The Refurbishment of the Orchestra Rehearsal Room of the Great Theater of Liceu

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The Refurbishment of the Orchestra Rehearsal Room of the Great Theater of Liceu

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ABSTRACT:
The original Orchestra Rehearsal Room of the Great Theater of the Liceu, inaugurated in October 1999, was sufficient to accommodate a medium sized orchestra but it was not suitable for a large orchestra because of its small volume and because the sound produced by the musicians was too loud. This initial deficiency has been corrected in many aspects by applying a new acoustic concept. We developed a 3D-Grid diffuser which resulted in a very significant increase in Reverberation Time and increased the clarity of communication between players and the subjective size of the room volume.

1. INTRODUCTION

The Orchestral Rehearsal Room in the Liceu Theatre, inaugurated together with the whole new theatre, in October of 1999, was fine for the purposes of a medium-sized orchestra, but was not appropriate for a larger orchestra, as dimensions could not accommodate an orchestra of this size, because the sound produced by musicians was too loud for them. The urban planning conditions of Barcelona had put limitations on the building of workspaces, rehearsal rooms and other spaces in the Theatre. This initial deficiency has been corrected in many ways in the Orchestral Rehearsal Room with a new concept in acoustic planning. With this new acoustic planning technique, we developed a 3D-Grid diffuser [1], obtaining an increase of Reverberation Time within the room and have managed to eliminate the issue of differentiating different instruments, which was off-putting and confusing for musicians. The physical effects obtained in this case have not previously been demonstrated elsewhere.

In July of 2007, we delivered our acoustic plan to the owner of the Liceu. Refurbishment work was carried out in August. The main purpose of the measurements reported here is to compare before and after refurbishment. The concept, planning and management of the building works were carried out by Dilmé - Fabré Architects, Barcelona, with collaboration from acoustic consultant “Arau Acustica”.

2. ROOM GEOMETRY

The volume of the space was marginally increased from 1433 m^3 case 1), (see figure 1a and 1b) to 1748 m^3 case 2), (see figure 2) by removing a lowered ceiling. Acoustic measurements, were made in the space before and after the volume was increased, and then after the labyrinth diffuser was installed case 3) (figures 3 and 4).

CASE 1) Rehearsal room before refurbishment

Volume of room V: 1433.60 m^3
Floor area: 277.9 m^2
Mean height: 5.16 m

The wood ceiling (shown in red) was removed, and the volume increased marginally - see case 2):

CASE 2) Rehearsal room during refurbishment (without diffuser)

New volume of room: 1747.99 m^3
Floor surface: 277.9 m^2
Mean height: 6.29 m

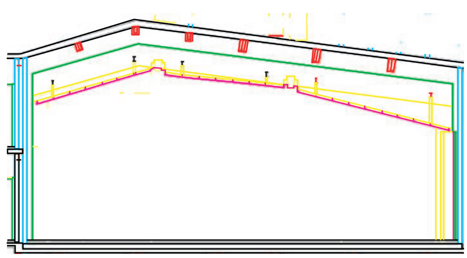

Figure 1a. Long. section of room before refurbishment.

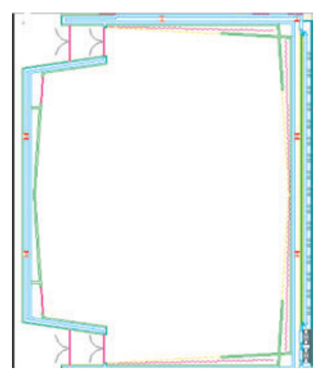

Figure 1b. Ground Section.

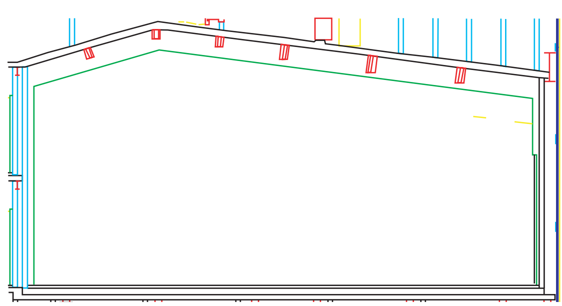

Figure 2. Longitudinal section of room after refurbishment (without diffuser).

