The Refurbishment of Tonhalle St. Gallen

by

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The Refurbishment of Tonhalle St. Gallen

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ABSTRACT
In this paper we describe one case of acoustic of refurbishment design. It is the refurbishment of Concert Hall of "Tonhalle St.Gallen. The centennial St. Gallen Concert Hall in Switzerland was a hall with many issues relating to the stage. High levels of sound, focusing, flutter echoes, and so on; the problem was never solved. The Director of the Orchestra and his musicians were generally very unhappy with this hall. In the last paper we analyse the St. Gallen Concert hall before refurbishment. In the Tonhalle St. Gallen the diffuser occupies only of stage area, but RT, EDT and G all are increased in audience zone, but in stage the G is decreased 3dB. The response by musicians, audience, and critics has been overwhelmingly favorable. Further research is needed to elucidate the mechanisms by which the labyrinth achieves these improvements, but the results in these venues suggest that this type of structure has an important role to play in acoustic design, particularly in smaller venues.

INTRODUCTION
The centennial St. Gallen Concert Hall in Switzerland was a hall with many issues relating to the stage. High levels of sound, focusing, flutter echoes, and so on; the problem was never solved. The Director of the Orchestra and his musicians were generally very unhappy with this hall.

In the last paper, [1], we analysed the St. Gallen Concert hall before refurbishment. The ST1 or ST_{early}, [2], [3], measured stage values were relatively good, but musicians had a lot of trouble focusing and the flutter echoes were very strong. We demonstrated in paper [4] that the criterion proposed by Gade does not, by itself, assure the prediction of good stage acoustics.

When we carried out subsequent analysis after the refurbishment of the stage then the acoustics on stage and in the hall was optimal, but in this case Gade's criterion measured was practically equal to old stage, because predictions were practically identical to those made previously. We have determined other effects that have contributed in the improvement of the stage and hall as a whole. These acoustic effects are new findings within the field of acoustics, discovered in compiling this document.

This hall was inaugurated in 1909; 100 years later an international tender was issued to refurbish this hall. In 1992-1993 there was a restoration project that lengthened the room from behind adding a new volume, which is the current volume has the room. It was an inclusion of more volume in the rear part of the hall and new seating were also part of the renovation.

During the refurbishment in 2010, the most significant change has been the new design of the new diffuser, though the stage boards and stage walls were also refurbished, the latter being reformed with plywood panels on an incline to avoid flutter echoes.

In this study we introduce and analyse the acoustic measurements gleaned on 29 October 2010 at the "Tonhalle St. Gallen" after the refurbishment and to perform a comparison we used the measurements taken in 2009 before work began. The main purpose of these measurements is to analyse the acoustic parameters of this characteristic hall, before and after refurbishment. In all measurements the hall was empty, or with unoccupied seats. The planning and the execution control of the building works were carried out by Bosshard Vaquer Architects, Zurich, with acoustic consultancy provided by Arau Acustica, Barcelona.

The most significant change during this project was the addition of the labyrinth diffuser, although the stage floor and stage walls were also refurbished, the latter being fitted with plywood panels on an incline to avoid flutter echoes.

Is known, by application user, that in computer simulations the reverberation time T is always reduced when scattering is introduced, and this is what the computer models of the project in this paper predicted. But the measured values in our completed project were quite different than the computer simulations we carried out.

2. GEOMETRY OF THE HALL & AUDIENCE SIZE

In this section, the geometrical and architectural characteristics of the hall are described, as well as the size of the audience.

Geometry	
Air volume	6100 m^3
Number audience	840 seat
Audience surface	$S_A = 588\ m^2$
Volume by seat	$V/N=7.32\ m^3/seat$
Volume by audiencie area	$V/S_A = 10.459$ m

Architectural details:

Walls: wood panelling beneath the balcony and on soffit under balcony: walls and decorations are of plaster above balcony; balcony fronts are of plaster. *Ceiling:* Plaster. *Floors:* wood parquet. *Stage floor:* oak wood over air space. *Stage height:* 95 cm above floor at first row seats. *Seats:* upholstered wood

This hall is used as a concert hall but its size is more characteristic of a chamber hall.

This geometry has two differing versions:

- Geometrical characteristics of the hall in 2009 before the refurbishment (without stage diffuser).

- Geometrical characteristics of the hall in 2010 after the refurbishment (with 3D-grid stage diffuser).

a) Geometrical characteristics before the refurbishment (without stage diffuser).
Below are images of the ground plan, and the longitudinal section before the refurbishment.

