COATINGS AND SURFACE TREATMENT EFFECTS ON SOUND QUALITY IN CONCERT HALLS: A CASE STUDY OF THE BIBLIOTHECA ALEXANDRINA CONFERENCE HALL, EGYPT

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ABSTRACT

In concert halls, interaction between music and features of the hall happens continuously. As the concert hall is considered a box full of sound reflections and waves which get reflected all the time from and to every surface in the hall. However, most concert halls are not in the ideal state to achieve the optimum experience for the attendees in terms of sound quality. The most common reason is that they were designed for multiple different purposes such as conferences or speeches. This research aims to study the effect of material characterizations and surface treatment; such as porosity, absorption and reflection, and their effect on the sound quality in concert halls. This research consists of two parts: Part one is a review of concert hall design principles and the materials used in its furnishing and finishing, plus a review of every advantage and disadvantage of most used materials. The second part is a case study on a conference hall turned to a main concert hall in Bibliotheca Alexandrina, where sound measurements took, and software application was held after suggesting some changes to surface treatment and coatings in that hall. The results of the research have proven that changing surface treatment and coatings can help positively in turning any hall to a concert hall and enhancing it's the sound quality.

Keywords: materials characterization, surface treatment, coatings, concert halls, seats materials, wall coatings, sound absorption, sound reflection, experimental techniques, computer sound simulation.

1 INTRODUCTION

The acoustic evaluation of the classical concert hall has been an important issue for a long time. Mostly because the flow of the sound waves moving from the stage among audience seats can determine the sound quality in that hall.

Sound quality in the concert hall is largely affected by the architectural features, the interior design, finishing materials, and surface coatings.

Several studies have conducted an acoustic simulation analysis through computer simulation programs during the early planning phase. Barron and Kissner presented a possible acoustic design approach for multi-purpose auditoriums. Two acoustic models were simulated using computer simulation programs [1].

Materials have a very important effect on sound quality in concert hall acoustics. The same materials can be used in different spaces and make different effects if arranged in a different way or used in different coatings. This is because the orchestra needs all the reflection and reverberation that it can get to make the sound richer.

Some concert halls were not originally designed as a concert hall, and some of them are multipurpose halls were music concerts can be held but with very complicated and expensive sound systems [2].

The objective of this research is to enhance the sound quality in concert halls or in auditoriums converted to concert halls, by changing characterizations of materials used in furnishing the hall and surface coatings.

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To achieve the objective of the research, it followed inductive and deductive methodology starting from the literature review to the results section. The research is divided into two sections, the first section is a theoretical framework using a literature review that discusses materials role in sound quality and discusses different material effects on reflecting and absorbing sound waves in concert halls. The second section is a two-phase section, where phase one was a case study of the Bibliotheca Alexandrina conference hall where different sound measurements were taken live during rehearsals and concert, as an observation of the current situation, while in phase two a *full model simulation* was made by applying different material characterizations and different surface coatings and checking sound reflections and absorptions in the new state. The results of the simulation were then represented in the form of a table of new measurements; the research is then continued by a discussion of those results and measurements, and a general conclusion.

2 LITERATURE REVIEW

2.1 Sound quality principles in concert halls

Sound interior designs depend on the acoustic properties of the hall or the auditorium. The sound is mostly reflected by hard materials and absorbed by soft ones, gradually fading away as its energy is dissipated through coatings and different materials [2]. Reverberation or echo is particularly noticeable when a sudden bang continues to be audible for several seconds as in musical concerts [3].

Good acoustic design requires high understanding of the engineering characteristics of materials and the unique attributes of music. Then applying this knowledge to building construction to create a facility that allows listeners to have an outstanding aural experience [3].

Three design principles have been mentioned in concert hall design:

- Music should be optimally heard equally in every spot in the music hall (including an excellent “ring”) throughout the entire performing venues, without having dead spots or echo spots [4].
- Sounds coming from outside the building needs to be minimized, if not entirely eliminated, to keep sound interference to a minimum. This includes the sounds of the traffic, or people on the streets, or the surrounding environment.
- If the building has different musical spaces, they shouldn’t disturb or affect each other. Sounds created in one space should not disturb adjacent music spaces in the building [4].

