AN ACOUSTICS MIRACLE OF "TONHALLE ST. GALLEN" HAS BEEN PRODUCED. BUT THE CRITERION OF GADE ON STAGE HAS FAILED BEFORE AND AFTER THE REFURBISMENT OF THE HALL

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Summary
The "support" parameter was proposed by Gade so the questions about stages could be analyzed. The last paper that we have delivered to Internoise 2010[1], we show that the criterion of Gade can fails.The centennial Concert Hall of St.Gallen in Swiss was a hall with much trouble on stage included in the hall. high levels of sound, focusing, flutter echoes, and so on, the problem never was solved. The Director Orchestra and his musicians were unhappy with this hall.
First, in old paper[1] we analyze the Concert hall of St. Gallen before the refurbishment. The ST1 or STearly measured stage values were relatively good, but musicians had a lot of trouble focusing and the flutter echoes very strong. We have demonstrated in that paper that the criterion proposed by Gade does not, by itself, assure the prediction of good stage acoustics.
Secondly, we then carried out after the whole refurbishment of the stage. The acoustics on stage and hall is optimal, but in this case the criterion of Gade[2] has been a bad parameter of analysis of the stage evaluation because it predicts practically equal to that it before. However we have determined other effects that have contributed in the improvement of the stage and including the entire hall. These acoustic effects are news in acoustics knowledge, never known until now.
Now in first, in this paper we analyze the Concert hall of St. Gallen before the refurbishment, where the STearly measured stage values are relatively good to accord the criterion of Gade, but musicians had a lot of trouble of focusing and the flutter echoes very strong. Therefore we show that the criterion proposed by Gade does not, by itself, assure the prediction of good stage acoustics.

1. INTRODUCTION

This hall was inaugurated in 1909; 100 years later was carried out a international competition to make a refurbishment of the hall.
In this study we introduce and analyze the acoustic measurements got on October 29th 2010 at the "Tonhalle St. Gallen" after of the refurbishment and to perform a comparison we the measurements carried out in 2009 before of refurbishment. The main purpose of these measurements is to analyze the acoustic parameters of the hall that characterize hall, before and after refurbishment. In all measurements the hall was empty, or with unoccupied seats. The the planning and the execution control of the building works were carried out by Bosshard Vaquer Architects, Zurich, with acoustic consultant Arau Acustica, Barcelona.

2. GEOMETRY OF THE HALL, AUDIENCE SIZE

In this section, the geometrical characteristics of the hall are described as well as the size of the audience. In addition, the values of the acoustical parameters are established according to the acoustical criteria that the hall should accomplish.
<u>TONHALLE ST.GALLEN</u>

- Air volume in the hall: V = 6100 m^3
- Audience (Number of seats): N =840
- Audience surface: S_A = 588 m^2
- V/N = 7.32 m^3/seat
- V/S_A = 10.459 m

This hall is used for concert hall but its size is more similar to chamber hall.

This Geometry has two versions:

- Geometrical characteristics of the hall in 2009 before the refurbishment (without stage's diffuser).
- Geometrical characteristics of the hall in 2010 after the refurbishment (with stage's 3D-grid diffuser).

This hall is used for concert hall but its size is more similar to chamber hall.

2.1 Geometrical characteristics of the hall in 2009 before the refurbishment (without stage's diffuser).

We show the image in ground plan, and longitudinal section before the refurbishment.

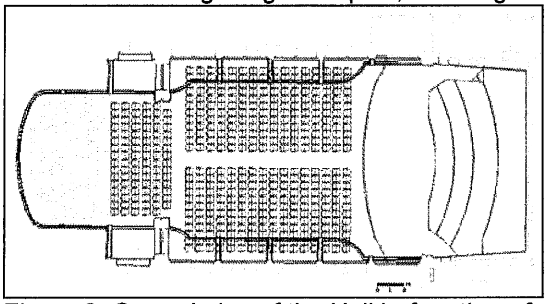

Figure 2: Ground plan of the Hall before the refurbishment

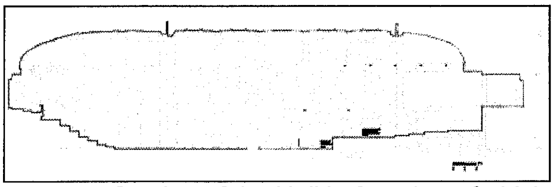

Figure 3: Section of the Hall before the refurbishment

2.2. Geometrical characteristics of the hall in 2010 after the refurbishment (with stage's diffuser).

We show the image in ground plan, and longitudinal section after the refurbishment.