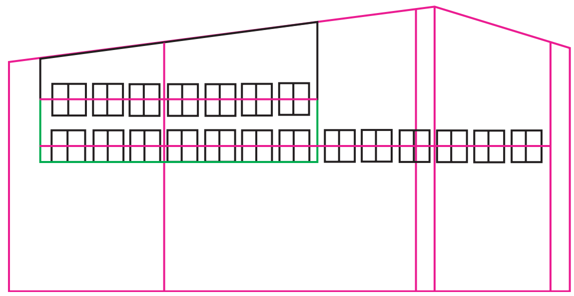

Figure 3. Long axis of room after refurbishment with diffuser.

Figure 4. Transversal section of room with diffuser.

CASE 3) Rehearsal room after refurbishment: (with diffuser)
We added the a volumetric - grid diffuser
Architectural details:
Walls: Plaster board, (the curtaining that can be opened over some of the wall area to provide extra absorption was not used in this study), *ceiling:* Plaster board + diffuser. *Floors*: wood parquet.

3. DESCRIPTION OF THE VOLUME DIFFUSER
The 'volume grid' diffuser is shown in figures 5, 6, 7 and 8. It is a matrix of polycarbonate plates (each having dimensions 800 mm height × 800 mm wide × 10 mm thickness), hanging from a grid of metal squares (200 mm × 15 mm). The entire system is hung from the ceiling. The main design criterion was to eliminate strong reflections between the hall's ceiling and floor and to scatter or diffract the sound in all directions.

The transparent polycarbonate panels are open to the ceiling, so there is little reduction in the real height of the room.

Unlike conventional diffusing surfaces the new structure guides sound through a myriad of small open 'tunnels' formed by parallel panels. Sound diffracts at the edges of the panels and takes a complex and varied path through the structure.

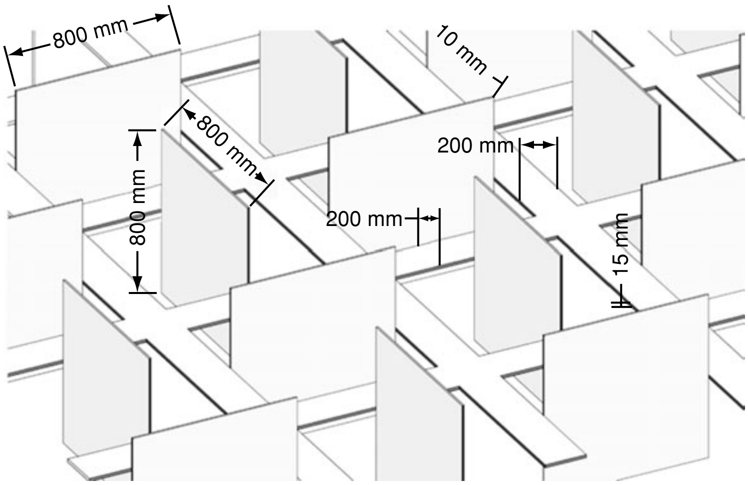

Figure 5. Detail of volumetric-grid diffuser.

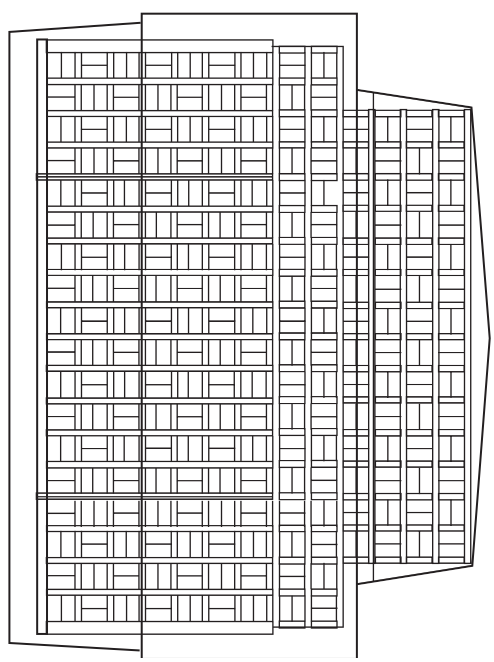

Figure 6. Overhead view of diffuser.

