IMPLEMENTING THE ACOUSTICAL CONCEPT FOR THE PHILHARMONIE DE PARIS, GRANDE SALLE

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1 INTRODUCTION

The concept design for the Grande Salle of the Philharmonie de Paris aimed at balancing early and late acoustic energies by nesting an intimate audience chamber within a larger acoustic volume. Though there were partial precedents for this concept (ref. Marshall's paper[1]), the architectural language for the Philharmonie required a systematic, yet creative approach. The complex geometry of the hall, with its inner and outer volumes, exceeded the capabilities of common acoustic simulation packages and processors. An interactive approach was adopted where the new technologies in 3D modeling and parametric design took an essential role, followed by the formal acoustic simulation in ODEON. The latter was subsequently validated by a scale model study. In this paper, we will present the steps of the acoustic design process and the tools used to deliver a radical but successful design. Commissioning measurements are reported in an accompanying paper.

2 THE CONCEPT

2.1 A complex geometry

In an accompanying paper[1], Harold Marshall presents the acoustical concept he developed with Jean Nouvel for the Grande Salle of the Philharmonie de Paris. The solution to the challenge posed by the "Programme Acoustique" from Kahle Acoustics[2] was found in an intimate inner chamber nested within a larger acoustic volume. Although this description is accurate and may speak to those who have been lucky to attend a concert at the Philharmonie de Paris, it does not convey the complexity of the geometry.

If indeed the bi-cameral concept can be represented by two coupled spaces, each with its own decay time, the geometry of the Philharmonie de Paris plays a significantly more important role than in most of the precedents mentioned in Marshall's accompanying paper. As the "Acoustique Programme" demanded high clarity and envelopment, the surfaces defining the boundary between the two chambers became our primary acoustic reflectors in the hall.

To add to the complexity, these surfaces also express a significant part of the room's architecture. Finally, the project constraints did not allow for any mechanized system to adjust, post construction, the opening between the inner and outer volume. The team at Marshall Day Acoustics, working closely with Atelier Jean Nouvel and his associates had to get it right with no scope for future adjustments.

The responsibility of developing the acoustic design through the schematic and detailed design phase was no small task. To the authors' advantages, during the course of the project, the Marshall/Nouvel concept was found to be very responsive to design changes yet robust against distractions in sometimes clumsy directions.

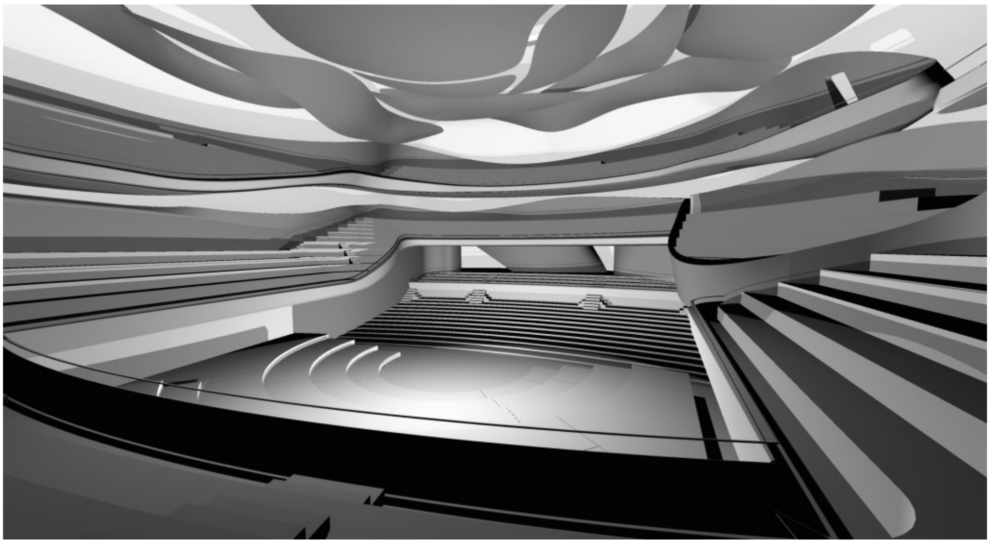

Figure 1 A complex geometry for the inner space

2.2 An iterative and evolving approach

With a design competition beginning in January 2007, it is fair to admit that as a project the Philharmonie de Paris has lived through, if not defined, a very significant period of evolution in acoustic design tools. One only has to realize that Grasshopper[3], the now commonly used three-dimensional parametric tool for Rhino[4], was first released in September 2007. This pivotal tool was then to be used on computers with, at best, a dual-core processor. In addition, the ray-tracing software Odeon was yet to make use multiple core processors.