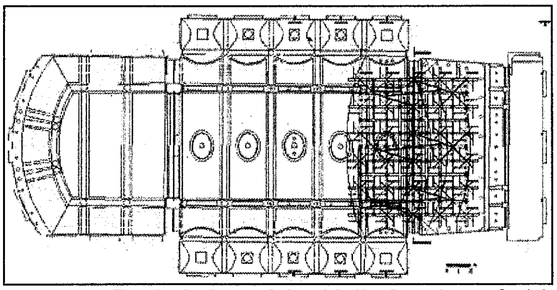

Figure 4: Zenital plan of the Hall after the refurbishment.

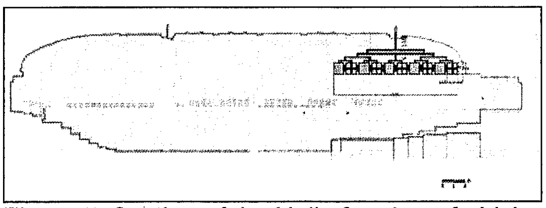

Figure 5: Section of the Hall after the refurbishment.

NOTE: Never the hall has been incremented of volume nor changed of type seat..

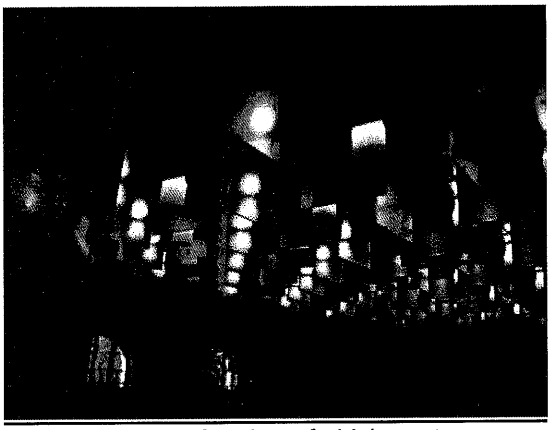

Figure 6: Photo after the refurbishment

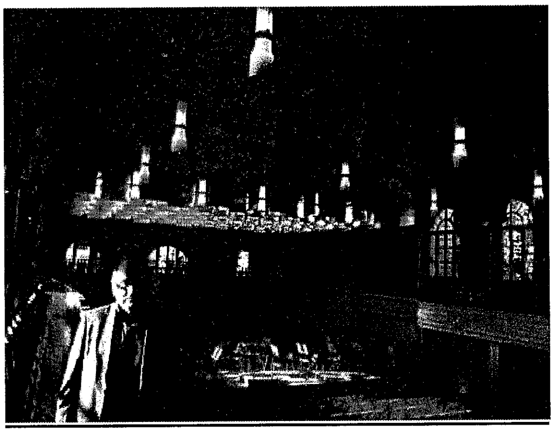

Figure 7: Photo after the refurbishment

The 3D-grid diffuser is matrix of plates of wood laminated with gold in two faces, supported by a pattern in squares of 0.925 m x 0,925 m of iron. Each plate of diffuser: 1 m height x 0.89 m wide. The all system is hanged by one iron structure from 3 points in ceiling, like a great lamp. The criterion of design defined is a reflector/ diffuser in grid form, that acts covering all possible directions to remove the sound focusing produced by the curvature existent among ceiling and walls in all the hall. This system never has been used before in a concert hall. The people of City St.Gallen judge it as a brilliant solution very beautiful. So part of the diffracted sound is scattered more or less in all directions

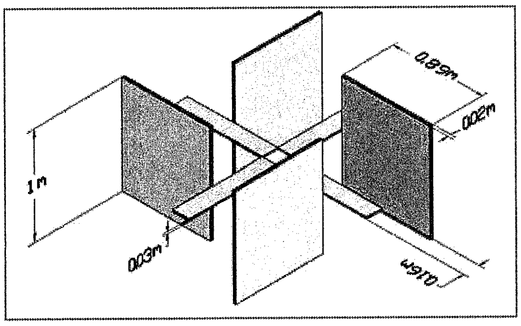

Figure 8: Detail of 3D-grid diffuser

Other volume diffuser existent, from 2002, is in Goteborg Koncerthus[3] developed by Niels Jordan in 2002. But it is very different to our 3D-grid diffuser of Swiss. The canopy designed by Niels Jordan is 80% percent open (none detail more we have about this diffuser). L. Beranek explains, in his book, that the result acoustic is an increase in the reverberation time, and especially EDT. This the same phenomenon found by us with our 3D-grid diffuser.