4. MEASUREMENT METHODOLOGY

All measurements were carried out according to ISO 3382-1 [2]. Monophonic impulse responses were measured in the 125–4000 Hz octave bands and the following values processed from them:

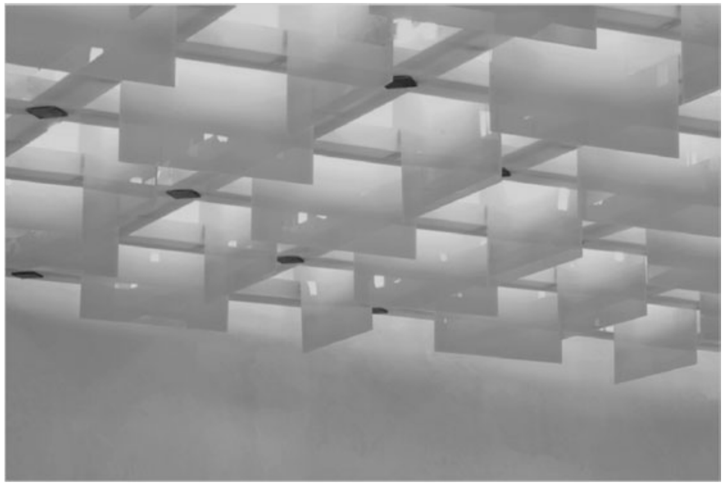

Figure 7. Detail of diffuser.

Figure 8. View after refurbishment.

Reverberation Time T_{30}
Early Decay Time EDT
Stage Support ST1
For all measurements chairs and music stands were present.

1. The reverberation time T_{30} and EDT were measured for each source, S_i, and receiver, R_j, shown in figure 9, and average values found.

   Both early decay time and reverberation time were derived from the slope of the octave band integrated impulse response curves - EDT from the initial 10 dB of the decay and T from the portion of the decay curve between –5 dB and –35 dB, below the initial level in decay curve.

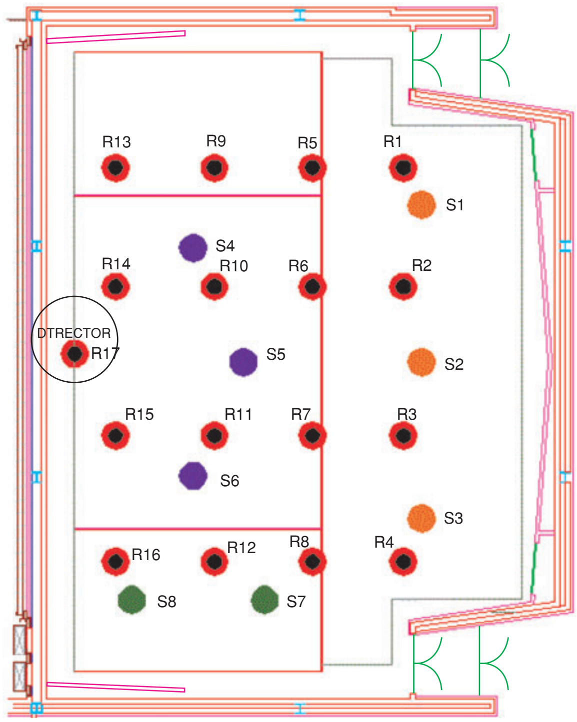

Figure 9. Position of sources S_i (blue, orange and blue) and receivers R_j (orange), source and receiver 1 m S_i-1 m (red with point inside blue).

In general, we show values as averages in octave bands from 125 to 4000 Hz but also we reduce the results to low, mid and high frequency values where, - for the measure X –

$$X_{Low} = (X_{125} + X_{250}) / 2; \;\; Xmid = (X_{500} + X_{1000}) / 2: X_{high} = (X_{2000} + X_{4000}) / 2$$

2. ST1 or ST_{Early} was measured from sound source positions, S_i, (for i = 1 to 4), to a microphone 1 m away with both microphone and source at a height of 1.2 m. In this case the results shown are the average of values obtained in the four octave bands 250 Hz to 2 kHz over at least three positions to give a single result for an effective stage.

5. MEASUREMENTS BEFORE AND AFTER REFURBIDSHMENT

These results are shown in figure 10.

We see that case 3 with the diffuser produces a significantly greater reverberation time than before the refurbishment, where no diffuser existed.

Table 1. Reverberation Time T average value all sources.