A great concert hall has both sound isolation and good sound reverberation. These two qualities have to be taken into consideration while designing any music hall [5]. When a sound is produced in a concert venue, the reverberation of the hall can be timed until that sound has completely disappeared. Longer reverberation is desirable for a music space as opposed to a theatrical space, where clarity and intelligibility of speech is more important than sound quality [6]. Longer reverberation is difficult to achieve. To be successful, planners must create an adequate cubic volume and limit sound absorbing material. An additional consideration when building is to have adequate mass (weight) in all exposed surfaces; since it’s important to have hard surfaces with no hollow spaces underneath [7].

2.2 Materials and coatings in concert halls

Designing good concert hall acoustics is a very delicate art as all elements unite to define the space in a very complex way. In this phase, I will explain the details behind the materials

used in concert hall construction and coatings and how they affect each other acoustically; and which materials are recommended based on that [8].

Table 1: Detailed comparison between hard acoustical materials used in finishes and furnishings and their properties and recommendations [9]–[11].

Material	Properties	Advantages	Disadvantages	Recommendations
Plaster	• Traditional material for ceilings and walls in concert halls. • Used in large areas and on surfaces.	• Used with extra thickness up to 1.5 to 2 inches. • Its stiffness and mass can resist vibration. • Low frequency absorption.	• Needs a very strong supporting structure. • Not very efficient in detailed decorative forms.	• Partly recommended • Better used in large spread areas than detailed areas. • Mostly used in simple ceilings and walls.
Gypsum board	• Gypsum board is a wallboard with a gypsum plaster core bonded to layers of paper fiber board.	• Used in detailed surfaces and ceilings. • Can be used in decorated ceilings in churches and auditoriums.	• Rarely used in concert halls as it has too much low frequency absorption. • Must be applied in two thick laminated layers in auditoriums.	• Partly recommended to be used in auditorium and concert halls with very large spaces and many frequencies.
Wood and wood panelling	• Wood panels applied on walls in concert halls and auditoriums for aesthetic reasons.	• Has an aesthetic appearance in concert halls. • Plywood can be bent with gypsum board over a curved wall or ceiling and be stressed so that it cannot vibrate strongly and will not exhibit so many low frequencies	• Thin wood panels with air behind it will allow unwanted low frequencies absorption due to panel vibration.	• Recommended to be used in concert halls. • Can't be used in thin panels and it should be backed with solid construction. • Should be used stressed to a back construction like gypsum board or plaster. • If used in curved system it should be rigidly supported.
Masonry	• Masonry materials such as brick, block, mason, and concrete. • Usually used in massive and thick way.	• Can fill large and huge spaces in massive and thick way.	• Masonry units porosity affects the sound reverberations significantly in the concert hall. • it absorbs middle and high frequencies but reflects low frequencies.	• Not recommended to be used in concert halls in large spaces and areas. • Its porosity should be coated and sealed before using it according to acoustical consultant recommendations.
Metals	• Metal sheets can be applied to walls and ceilings.	• Can be flexibly formed.	• Metal movement due to sound pulses can cause rattles. • It causes so many echoes and unwanted reverberations	• Not recommended to be used in concert halls but it can be limitedly used but fixed to solid core material.
Glass	• Glass pieces can be used in decorative purposes.	• Can be used in small decorative design and lightings.	• If used in large areas in concert hall walls or windows it can cause unwanted noise transmission.	• Not recommended to be used in large areas in concert halls. • Can be used in small decorative elements so they can provide some useful sound diffusion.

2.2.1 Hard Acoustical finishes and furnishings

A detailed comparison between hard acoustical materials used in finishes and furnishings and their properties and recommendations are shown in Table 1.

2.2.2 Soft acoustical finishes and furnishings

A detailed comparison between soft acoustical materials used in finishes and furnishings and their properties and recommendations are shown in Table 2.

Table 2: Detailed comparison between soft acoustical materials used in finishes and furnishings and their properties and recommendations [12]–[14].

