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# Feasibility of inhomogeneous MPPs in multipurpose halls : The case study of Bilkent Concert Hall in Ankara

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**Abstract**

For multipurpose halls, there are additional constraints in planning for good visual conditions and sightlines, meeting specific social demands concerning layout, and providing good acoustic conditions. Regarding the latter, they require a compromise between the auditory needs of speech and music. While conventional materials fail to absorb sounds in the low-frequency range, Helmholtz resonators show a very narrow absorption bandwidth. The current study investigates the potential created by inhomogeneous Micro-Perforated Panels (MPPs), which literature demonstrated to have a wider absorption bandwidth in the low-mid frequency spectrum. This work uses Bilkent concert Hall, a 700-seat capacity multipurpose trapezoid-shaped hall located in Ankara, Turkey, as a case study to examine its current acoustic condition and provide material-based solutions for the existing problems. It analyzes the hall by assessing the fundamental acoustic parameters such as reverberation time (T30), sound pressure levels (SPL(A)), and speech transmission index (STI). Comparative simulations between the existing and the proposed material-based solution of the Bilkent Concert hall showed an improvement in the reverberation time and other objective acoustic criteria when inhomogeneous MPPs were used as wall panels instead of conventional materials. This comparison enhances the existing problems in the multipurpose hall and emphasizes the viability of those "next generation" absorbing materials, which are at the same time in demand from architects due to their design feasibility.

**Keywords:** inhomogeneous MPPs, multipurpose halls, reverberation time, absorption

# 1 Introduction

The arts of music, drama, and public discourse have both influenced and been influenced by the acoustics and architecture of their presentation environments [1]. Despite the use of halls for more than one purpose, the practical design of those spaces to accommodate more than one type of function is quite recent. A degree of flexibility in use is now becoming the norm rather than the exception. From the Sabine equation, the two variables influencing the reverberation time (RT60) are the internal volume and the amount of acoustic absorbing material. Optimum reverberations values for multipurpose halls should result in an RT60 (1,4 - 2 sec) appropriate for the program that can be speech and/or music. This flexibility is made possible in literature by architectural elements such as mobile bridges, automatic curtains, and retractable walls [2]. In an acoustic analysis of Gottingen Stadthalle [3], where RT was higher than predicted, the authors pointed out that the use of absorbing materials is more effective than geometrical changes because the former is not affected by diffraction.
State of the art in absorbing materials clearly shows that passive absorbers such as fibrous or porous materials are indispensable for high-frequency damping noises. For treating low-frequency problems, resonant structures are usually used. These reactive structures, also known as resonant absorbers, are mass-spring systems with damping to absorb the system's resonant frequency. They are most commonly used in room acoustics in the form of membranes, Helmholtz resonators, perforated, slotted, and micro-perforated panels (MPPs) [4]. This study investigates the potential of inhomogeneous Micro-Perforated Panels, which are known to have a wider absorption bandwidth, especially in the low-mid frequency range, when used as wall panels in a multipurpose hall located in Bilkent University, Ankara, Turkey.

## 1.1 Micro-Perforated Panels (MPPS)

MPPs were installed for the first time in 1992 to solve acoustic problems during the opening of the German Bundestag in Bonn. They can be made of transparent or colorful plates or membranes, so they are also in demand by architects for sound quality control in auditoriums [5]. As all resonant mechanisms, they come with the handicap of having a very narrow absorption bandwidth. A series of structures based on MPP networks in series and parallel have been explored to introduce multiple resonances [6-7] to broaden the absorption bandwidth. The results yielded excellent agreement between theory and measurement, showing show that the absorption bandwidth is expanded to lower frequencies due to the additional multi resonance peaks. This approach is viable to be integrated into room acoustic applications. The authors of this study have developed and tested an inhomogeneous (4 perforations of 0.7mm, 1mm, and 2mm with different perforation ratios) Micro-Perforated Panels with various cavities (8cm, 6cm, 4cm, 2cm) made of acrylic, having a thickness of 6 mm and density of 1190 kg/m3. The absorption coefficients of the proposed material are tested in an impedance tube by the transfer function method, and the results are as follows:

Table 1. The absorption coefficient of the proposed Inhomogeneous MPP

| Inhomogeneous MPP proposed by the authors | *125 Hz* | *250 Hz* | *500 Hz* | *1000 Hz* | *2000 Hz* | *4000 Hz* |
|---|---|---|---|---|---|---|
| | 0,09 | 0,27 | 0,86 | 0,76 | 0,54 | 0,24 |

The material will be tested for its performance when used as a wall treatment in room acoustics applications such as multipurpose halls. In the hypothetical case, the proposed material will replace the adjustable wood panels used to enhance different modes of the Bilkent Concert hall located in Ankara.

