ACOUSTICAL PLANNING FOR THE NEW PARIS "OPERA DE LA BASTILLE"

J.P. Vian

Department of Building Acoustics
CSTB, Rue Joseph Fourier - 38400 SAINT MARTIN D'HERES / FRANCE

INTRODUCTION

Six years ago the French President de la République has decided to build in Paris a new modern and popular opera house, fitting as well as possible the contemporary requirements for lyric art. Eighteen months later, the canadian architect Carlos OTT was appointed as the architect of the project after an international competition. The acoustical planning started immediately.

Now the concrete work is almost finished and everything is going very fast on the working site to make possible an opening on July 14th, 1989, two hundred years after "la prise de la Bastille".

GENERAL OVERVIEW ON THE PROJECT

The two basic points of the project which have influenced deeply the programme are the words "modern" and "popular".

Modern is easy to understand. But popular means different things. First of all, it means a large number of seats at a reasonable price, which in turn has a lot of consequences about the number of performances, alternation, and therefore large spaces to rehearse to store decors etc... Second, it means that the very classical and a little bit aristocratic organisation of the horse shoe italian theater has to be replaced by a more democratic approach, giving the best and the most equal view and acoustical conditions to the largest number of people as possible. This last point corresponds to an actual acoustical challenge for a large lyric theater.

The building contains four main halls :

- the large hall for operas and concerts - 2700 seats

- the modular room for operas, concerts, dramas which can be transformed from a classical concert hall to an italian theater or an experimental hall,with seating capacity ranging from 300 to 1300 seats

- the amphitheater (semi-circular) for small, simple and varied performances - 800 seats

- the studio - 300 seats, already opened in April 87 in an attached building called Tour d'Argent, for conferences, master classes, recitals and small musical performances.

The tremendous large stage system is composed of 7 stages of the same size as the main stage, with elevators, turning table and corresponding storing area at the basement of the building.

A lot of rehearsal rooms are also provided for orchestras, chorus, ballet and so on...

The acoustical program specified a reverberation time of 1.1 s to 1.4 s, an EDT of 1.3 s, and a strengh index greater than -29 dB. The background noise had to fulfill the NR 20 curve, and the sound insulation had not to be less than 70 dB(A) between sensitive or noisy rooms. Wishes about early reflections from the auditorium to the singers was also expressed along with some general rules such as angles of the walls, ratios of underbalconies spaces to the main space, and maximum width of the hall.

It is also important to point out that all the proscenium area around and above the stage opening and the orchestra pit are movable to achieve various relations between audience and stage, depending on the kind of opera performed and the stage design. Consequently the iron curtain must be placed between the orchestra pit and the audience and all the very important surfaces around the singers' place are light weighted and might be not perfectly connected or oriented.

The client has committed the CSTB together with Müller BBM to do the acoustical planning of the whole building, including sound insulation, noise from scenographic or technical equipments, and vibrations from the metro.

ACOUSTICS OF THE MAIN HALL

In harmony with the client, we have proposed for the main hall, beyong the classical high clarity for speech intelligibility in a lyric theater, a rich acoustics a little bit more reverberant than the usual lyric theaters (1.6 s), with strong lateral reflections, and the loudest sound as possible to take up the large distances of the hall.

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1) Computer simulation

As usual the first step of the acoustical planning was to discuss the gross shape of the hall. Without going into details we can tell that we have proposed several modifications on the competition sketches, mainly to change the radial orientation of the walls, to adjust the volume and to improve the use of the ceiling.

To support these demands and to evaluate their actual influence we have run computer tests using the Epidaure programme at different steps of the design.

As already published, the Epidaure programme is based on a cone tracing method to easily determine the image sources up to a very high order, whatever the shape of the hall. It calculates impulse responses for different receiving points in a hall, maps of criteria over the audience area, and it allows to listen to the sound of the hall.

The figure 1 shows one of the numerical model tested, with two balconies extending along the lateral walls. Up to 10 different numerical models were tested and for each most of the usual criteria (SPL, RT, EDT, C80, D50, LE) were analyzed. Echoes' occurance were also investigated. The figure 2 shows some examples of impulse responses calculated in the previous model at four different seats.

Two important questions were strongly discussed with the architect, one about the width of the hall and the second about the shape of the proscenium (side walls and ceiling). From an acoustical point of view the proposed width of 38 meters seemed much too large but the large number of seats of the hall made difficult to reduce it. When considering the SPL map and the lateral efficiency map over the orchestra seats calculated with 38 m between lateral walls and with only 32 m, it has been decided to reconsider the positionning of the seats and to place the walls at only 32 m (slides 4 - 5). The differences between the SPL at the front seats and at the back seat has been reduced from 12 dB(A) with radial walls, to 6 dB(A) with the parallel walls (38 m), and then to 4 dB(A) with parallel walls (32 m) (slide 3).