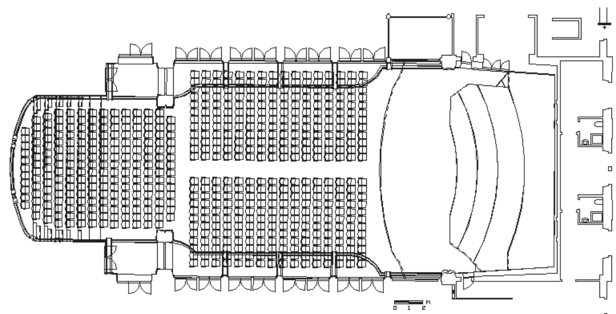

Figure 1. Ground plan of the Hall (identical before 2009 and after refurbishment 2010)

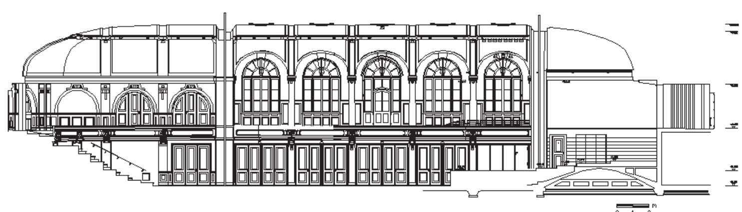

Figure 2. Section of the Hall before refurbishment

b) Geometrical characteristics of the hall after the refurbishment (with stage diffuser).
Below are images of the ground plan and longitudinal section after the refurbishment.

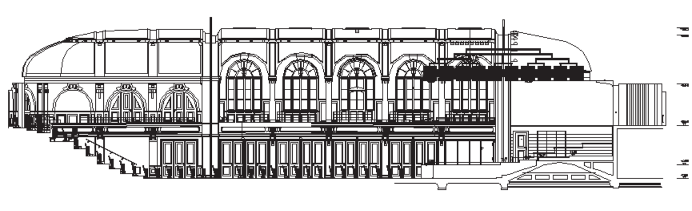

Figure 3. Section of the Hall after refurbishment 2010.

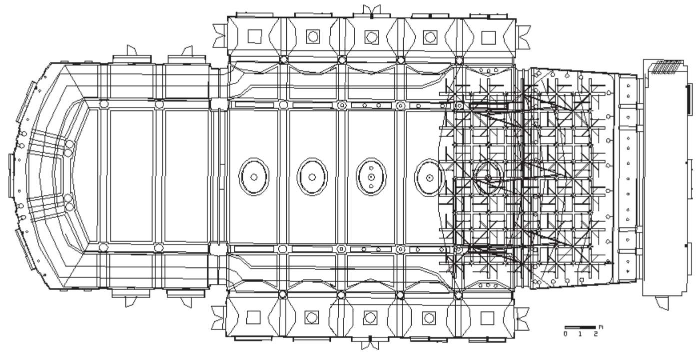

Figure 4. Overhead view plan of the Hall after refurbishment 2010

NOTE: The hall has never been undergone volume nor seat changes.

Figure 5. Photo of diffuser after the refurbishment

Figure 6. Photo of hall after the refurbishment

The 3D-grid diffuser is a matrix of gold-laminated plywood plates, supported by a pattern of iron squares. Each diffuser plate measures 1000 mm height x 890 mm wide. The entire system is hung by one iron structure from 3 points in ceiling, like a great lamp. The design criterion defined is a reflector/ diffuser in grid form that covers all possible directions to remove the sound focusing produced by the curvature between the ceiling and walls in the hall. This system had never been used before in a concert hall. The people of City St. Gallen consider it to be a brilliant and very beautiful solution. Part of the diffracted sound is scattered more or less in all directions.

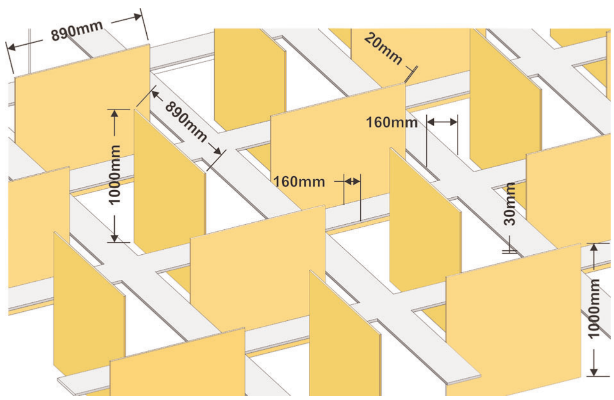

Figure 7. Detail of 3D-grid diffuser

The structure discussed in this paper consist of a three-dimensional labyrinth formed from vertically oriented parallel panels approximately one metre square, held in place by a steel grid and suspended from the ceiling. It is essentially a volumetric diffuser. The initial goal of the structure was to reduce the strength of ceiling reflections by sound diffraction, and this goal was amply accomplished. The dramatic increase in the subjective size of the spaces 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 - here demonstrated as real - is difficult to calculate precisely. The structure described in this paper combines elements that behave 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.

3. MEASUREMENT METHODOLOGY AND SYSTEM

The experimental procedure was carried out according to the ISO 3382-1(2009), [5], where monophonic impulse responses were measured using sweep signals in the 125-4000 Hz octave band range. For each source - microphone couple impulse response measurements were carried out from which the following parameters were obtained:

Parameter
Reverberation Time, T_{30}
Early Decay Time, EDT
Strength G
Support objective of Stage ST1.

Calibration G Level reference: For a true omni-directional sound source a reference measurement in a single direction would be sufficient. Most practical sources are 12-faced speakers that start to show lobes in the polar pattern around 1kHz. The ISO 3382 standard therefore specifies that a proper reference level measurement shall be made in a free-field, and data from at least 29 directions shall be energy averaged. Win MLS can handle such a reference measurement, as well as any other less accurate reference that might be chosen.