Nevertheless, the Philharmonie de Paris was not to escape the systematic and scientific design approach preferred by Marshall Day Acoustics. The significance of the project dictated that every step in the acoustic design development had to be carried out rigorously and then quantified. With the benefit of hindsight and given the project political climate, no other approach would have succeeded in maintaining acoustic quality as a top priority.

2.3 The key geometrical elements

Once the new architectural and acoustical paradigm had been invented, one had to realize in full the purpose of key acoustic elements in the design and establish an acoustic objective for each.

Key acoustic elements	Acoustic contribution
Inner volume	Controls the distance between the audience and the stage. Controls the distribution of the audience areas and the total acoustic area of the seat absorption and therefore the reverberation time and loudness.
Outer volume	Controls the energy level of the late response of the room.
Opening between the outer and inner volume	Controls the proportion of energy used for the early and late responses of the room. Controls the distribution of late energy returning into the inner volume across the audience.
Suspended reflectors "Nuages"	Provide first order early lateral reflections for the audience and the primary means to achieve exceptional Loudness, Clarity and Envelopment.
Balcony fronts and walls "Ribbons"	Provide first and second order early lateral reflections for the audience and the primary means to achieve exceptional Loudness, Clarity and Envelopment, in particular for seats

	under the overhangs.
Canopy above the stage	Provide ensemble reflections for stage support and communication between orchestra sections and with the choir.
Distribution of diffusion	Avoid acoustic anomalies and assist with orchestral balance.
Material selections Assemblies of finishes	Limit the low frequency absorption.

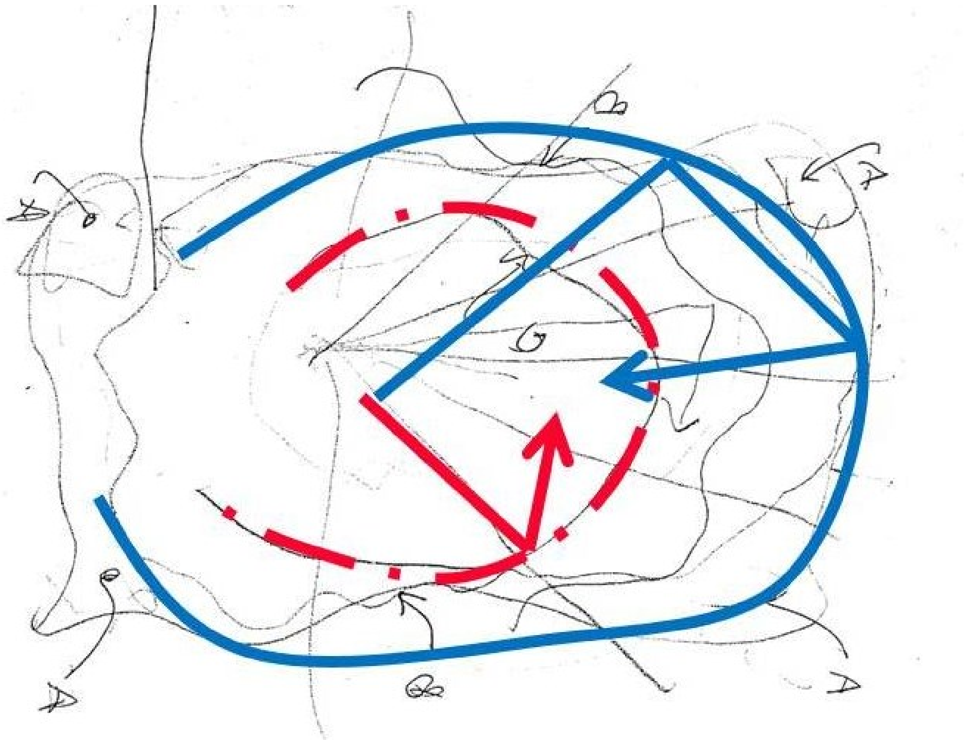

Figure 2 The inner volume (red) defines the early response, the outer volume (blue) defines the late response (on Harold Marshall's conceptual sketch)