A similar procedure happened about the proscenium area. The decision was made to design the movable vertical and horizontal elements in such a way that it cannot be possible to misorientated them or to make them too much absorbing by letting open the light windows, because of the loss of level at the farthest seats. (slide 6)

ACOUSTICAL PLANNING FOR THE NEW PARIS "OPERA DE LA BASTILLE"

2) 1/20 scale model test

As the client had ordered a scale model test of the final design, we didn't make computer simulation till the end of the studies, and we ended the project with the acoustical model.

The mean dimensions of the hall are : -main floor lenght 36 m - width 32 m - heigth 23 m - maximum distance from the singer at the first balcony 41 m - at the second balcony 48 m. The volume is 21000 m3 and the volume per seat is 7.7 m3. The walls in the audience area are covered by granit stones, the floor is made out of thick wood, the ceiling is made out of 6 mm glass tiles rigidly clamped together, the under-face of the balconies are staff and all the remaining surfaces around the stage are wood. The seats have a wooden reflecting back. They are designed to have the upholstered part completly covered by the spectator when occupied and to be the most absorbing when unoccupied.

The acoustical model was build with dense polystyrene board or lacquered wood for all the reflecting surfaces. The seats rows were simulated by small vertical partitions of the scaled down shoulders' heigth, partly covered by a strip of velvet. The seats' absorption was adjusted to the known values of occupied seats, using a 1/20 scale reverberant room. The model reproduced the architectural details greater than around 10 cm full scale and was filled up with dry air (relative humidity lower than 3 %) to ensure the rigth high frequency air absorption.

The microphones used were the BK 1/8" with nose cone. For binaural measurements we have used a small and simple dummy head with two microphones on each side. The source was a spark generator specially designed for model test measurements. 15 measurement points were spread over the audience, and the source positions tested were either on the stage or in the pit. Several measurements were done to analyze the stage-pit relation and the acoustical feedback from the hall to the singers and orchestra.

For each receiving point the impulse response was digitaly recorded, and all the following criteria were derived by computer (RT, EDT, C80, D50, S/N, G). The strengh coefficient G was directly calculated from the impulse response for integration times of 50 ms and 500 ms by the formula:

$$G = 10 \text{ LOG } (S0*E500 / 4\pi r2*EDir)$$

with S0 = 1 m2, r = distance to the source, E500 = energy of the impulse response before 500 ms, EDir = energy of the direct sound measured on the first peak, if the source is visible from the receiver.

ACOUSTICAL PLANNING FOR THE NEW PARIS "OPERA DE LA BASTILLE"

Echograms for each receiving points were also calcuated and integrated with an exponential time constant of 35 ms to check the possibility of echoes. In addition every recorded impulse response was listened after scaling down the frequency to detect echoes. The sound of the hall was also investigated by listennig to anechoic music convolved with binaural impulse responses in order to to feel the difference between good seats and far seats or seats below overhang balcony.

The results of the tests were quite satisfactory. With small adjustements of the first part of the ceiling it was possible to maintain the strengh coefficient between -31 dB(A) at 10 m from the singer and -36 dB(A) at the worse seat. The reverberation time was 1.6 s at 500 Hz and the clarity 80 ms ranged at 500 Hz between 2 and 6 dB. Figure 4 give some values of the above mentioned criteria.

Due to an architectural demand to simplify the appearence of the fixed proscenium surface we have proposed to replace the random diffuse reflecting elements by 2D primitive roots diffuser. No change in reverberation time could be observed, but a slight improvement in homogeneity of most of the criteria was sensible.

CONCLUSION

To conclude such a presentation a very important thing is missing, that is the possibility to report on the acoustical quality of the real hall and the judgement of the critics. We can only say that we have made all the possible, using the most modern technics, to optimize the acoustical solutions compatible with the various constraints. Within one or two years, I hope to be able to give you comparison between the measurement results and what we have predicted.

