seats and for all instruments, even those with high directivity such as the human voice.

Finally, the client's wish for exceptional theatre technical as well as acoustical flexibility provides further challenges in the design of the hall. The Philharmonie de Paris is supposed to be acoustically optimised for the symphonic repertoire, but will also need to have good acoustics for events such as recitals, chamber music concerts, opera, and other musical expressions such as jazz, world music and contemporary amplified and/or spatialised music. For amplified events, a more frontal stage is required. This second stage is obtained by removing and lowering the choir balcony, creating the end stage for amplified music; the classical music stage is lowered to audience level, either for additional audience seating or – together with a section of the raked parterre – transformed into a flat area for standing audience.

Our first reaction to the client's wishes was to inform them of the acoustical challenges originating from this very ambitious brief. But putting things into a wider context, as well as analysing the specific challenges (both acoustic and non-acoustic) of the Paris project, we began to understand the reasons for such a (at least at first sight) risky ambition. The role of the new Phiharmonie de Paris, in addition to being the major venue for classical concerts that has always been lacking in Paris, is to attract and educate the younger generations and new audiences. In order to give a modern appearance to the world of classical music, modern concert halls should be radical, innovative, astonishing. The site of the Philharmonie de Paris was purposely chosen at the borders of the Paris suburbs, and both the building and its concert hall should not be a temple of bourgeoisie but a venue open to all social classes and all musical expressions. There is a real need for innovation and modernity in concert hall design and acoustic design should not be conservative and rigidly attached to conventions. It should be noted that the diversification of uses can be seen in many concert halls – old and new-built, adapted acoustically or not – to include popular amplified events as well as film screenings, conferences or commercial events. Times are changing and the acoustical concepts for new halls need to cater for all of these uses.

The growth of the theoretical knowledge in room acoustics and the experience in acoustical design gained from a century of new concert halls has made it possible to avoid some of the acoustical mistakes that originated from the architectural experimentations of the beginning of 20th century. The requirements for acoustic excellence are now much better understood. Research studies from Beranek [1,2], but also from the laboratories in Berlin and Göttingen [3,4,5], Barron [6] and by IRCAM in France [7,8] has contributed to this growth of knowledge. Using this research, it is possible to define a full set of acoustic criteria both in perceptual and objective terms. Furthermore, the aim in the acoustic brief for the Philharmonie concert hall competition was to equally translate these criteria into architectural criteria – giving the architects the tools and constraints in which a completely new architectural shape can be imagined and designed. Given the challenges of the brief, the acoustic design of the Philharmonie de Paris will not be an easy task but an ambitious one – to scale with the general ambition of the project, and our aim was to facilitate the work of the design teams in the development of their concepts.

The acoustic brief for the Philharmonie de Paris architectural competition did not specify any precise architectural form. A full set of subjective acoustic criteria was defined, as well as a corresponding set of objective and measurable acoustic criteria that constitute the brief for the design teams, in order to fulfil all subjective requirements for each type of event. More importantly, the architectural implications of these acoustic goals were explained, and open-minded suggestions and guidelines to resolve each of the major challenges were proposed. The aim was to express the acoustical requirements in terms that could also be understood by architects, so that acoustics would not be a limiting factor to architectural creativity but a well-defined constraint stimulating new architectural concepts.

PERCEPTUAL AND OBJECTIVE ACOUSTIC CRITERIA

The set of criteria considered significant for the Philharmonie de Paris competition is described below.

Reverberance

Defined as the perception of reverberation, reverberance is commonly described by reverberation time parameters. In practice, one distinguishes between the reverberation perceived during musical phrases and that perceived once the musical phrase is over (on stopped chords). The latter is more or less directly related to the standard RT parameter (calculated over a 30 dB decay from -5 to -35 dB), while the former is more related to the early decay time and often calculated over a decay of 10 or 15dB (EDT10 and EDT15), or early to late ratios.

The brief for the Philharmonie de Paris includes the installation of an organ in the room; furthermore, there will be a resident choir. The acoustic brief therefore includes music performances with organ as well as religious musical works for orchestra and choir. Thus, the maximum reverberation time goal defined for the Philharmonie de Paris concert hall (fully occupied and with musicians on stage, without curtains or any movable acoustic feature) is 2.3 seconds. To obtain such a maximum RT, an acoustic volume of 12m^3 to 13m^3 per person of the audience is specified, and consequently a total acoustic volume of around 30000m^3 or slightly above. A considerable amount of thought was given to the question whether a volume in excess of 30000m^3 would be dangerous for other acoustical parameters such as impact, loudness and source presence. It was finally concluded that the large volume – required to obtain the reverberation time goal – is not a problem in itself, but that the challenge will be to place a sufficient amount of efficient early reflection surfaces inside this large volume in order to maintain impact and source presence (see below).