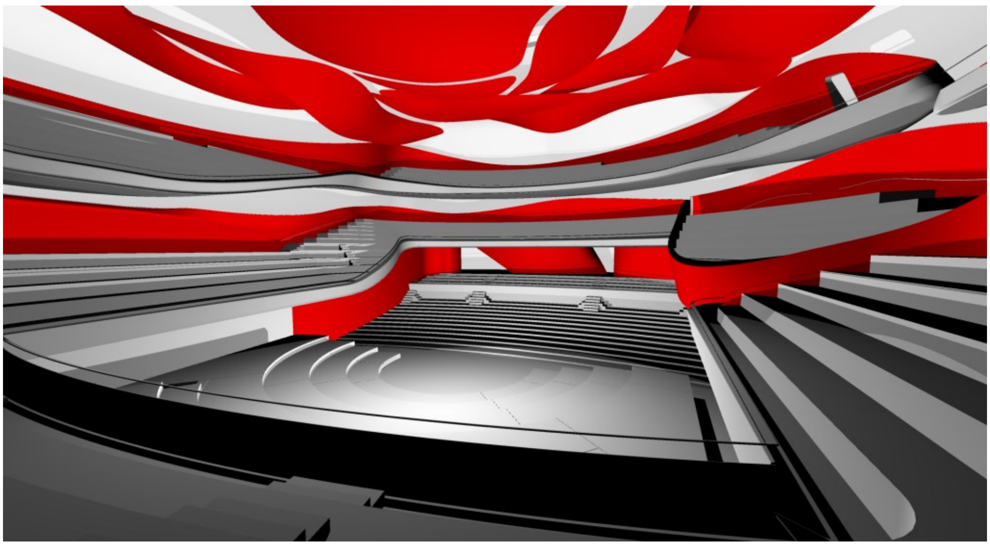

Figure 3 The ensemble of surfaces contributing to the early response for the audience

All the above key acoustic elements have been the subject of multiple and dedicated studies. These studies were of course not independent as the outcome of one is often the input parameter of another. It is only when all elements were considered that the significance of a design change could be assessed.

3 DESIGN AND REVIEW

3.1 Balance between inner and outer volumes

The acoustician typically must ensure early on that the building design provides sufficient volume for the hall and that the acoustic volume of the hall itself is appropriate. The case of the Philharmonie de Paris was not different, except that there are two volumes involved, both of which are architecturally important.

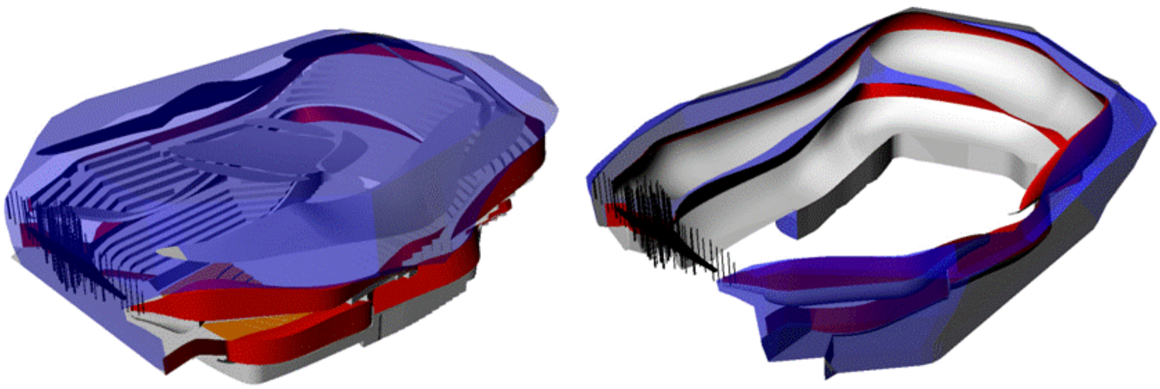

Figure 3 The inner volume on the left. The outer volume on the right.

From a purely theoretical point of view, early investigations were made to determine the energy transfer between the two spaces. These calculations were detailed in a previous paper[5],presented in Paris in 2008. Various prediction models were used to determine the two slopes of a non-exponential decay curve and the coupling area at which the effect of the outer space became noticeable. The models included the steady-state statistical model from Eyring[6], followed by a more elaborate model called the semi steady-state statistical model where the outer volume is not fully charged and may not achieve the equilibrium before the decay begins. Finally, a model that was more elaborate but significantly better suited to the complex geometry of the Philharmonie was investigated using the diffusion equation.

Unfortunately, even by today's standards, such investigation requires significant computer power and programming time, neither of which was readily available within the course of a project in 2008. The decision was made to rely on experience, common sense and other prediction tools such as Odeon and the 1:10 scale model study that was by then under way.

3.2 Physical model

Although the Philharmonie de Paris in 2015 is often cited as defining the 21st century the state-of-the-art concert hall, a traditional and simple approach was adopted very early on to determine a useable reflection sequence within the inner volume.

In a previous paper[7] on whole stage imaging in concert hall design, the concept of subdivision of space and time was presented. This concept can be summarised as follows: to each zone of audience is assigned a subset of the reflecting surfaces that contribute to the early acoustic efficiency of the room, as defined by Jurkiewicz[8]. This implies that the acoustic reflectors are to be developed using a reverse approach, as previously argued for the more general case of parametric design[9].

For the Philharmonie de Paris, the exercise was to match, amongst the many possibilities in such a fluid architectural language, surfaces within the inner volume to specific zones of audience. For this, a traditional 1:50 cardboard and polystyrene model of the inner volume was built. Basic laser ray-tracing and careful note taking informed the design and narrowed down the lengthy investigative work in the pre-Grasshopper (and the likes) digital environment.

