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CARMEN® in the "Théâtre des Quinconces"

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The “Théâtre des Quinconces” in Le Mans, France, is a new build designed by architects Babin-Renaud and OAB which opened in 2014. The acoustics has been designed by ASE acoustics and provides good acoustic conditions for amplified music. Nevertheless the theater manager needs a multipurpose venue offering also classical concerts such as chamber music, symphonic music, choir and opera which require enhanced acoustics. The CARMEN® system has been chosen to provide for the lack of reverberation which permits to host this kind of performances. It is based on picking up the sound in the reverberant field and enhancing existing reflections to lengthen the reverberation time. The architectural fan-shaped layout of the Quinconces theater provides acoustics with poor early reflection content. In this installation, the CARMEN system has first been used to strengthen the early energy content of the auditorium acoustic response. Then, reverberation has been enhanced as in standard CARMEN installations. The acoustic results are presented and the limitation of this method will be discussed.

1 Introduction

The “Théâtre des Quinconces” is a 825-seat multipurpose venue which opened in Le Mans in 2014. The city of Le Mans is known worldwide for its acoustic facilities both in the fields of education and research. The construction of a new theater was carried out with special attention to its architecture as the architects Babin-Renaud/OAB won several prices for this design. The theater acoustics were not left apart neither. They are designed mainly for theater and amplified music but early in the construction process, the sound director and the acoustic consultant (ASE) expressed their wish to broaden the scope of this facility to symphonic music and opera. To appreciate symphonic music, more reverberant acoustics are needed and hence, a variable acoustics solution has been proposed for the Théâtre des Quinconces : the CARMEN system.

Figure 1 – Stage view of the Théâtre des Quinconces

This paper presents the ambition of an assisted reverberation system as CARMEN by presenting the different steps of its integration in an architectural project as the Théâtre des Quinconces. First, the principle of the CARMEN system is presented. Then, the passive acoustics of the theater are analyzed to evaluate the necessary layout of the CARMEN system in the hall. The tuning process of the different acoustic presets is detailed and finally, the results of the acoustic measurements for the main settings of the CARMEN system are presented.

2 Variable acoustics for a multipurpose venue

2.1 The need for variability

The acoustics of a concert hall are the unavoidable path between the performers and the audience. They can either magnify the artists work or simply degrade it if they are inappropriate to the performance. A wide variety of halls for all possible representations exist. There are theaters, opera houses or music halls for example and each of these hall types is characterized by different acoustic features [1]. One of the most important acoustic parameter is reverberation time. Table 1 presents the ideal reverberation time ranges for different types of representations. If a theater manager wishes to host all these representations in optimal acoustic conditions, variable acoustics are the only solution [2]. There are passive solutions that imply significant changes in surface materials in the hall between different representations. However, such solutions represent an important investment both in the construction phase as in the exploitation phase. Active systems, such as CARMEN, are the perfect solution for instantaneous changes in the hall acoustics as, once the system tuned properly, a simple interaction with a remote control transforms a theater into a symphonic concert hall.

Tableau 1 – Ideal reverberation time for various types of representation.

Representation	Reverberation time (s)
Amplified music, jazz	0.8-1.2
Conference	0.7-1.0
Theater	1.0-1.2
Chamber music	1.3-1.5
Opera	1.0-1.6
Symphonic music	1.8-2.5
Choral music	≥ 2.0

2.2 The Carmen system

All assisted reverberation systems are composed of a set of microphones capturing sound and a set of speakers transmitting it back to the audience. In-between, microphone preamplifiers, speaker amplifiers and a processing unit perform various types of sound transformations using filters, delays and gains (see Figure 2). Assisted reverberation systems differ by the location where the sound is captured, the number of microphones and loudspeakers and obviously the signal processing necessary to keep the system stable and natural sounding.

In CARMEN, every microphone is associated to a unique speaker placed less than one meter away ; it is a CARMEN cell. CARMEN cells are installed all over the lateral walls, the ceiling and the stage canopy of a hall. Together, they act as virtual walls. This principle is represented in Figure 3 and also described in several papers [4, 5, 6].