No EDT value was defined in the acoustic brief. First of all, it is difficult to translate EDT parameters into architectural implications, other than the general rule of thumb stating the more early sound for a given late sound field, the smaller the EDT. Secondly, other parameters such as clarity (C80) and early and late strength (G80 and G[80ms, ∞]) were defined – see below; those parameters were considered more relevant in terms of architectural implications and are known to be highly correlated to EDT.

Loudness

The human ear is very sensitive to acoustic power and below a certain threshold the attention diminishes and the audience does not feel as being part of the event any longer. Given the seat count of 2400, the loudness criterion was consequently considered as one of the most important parameters. The subjective parameter of loudness is related to the objective strength G. (In more detail, the subjective parameter of loudness is related to a good source presence and a good room presence - these parameters are defined below - loudness being a higher-level perceptual notion, see for example [8].)

For a large concert hall, it is generally admitted that G must be positive (greater than 0dB for the mid-frequencies) for all seats [e.g. 1]. One generally considers that the ideal value of G is between +2dB and +8dB. For the Philharmonie de Paris, the goal for the mean value of G has been set to an interval of +3dB to +6dB. The spatial variations of the loudness G in the room, excluding the seats within 5m from the stage, are required to be less than ± 3dB with respect to the mean over the entire room.

These goals are deliberately very ambitious and directly call for innovative solutions. It should however be noted that these goals are not completely unrealistic as several halls of similar size achieve these criteria.

Source presence, early energy and clarity

Recent studies in psychoacoustics have demonstrated that the perception of acoustic power is more complex than the simple correlation with the strength parameter G. Indeed, the human ear – and the brain – differentiates the audio information into two different "data streams". One is related to the perception of the source while the other one is related to the perception of the space [8,9,10]. Consequently, the design should not only optimise the global loudness of the room, but should also aim to optimise separately the early response (presence of the source) and the late response (presence of the room).

The perceptual process of early sound integration by the human hearing system is quite complex. However in the context of the design of the Philharmonie de Paris, it was decided to simplify this process to the integration of reflections within the first 80 ms following the direct sound. Concerning the objective acoustical criteria, G80 (defined as a strength parameter G limited to the first 80 ms following the direct sound) was considered as a simple and good representative of the perception of presence of the source. This parameter is not universally used, but has the advantage of being easy to translate into architectural consequences. For the Paris auditorium, the mean G80 value has been specified to be between -2dB and +2dB in order to obtain sufficient and non-excessive presence of the source. A negative clarity parameter C80, between -3dB and 0 dB (without audience), required to achieve adapted clarity, was equally specified.

Room presence, late energy and reverberation level

As explained above, the perception of stopped reverberation is related to the reverberation time of the room, but for reverberation to be perceived during ongoing music requires a sufficient reverberation level, and therefore room presence. It was chosen not to use the less intuitive EDT parameter but to specify a loudness level for the late energy using G[80ms, ∞], defined as a strength parameter G limited to sound energy later than 80ms after the direct sound. The mean G[80ms, ∞] value was specified to be between 0dB and +4dB in order to achieve good presence of the room without compromising sound clarity.

Lateral energy and envelopment

It is now universally recognised that the sensation of being enveloped by the sound is extremely important to acoustical quality of concert halls, and that the sensation of envelopment is linked to lateral reflections and/or inter-aural differences in the sound field at the listening positions. The two objective parameters most widely used to quantify acoustic envelopment are the lateral energy fraction (LF) and the inter-aural cross correlation (IACC). For the Philharmonie de Paris auditorium, the spatially averaged LF has been specified to be greater than 0.15 for each of the 250, 500 and 1000Hz octave bands, and the averaged LF over all three octave bands is required to be greater than 0.16. In order to avoid false localisations, LF is required to remain inferior to 0.30 for all seats. A mean value of 1-IACC greater than 0.50 was also specified for each of the 500, 1000 and 2000Hz octave bands.

Once again, these goals are deliberately ambitious, and this was clearly expressed in the brief. It should be noted that the Philharmonie in Berlin, as well as several other vineyard-style halls, do not fulfil the requirements set in the brief for Paris.

Spectral balance and building materials
A gentle roll-off was specified for high frequencies, in both RT and G, requiring adapted surface finishes and/or high-frequency acoustic diffusion in moderate quantity. Especially given the large acoustic volume of the hall, a bass frequency increase in RT was specified. It is interesting to note that for most measured halls the rise in low-frequency reverberation time is not accompanied with a corresponding rise in low-frequency strength.