Each source F_i, i =1 to 4, located on different places on the stage with a view to searching all focusing types, shown in the figures below. The measurements were carried out for each individual source for all receiver points 1 to 21 placed in the audience area and were subsequently averaged.

To analyze the effects of the ST1stage support and T_{30} and EDT, the measurements were performed at 21 source points on the stage, 4 points on the stage Ei and the remainder of the sound sources Fi which were not used. When determining the ST1, the microphone should be situated a distance of 1m and at 1.2m in height (see figure 25). There were chairs and music stands located on the stage.

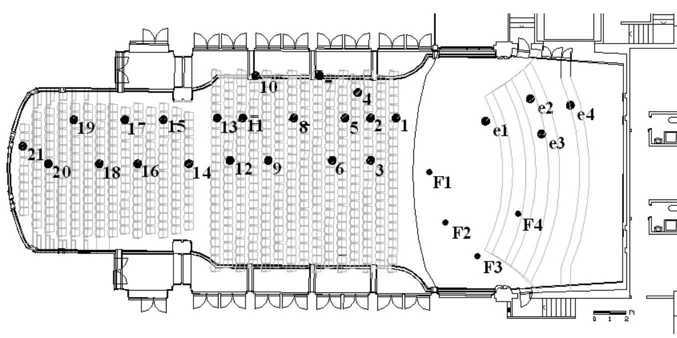

Figure 8. 21 receiver points in hall+ 4 receivers points on stage and 4 sound sources on stage

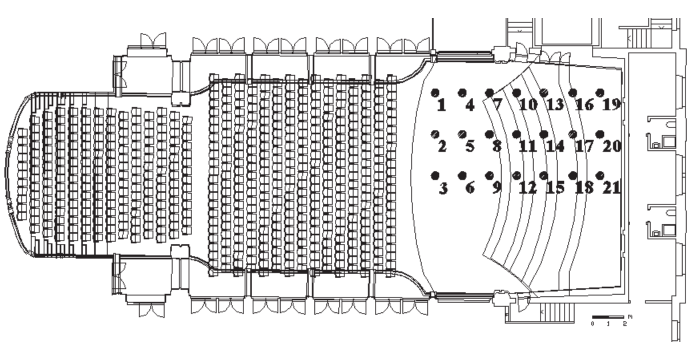

Figure 9. 21 sources points on stage for ST1.

NOTE: Nomenclature and general terminology

In this publication, we will provide a glossary of terminology used frequently throughout this paper: In general, we show values as averages in octave bands from 125 to 4000 Hz.

In simple terms, if X is an acoustic parameter of any kind, on occasion we will express this more simply using the following, more widely known formula:

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

Equipment used:
WinMLS 2004 Morset Sound Development:
Microphone Bruel & Kjaer 4942
Preamplifier of microphone Bruel & Kjaer 2690
Sound Card digigram vxpocket v2
Omni power sound source BRÜEL & KJAER model 4296
Power Amplifier Brüel & Kjaer model 2716, 300 W.

4. COMPARISON OF AVERAGE VALUES BETWEEN 2009 AND 2010.

Measurements taken time ago were done using symmetrical and asymmetrical sources distributed on stage with a view to discovering the origin of all possible defects of this hall.

We know that the most basic academic form of measuring symmetrical halls, as in this case, is to put a centralized source on the stage, depending on the longitudinal axis of the hall; in this case this is source F1. We will provide results using these standard measurements. Regarding the choice of measurement positions, it is fair to measure only on one side of the long axis when the hall is symmetrical as in this case; but this actually requires that the source positions are chosen symmetrically around the long axis.

Consequently, first we present the average values of each source and each parameter studied in table format, with additional figures provided on occasion:

A) Hall Measurements.

Table 1. Reverberation Time T mean values all sources in audience

Reverberation Time (T) Mean Values All Sources in Audience									
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**	**T_{30mid}**	**$T_{30\,low}$**	**$T_{30\,high}$**
T_{30}(s) 2009	2.47	2.27	1.94	1.9	1.83	1.57	1.92	2.37	1.7
T_{30}(s) 2010	2.42	2.3	2.1	2.06	1.96	1.64	2.08	2.36	1.8
Comparison ΔT_{30}									
$\Delta T_{30}=T_{30}(s)_{2010}.T_{30}(s)_{2009}$	**-0.05**	**0.03**	**0.16**	**0.16**	**0.13**	**0.07**	**0.16**	**-0.01**	**0.10**

The average values of T_{30} for all sources in 2009 and 2010 are showed in next figures: The red line we have the average value.