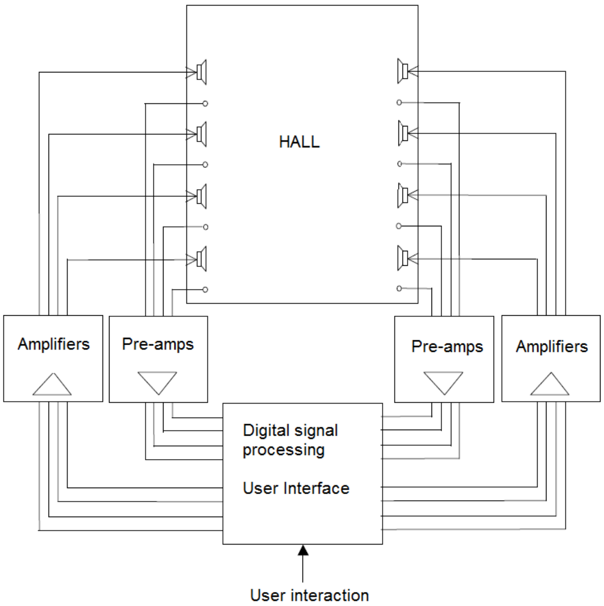

Figure 2 – Schematic of an assisted reverberation system.

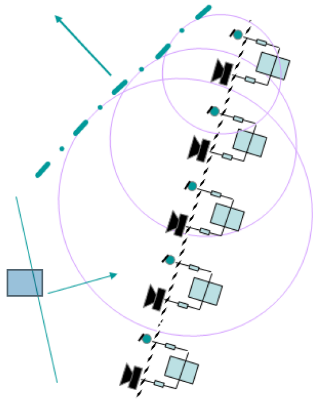

Figure 3 – The virtual wall principle.

The incident sound is captured by the microphones and emitted by the associated speakers with carefully chosen gain and delay. The gain and the delay are the two main parameters that are used to control the reverberation time in the hall. An increase in the gains of the cells simulate a decrease of the absorption coefficient of the wall surface (see Figure 4). An increase in the delays of the cells simulates a longer propagation to the wall and hence, increases the perceived volume of the hall (see Figure 5). Both methods result in an increase of the reverberation time.

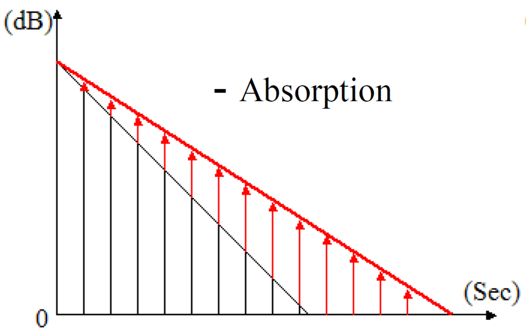

Figure 4 – Schematic representation of the effect of an increase of the gains on the impulse response of the hall [3].

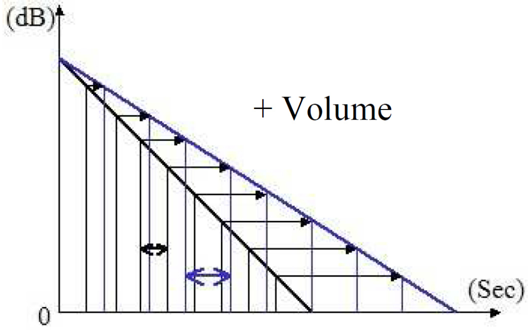

Figure 5 – Schematic representation of the effect of an increase of the delays on the impulse response of the hall [3].

Naturally, these sound manipulations are possible only if the overall system remains stable. In fact placing a microphone close to a loudspeaker and increasing the gain is not a trivial task due to the Larsen effect. A specific feedback cancellation method is used to push the limits of physics and set the gain values to their optimal values. In practice, it consists in filtering out from the output, the signal captured by the microphone coming from the speaker itself (see Figure 6).

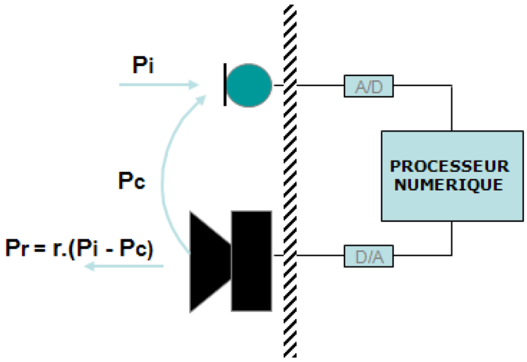

Figure 6 – Simplified representation of a CARMEN cell.