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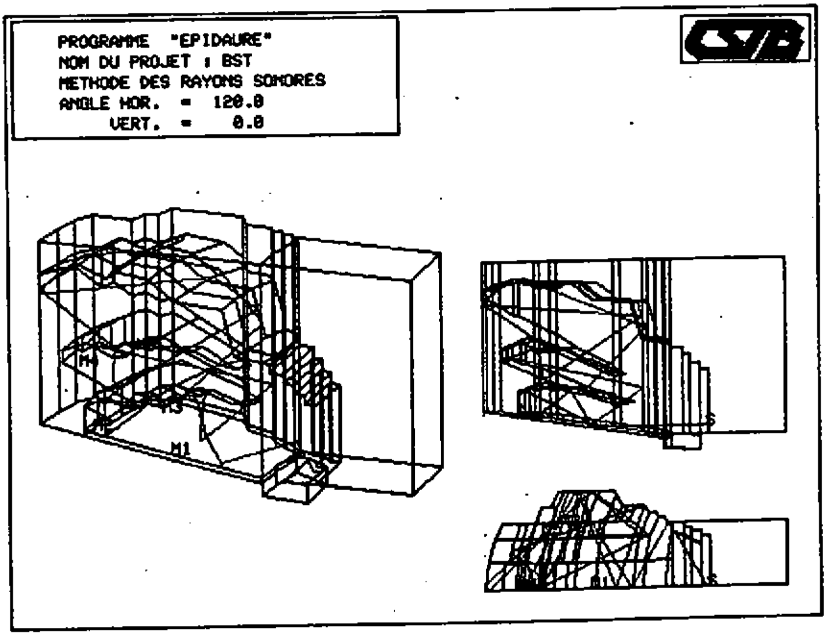

Fig 1: Numerical model of the "Opera de la Bastille" hall, with a ray propagating.

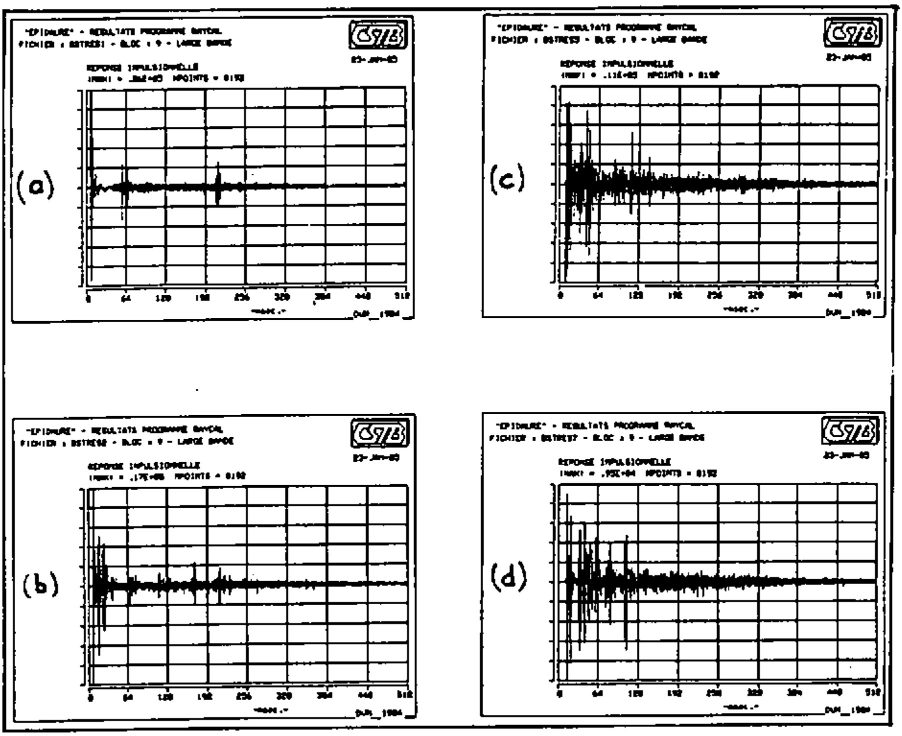

Fig 2: Examples of impulse responses calculated in the above numerical model. - (a) first part of the orchestra seats - (b) last row of the orchestra seats - (c) first balcony, side - (d) second balcony, axis