Features	Properties	Recommendations
People	• People attending concerts. • Orchestra members. • Performers. • People are the most absorptive surface in concert hall.	• Room volume must be compared to the number of seats. • The most appropriate volume\seat ratio used in concert halls is 250:300 cubic feet per seat.
Seating	• Seats in concert halls are formed in rows and columns with different spacing between them. • It can absorb a generous amount of frequencies.	• Seating absorption should match the absorption of audience, so that when people are absent as in rehearsals or in low attendance, there will be a very limited change in reverberation times in the hall. • Seats should be upholstered on the cushion and the back rest. • The seat back shouldn't be upholstered. • Seat material should be a woven breathable fabric stretched over thick breathable foam padding.
Carpet	• Carpet used limitedly in concert halls in aisle runners.	• Carpet should rarely be used in concert halls. • It's not acoustically preferred. • It has a very strong absorption effect on frequencies. • It should be used only in aisle runners and in a thin layer with no padding.
Walls	• Back walls following the seats shape (curve), can reflect sound waves to the front, focused and strengthened, and with a time delay that makes strong echoes. • Balcony faces, can cause a serious echoes by doing the same thing unless it was treated. • Low wall at the cross aisle can do the same.	Two recommended approaches for wall treatments: • Making them very absorptive. • Shaping them to send sound reflections to the other walls. • According to the calculations of the reverberations number, it can be decided either absorption treatment is needed or it will add too much absorption to the room.
Draperies	• Draperies are used in concert halls, and they are generally absorptive.	• They should be rarely used in concert halls, especially around the orchestra platform, as they need the entire solid sound reflective backup.

3 CASE STUDY AND APPLICATION

3.1 Case study

The chosen case study is a conference hall in Bibliotheca Alexandrina, which was originally designed as a conference hall but by the time it became one of the most important concert halls in Alexandria.

The study is divided into two parts; the first part is studying materials and coatings used in the hall in the current situation. The second part is live sound measurement were taken during live concert and rehearsals.

3.1.1 Materials used and coatings

By studying the hall it was found that all seats are totally upholstered from all sides and contain thick sponge padding as shown in Fig. 1. Also a layer of thick carpets is used in furnishing the hall floor everywhere inside including aisles, runners, stairs, and the front of the hall as shown in Fig. 2. The ceiling is made mainly of Gibson Board panels as shown in Fig. 3. The stage is made of concrete, but after using the hall for musical concerts it was treated by a layer of rubber as shown in Fig. 4. Walls of the hall are coated with two materials. The upper part is coated by wood panels, while the lower part is coated by a wool layer as shown in Fig. 5. There are also very long and thick velvet draperies around the stage as shown in Fig. 6. The hall also contains some balconies.

3.1.2 Sound measurement

These are the sound measurements that were taken during a live concert and live rehearsals of a musical concert. It consists of instruments, solos, human voice, and choir using a sound level meter (SLM) as shown in Table 3.

Figure 1: Seats are totally upholstered from the back.

Figure 2: Thick carpets furnished all floors.

Figure 3: Hall ceiling and the bottom of the split level are totally covered with gypsum board panels.

Figure 4: Stage covered with rubber sheets.

Figure 5: Wall covered by a carpet layer.

Figure 6: Long and thick velvet draperies around the stage.

Table 3: Sound measurements were taken in 15 points in different spots.

Point no.	Tutti		Strings		Wind instruments		Opera soloist		Choir		Human voice talking	
	(Forte)	(Piano)	(Forte)	(Piano)	(Forte)	(Piano)	(Forte)	(Piano)	(Forte)	(Piano)	Forte	(Piano)
1	73	67	74	64	70	65	67	55	74	60	57	50
2	84	76	70	65	74	66	87	65	77	65	66	55
3	72	65	74	63	75	63	80	72	74	66	58	53
4	70	64	60	56	65	50	69	46	65	47	55	43
5	88	79	79	64	76	64	79	66	76	65	64	56
6	71	63	62	57	63	49	67	47	64	48	57	46
7	69	57	67	55	67	45	67	48	66	49	58	44
8	86	77	78	63	75	63	78	64	74	63	64	53
9	68	55	68	56	64	46	68	48	65	50	57	47
10	75	65	73	59	72	60	75	65	73	60	64	52
11	84	74	78	60	74	61	75	63	75	61	62	53
12	74	64	72	58	71	61	74	64	72	60	63	51
13	63	50	64	52	60	44	63	47	65	44	55	46
14	65	52	63	54	62	50	64	49	66	48	57	48
15	64	51	63	53	62	52	63	48	64	49	54	47
Concert	86	74	84	68	84	78	76	64	86	74	74	64

The measurements were taken by a sound level meter to measure the sound level reaching different points all over the hall as shown in Fig. 7. Points were chosen to cover every spot in the hall on the sides, front rows, back rows, and the upper part of seats in balconies.