## 2 Case study: Bilkent Concert Hall

The Bilkent Concert hall (Figure 1) is a part of the Faculty of Music and Performing Arts building designed during 1993-1994 by architect Ilhan Kural. It is like a trapezoidal room in a plan which is enlarged from the stage through the back rear wall. It consists of the main floor, a second floor with space for the chorus, side aisles, and the main balcony, and the third floor with only a small balcony (Figure 2). It has a volume of nearly 6500m$^{3,}$ and the clear height is 15,2m. For the time being, the hall is used mainly for music purposes by the Bilkent Symphony Orchestra and for speech purposes when important lectures are given. There are 685 seats on the main floor and the second floor of the concert hall. 473 are placed on the main floor, 151 are placed on the second floor for the audience, and the remaining 61 seats are reserved for the chorus.

Figure 1. Interior view of the Bilkent Concert hall

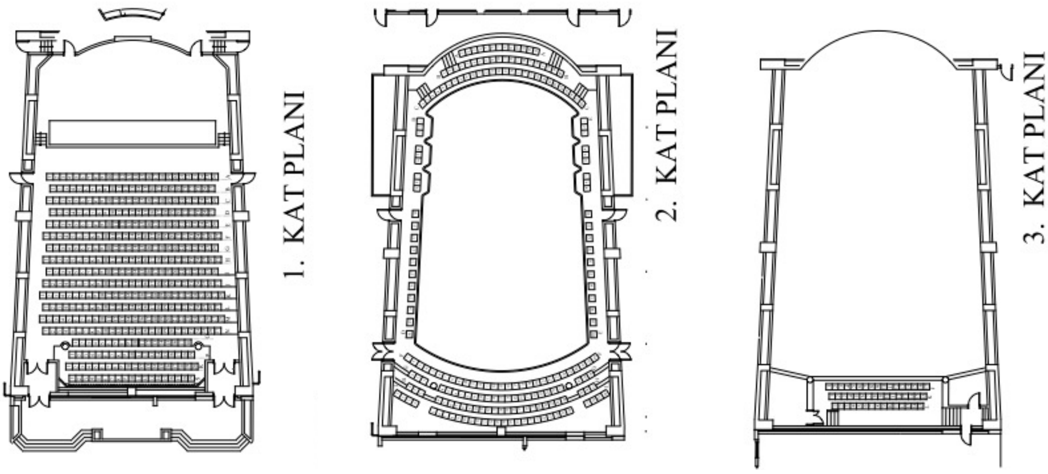


Figure 2. Plans of the Bilkent Concert hall

The materials for the respective surfaces are present in Table 2. The back walls are made of wood/gypsum panels, a layer of fibrous material such as rock wool, and an air cavity. Sidewalls are also separated with an air space and have travertine veneering and a 10 cm rockwool layer. On the sidewalls of the second floor, there are adjustable wooden panels. Simply folding wooden panels on sidewalls has carried out a flexible solution to adjust the reverberation time and other acoustical concepts. For the auditorium mode, the panels are folded on themselves to be able to face the highly absorptive material underneath with the hall medium, whilst concert mode is created by the folding of wooden panels on the highly absorptive material.

The wall behind the chorus area is made from fixed, veneered chipboard and a 10 cm layer of rock wool. The stage has a curved wall made from fixed, veneered chipboard, rock wool, and a concrete backing. There are plastered columns in front of this wall placed at the same angle as the stage wall's curvature. The balcony fronts and the ceiling are all plastered surfaces. The finishing material used for the floor and the stage is wood parquet, and there are upholstered seats for the audience (see Figure 3).