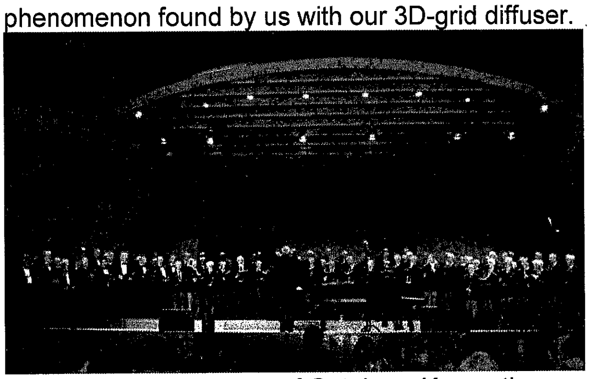

Figure 9: Detail Canopy of Goteborg Konsertkus

3. MEASUREMENT METHODOLOGY AND SYSTEM

The experimental procedure was carried out according to the - ISO 3382-1[3], where monophonic impulse responses where measured using sweep signals in the 125-400 Hz octave band range. The measurements were performed to find the following magnitudes, or parameters through the impulsion response:

Parameter
Reverberation Time
Early Decay Time
Strength G
Support objective of Stage ST1

Every group of measurements was done with every single source F_i, i =1 to 4, located on different places on the stage with the objective to search all type focusing. It is shown on the next figures. The measurements were carried out for each single source for all receiver points 1 to 21 placed in area audience, after were averaged.

To analyze the effects of the stage support ST1, the measurements were performed in 21 points of the source on the stage. They were measured individually at a distance of 1 meter. and 1.2 m height, to see figure 11. Also on these points we have included the reverberation time T/EDT measured.

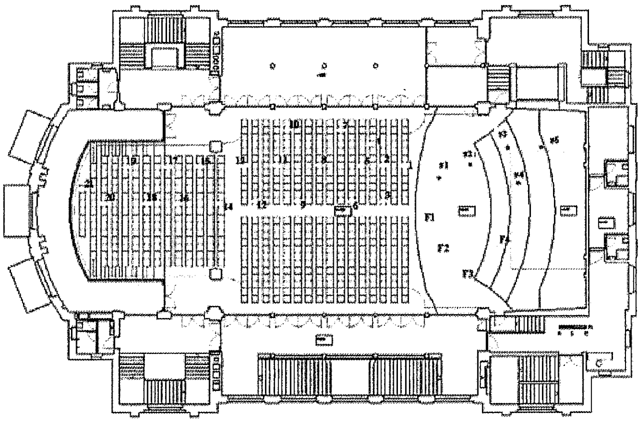

Figure 10: Disposition points of measurement for source Fi, i=1,2,3,4. Measurements
Tonhalle – st gallen – stage support (ST1) and reverberation time (T_{30}) - total average stage (1 m from the source to 1.2 m height)

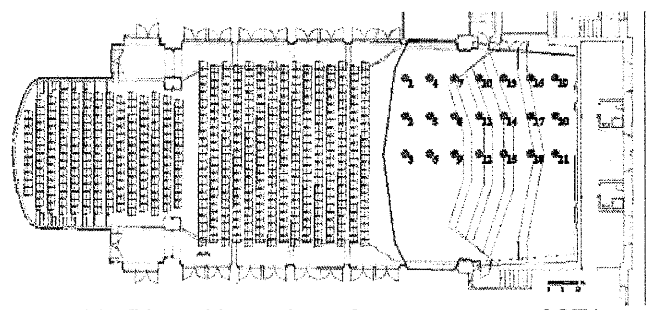

Figure 11: Disposition points of measurement of ST1.

4. COMPARISON OF AVERAGE VALUES AMONG 2010- 2009.

a) Measured in the hall.

REVERBERATION TIME (RT)

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 $\Delta T_{30}=T_{30}(s)_{2010}-T_{30}(s)_{2009}$	**-0.05**	**0.03**	**0.16**	**0.16**	**0.13**	**0.07**	**0.16**	**-0.01**	**0.1**

EARLY DECAY TIME (EDT)

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 $EDT(s)_{2010} - EDT(s)_{2009}$	**-0.13**	**0.18**	**0.21**	**0.18**	**0.12**	**0.04**	**0.19**	**0.03**	**0.08**