Reverberation Time T(s)	125	250	500	1000	2000	4000	RT_{mid}	RT_{low}	RT_{high}
$T_{30\ \mathrm{CASE\ 1)}}$	0.91	1.03	0.89	0.86	0.86	0.85	0.87	0.97	0.85
$T_{30\ \mathrm{CASE\ 2)}}$	1.10	1.25	1.10	1.05	1.07	1.03	1.07	1.17	1.05
$T_{30\ \mathrm{CASE\ 3)}}$	1.53	1.81	1.92	1.78	1.75	1.67	1.85	1.67	1.71
COMPARISON Δ T_{21}									
$\Delta T_{21} = T_{30\ \mathrm{CASE\ 2)}} - T_{30\ \mathrm{CASE\ 1)}}$	0.19	0.22	0.21	0.19	0.21	0.18	0.20	0.2	0.20
COMPARISON ΔT_{32}									
$\Delta T_{32} = T_{30\ \mathrm{CASE\ 3)}} - T_{30\ \mathrm{CASE\ 2)}}$	0.43	0.56	0.82	0.73	0.68	0.64	0.77	0.50	0.66
COMPARISON Δ T_{31}									
$\Delta T_{31} = T_{30\ \mathrm{CASE\ 3)}} - T_{30\ \mathrm{CASE\ 1)}}$	0.62	0.78	1.03	0.92	0.89	0.82	0.97	0.70	0.86

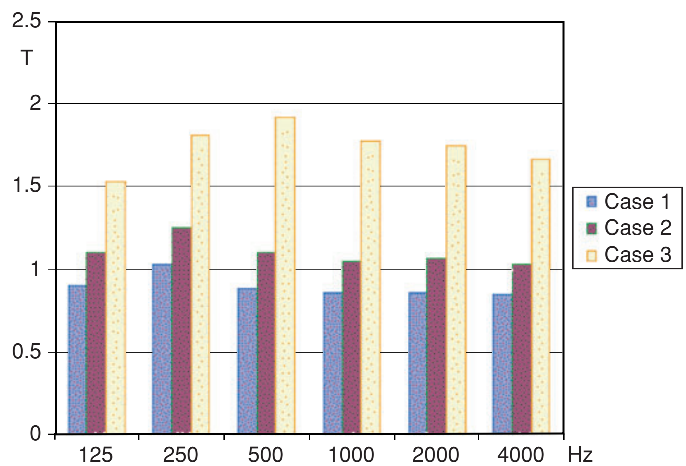

Figure 10. T_{30} Reverberation graphic for cases 1), 2) and 3).

Figures 11 and 12 show typical decay curves obtained for the 500 and 1000 Hz bands illustrating the lengthening of the sound decay without double sloping when the diffuser is added.

Thus the hall reverberation has increased although the mechanism of this increase is not clear.

The sound decay with the diffuser in place is linear, just as if the room volume had increased without any change in the total absorption.

The octave values of Early decay time EDT are also plotted in figure 13.

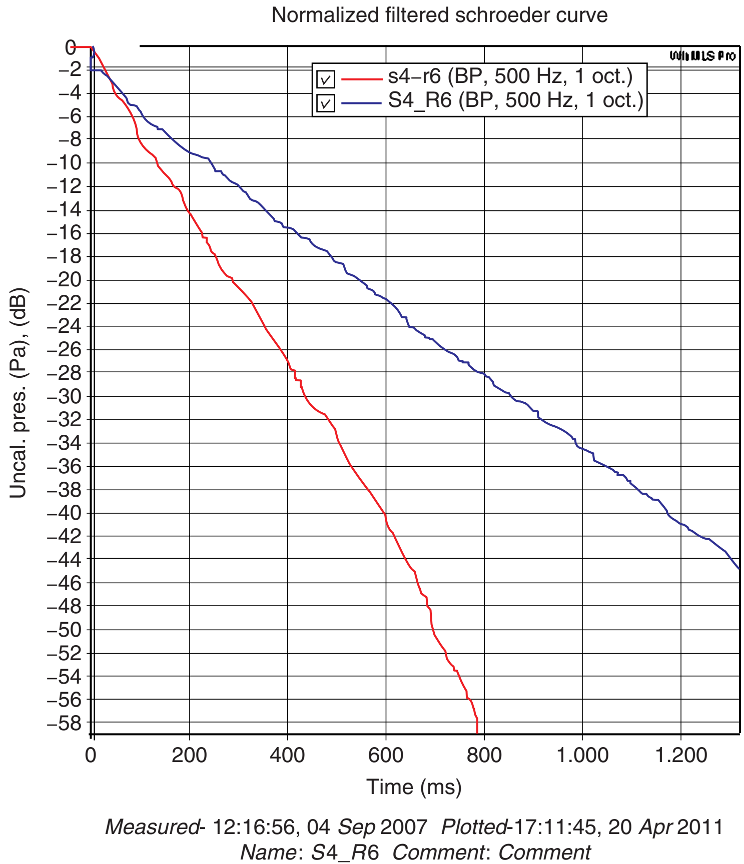

Figure 11. S4-R6, 500 Hz. Blue colour is case 3), Red colour is case 1).