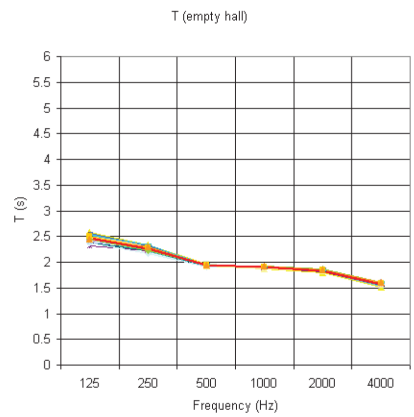

Figure 10. Average values of T_{30} for all sources in 2009 in audience

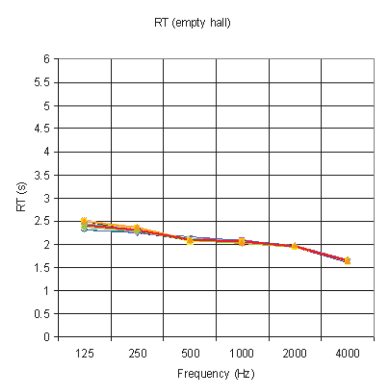

Figure 11. Average values of T30 for all sources in 2010 in audience

Here we show the reverberation time T with the distance: F1 to receiver points

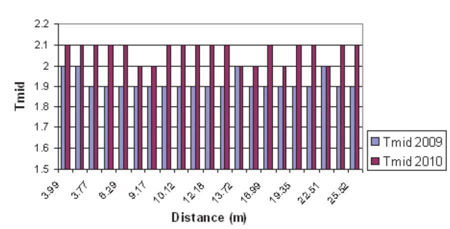

Figure 12. Average values of T_{30} in hall with distance to F1 source in 2009 and 2010 in audience

On observing Figure 12, which represents the Tmid in relation to the distance from source F1, we can see that Tmid figures in 2010 are almost always greater than those from 2009.

Following here we show the sound decay curves Schroeder method for two any cases on two frequencies 500 and 1000 Hz.

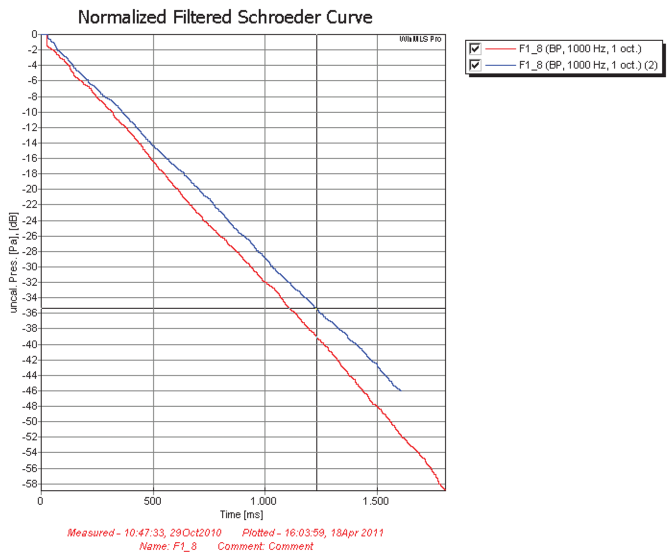

Figure 13. F1-3, 500 Hz. Red colour in 2010
Blue colour in 2009

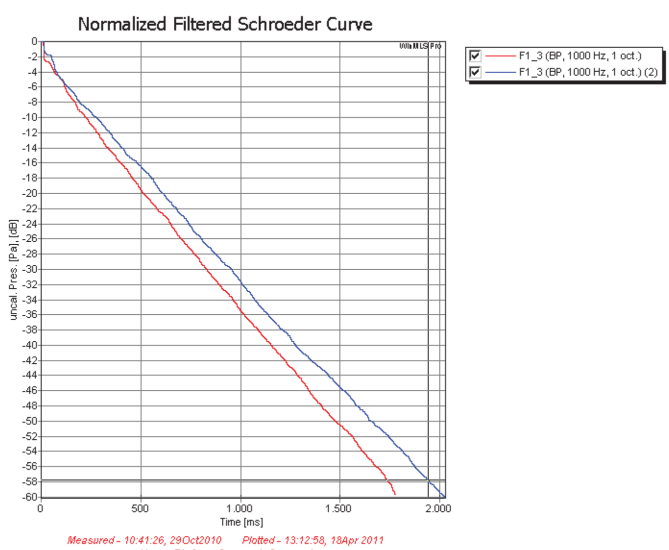

Figure 14. F1-3, 1000 Hz. Blue colour in 2009
Red colour in 2010

Table 2. Early decay time EDT mean values all sources in audience

Early Decay Time (EDT) Mean ValueS All Sources in Audience									
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**	**EDT_{mid}**	**EDT_{low}**	**EDT_{high}**
EDT(s) 2009	2.32	2.08	1.91	1.84	1.79	1.41	1.88	2.20	1.60
EDT(s) 2010	2.19	2.26	2.12	2.02	1.91	1.45	2.07	2.23	1.68
COMPARISON ΔEDT s									
Δ EDT= $EDT(s)_{2010}$ - $EDT(s)_{2009}$	**-0.13**	**0.18**	**0.21**	**0.18**	**0.12**	**0.04**	**0.19**	**0.03**	**0.08**

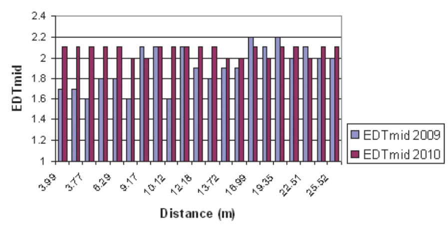

Figure 15. Average values of EDT in hall with distance to F1 source in 2009 and 2010 in audience

In this case, we can see that the EDT in relation to source F1 with diffuser in 2010 is normally greater than that of 2009 without a diffuser up to a distance of 14m from the stalls, and from this point until the end of the hall the EDT variation values fluctuate between 2009 and 2010.