Stage acoustics and acoustic quality for musicians
Regarding stage acoustics, two main aspects are to be considered: firstly, each musician must be able to hear himself or herself clearly (sufficiently but not to the point that his own sound masks that of the others). Secondly, each musician must clearly hear the other musicians of the orchestra, even those that seat relatively far. The most commonly used objective parameter to define listening comfort for musicians on stage is the support criterion ST1 for which the optimum value is generally accepted to be -15dB to -12dB [11]. This is an ideal value that can be applied to smaller symphonic concert halls but is difficult to achieve in very large rooms. However, a lower limit for ST1 value can be found from the example of the Amsterdam Concertgebouw where ST1 is about -17 to -18dB. The listening comfort on the stage is difficult (according to the musicians in residence and other orchestras) but remains reasonable. Consequently, any value of ST1 lower than -18 dB will be considered unacceptable.

It is also important that ST1 is constant and homogeneous over the entire stage. Especially, a localised increase of ST1 at the back of the stage (where the brass instruments and percussions are) must be avoided. Because these instruments generate high sound levels (which increase the difficulty of listening to the others) one must avoid increasing their own feedback.

Given the variability of uses of the Philharmonie de Paris, it was decided to not only specify an interval for on-stage support, but to equally specify a variability for the on-stage support parameter, using variable height reflectors or arrays of reflectors above the stage. Large symphonic ensembles (possibly with choir and organ) require a lower ST1 value than smaller groups playing chamber music.

Acoustic variability
Given the high degree of flexibility required for the use of the room, one of the acoustic challenges of the design is to integrate a sufficient quantity of variable acoustic absorption into the architecture of the hall. The acoustic brief specified that there need to be different means of acoustic variability, influencing early energy and late energy independently, therefore achieving not only a variation in reverberation time but equally of loudness and early energy.

Table of acoustic criteria
The following summary table of acoustic criteria was given in the acoustic brief:

Acoustical Parameter	Value at mid-frequencies
Reverberation Tim (RT)	Mean between 2.2 and 2.3s with all variable acoustic absorption retracted (*fully occupied with orchestra on stage*) Mean between 1.4 and 1.6s with all variable acoustic absorption in place (*empty auditorium*) Mean between 1.2 and 1.4s with all variable acoustic absorption in place (*full house, empty stage*)
G, without audience	Mean between 3 and 6dB. The variation with respect to the position of the source and receiver (ΔG) must be ±3dB. Acoustic variability (mean of G using the variable acoustic features) must be greater than 2dB.
G80, without audience	Mean between -2 and +2dB. Required variability: >3dB.
G[80ms, ∞], without audience	Mean between 0 and 4dB. Required variability: >1.5dB
C80, without audience	Mean between -3 and 0dB. Required variability: >2dB
LF, without audience	Mean > 0.16, LF >0.15 for at least 80% of the seats.
1-IACC, without audience	Mean >0.55. 1 – IACC >0.5 for at least 80% of the seats.
Bass ratio, without audience	Between 1.1 and 1.3.

Treble ratio, without audience	Between 0.9 and 1.0 at 2kHz and between 0.75 and 0.85 at 4kHz.
ST1, without audience	Required variability: >3dB. Possibility to reach values ≤ -16dB Possibility to reach values ≥ -14dB. Variation across the stage: < 2dB with respect to the mean value.
Noise rating	< NR10 and 15dB(A)
Tolerances	Corresponding to the threshold of hearing (5-10% for the RT, usually 1dB for the other criteria, 5% for the LF and 1-IACC).

ARCHITECTURAL CRITERIA AND GUIDELINES TO SOLVE MAIN ACOUSTIC CHALLENGES

The full discussion of architectural criteria can be found in the online version of the acoustic brief, at www.kahle.be. In the context of this paper, after giving the full summary table of architectural criteria given in the acoustic brief, we shall focus on two interesting aspects related to specific challenges of the project.

Architectural Parameter	Requirement
Volume per person	Ideal: between 12m^3 and 13m^3. Acceptable: between 11m^3 and 14m^3.
Total volume	Approx. 30000m^3 (between 28000 and 32000m^3) to obtain 12 to 13m^3 per person in the audience and for 2400 seats.
Reflective surfaces	1400m^2 including 500m^2 close to the musicians (less than 15m from a point of the stage).
Height of the auditorium	The height will be chosen by the design team to obtain the appropriate volume of 30000m^3. It is understood and considered acceptable that the total height (omitting the acoustic reflectors) above the stage can be greater than 20m.
Height of the reflectors above stage	Required variability: between 10 and 16m for a continuous big reflector (canopy) and 8 to 14m for a set of smaller acoustic reflectors
Variable acoustic absorption (curtains or other elements)	More than 1200m^2 of removable absorbing material is required.