TOTAL SOUND LEVEL OR STRENGHT G

Frequency	125	250	500	1000	2000	4000	G_{mid}
Strength G (dB) 2009	10.8	8.2	7.8	8.2	9.3	7.3	8
Strength G (dB) 2010	9.5	9.4	9.2	9.1	10	8.9	9.15
COMPARISON $G\ (dB)_{2010} - G\ (dB)_{2009}$	**-1.3**	**1.2**	**1.4**	**0.9**	**0.7**	**1.6**	**1.15**

b) Measured on the stage

STAGE SUPPORT (ST1)

Frequency	125	250	500	1000	2000	4000	Average
Stage Support ST1(dB) 2009	-8.28	-9.96	-10.12	-11.05	-9.41	-11.60	-10.14
Stage Support ST1(dB) 2010	-8.88	-9.38	-9.68	-9.10	-8.66	-8.68	-9.20
COMPARISON $ST1(dB)_{2010} - ST1(dB)_{2009}$	**-0.6**	**0.58**	**0.44**	**1.95**	**0.75**	**2.92**	**0.94**

REVERBERATION TIME (T)

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

EARLY DECAY TIME (EDT)

Frequency	125	250	500	1000	2000	4000	EDT_{mid}	EDT_{low}	EDT_{high}
EDT(s) 2009	2.11	1.83	1.55	1.57	1.5	1.17	1.56	1.97	1.34
EDT(s) 2010	1.89	1.97	1.95	1.86	1.77	1.36	1.91	1.93	1.57
COMPARISON $EDT(s)_{2010} - EDT(s)_{2009}$	**-0.22**	**0.14**	**0.40**	**0.29**	**0.27**	**0.19**	**0.35**	**-0.04**	**0.23**

TOTAL SOUND LEVEL OR STRENGHT G dB

Frequency	125	250	500	1000	2000	4000	G_{mid}
Strength G (dB) 2009	11	8.4	8	8.6	9.6	7.6	8.9
Strength G (dB) 2010	5.7	7	6	5.6	6.3	4.6	5.8
COMPARISON $G\ (dB)_{2010} - G\ (dB)_{2009}$	-5.3	-1.4	-2	-3.6	-3.3	-3	-3.1

5. CONCLUSIONS AND FINDINGS

5.1. Conclusions

a) Measured in Hall

Remark 1, 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 annihilated the increment of RT produced by the diffuser, after the high frequencies the T have grown a ε = 5.88 %. The diffuser placed on stage produce an important improvement in hall.

Remark 2, EDT: We have seen that in general the early decay time in hall is now largest that before. In the middle frequencies is ε = 13.47 % greatest. In the low frequencies is practically similar before, due perhaps to absorption of wood panels of diffuser have removed the increment of T produced by them. And the high frequencies T have grown a ε = 5 % .

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

b) Measured on stage :

Remark 1, ST1:
The stage on musicians area[1] has 192 m^2, fictitious volume is1152 m^3. The predicted value given by Gade[2] is: ST1 ≈ -10 dB. The average measured value of ST1 support on the stage in 2009 is ST1= -10.14 dB, and 2010 is ST1= -9.20 dB. The criterion Gade for stage is practically the same before and after refurbishment. However the reality has been other well different because St.Gallen hall was very bad by its acoustics and now after refurbishment the hall is optimal. Therefore in our opinion this criterion ever has failed. Our experience of this case has shown that this criterion is not good, because the reality subjective of musicians is different to predicted by Gade, by measurements. We are sad that the support ST1 has failed because it is the only technical criterion for stage parameter which has acquired some recognition.

Remark 2, T_{30}: We have seen that in general the reverberation time in the hall is now major that before. In the middle frequencies is ε = 9.8 % greatest, in the low frequencies is 6.48 %, although the absorption wood panel in low frequencies possibility removed something, and the high frequencies have grown a ε = 7.05 % The diffuser placed on stage produce a important improvement in stage and all the hall..

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

Remark 4, G: We have seen that the intensity of sound above musicians has decreased practically to a half, approximately 3 dB. It is a very much quantity of energy removed. , now the sound is homogeneous and transparent.

5.2. Findings

Here we indicate two phenomena never discovered before, because never have been used a 3D-grid diffuser transparent to sound as we have did in Tonhalle St. Gallen. Only we know now the canopy of Gotenborg indicated by Beranek.

First phenomena:

The 3D-grid diffuser designed, we assume works by effects of the diffraction, which it is belonging to wave sound field. This produces an effect of barrier among ceiling and on stage of hall. This barrier has acoustic impedance that removes the strength of sound among two surfaces ceiling and stage platform. This impedance acts as an air opposition of sound wave when it cross, up and down, the plane formed by 3D-grid plates of diffuser. It depends on the frequency. We can imagine that the structure of plates gives an inertial effect which must be added to air, as a special structure factor. This impedance is not possible to be calculated by us now. It produces a sound attenuation that has diminished much the value of G in very noticeable in musicians zone. After refurbishment, the sound is listening by musicians more soft and homogeneous without focusing, nor does sound strong exist above them. The musicians and audience people say that sound is optimal in all stage and hall also.