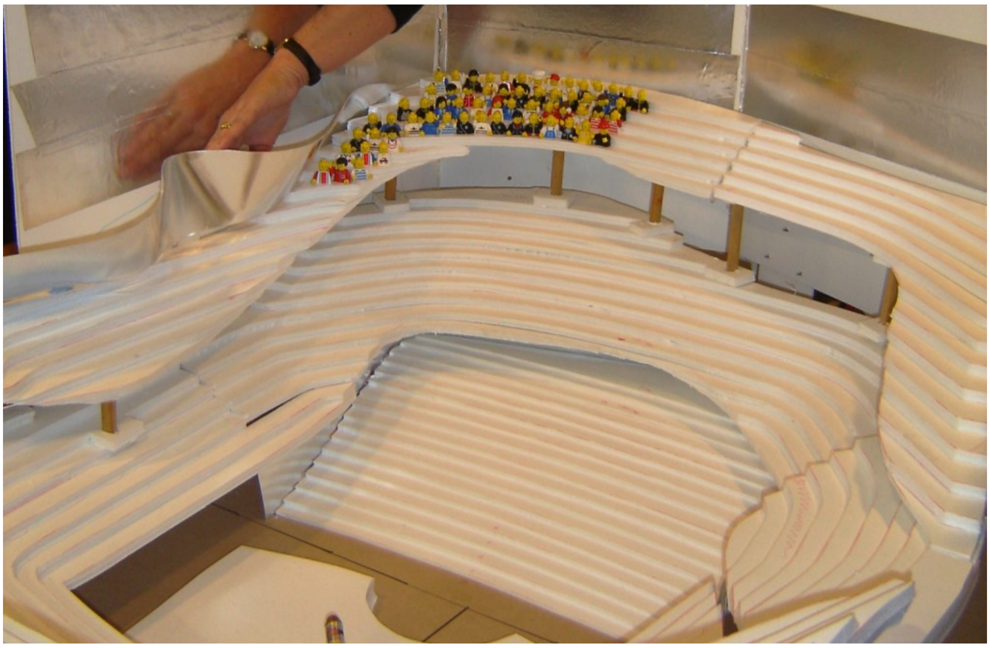

Figure 4 The initial scale model for the Philharmonie de Paris - work on the ribbons

3.3 Early Odeon simulations

As many acousticians know, acoustic simulations are only a crude estimation of the performance of a concert hall. Their value lies in preventing gross errors and confirming one direction of design development over another. Yet, they remain an essential milestone in the design of a concert hall and the results can be excellent supports when communicating recommendations.

The systematic and quantifiable approach adopted by Marshall Day Acoustics includes the submission of simulation results. All results of our Odeon simulations were submitted, alongside our recommendations, for review and comments from the client's own acoustician, in this case Kahle Acoustics.

With such a complex geometry, Odeon simulations remained however a luxury and were carried out only when the effects of accumulated design changes where noticeable over the uncertainty of 3D modeling. With over 140,000 surface elements constituting the complete 3D model of the Philharmonie de Paris, and using only a single processor, a complete Odeon grid response would require up to 24 days per source position. The accuracy of such simulations was questioned as the complexity far exceeded the 1,000 surfaces limit specified by the Odeon development team. These results were however to be confirmed at a later stage of the project with the help of Katz's model study[10] mentioned below.