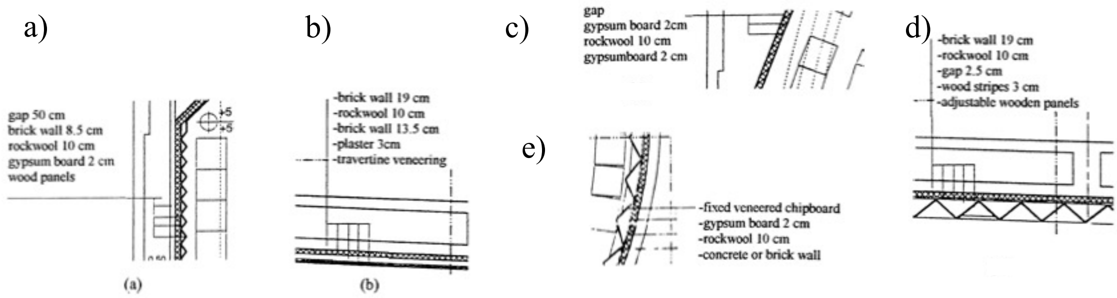


Figure 3. a) back wall (1), b) sidewalls of the main floor (1), c) back wall (2), d) side walls (2), e)chorus wall (2) [8]

## 3 Comparative simulations

The 3D model of the hall was achieved by using 3D SketchUp and then imported into ODEON Room Acoustics software version 16 Basics version suitable for educational purposes. It was composed of 612 surfaces, resulting in a level of details accurate for acoustics simulations. GA software describes the sound propagation by using ray-tracing methods. The water tightness of the model was verified, as seen in Figure 4.

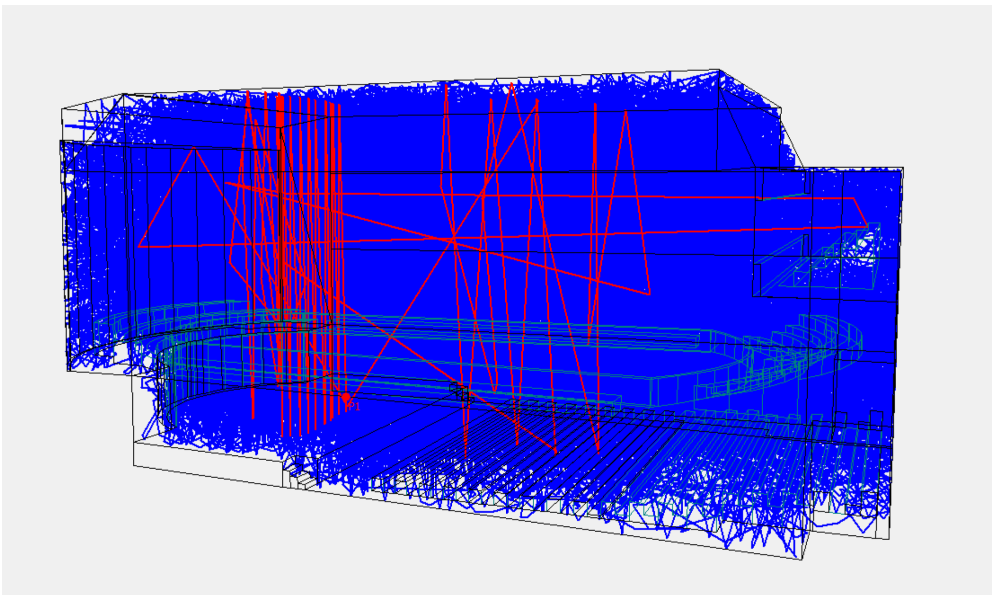

Figure 4. Water tightness of the model

The modeling process was carried out according to the state-of-the-art recommendations, and an omnidirectional point source of 60 dB is located in the middle and 2 m away from the stage front. Six different positions for receivers were also located, representing various audience locations. The source height was decided to be 1,5m, whereas the receivers' height was selected to be only 1,1m, resembling the eyesight of a human head when they sit on the seat (Figure 5).