Besides reverberation enhancement, CARMEN allows to increase intelligibility in the hall with directional microphones capturing sound close to the source and sending it to the loudspeakers with pertinent delays. It's an optional voice reinforcement system that needs to be tuned carefully so as to respect the spatial localization of the sound source and remain undetectable by the audience.

3 Carmen in the ”Théâtre des Quinconces”

3.1 Installation

In the Théâtre des Quinconces, the passive reverberation time of the hall is about 1.0s in the mid frequencies. It is well suited for amplified representations and theater but the fan shape of the theater do not provide enough early reflections. Besides, visibility constraints on the lighting bridges enforces the ceiling reflective panels to be set in non-optimal inclination relative to the audience (this can be noticed in Figure 1). Therefore, in this CARMEN installation, the system is used both to enhance the reverberation and to reinforce the early reflections.

The system is composed of 32 cells and 2 forestage microphones for the voice reinforcement system. There are 6 cells in each wall, 3 under the balcony, 12 in the ceiling and 5 in the stage canopy. Figure 7 shows the positions in the ceiling and the stage canopy of the CARMEN cells and the positions of the two forstage microphone noted "33" and "34" on the plan. The cells close to the stage contribute to the strength of the early reflections. Those in the stage canopy reinforce the canopy effect for both the audience and the performers. The cells under the balcony ensure a better coupling of this volume with the main volume of the hall. Overall, all cells have a specific purpose in the enhancement of the reverberation of the hall.

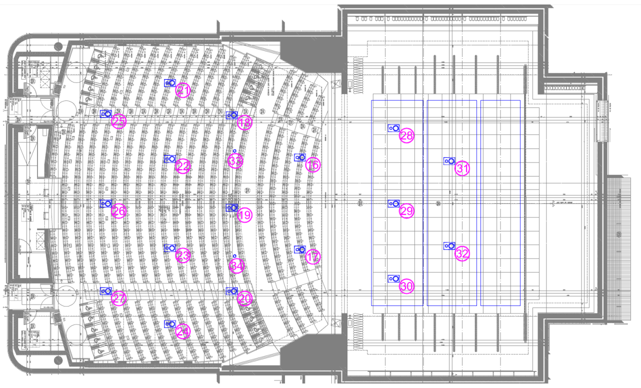

Figure 7 – Layout of the Carmen cells in the ceiling and the stage canopy.

The microphones and the speakers are discretely integrated in the hall architecture as shown in Figures 8 and 9. It is important for the audience but also the performers that the system remains "invisible". The purpose is to make the performers feel comfortable in their acoustic environment without having the impression that their performance undergoes any kind of electronic post-processing.

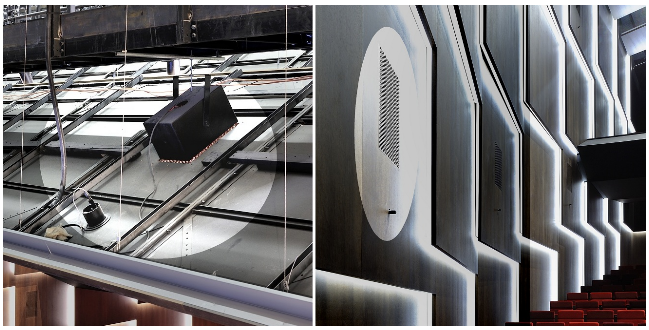

Figure 8 – Integration of the CARMEN cells in the hall's architecture.

3.2 Tuning of the system

Nine different presets have been tuned in the Théâtre des Quinconces :

- **Theater** : a simple voice reinforcement preset to increase speech intelligibility using the forestage microphones. No reverberation enhancement.

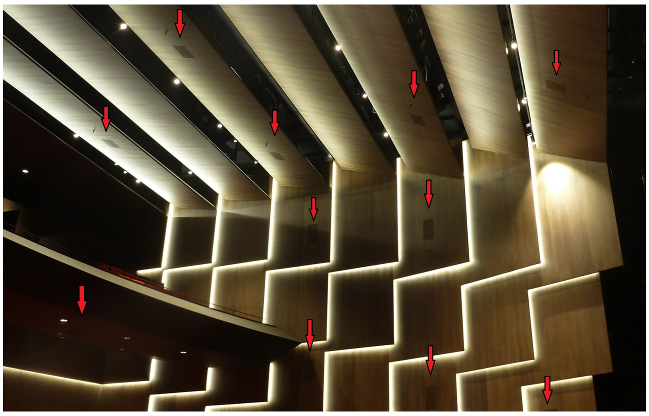

Figure 9 – Carmen cells in the ceiling and the stage right wall.