4 DISCUSSION

After taking those measurements it was found that points no. 1,4,7 (Right side), and points no. 3,6,9 (left side) had a very low sound level specially in piano parts (low sound levels) as they are surrounded with carpet coatings on the lower half of the side walls and the back walls of the hall. And since carpets have a great absorption capacity, it causes high sound absorption around those points.

Points 13, 14, and 15, had the lowest sound level in the hall as they are at the far end of the hall and there is a huge split level elevated over all the audience steps in that area. So sound coming out of the stage travelling all the way through the audiences loses its power and level, then hits upper balcony walls and the huge ceiling before reaching those three points.

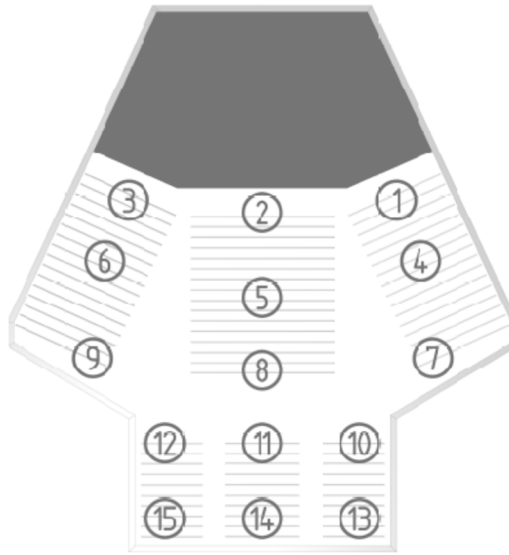

Figure 7: Points where measurements were taken live.

Points 2, 5, 8, and 11, had the best sound levels as they are at the centre of the hall and not surrounded by any extra absorption or reflection elements.

Points 10, 12 had an average sound level as they are partly surrounded by walls and carpets but have enough clearance between them and the stage allowing sound waves to reflect and reverb and reach the audience.

Fig. 8 shows the gradient of the sound level reaching every spot in the hall, where we can see that the red spots represent high sound level, and the grey and blue spots represent low sound level.

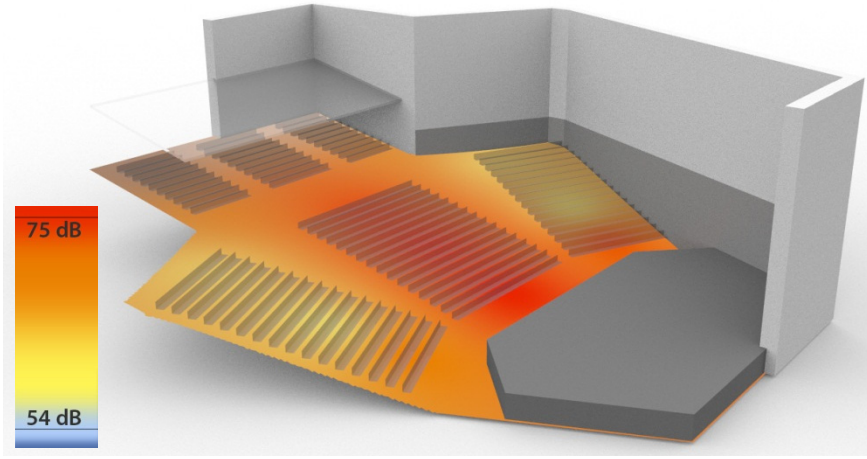

Figure 8: Diagram produced by Rhino Grasshopper to represent weak and strong spots in the hall.