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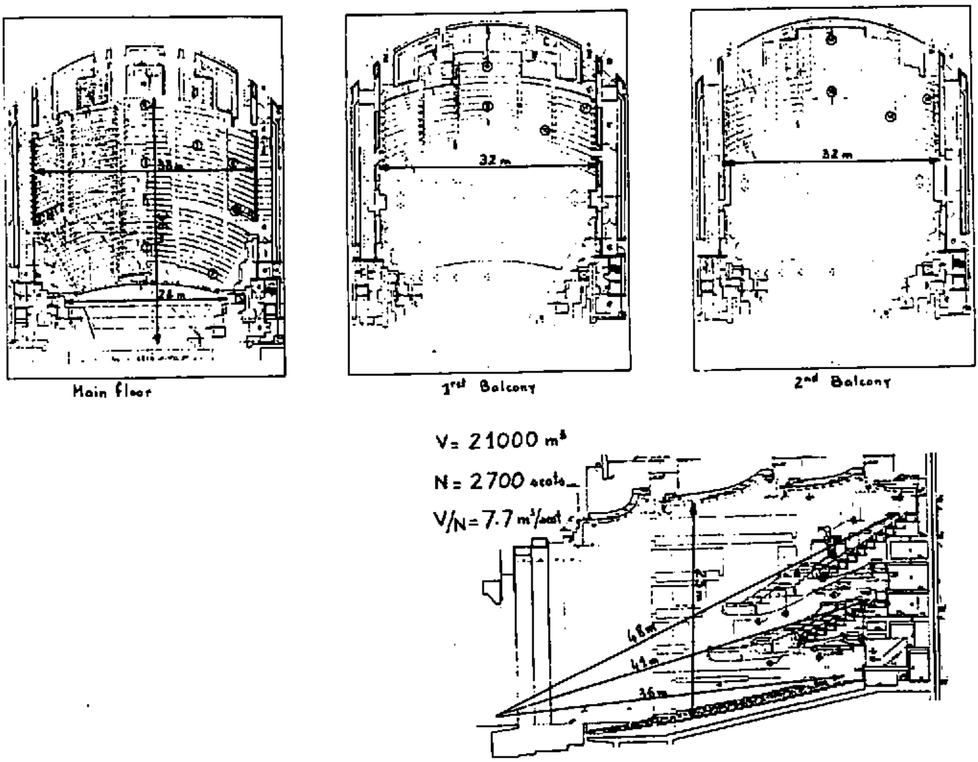

Fig 3: Dimensions of the "Opera de la Bastille" hall.

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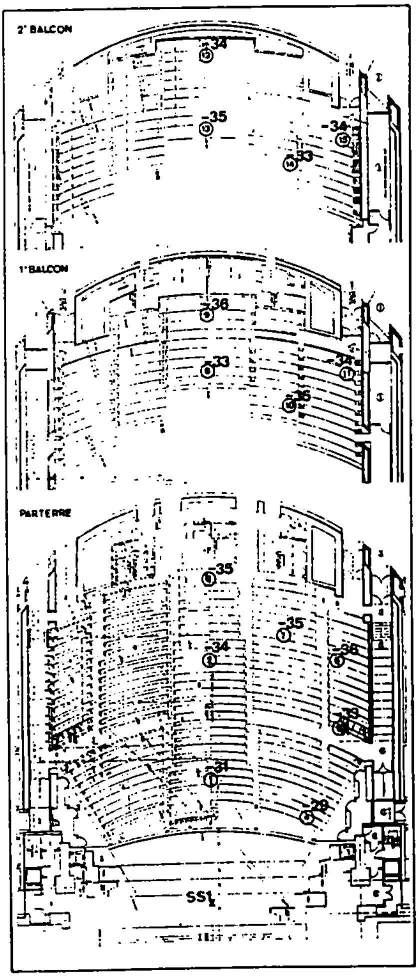

SS1	Tr 60 (s)		EDT (s)		C80 (dB)		D50 (%)		S/N (dB)	
	500	1 k	500	1 k	500	1 k	500	1 k	500	1 k
Micro 1	1.6	1.3	1.9	1.6	4.7	6.3	69	76	4.6	7.4
Micro 2	1.5	1.4	1.6	1.4	3.3	5.5	54	69	3.0	5.4
Micro 3	1.5	1.2	1.4	1.2	2.2	5.0	53	71	3.0	5.6
Micro 4	1.6	1.4	1.6	1.5	5.4	6.5	71	73	5.0	6.3
Micro 5	1.6	1.4	1.5	1.4	4.1	4.9	60	67	3.8	4.7
Micro 6	1.7	1.4	1.5	1.2	5.7	6.4	69	73	5.8	7.1
Micro 7	1.6	1.3	1.4	1.2	6.0	6.3	69	68	6.3	6.3
Micro 8	1.5	1.3	1.5	1.4	2.1	3.0	54	56	1.7	2.8
Micro 9	1.5	1.3	1.3	1.2	4.4	7.1	65	78	4.7	7.2
Micro 10	1.7	1.3	1.5	1.3	3.2	3.6	57	61	3.0	3.4
Micro 11	1.5	1.5	1.4	1.3	3.6	6.3	58	76	3.3	6.5
Micro 12	1.6	1.4	1.2	1.2	5.1	6.3	69	75	5.1	6.8
Micro 13	1.4	1.3	1.3	1.2	2.9	3.9	47	63	2.2	3.9
Micro 14	1.7	1.5	1.4	1.4	2.5	1.3	46	48	2.4	1.2
Micro 15	1.6	1.4	1.2	1.2	6.3	5.6	77	70	6.9	5.6
Moyenne	1.6	1.4	1.5	1.3						

Fig 4: Strengh coefficient in dB(A) (drawing) and values of room acoustic criteria for the 500 and 1KHz frequency bands.