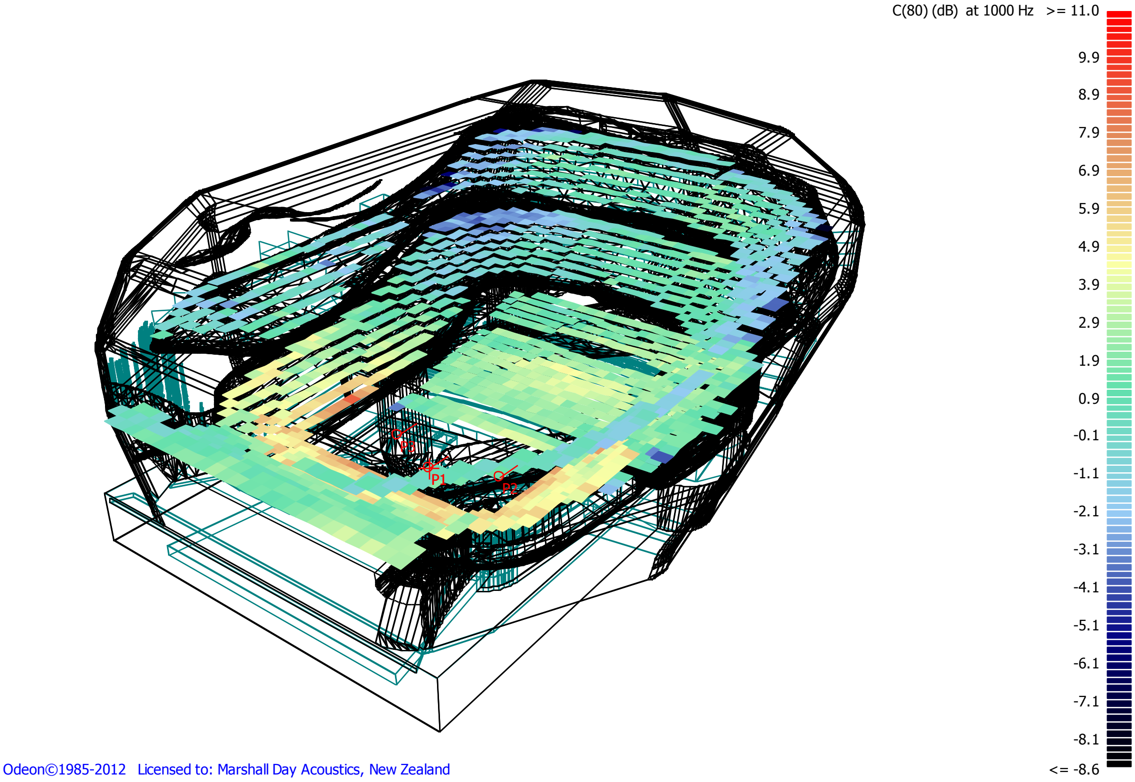

Figure 5 One of the Odeon simulations run for the project at the end of Schematic Design (24 days)

An alternative systematic approach was required for the acoustic review to be delivered in a timely fashion and to allow the architect the freedom necessary to further develop the concept. Acoustic analysis in the Rhinoceros 3D modeling software, selected by the architect, was an evident solution.

3.4 Rhino-based reviews

In 2008-2009, during the schematic design phase, most of the acoustic work was carried out directly in Rhinoceros 3D modeling software. If it is an obvious option today, it was not common practice at the time.

As mentioned in Section 3.2, the subdivision of potential reflecting surfaces was applied to the suspended reflectors "nuages", the balcony fronts and the balcony walls "ribbons". In the case of the nuages, starting from the projection of the reflectors provided by the architect, each "nuage" surface was subdivided. Basic ray-tracing was carried out manually, one ray at the time, in Rhino to determine the desirable orientation for each element, we called them "pixels", representing the subdivision of the "nuages".

Information such as time delay (△t), level difference (△L) with the direct sound and the reverberant sound level became readily available to optimize the design and ensure that the right "pixel" was creating early lateral reflections for the right audience area. At the end of the schematic design, more than 40 pixels where used for "nuages", 34 for the "ribbons" and 19 for the balcony fronts.

Though the pixels were a great tool to explain the acoustic design intention to the architects, they were not necessarily the most efficient tool to convey our requirements in terms of dimensions of the appropriately orientated section of "nuage". From the detailed design phase, the concept of the pixel had become an intermediate step and the "nuages" were directly rebuilt according to our requirements before the 3D model was issued to the team.

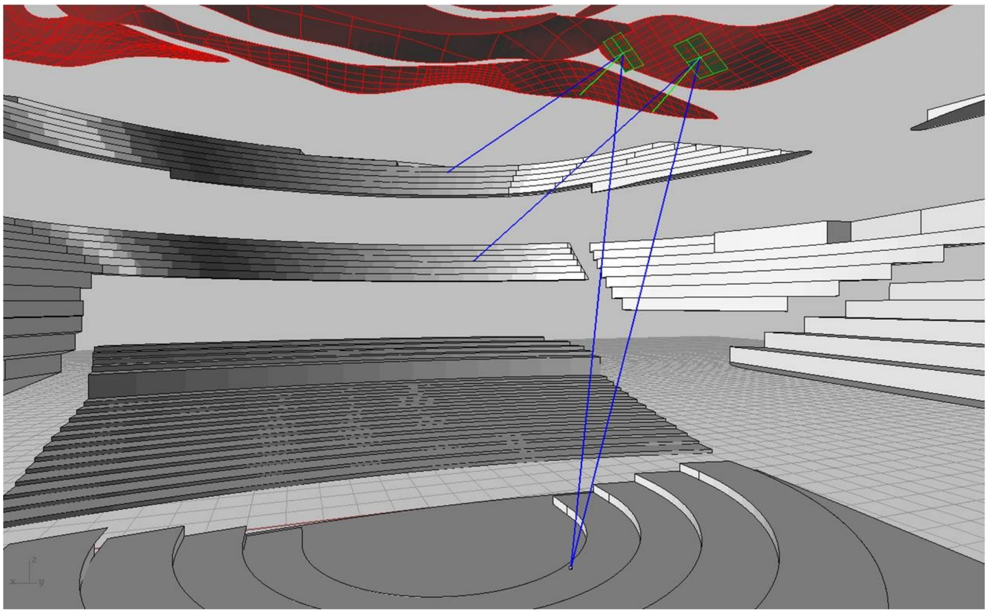

Figure 6 Two acoustic pixels and the surface regenerated by combining them

3.5 Grasshopper design

The obvious next step was the automation of the above process using the parametric Grasshopper design aid. This allowed not only the rapid analysis of the models received from the architect but also the rapid regeneration of surfaces. The tools developed within Grasshopper to assist with the Philharmonie de Paris were presented in a separate paper[9].