Table 3. Strenght G average values all sources in audience

Total Sound Level or Strength G Average Values All Sources in Audience							
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**	**G_{mid}**
Strength G_{2009} (dB)	10.8	8.2	7.8	8.2	9.3	7.3	8
Strength G_{2010} (dB)	9.5	9.4	9.2	9.1	10	8.9	9.15
Comparison							
$\Delta G = G_{2010} - G_{2009}$ (dB)	**-1.3**	**1.2**	**1.4**	**0.9**	**0.7**	**1.6**	**1.15**

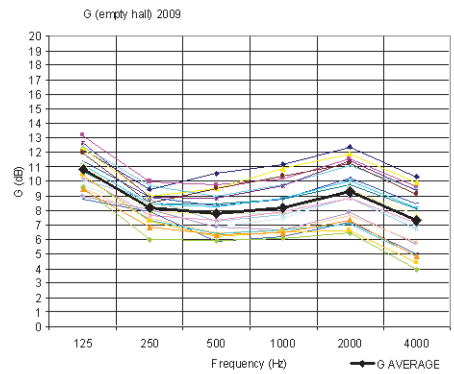

Figure 16. left: Average values of G in hall 2009 in audience
The average value black colour

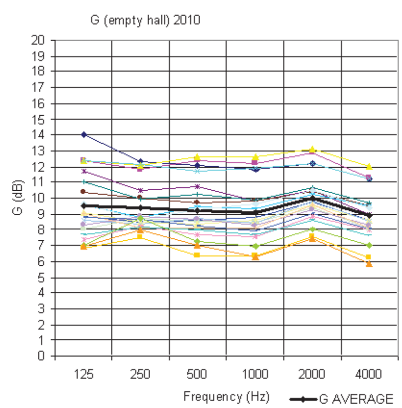

Figure 17. right: Average values of G in hall 2010 in audience.
The average value black colour

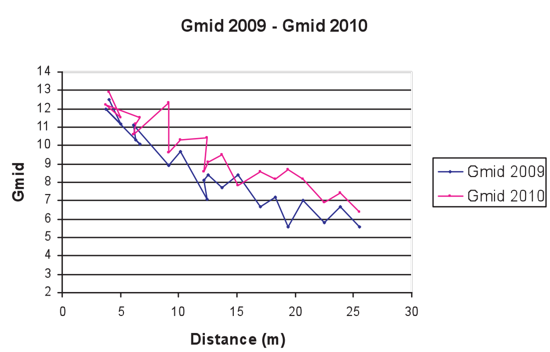

Figure 18. G_{mid} with distance F1 and receiver points in audience
Red colour is G_{mid} for 2010 and blue is G_{mid} 2009

Below, we will demonstrate each year's G_{mid} variations, before and after refurbishment, in comparison with M. Barron's revised G_{mid} [6].

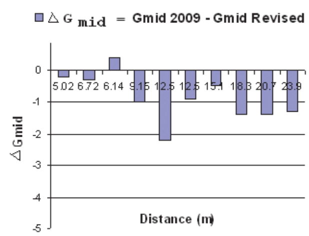

Figure 19. ΔG_{mid} = Gmid $_{2009}$ - Gmid$_{revised}$ with distance F1 and receiver points

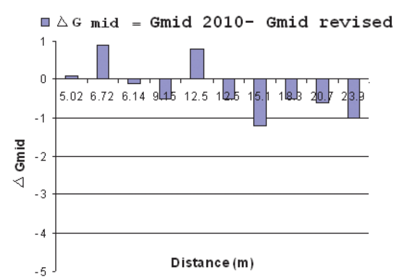

Figure 20. ΔG_{mid} = Gmid $_{2010}$ - Gmid$_{revised}$ with distance F1 and receiver points

Examining the final two figures 19 and 20, we can see that the precision of Barron's theoretical calculations are very good.

Table 4. Stage support ST1

Stage Support (ST1)	
Frequency	**Average**
Stage Support $ST1_{2009}$ (dB)	-10.14
Stage Support $ST1_{2010}$ (dB)	-9.20
COMPARISON ΔST1	
$\Delta ST1 = ST1_{2010} - ST1_{2009}$ (dB)	**0.94**

Table 5. Reverberation Time T mean values all sources on stage

Reverberation Time (T) Mean Values All Sources									
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**	**T_{30mid}**	**$T_{30\,low}$**	**$T_{30\,high}$**
Reverberation Time $T_{30\,2009}$ (s)	2.20	2.12	1.87	1.79	1.72	1.39	1.83	2.16	1.56
Reverberation Time $T_{30\,2010}$ (s)	2.38	2.21	2.06	1.98	1.86	1.48	2.02	2.30	1.67
Comparison									
$\Delta T_{30} = T_{30\,2010} - T_{30\,2009}$ (s)	**0.18**	**0.09**	**0.19**	**0.19**	**0.14**	**0.09**	**0.19**	**0.14**	**0.11**

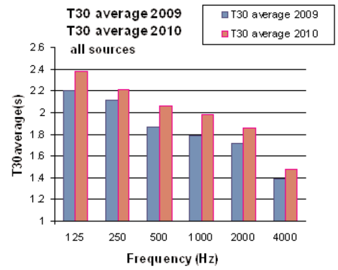

Figure 21. T_{30} averaged all sources
Red colour is T_{30} for 2010 and blue is T_{30} for 2009

Examining data from T_{30} obtained prior to and after refurbishment, (average values from all sources and mean value of source F_1), we can see that after 2010, where a diffuser is present hanging in the stage area, the T_{30} is higher than in 2009 when no diffuser was present.