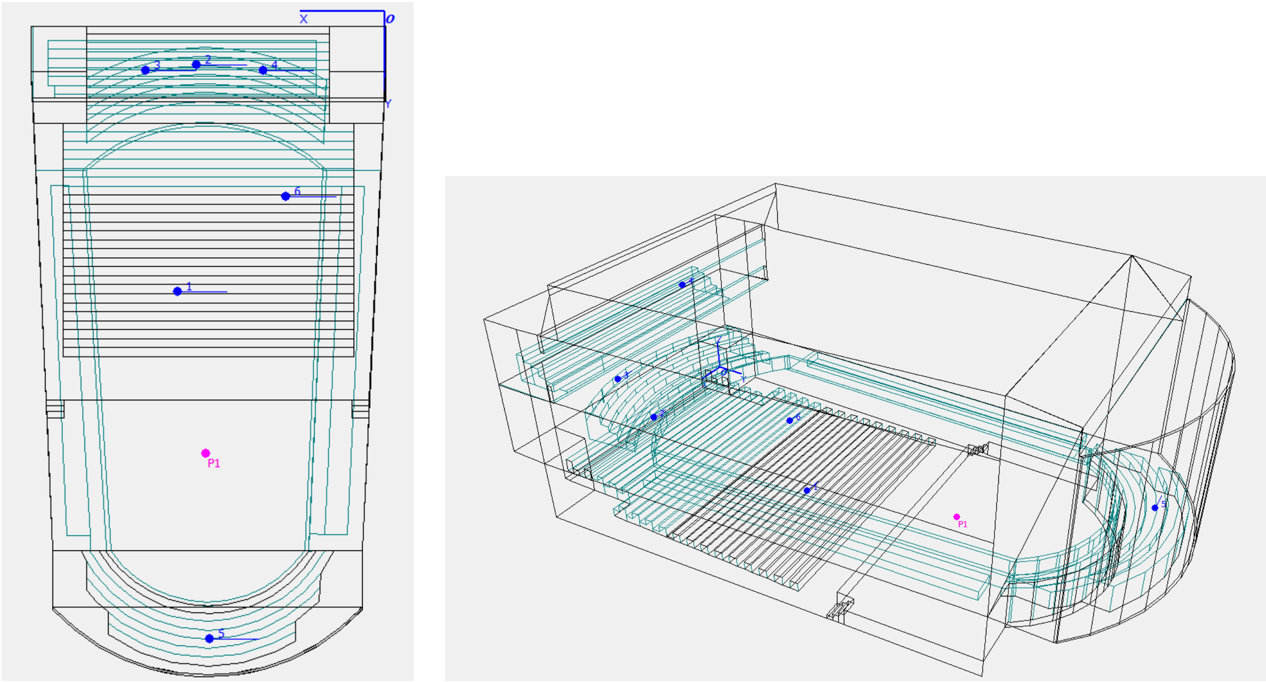

Figure 5. Position of source and receivers

Then existing materials, as shown in Table 2, are assigned respectively to the surfaces. When halls are used for classical music purposes, the Reverberation Time (T30) should be around 1,4-1,6 s as an optimum value. In contrast, when used for theatre and other speech performances, the range should lay 0,8-1,0s. The Speech Intelligibility Index (STI) should be larger than 0,6.

Table 2. Materials of the space

| **Surfaces** | **Materials** | **Absorption coefficient** | | | | | |
|---|---|---|---|---|---|---|---|
| | | ***125*** | ***250*** | ***500*** | ***1000*** | ***2000*** | ***4000*** |
| **Walls** | Stage Wall: veneered chipboard | 0,10 | 0,11 | 0,10 | 0,08 | 0,08 | 0,11 |
| | Chorus Wall: veneered chipboard | 0,10 | 0,11 | 0,10 | 0,08 | 0,08 | 0,11 |
| | Rear Wall (1): Wood panels + rockwool (10cm) + cavity (50cm) | 0,40 | 0,80 | 1,00 | 1,00 | 0,95 | 0,80 |
| | Rear Wall (2): Gypsum board + air cavity (2,5cm) + rockwool (10cm) | 0,10 | 0,07 | 0,05 | 0,05 | 0,04 | 0,04 |
| | Side Walls (1): Travertine veneering | 0,36 | 0,44 | 0,31 | 0,29 | 0,39 | 0,25 |
| | Side Walls (2): adjustable wooden panels (auditorium) | 0,40 | 0,8 | 1,00 | 1,00 | 0,95 | 0,80 |
| | Side Walls (2): adjustable wooden panels (concert) | 0,10 | 0,11 | 0,10 | 0,08 | 0,08 | 0,11 |
| **Floor** | Wooden flooring | 0,20 | 0,15 | 0,10 | 0,10 | 0,05 | 0,10 |
| **Ceiling** | Paster | 0,10 | 0,07 | 0,05 | 0,05 | 0,04 | 0,04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Other** | Balcony fronts: Plaster | 0,10 | 0,07 | 0,05 | 0,05 | 0,04 | 0,04 |
| | Door: Solid wood | 0,20 | 0,65 | 1,00 | 1,00 | 1,00 | 0,90 |
| | Audience: Upholstered concert hall chairs | 0,56 | 0,64 | 0,70 | 0,72 | 0,68 | 0,62 |