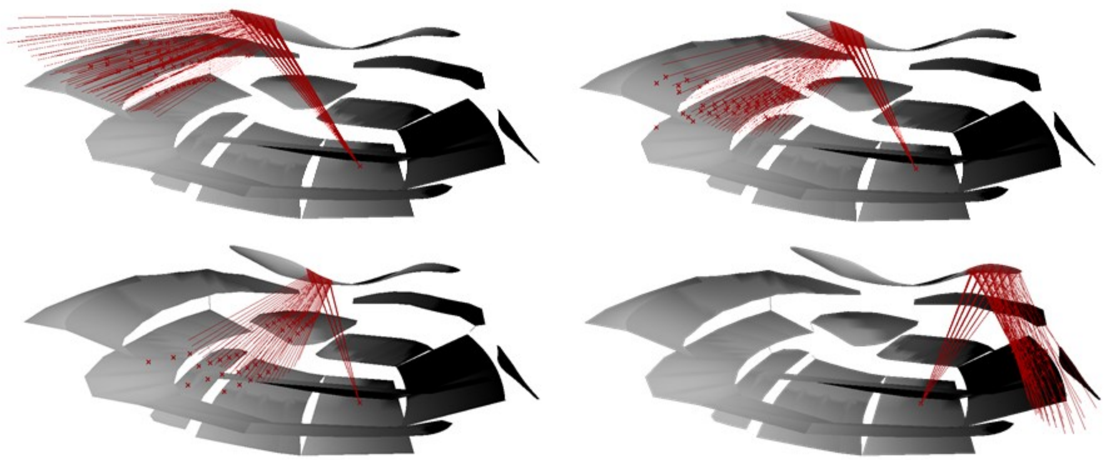

Figure 7 The subdivision of a 160m^2 reflector over the entire length of the hall

This tool suite includes routines to reorient surfaces, adjust curvature of surfaces, automate the coverage of a large audience area by combining the coverage from multiple reflectors and ensure that all reflections met the requirements for early lateral reflections as defined by Marshall and Barron[11].

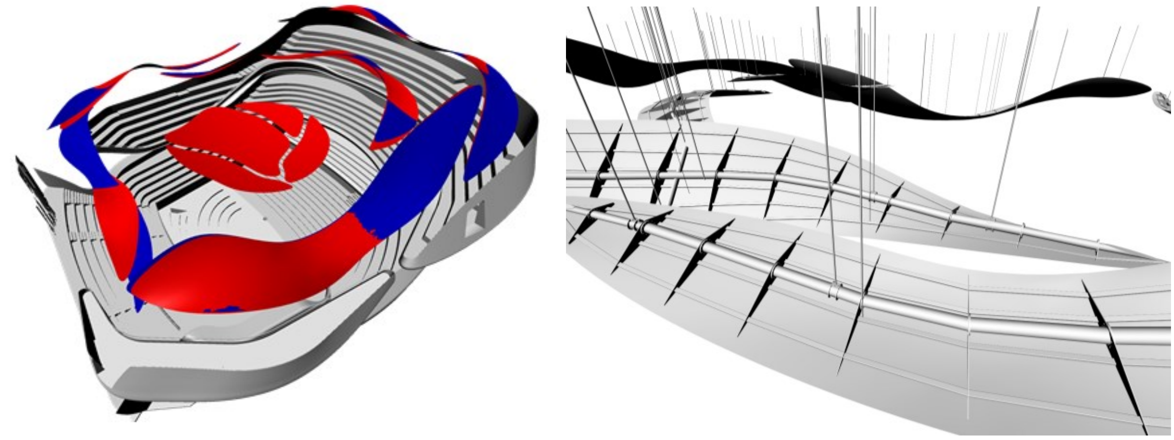

Figure 8 The suspended reflectors optimised for acoustics (red on left), with structure (right)