Below, we will demonstrate the slopes of decay produced in a small sample of a point between Ei, i=1 to 4 on the stage and also a sample of the 21 points on the stage

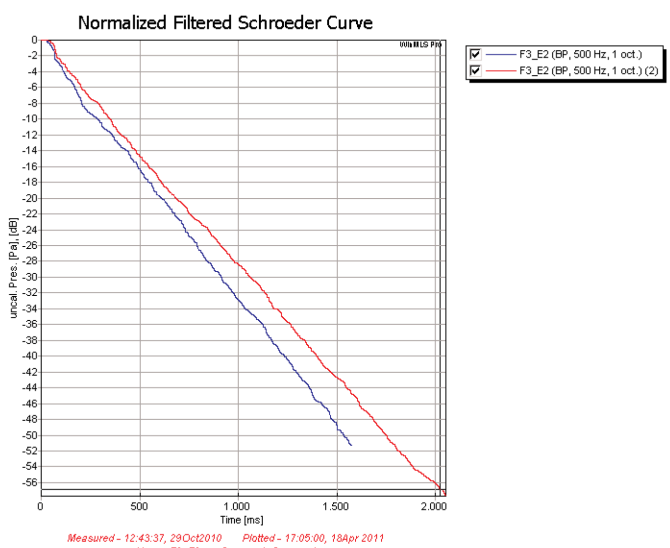

Figure 22. F3-E2, 500 Hz. Red colour in 2010
Blue colour in 2009

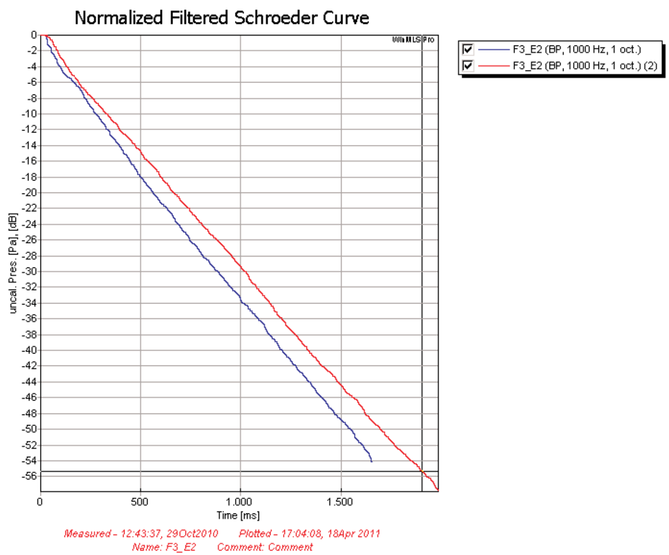

Figure 23. F3-E2 1000 Hz. Blue colour in 2010
Blue colour in 2009

Table 6. Early decay time EDT mean values all sources on stage

Early Decay Time (EDT) Mean Values All Sources									
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**	**EDT_{mid}**	**EDT_{low}**	**EDT_{high}**
EDT_{2009} (s)	2.11	1.83	1.55	1.57	1.5	1.17	1.56	1.97	1.34
EDT_{2010} (s)	1.89	1.97	1.95	1.86	1.77	1.36	1.91	1.93	1.57
Comparison: ΔEDT (s)									
$\Delta EDT = EDT_{2010} - EDT_{2009}$	**-0.22**	**0.14**	**0.40**	**0.29**	**0.27**	**0.19**	**0.35**	**-0.04**	**0.23**

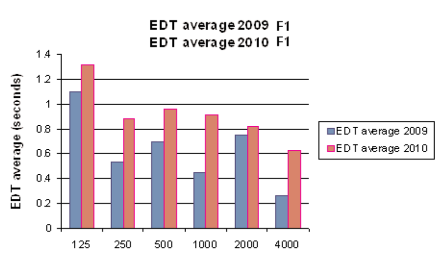

Figure 24. EDT average value F1 source
Red colour is EDT for 2010 and blue is EDT for 2009

Examining all the EDT data obtained before and after the refurbishment, using the average value of each source and the mean of source F1, we can see that after the installation of a diffuser hanging in the stage area, the EDT is higher than in 2009 when no diffuser was present.