STAGE SUPPORT (ST1)

The early support relates to ensemble, i.e. ease of hearing other members of an orchestra. We observe in case 3) that ST_{early} has improved remarkably.

6. DISCUSSION OF FINDINGS

The labyrinth diffuser was designed and installed in an effort to reduce the strength of reflections from the ceiling. The result was remarkable. Not only were the musicians able to hear each other better, but also the reverberation time increased markedly. The initial goal to reduce the strength of ceiling reflections was amply accomplished.

A dramatic increase in the subjective size of the space came as a surprise. In retrospect it may seem obvious that a labyrinth structure might increase the effective path length a sound wave needs to travel before it strikes an absorbing surface, but the effect is difficult to calculate precisely. The structure combines elements that behave

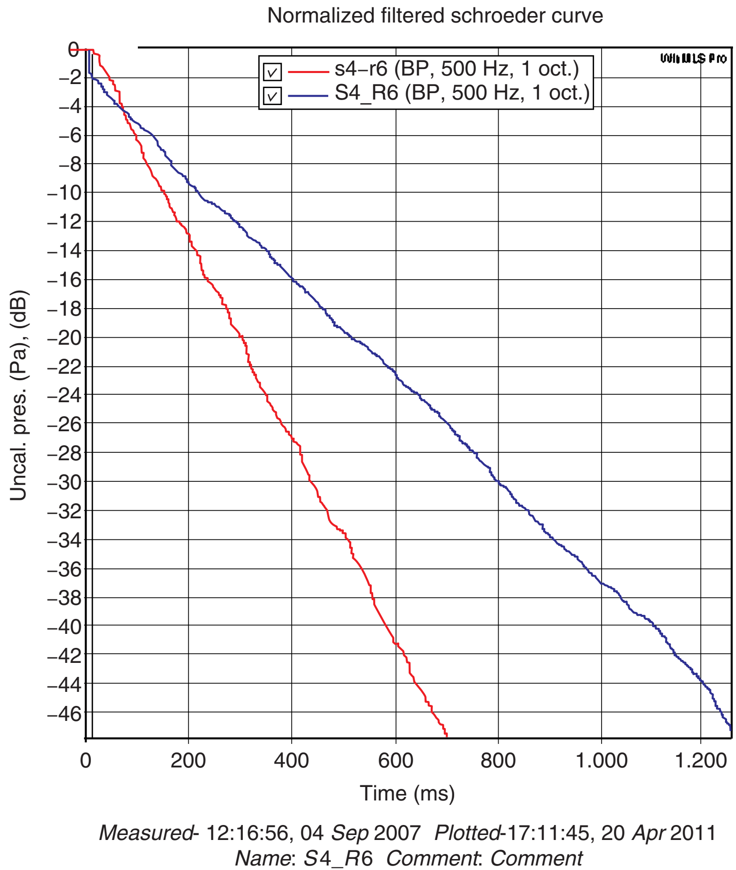

Figure 12. S4-R6, 1000 Hz. Blue colour is case 3), Red colour is case 1).

Table 2. Early Decay Time (EDT) average value all sources.

Early decay time EDT	125	250	500	1000	2000	4000	EDT_{mid}	EDT_{low}	EDT_{high}
$EDT_{CASE\ 1)}$	0.90	0.73	0.78	0.77	0.75	0.72	0.78	0.82	0.74
$EDT_{CASE\ 2)}$	1.10	0.95	0.90	0.95	0.90	0.85	0.92	1.02	0.87
$EDT_{CASE\ 3)}$	1.03	1.44	1.68	1.65	1.60	1.41	1.67	1.24	1.51
COMPARISON Δ EDT_{21}									
$\Delta EDT_{21} = EDT_{CASE\ 2)} - EDT_{CASE\ 1)}$	0.20	0.22	0.12	0.18	0.15	0.13	0.15	0.20	0.13
COMPARISON Δ EDT_{32}									
$\Delta EDT_{32} = EDT_{CASE\ 3)} - EDT_{CASE\ 2)}$	–0.07	0.49	0.78	0.70	0.70	0.56	0.75	0.22	0.64
COMPARISON Δ EDT_{31}									
$\Delta EDT_{31} = EDT_{CASE\ 3)} - EDT_{CASE\ 1)}$	0.13	0.71	0.9	0.88	0.85	0.69	0.89	0.42	0.77