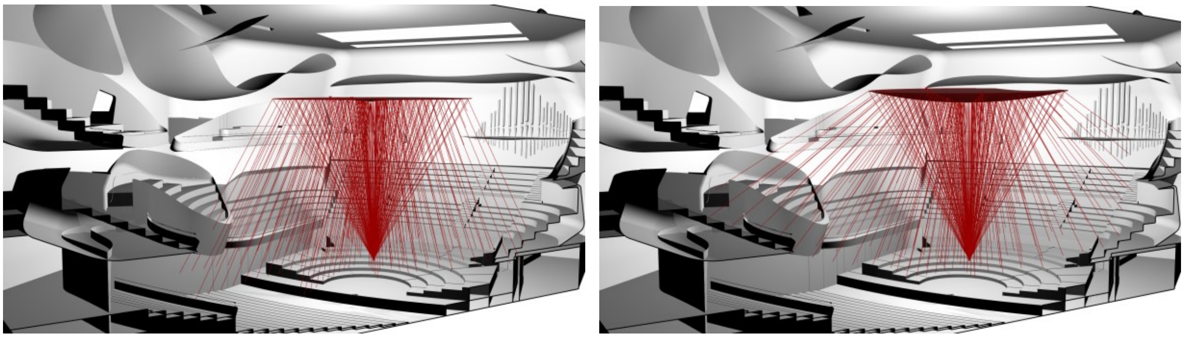

Figure 9 Optimization of the curvature for the canopy. Flat on the left, final curvature on the right.

This approached was used for all surfaces identified as potential sources of early lateral reflections, including stage support. Most of these where finalized during week long workshops, in real-time with the architects, builders and client.

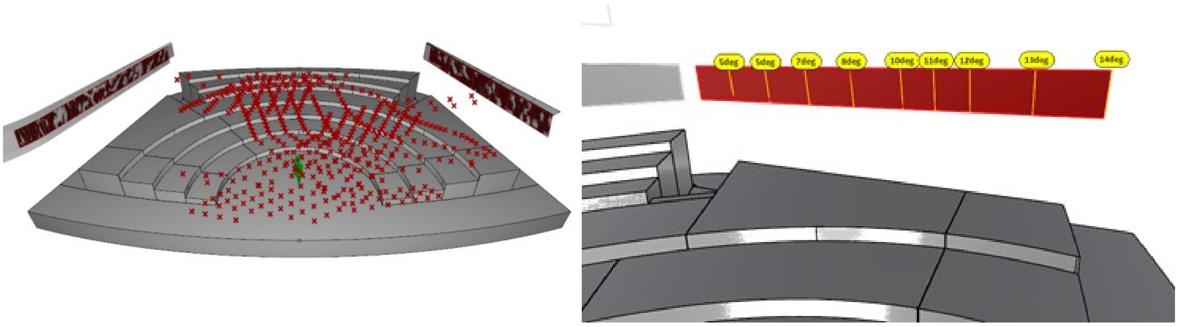

Figure 10 Stage support design using the balcony fronts. Ray tracing on left, advice on the right.

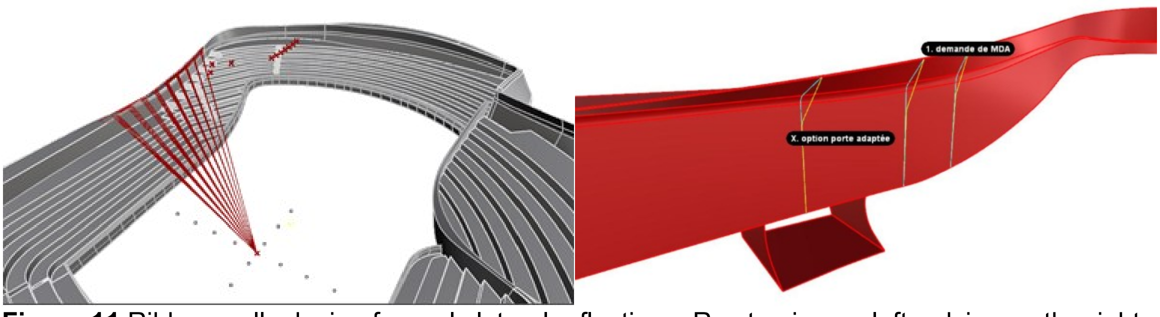

Figure 11 Ribbon walls design for early lateral reflections. Ray tracing on left, advice on the right.

3.6 Physical model

Validating such a new paradigm, and providing the needed confidence that Odeon simulations were meaningful with 140,000 surfaces, Marshall Day Acoustics recommended to the Philharmonie de Paris that a 1:25 scale model be built for the sole purpose of validating the concept and calibrating our simulations. The recommendation was accepted and, to provide additional exposure and public interest to the project, the decision was made to commission a 1:10 scale model instead.

The task of conducting such a peer review of the design was assigned to two teams of acousticians. Brian Katz led one of the teams and performed, under significant time and material pressure, a vast campaign of measurements. His valuable work is summarised in an accompanying paper[10].