The results show that the hall has a reverberation time of 0,95s in the auditorium mode (Table 3)and 1,45s in the concert mode (Table 4) for mid frequencies. It is seen that the hall is in the optimum levels for both modes due to the adjustable wooden panels on the side walls. Moreover, in the hypothetical simulation, when only an inhomogeneous MPP with no fibrous material and different cavities (max cavity 80mm) is used instead of adjustable wooden walls, the T30 values lie in the optimum range for multipurpose halls (Table 5).

Table 3. (T30) values for Auditorium mode

| Existing | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000Hz | 4000 Hz |
|---|---|---|---|---|---|---|
| Reverberation Time (T30) Auditorium mode | 1,22 | 1,04 | 0,95 | 0,93 | 0,9 | 0,87 |

Table 4. (T30) values for Concert mode

| Existing | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000Hz | 4000 Hz |
|---|---|---|---|---|---|---|
| Reverberation Time (T30) Concert mode | 1,45 | 1,42 | 1,45 | 1,42 | 1,40 | 1,24 |

Table 5. (T30) values for hypothetical mode

| Hypothetical | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000Hz | 4000 Hz |
|---|---|---|---|---|---|---|
| Reverberation Time (T30) Multipurpose hall | 1,37 | 1,25 | 1,02 | 1,03 | 1,11 | 0,99 |

Calculations about (SPL(A)), indicating the sound pressure level perceived by the human ear as a subjective judgment of Sound Pressure Level, clearly show the decrease in the sound energy and intensity with the increasing distance. Table 6 shows the changes of SPL(A) for six receivers in the three modes: existing - Auditorium, existing (Concert), and hypothetical when inhomogeneous MPPs are used. The results show that there exist significant problems with the energy distribution, especially in the receivers positioned under the balconies (R2, R4).

Table 6. SPL(A) levels for the respective receivers in the three modes

| SPL(A) | Existing-Auditorium (dB) | Existing-Concert (dB) | Hypothetical (dB) |
|---|---|---|---|
| Receiver 1 | 43,4 | 44,2 | 43,7 |
| Receiver 2 | 37,4 | 38,1 | 37,7 |
| Receiver 3 | 40,1 | 42,4 | 41,2 |
| Receiver 4 | 38,0 | 40,9 | 39.4 |
| Receiver 5 | 42,0 | 43,1 | 42,5 |
| Receiver 6 | 41,2 | 42,4 | 41,8 |

The following evaluation was carried out about Sound Transmission Index (STI) value among the audience area. The STI of the hall is found to be between 0,48 to 0,60, which satisfies the range for fair speech intelligibility value, as the value lies between 0,45 and 0,60. The slight decrease in the central region can be explained by the sharp ceiling and lateral reflections, which will tend to decrease intelligibility. The slight increase in rear seats occurs due to highly absorbing materials, which tend to absorb sound energy and enhance intelligibility.

Table 7. STI values for the respective receivers in the three modes

| STI | Existing-Auditorium | Existing-Concert | Hypothetical |
|---|---|---|---|
| Receiver 1 | 0,58 | 0,52 | 0,55 |
| Receiver 2 | 0,60 | 0,54 | 0,57 |
| Receiver 3 | 0,58 | 0,49 | 0,53 |
| Receiver 4 | 0,55 | 0,48 | 0,51 |
| Receiver 5 | 0,59 | 0,51 | 0,55 |
| Receiver 6 | 0,57 | 0,50 | 0,54 |

# 4 Conclusions

This study aimed to investigate and introduce newly designed materials such as inhomogeneous MPPs in room acoustics applications instead of conventional materials. The simulations related to T30, SPL(A), and STI run in the case study showed that inhomogeneous MPPs can substitute large composite walls of considerable thicknesses by accurate design and an overall thickness of less than 10cm. Those materials pose a great potential in interior architecture as fiberless absorbers that can cope with the highest hygiene demands by having a tunable design according to the needs of the space.

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