Table 7. Strength G dB mean values all sources on stage

Total Sound Level or Strength G dB Mean Values All Sources							
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**	**G_{mid}**
Strength G_{2009} (dB)	11	8.4	8	8.6	9.6	7.6	8.9
Strength G_{2010} (dB)	5.7	7	6	5.6	6.3	4.6	5.8
Comparison:							
$\Delta G = G_{2010} - G_{2009}$ (dB)	**-5.3**	**-1.4**	**-2**	**-3.6**	**-3.3**	**-3**	**-3.1**

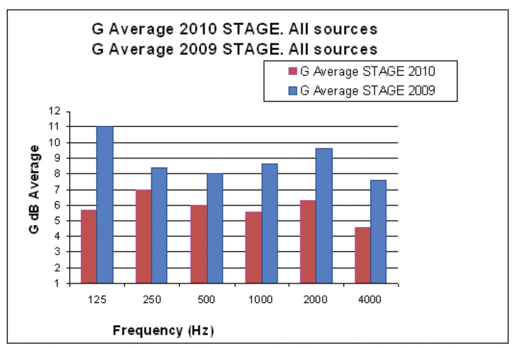

Figure 25. G average value all sources
Red colour is G for 2010 and bue is G for 2009

With the design of the volumetric diffuser, we managed to increase the reverberation time and EDT in the hall, particularly on the stage, simply by carrying out an acoustic treatment in the stage area.

Interestingly, the diffuser produced sound reduction in the stage area of the G parameter in 3dB, and in the audience area the diffusing cloud acted as a reflective barrier, increasing G sound levels in this area by 1dB.

Both musicians and audience now say the hall has surprisingly good acoustics. The sensation is one of a larger volume in the room, though this is not the case.

5. CONCLUSIONS AND FINDINGS

The primary unexpected advantage of the labyrinth diffuser is an apparent volume increase, of two spaces: stage and hall, because to an increase of the reverberation time in all octave frequency bands. At low frequencies the RT is decreased slightly by membrane absorption of wood plates, which compensates for so increase produced by the diffuser.

1. Conclusions:

a) Measured in Hall

Remark 1, T=T_{30}: We have seen that in general the reverberation time in the hall is now greater than before. In the middle frequencies the relative increment is ε = 8.3 %. In the low frequencies is ε = -2.02 %, due perhaps that the absorption of wood panels have eliminated the increment of T produced by the diffuser, after the high frequencies, the T had grown to ε = 5.88 %. The diffuser placed on stage produced an important improvement in the hall.

Remark 2, EDT: We have seen that in general the early decay time in the hall is now quite a bit greater than before. In the middle frequencies is ε = 13.47 % at the highest point. In the low frequencies is practically the same as before, due perhaps to absorption of diffuser wood panels removing the increment of T. High frequencies T have also grown to ε = 5 %.

Remark 3, G: We have seen that the intensity of sound above audience has incremented mainly in middle frequency and frequencies of approximately 1 dB. We believe this increment of G is produced because the many sound rays, or plane waves are hitting tangentially with virtual lower planes defined by the edges of all vertical plates of our grid diffuser. Here it seems the air impedance is high, creating a soft plane reflection. The audience obtains a mirror reflection due to this air plane described. Additionally, other sound rays obtained are the result of ceiling collisions.

b) Measured on stage:

Remark 1, ST1: The Gade criterion measured for the stage is practically the same before and after refurbishment. However the reality has been particularly different, as St. Gallen's hall had considerably bad acoustics and now after refurbishment the hall is optimal, as it should be. Therefore, in our opinion this criterion has failed. Our experience of this case has shown that this criterion is not ideal, because the subjective reality for musicians is different to that predicted by Gade in his measurements. It is unfortunate that the ST1 support has failed because it is the only technical criterion for stage parameters, which has acquired some recognition thus far.

Remark 2, T_{30}: We have seen that in general, the reverberation time in the hall is now greater that before. In the middle frequencies, ε = 9.8 % greatest, in the low frequencies, 6.48 %, although the absorbent wood panels in low frequencies possibly played their part in reducing this, and the high frequencies have grown to ε = 7.05 % The diffuser placed on stage produces an important improvement on the stage and in the hall as a whole.

Remark 3, EDT: We have seen that in general the early decay time on the stage is now greater than before. In the middle frequencies, ε = 22.4 % greatest, in the low frequencies it is the same and the high frequencies have grown to ε = 17.16. We believe that this parameter has contributed greatly in the subjectivity of sound improvement among musicians.

Remark 4, G: We have seen that the intensity of sound above the musicians has decreased by almost half, to approximately 3 dB. This is a particularly high quantity of energy removed, meaning that now the sound is homogeneous and transparent.

2. Findings

1. Strength:

The value of G, and thus the strength of the orchestra in the audience area, significantly increased when the labyrinth diffuser was added. A possible explanation for this increase can be inferred from measurements of G on the stage. In audience area the diffuser works as a specular reflection for obliques waves incidence, and for stage area it acts as a transparent zone between vertical plates producing diffraction two times going up to ceiling and after of to hit with the ceiling produces two times more going down to stage where there are the absorption of musicians. In each diffraction process of the waves traveling the acoustic energy is removed..

Mitigating the focused reflections that bombarded the stage was one of the main goals of the renovation, and the data in Table 8 show that the diffuser substantially reduced the excess sound strength.

It is not obvious from classical acoustics why the value of G in the hall should increase while the value of G on stage decreases. But there is a simple explanation. The stage area when occupied with stands and chairs is somewhat sound absorptive, and is very absorptive when fully occupied by musicians.

The labyrinth diffuser does not absorb this energy, but re-directs it into the audience area. Thus we expect that a decrease in G on stage will result in an increase in G in the audience area. The data show that this transfer of energy takes place, and can be measured even in the unoccupied hall. Comments from audience and musicians confirm that the transfer also takes place - probably to a greater degree - when the hall is occupied.