Second phenomena

The reverberation time T has grown in the hall. On stage zone this effect has been largest than on hall. In consequence the EDT has been influenced by the same effect that T, and it has been more important.
This phenomenon was unexpected and 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, we believe none other effect similar had been known before, with this style design, as now we have obtained in "Tonhalle St. Gallen", except other case performed before of Tonhalle, known by "The rehearsal room of orchestra of the Great Theatre of Liceu", where the acoustic results are even better and surprising. Also the Gotenborg design[3] can be considered perhaps the same type although is well different shape to our 3D-Grid Diffuser.

We know that when a new element is installed in a room the mean free path can only be reduced especially for surface diffusers. According to H. Kuttruff (2000) we knows for rooms with suspended "volume diffusers", the distribution of the free path length is greatly modified by the scattering obstacles, that could modify the relative variance of the path length distribution but not the mean free path length. It is logical due that physical magnitude lm does not change. Also we know according R.W.Young[5] that when is increased the number of reflections N then the decay rate D, ($D=10N\alpha$ $\log e$), also is incremented and T ($T=60/D$) is diminished. This last assert contradicts the reality experimental obtained in our case where T suffers an increment of value.
If we do not get go against physical known laws about T/EDT, we may say that is impossible to solve a physical theory that explains the acoustic facts obtained about T/EDT.
In first time is required to obtain a new theory that describes how many large and wide and separation gap among plates must be them, to get a determinate T.

In second time we know that the subjective sensation for musicians after refurbishment was that the hall had grown when they listen music. They felt that the hall was much higher than before the refurbishment. This sensation subjective may be described by the following formulas: We know the general formula of reverberation is:

$$T= 0.16\ V/Sa + 4mv \ldots\ldots(1),$$

where a= α for Sabine[6]; a = - ln(1-α) for Eyring[7] and $a = a^{Sx/S}.a^{Sy/S}.\ a^{Sz/S}$, a_i = -ln(1-αi), i = x,y,z, S =Sx+ Sy+ Sz respectively of H.Arau-Puchades[8]. As the real volume V and total surfaces S of hall do not can change, because it is a physical law. We assume now a subjective volume V_s immaterial that increase the real volume such as the musicians feel the new phenomenon. V_t = V+Vs. V_t is the volume when the 3D-grid diffuser is installed among ceiling and stage platform and V is the real volume without diffuser. Here we have neglected the absorption and area of plates of diffuser, because it is small in relation to unit absorption of surfaces of hall. So we can write for this case:

$$T_t= 0.16\ V_t\ /\ (Sa +4mv) \ldots\ldots(2),$$

Therefore subtracting (1) from (2), we have: $\Delta T = T_t - T = 0.16\ V_s\ /\ (Sa + 4mv) \ldots\ldots(3),$

Being T the reverberations time for hall without diffraction and T_t is same but with diffuser. Therefore T represent the reverberation time of year 2009 and T_t represent the the reverberation time of year 2010. Therefore here we may calculate, an approximation, of the subjective volume V_s felt by the musicians from stage or audience from hall using ΔT.
Knowing that our case is: V = 6100 m^3, S = 2037.2 m^2, l_m = 8.96 m and **α** = 0.238 (Sabine) we can to derive:
Now the increased volume of the hall that is felt by the audience in the mid frequencies is:
Vs = (0.16 / 0.16) x (2037.2 x 0.238 + 2.44) = 486.85 m^3. This value that in comparison to real volume V of hall, give us: V_s / V = 0.079, or 7.9 %. Being the total volume felt by people is V_t = 6586.8 m^3.
The subjective increased volume of hall felt by the musicians on stage is: Vs = 578.13 m^3, being the total volume V_t = 6678.13 m^3.

5.3. Last conclusion

With this diffuser, or others similar, we have obtained by chance a new method to increase the reverberation time of a room. It is especially applicable to small rooms in conservatory of music and also little chamber halls, concert halls, reverberation chambers or also for design a new spaces where we wish to obtain a great volume by audible subjective sensation against a reality well different. A new time of researching and experience in acoustics must to arise in this field; field very connected to the sound waves phenomenon in where in reality we know very few about this subject.

6. REFERENCES

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