Scale and early reflections

In a large concert hall dedicated to the symphonic repertoire such as the Philharmonie de Paris, outstanding acoustics needs to combine great clarity and good reverberance. Ideally these two aspects should not be conflicting. The achievement of adequate reverberance in a 2400 seats concert hall calls for a rather huge volume whereas the achievement of adequate clarity and presence of the source calls for an important amount of reflecting surfaces close to the stage and each part of the audience. These two architectural requirements may first seem conflicting when considering the scale of – and therefore the mean distances within – the hall. Looking in more detail, it appears that a good solution to optimise both early and late sound energy independently is to design a concert hall of important acoustic volume within which a smaller and more intimate volume will be shaped by reflectors or wall elements set closer to the stage and the audience.

A new architectural criterion was developed, aiming at correlating an architectural shape to its acoustic efficiency in terms of early reflections. This early efficiency parameter is defined as the total surface area of all surfaces of the room that are located less than 15 m from the source(s) and/or from the audience and the orientation of which creates reflections towards the audience or back to the musicians. Another, more accurate definition of the efficiency has also been developed: for each of the acoustically efficient surfaces defined above, the factor $S / (16d^2)$ is representative of the fraction of energy produced on stage that is reaching it (with some approximations on solid angles, such as $S << d^2$). The sum of all acoustically efficient surfaces is consequently representative of the percentage of emitted sound energy that is reflected towards the audience or back to the stage and that will contribute to early energy.

The parameters were calculated and checked for several concert halls, with different architectural shapes. Results suggest – for large concert halls with more than 2000 seats – the need for 1400 square meters of acoustically efficient reflector surfaces, 500 square meters of which need to be less than 15 meters from the stage. An efficiency factor close to 24% was found to be optimal for symphony concerts – irrespective of room shape. The fascinating aspect of this criterion is that it defines the quantity of reflecting surfaces, and there relative distances, while maintaining freedom for the architect to place them and to shape them as desired.

The need for a large acoustic volume and for acoustically efficient reflectors that are sufficiently close to the sources and/or audience members suggests that at least some of the reflectors are inscribed within the acoustic volume of the space, rather than forming the perimeter walls of the space. This was identified in the brief, as well as the possibility – if the architect chose to do so – to use these reflector surfaces to define a more intimate inner architectural space, and/or to use the variability of some of those reflectors to give the room a more intimate feeling for chamber music concerts. This leads to the concept of two interconnected acoustical volumes: a smaller scale inner volume where the concert is taking place, and a larger scale outer volume behind the reflectors which is also active acoustically and contributes to the development of late reverberation. Reverberation chambers are one example of such a configuration where an outer volume is coupled to the inner volume of the auditorium through motorised doors that tune the coupling effect. But other existing concert halls exhibit this configuration by other means. The Christchurch Town Hall and the Michael Fowler Center, for example, incorporate optimised large reflectors that are set within the large acoustic volume of the hall and subdivide the acoustic volume into an inner and an outer volume. The two concepts can lead to similar acoustic results, it is the point of departure that is different: in the reverberation chamber approach one normally considers the inner room as the "designed" room, with an additional volume attached to it, in the early reflection design one considers the outer volume as being the architectural volume, with acoustic reflectors inscribed in it – with reflectors inevitably altering the architectural impression to a significant degree. For the Paris concert hall, it was decided not to specify reverberation chambers or any other particular solution but to only define the acoustic and architectural constraints, making it possible for the competitors to shape a new type of auditorium while respecting the acoustical requirements.

Lateral energy and blending in an enveloping concert hall

As discussed above, achieving strong lateral energy in an architecturally enveloping concert hall is difficult, mainly as by definition the width of the hall is greater than for a shoebox type hall. In addition, with audience members seated both behind and to the side of the stage, lateral reflections as well as good orchestral blend need to be provided for all seats in the house. The most common solution to create lateral reflections and blend is to break up the audience seating into several segments, creating vineyard terraces that have given the name to this type of acoustic design. For a larger seat count, the size of the available surfaces for vineyard walls tends to be somewhat insufficient, and in addition grazing incidence reduces the efficiency of those reflections. In the acoustic brief for the Paris Philharmonie a lateral efficiency closer to the values measured in good shoebox-type halls was specified, and the designers were invited to consider additional means for creating lateral reflections and blend that are not prone to grazing incidence, for example the acoustic reflectors discussed in the precedent section, or optimised reflector shapes, possibly using reflections of higher order. We believe that some of this acoustic "work" will need to occur in the upper part of the acoustic volume of the hall, creating acoustic diffusion that leads to lateral reflections and blending of the different sound sources.

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