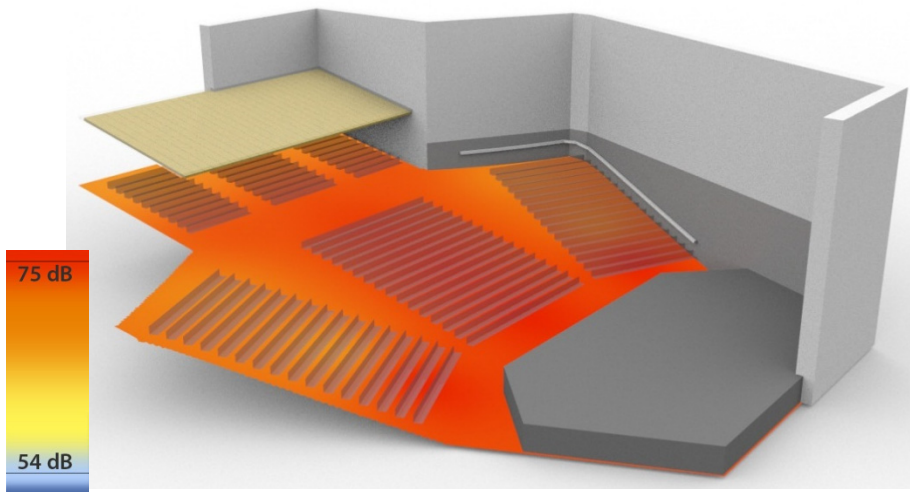

Figure 9: Diagram produced by Rhino Grasshopper to represent progress in sound quality inside the hall after applying the metal part and the wooden cladding on the bottom of the split level.

4.1 Application

4.1.1 Materials recommendations

After studying the characteristics of the materials used in that case study, and studying other materials used in concert halls and their absorption and reflection effects; some of the material recommendations were concluded to solve current sound problems while using that conference hall as a concert hall [15].

a) Seats: The backs of all the seats are upholstered with a very thick layer of wool, and since wool is a very absorptive material which has high porosity [15], so I recommend replacing the back material with wooden backs which have relatively low porosity and high reflection effect.
b) Side walls: Side walls are divided into two halves, the upper half is covered by wooden panels, and the lower half is covered by a thick layer of carpets. This causes a very high absorption of sound coming from the stage reaching the audiences [16]. To solve that problem in the current situation, I suggested two solutions: The first one was adding wooden panels to the lower part of the wall, but that wouldn't be a practical solution for the existing situation as it would need a lot of major changes to the architectural interior and would incur high expenses. The second solution was adding some thin metal panels to the carpet layer where required in the shape of a handrail. We can determine its size and place by simulating sound level needed in that spot. I recommend that solution as it can be applied easily to the existing situation.
c) Balcony walls for the upper part of the hall: The split level covering the back area of seats has two problems. The walls of the balconies and the bottom of that level hanging over the back seats; which is made of large area of Gibson Board. As mentioned in Table 1 Gibson Board is not recommended to be used in concert halls in large areas and low heights as it is originally used in sound insulation purposes and has too much low frequency absorption. This leads to losing sound level power as appeared in last

measurements as shown in Table 3. I recommend adding some wooden sheets strongly fixed to the ceiling to provide the required amount of sound reflection. A simple simulation was carried out to prove the result as shown in Fig. 8.

Fig. 9 shows the sound level in the hall after simulating adding suggested materials. We can obviously notice the difference in the sound quality reaching all the spots in the hall after the modification of the existing situation without major changes to the hall layout.

5 CONCLUSION

Materials and coatings have a major effect on acoustics in concert halls. The two factors in materials characterizations that strongly affect the sound quality are absorption and reflection; which depend mainly on the material porosity.

In concert halls to reach the perfect sound quality and level, there are some recommended materials to be used in coatings and surface treatment according to their absorption and reflection properties. Designers should take these into consideration during the design process. Many auditoriums or conference halls have been changed to be used as concert halls for musical events. This greatly affected the sound quality reaching the audiences in such mixed use facilities. There have not been previous studies that focused on the modification of auditoriums or conference halls to support a pleasing musical experience. In this research the aim is to prove that adding or removing some materials according to their characterizations of absorption or reflection can strongly affect sound quality in the whole venue; which is proved by simulation and measurements. This study uses a qualitative analysis using a methodological and applicable framework of the sound level variable, mainly by changing materials used in the most affected areas in the hall to improve sound quality.

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