- **Chamber Music** : Slight increase in reverberation time to reach 1.3 seconds in the mid frequencies with the active stage canopy.
- **Opera** : Moderate increase in the reverberation time to 1.4 seconds in the mid frequencies without the stage canopy. The orchestra pit is deep in this hall. Therefore, the balance between the singer and the orchestra is correct and does not require voice reinforcement with the forestage microphones.
- **Concerto** : Moderate increase in the reverberation time to 1.5 seconds in the mid frequencies with the active stage canopy. Lateral reflections are strengthen provide the effect of a wider source on stage and a better sound envelopment in the audience.
- **Classic symphony** : Moderate increase in the reverberation time to 1.5 seconds in the mid frequencies with the active stage canopy. The cells contributions are homogeneous over the hall.
- **Ballet** : Important increase in the reverberation time to 1.7 seconds in the mid frequencies without the active stage canopy. Tuned for representations with the orchestra in the pit.
- **Romantic symphony** : Important increase in the reverberation time to 2.2 seconds at 500Hz and 1.6 at 1kHz. The contributions of the cells are homogeneous over the hall and the bass frequencies are slightly enhanced. This preset is intended for the symphonic repertoire with the active stage canopy.
- **Oratorio** : Important increase in the reverberation time to 2.1 seconds at 500Hz and 1.7 seconds at 1kHz. This preset is intended for the symphonic repertoire and oratorios with the active stage canopy.
- **Diffusion** : Sound diffusion configuration using only the loudspeakers and the line inputs of the system. No acoustic modification of the hall.

All these presets have been created separately over a two-week tuning campaign. Each preset has been tested in real conditions with performers on stage and a jury of listeners in the audience. The subjective impressions of the listeners were collected and analyzed to apply fine tuning on each preset.

3.3 Acoustic results

In this section, the results of the measurement campaign for some of the presets are presented for four important acoustic indicators : early decay time (EDT), reverberation time (RT20), clarity (C80) and energy increase brought by the system (ΔL). The results are presented in two sets of figures depending on the location of the sound source. For Opera and Ballet, the sound source is placed in the orchestra pit while for Chamber music, Concerto and Romantic symphony it is placed on stage. For each preset, the values presented in Figures 11 to 14 where obtained by averaging the measured results over 9 different positions in the hall (3 in the balcony and 6 in the main stalls).

Figure 10 shows an example of echograms of impulse responses with and without the system at seat J23. One can notice that the system effect on the impulse response occurs only 30 ms after the direct sound contribution. Thus, CARMEN creates important diffuse early reflections and then, generates an homogeneous sound decay as in passive reverberant concert halls.

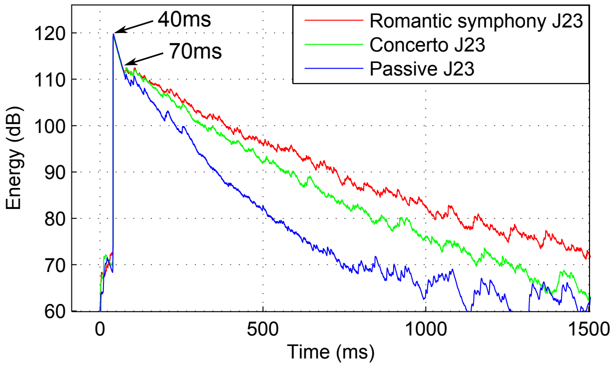

FIGURE 10 – Example of integrated echograms (15ms) of impulse response measured at seat J23 with and without the CARMEN system.

Figures 11 and 12 present early decay times and reverberation times for the passive hall and different CARMEN presets as a function of frequency. It can be seen that the Carmen system allows to double the reverberation time of the hall in the mid frequencies without using any electronic reverberation algorithms. When comparing Figures 11 and 12, it can be noticed that early decay time values are very close to reverberation time values. This indicates that the reverberation effect is homogeneous over time without any double slope effect.