2. Reverberation Time T and EDT

Musicians comments reveal that the labyrinth diffuser decreases the early reflected energy coming down onto the musicians. This early energy is deflected by the diffuser away from the floor, but it is not absorbed. Reflected sound is forced to bounce around for a while before finding an absorptive surface, and thus the reverberation time is lengthened. It may be easier to think about this process as an increase in free path length between the source of a sound and a surface that will absorb it - something that would happen if the hall volume was increased. This is precisely what we hear subjectively.

It is critical that the labyrinth is not composed of closed channels. A sound wave traveling through free space decreases in energy proportional to the square of the distance it travels. But a sound wave traveling in a channel or tube does not lose energy as it moves along. Thus to emulate an increased path length effectively the labyrinth design must allow for the sound energy to spread out as it travels through the device. This is precisely what the design presented here does. It combines parallel surfaces and open spaces, maximizing the opportunity for both reflection and diffraction to occur..

The ability of the labyrinth to guide and diffract sound is frequency dependent. The panel size in both cases is about one meter square - implying that sound with a frequency below 300Hz will not be substantially guided by the structure.

In fact, we see in table 1 that the reverberation time in St. Gallen at 125Hz and 250 Hz decreased slightly when the diffuser was installed, probably due to membrane absorption from wood plates it increased the effect of absorption. At 500Hz and above, the reverberation time increases significantly. At frequencies above 1000Hz it may be possible to model some of the characteristics of the structure with ray tracing, as the panels are large enough to create specular reflections. But above 2000Hz the structure may start to act as a waveguide - with insufficient spreading of sound. We see in table 1 that at higher frequencies there is less increase in RT due to the diffuser. It may be possible to design a similar structure that is more independent of frequency. The intuition to make the structure open and the panels about one meter square has been amply justified.

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.

We need a new mathematical theory, which does not exist today, to explain the physical phenomena found. A theory for calculating what size the plates and thickness diffusers should be, the distance they should be from the floor and the ceiling, the surface they should have in relation to the ceiling area, so that the designed diffuser provides us with N (s) of additional reverberation to the reverberation time of the room T_0: $T = T_0 + N$ (s).

Physical Analysis: How is changing the free path mean lm by diffuser.

Here we indicate one phenomena never discovered before because never have been used a 3D-grid diffuser transparent to sound as we have did in.

The reverberation time T has grown in the hall. In consequence the EDT has been influenced by the same effect of T.

This phenomenon never has been discovered before. It is a contradiction to the common knowledge of reverberation time that says that the reverberation time is proportional to volume hall V and it is inversely proportional to unit area of absorption. Never, none other effect similar has been known before we have obtained in Rehearsal Room Orchestra of Liceu and the Goteborg Konserthus [7].

The formula more general of Reverberation Time is:

$$T = (13.9/c) \times l_m / \mathbf{a} = 0.0408 \times l_m / \mathbf{a}\ , \tag{1}$$

where l_m is the mean free path of room, (being $l_m = 4V/S$), c is the sound velocity and a is the averaged coefficient absorption of the hall that depends theory of calculation, [5], [8], [9], [10], and V and S are the air volume and the whole surface of the hall.

We can to think that the Reverberation Time of hall has changed because the mean free path have increased thanks to volume diffuser.

Analysing it now we assume a new mean free path for hall with diffuser, is equal to:

l_m(with diffuser) = l_m(without diffuser) + Δl_m. Using equation (1), we have:

$$T_{30}(\text{with diffuser}) = T_{30}\ (\text{without diffuser}) + 0.0408 \times \Delta\ l_m\ /\ \mathbf{a}\ , \quad (2)$$

substituting in last formula (2) lm = 4V/ S, we find:

$$T_{30}(\text{with diffuser}) - T_{30}(\text{without diffuser}) = 0.16 \times \Delta V/\ S\ \mathbf{a}, \quad (3a)$$

$$\Delta T = 0.16 \times \Delta V/\ S\ \mathbf{a}, \quad (3b)$$

This increase of reverberation of the listener, produce a subjective effect of growth of air volume, due it is the only quantity that can grow without damage to the physical laws. The surface of the room is untouchable.

Subjective volume growth of hall perceived by audience:
Knowing our case is in mid frequencies: **ΔT = 0.16** (to see table 1), being V = 6100 m^3, S = 2037.2 m^2, lm = 8.96 m and **a** = 0.238 (Sabine), we can to find the increased volume of the hall that is felt by the audience. It is obtained from (3b):
ΔV = (0.16 / 0.16) x 2037.2 × 0.236 = 480.78 m^3, value that in comparison to volume V real of hall, is: ΔV/ V = 0.0788, 7.88 %.

Subjective volume growth of hall perceived by musicians on stage:
Knowing that our case is in mid frequencies: **ΔT = 0.19** (to see table 4), being V = 6100 m^3, S = 2037.2 m^2, lm = 8.96 m and **a** = 0.238 (Sabine), we can to find the increased volume of the hall that is felt by the musicians. It is obtained from (3b):
ΔV = (0.19 / 0.16) x 2037.2 × 0.236 = 570.92 m^3, value that in comparison to volume V real of hall, is: ΔV/ V = 0,0935, 9.36 %.

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