One of the many interesting results demonstrated by Katz's measurements and subsequent comparisons with the Odeon simulations is that the physical scale model was not able to validate the acoustic parameters that depend on material properties. These include the reverberation time RT, EDT and Loudness G, all key parameters in this design, in particular G.

4 IMPLEMENTING THE DESIGN ON SITE

It is a well-known fact that the implementation of the design on site has raised controversy. Yet, amongst all the noise, the acoustic quality of the Philharmonie de Paris Grande Salle and its intimacy have been unanimously praised. So something went right. The authors would like to think that in addition to a successful design, our regular site visits, detailed and sometimes stubborn inspections and interactions with the workers on site have contributed to this success.

Figure 12 The Philharmonie de Paris, three weeks prior to opening

It is impossible to report within such a paper, on the construction of this project, and most notably the two months leading to the opening. However, for the "acoustics to prevail" [12], one cannot simply hope for the best. It is the combination of a scientific approach, engineering common sense, patience and diplomacy, that allows one to decide whether a reflector is acceptable or needs to be reassembled (and how) even if planning, costs and politics say otherwise. Not all debates have been won and nor should they be.

5 CONCLUSIONS

This paper does not present the equations and engineering rules that guided the acoustic detailed design of the Philharmonie de Paris. It does however provide a recollection of how the acoustics of this state-of-the-art concert hall has been handled by Marshall Day Acoustics from the concept to the opening. It is fair to say that the Philharmonie de Paris is the perfect example of a design masterpiece underpinned by science and engineering. Everything has been investigated, quantified, designed and iterated by Marshall Day Acoustics and Atelier Jean Nouvel and his associates.

In his lectures[13], Marshall has often discussed the role of the acoustician, a role that oscillates constantly between scientist, engineer and designer. Indeed, the success of any creative design needs to be proven in the fields of physical science and engineering. The difference between an acoustical debacle and the huge acoustic success of the Philharmonie de Paris has, we believe, been the systematic bridge between the non-linear realm of design (and other fields) and the linear one of science and construction.

Finally, the project outcome seems to confirm the excellence of conformity with the objectives set by the Programme Acoustique and maybe more importantly, by all the stakeholders. It would seem appropriate to end this paper with two quotes:

From Marshall Marcus, former Head of Music at London's Southbank[14]

"*Well done Paris, well done master acousticians Marshall Day Acoustics*".

From Sir Simon Rattle, OM CBE, artistic director of the Berliner Philharmoniker who conducted his orchestra in the Philharmonie de Paris in February 2015[15]:

"*playing one of the very early concerts in the Philharmonie de Paris and realising that this one of the world's greatest acoustics*."

6 REFERENCES

1. A. H. Marshall, "*The conceptual acoustical design for la Philharmonie de Paris, Grande Salle"*, Proc. Auditorium Acoustics, Paris (2015)
2. Kahle Acoustics and ALTIA, "*Le Programme Acoustique de la Philharmonie de Paris*", 2006
3. Grasshopper: Algorithmic modelling for Rhino. www.grasshopper3d.com
4. Rhinoceros: Modelling Tools for Designers v5.0. www.rhino3d.com
5. T. Scelo, A.H. Marshall, J. Valentine, "*Theoretical considerations in the prediction of decay times for the Philharmonie de Paris*", Proc. IOA Acoustics 08, paper No.960, 2008
6. C. F. Eyring, "*Reverberation time measurements in coupled rooms*", Journal of the Acoustical Society of America, Vol. 3(2), pp. 181-206, 1931
7. A.H. Marshall, P. Exton, T. Scelo, " *Whole stage imaging for the control of sound strength in concert halls*", Proc. International Symposium on Room Acoustics, Melbourne (2010)
8. Y. Jurkiewicz, Y., et al., "*How far should the geometry of a concert hall be optimized?*", Proc. International Symposium on Room Acoustics, Toronto (2013)
9. T. Scelo, "*Integration of acoustics in parametric architectural design*", Acoustics Australia, Vol(43), 2015
10. B. Katz, "*La Philharmonie de Paris - Acoustic scale model study*", Proc. Auditorium Acoustics, Paris (2015)
11. M. Barron, A.H. Marshall, "*Spatial impression due to early lateral reflections in concert halls*", J. Sound Vib. 72, 211–232 (1981)
12. Blog from The Angry Architect published on Architizer.com on 1 February 2015
13. A.H. Marshall, "The acoustical design of concert halls", Study Paper No.75, School of Architecture, University of Auckland, 1983
14. https://marshallmarcus.wordpress.com/2015/01/14/ce-soir-nous-sommes-tous-la-philharmonie/, 15 January 2015
15. http://philharmoniedeparis.fr/en/node/3584 , Interview of Sir Simon Rattle, published on 17 June 2015