Figure 13 presents clarity values for different CARMEN presets. The system naturally decreases clarity when it increases reverberation time. However clarity values remain in the typical range for such reverberation times [1] and ensure a sufficient intelligibility for opera and sufficient precision for fast musical passages for concertos for example.

Finally, as it could be expected when analyzing the hall geometry, the CARMEN system induces a significant increase in the perceived energy level in the audience. This is due to the diffuse early energy content brought by the system. On the one hand the CARMEN system is more "present" than in most CARMEN installations due to this important energy increase. On the other hand, it provides an impressive sound envelopment to the audience which clearly enhances musical performances and especially choirs.

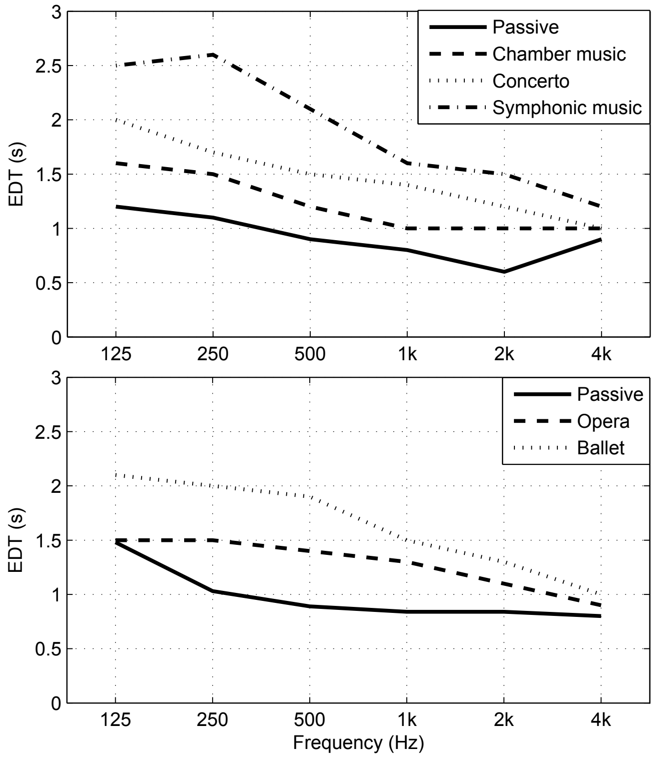

FIGURE 11 – Early decay time measurements for presets Chamber music, Concerto and Symphonic music (top) and Opera and Ballet (bottom).

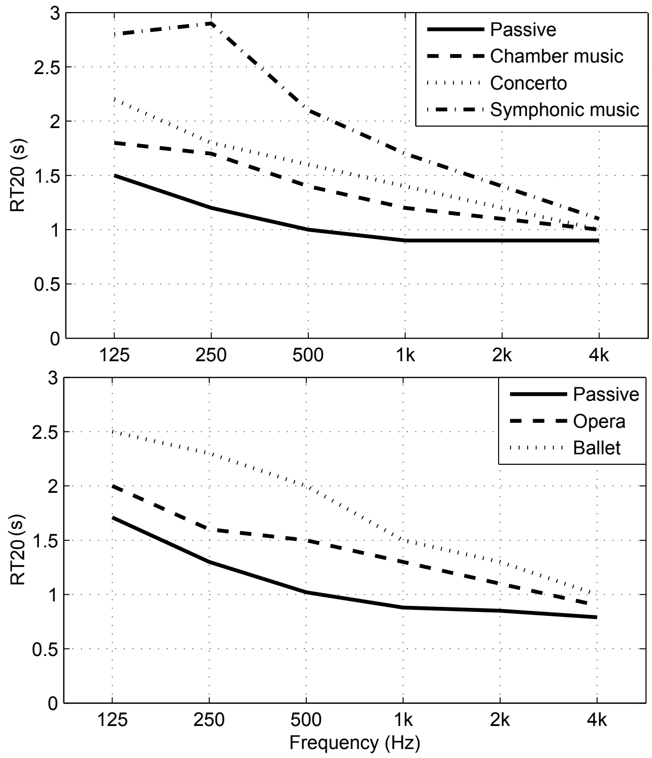

FIGURE 12 – Reverberation time measurements for presets Chamber music, Concerto and Symphonic music (top) and Opera and Ballet (bottom).