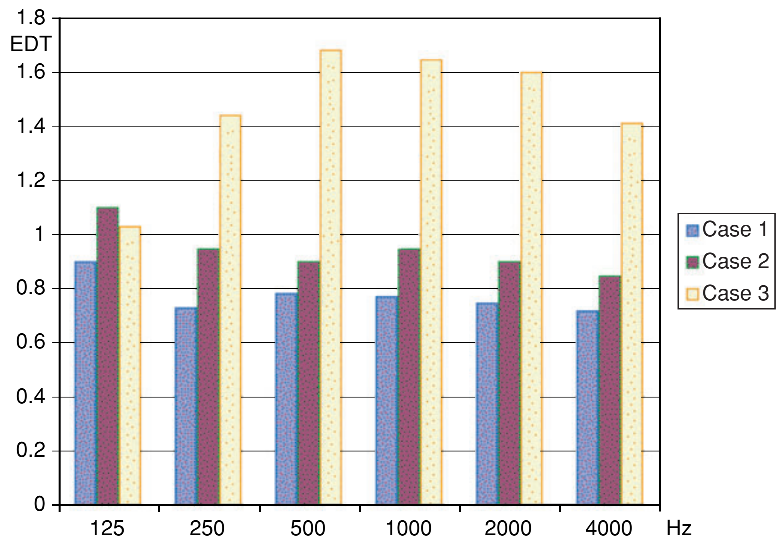

Figure 13. Early decay time EDT graphic for cases 1), 2) and 3).

Table 3. Stage support $ST_{Early.}$

Stage Support ST1 (dB)	Average
$ST1_{\text{CASE 1)}}$	2.52
$ST1_{\text{CASE 2)}}$	0.5
$ST1_{\text{CASE 3)}}$	–7.26

like waveguides with openings and edges where considerable diffraction and diffusion takes place. The essential randomness of this process appears to produce a lengthening of sound paths, resulting in an increase in reverberation time without an increase in the physical volume of the room.

For the reverberation time at *mid frequencies* the relative increment of RT between case 3 and 2 is: $\varepsilon = \Delta\, RT/RT_{case2} = 71.9\%$ which is solely the effect of the 3D-Grid diffuser.

At *low frequencies* $\varepsilon = 35.4\%$ which is less of an increase in reverberation time, perhaps because of panel absorption by the diffuser plates at low frequencies.

At *high frequencies* $\varepsilon = 62.8\%$.

The results for EDT show that the behaviour of EDT is similar to that for RT.

For the measure of stage support, ST1, the case 3 values are much better than cases 1 and 2, and this matched the perception of players. Judged by Gade's criterion, [3], the value achieved is optimum.

We believe we have produced a phenomenon that appears to be quite novel because 3D-grid diffusers transparent to sound have not been used and studied before.

The increases in RT and EDT seem to contradiction conventional understanding where reverberation time is simply proportional to volume and inversely proportional to total absorption [4], [5], [6], [7]. The only case of an effect similar to that experienced here in the Liceu Rehearsal Room is in the Goteborg Konserthus as noted by Beranek [8].

We may hypothesise that the Reverberation Time of hall has changed because the mean free path has increased due to the volume diffuser.

We would expect the increase in room reverberation to have the subjective effect of an increase in room volume for listeners.

For mid frequencies: Δ **T_{32} = 0.77,** and a simple calculation using the Sabine formula shows an effective $\Delta V = 1254.3\ m^3$ which compared with the actual hall volume is an increase of 71.7%.

7. SUBJECTIVE PERCEPTION OF THE EFFECT OF THE DIFFUSER

When Orchestra Director Florian Schreiber visited the rehearsal room he enthusiastically described the experience: "It was breathtaking, it was a small room without a stage and I know how music should sound in such a room normally. But the space acoustically had the sound of a room three to four times larger." [translated from 9]

8. CONCLUSIONS

This paper has presented the design of a novel labyrinth structure that is capable of improving listening conditions in small spaces. The structure combines the properties of multiple reflections and edge diffraction in such a way as to increase the effective path length of randomly diffused sound. The result is greater clarity and increased reverberance at the same time.

A revised theory is needed to explain the physical phenomena found. This theory would be used for optimising the design e.g. the size and thickness the diffusers should be, the distance they should be from the floor and the ceiling, and the area they should have in relation to the ceiling area.

Comments by both performers and audience in the two spaces where the structure has been installed have been exceedingly enthusiastic. They typically report that the sound has become both more open and more reverberant – properties of larger spaces that have been previously impossible to achieve in smaller halls.

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