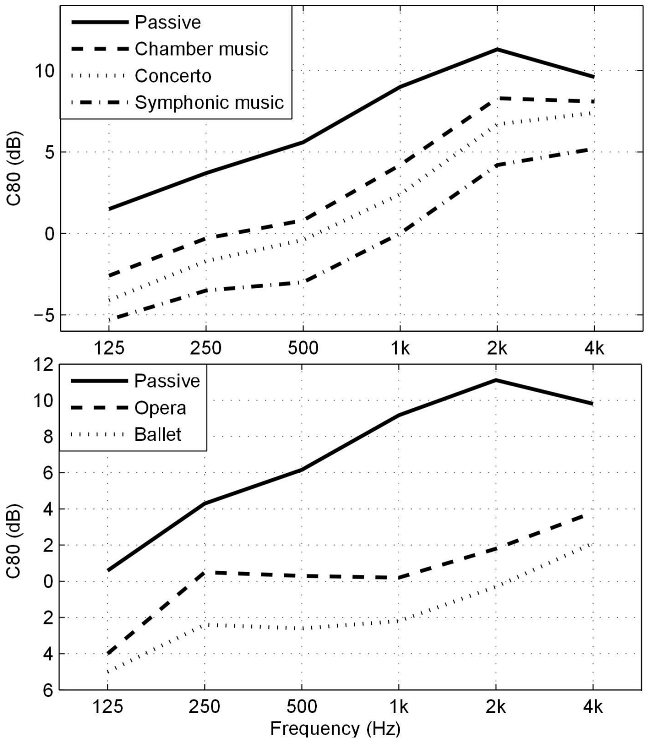

FIGURE 13 – Clarity measurements for presets Chamber music, Concerto and Symphonic music (top) and Opera and Ballet (bottom).

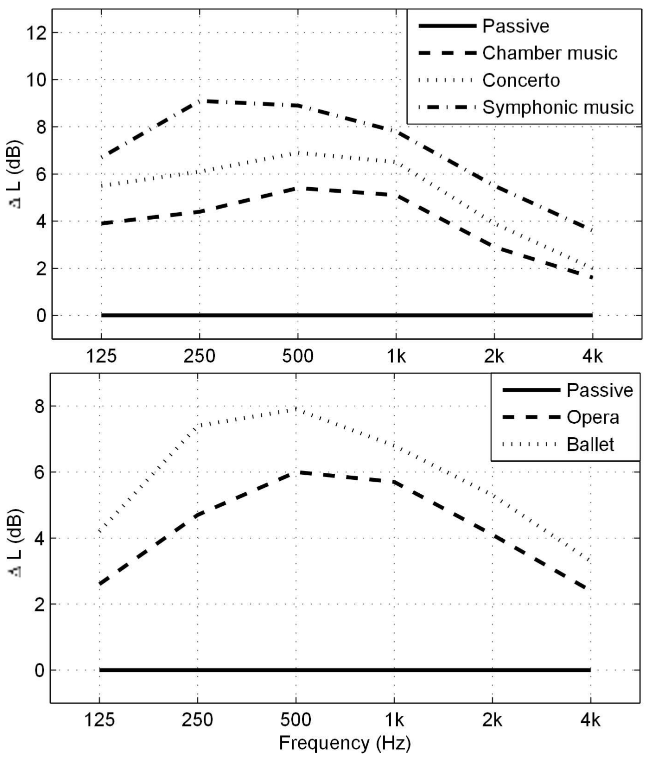

FIGURE 14 – Energy increase for presets Chamber music, Concerto and Symphonic music (top) and Opera and Ballet (bottom).

4 Conclusion

The CARMEN system installation in the Théâtre des Quinconces has been carefully prepared early on in the design process of the theater. It has been successfully installed and it is nearly invisible to the audience and the performers thanks to a discreet integration in the architecture of the theater. CARMEN provides the reverberation enhancement necessary to host various types of representations ranging from theater to symphonic music and choir. The results of the measurement campaign in the theater reflect the quality of the different acoustic presets. CARMEN also corrects minor imperfections in the acoustics of the hall by bringing the missing early reflections and hence, enhancing the subjective impression of sound envelopment in the hall.

Acknowledgments

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