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Musical Comfort Evaluation of The Natural Acoustics and Architectural Design of Three Performance Spaces in Kocaeli-Izmit

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Abstract

This study was conducted to evaluate the auditory comfort level of Western art music performances performed in natural acoustic conditions in multi-purpose performance halls, which are widely preferred today, on the listener. In this context, first the reverberation time, one of the acoustic comfort parameters, is expressed and the Sabine formula, which is the empirical method used in the study, is explained. Subsequently, the table "absorptivity coefficients of various materials at different frequencies" is presented, as it will be used in the calculation of reverberation time, and the graph "recommended optimum reverberation time for volume-dependent speech and music" is presented to make comparisons at the end of the calculation. Then, information was given about the geometry of performance spaces and acoustic defects that may occur due to structural errors in closed volumes were explained. After explaining why this study was conducted in Izmit district of Kocaeli province, the selection criteria of the three selected performance halls were explained. After giving brief information about the historical background of each place, the reverberation time of the halls was calculated. As a result of the calculations, the acoustic comfort conditions of the halls in natural acoustics and when used for musical purposes are presented comparatively in the table, and it has been revealed that all three halls will not provide a suitable acoustic comfort experience to the audience. The improvement suggestions that can be made to ensure acoustic comfort during the Western classical music performance without the use of an electro-acoustic system are presented in tables for each hall.

Keywords:
Acoustic comfort, Concert hall, Interior, Performance hall, Reverberation time.

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INTRODUCTION

Performance halls are important spaces for the execution of entertainment and cultural activities, which are expressions of the values that constitute the social fabric of society. Multipurpose performance halls, which can host a multitude of events in bustling and dynamic cities, are preferred over single-purpose auditoriums because of their versatility and economic feasibility, effectively serving as 'social facilities' (Gao et al., 2020: 1).

There are numerous examples of multipurpose halls around the world that employ automation systems. For instance, depending on the genre of music to be performed at the Pier Boulez Saal (Pierre Boulez Saal, 2020), solutions are produced by reducing the number of seats. Another example is the "The Concert Hall of Aarhus", equipped with panels that transform the hall within seconds with an automation system, ensuring optimum sound experience and performance for various music styles from choir to chamber music, from band performances to rock concerts, with ideal reverberation time in every frequency band without visual changes (Flex Acoustics, 2024; Niels w. Adelman-Larsen, 2022).

The aim of this study is to illustrate the status of three multipurpose halls in Izmit, and to shed light on the importance of acoustic values in future hall designs. While there are examples of multipurpose halls in the world that are designed to serve both techno and natural acoustic sounds, there are only techno-acoustic hall designs in Izmit that can transform according to the genre of music using the automation systems mentioned above. Feasible solution proposals for implementing natural acoustic capabilities have been generated based on the results of the study. The selection of performance halls was based on the following criteria:

- Being designed as spaces completely closed to atmospheric effects and environmental noise,
- Being located in central areas of the city, where residents can easily access,
- Having a seating capacity of at least 400 considering the density of the urban population,
- In addition to different usage purposes, having hosted Western music performances.

Halls meeting these criteria have been selected as Sabanci Cultural Centre, Suleyman Demirel Cultural Centre, and Kocaeli Congress Centre, listed according to their construction years.

LITERATURE REVIEW

According to the literature review on the subject, Ozis and Vergili, in their 2008 study, stated that concert halls, as one of the primary venues for music listening, face quality demands from musicians, conductors, and listeners (Ozis & Vergili, 2008: 35). Von Joachim Mischke, in a 2017 news report, wrote that in a concert hall opened in Hamburg in 2017,

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listeners expressed their dissatisfaction by saying, "We can't hear anything from here" (Mischke, 2024).

In his 2008 study, Vergili emphasized that the reverberation time calculation is a useful indicator for determining the average acoustic properties of enclosed spaces (Vergili, 2008: 10). Kurtay et al., in their 2021 study, stated that various formulas have been developed to calculate reverberation time, but the Sabine equation is particularly preferred in the context of room acoustics (Kurtay et al., 2021: 2072).

Ahnert and Schmidt argued that reverberation time calculations should be conducted separately for speech and music, depending on the volume (Ahnert & Schmidt, 2024).

In his 2006 study, Long identified the acoustic defects that need to be avoided for musical purposes and outlined performance criteria for acoustic comfort (Long, 2006: 589, 697-706). Barron, in his 2010 study, wrote that the accepted standard for stage height in halls designed for musical purposes should be at least 50 centimeters above the ground floor level (Barron, 2010: 59). Maekawa, in a 2011 study, stated that the optimum volume per person for venues designed for concerts should be between 8 and 10 m^3 (Maekawa et al., 2011).

Toktas, in his 2011 study, emphasized the importance of designing the stage area as a reflective surface to ensure adequate early reflections in the listening area (Toktas, 2011: 9). Similarly, Turk, in his 2011 study, stated that the maximum distance between the sound source and the farthest listener should not exceed 40 meters, and to prevent a narrowing hearing angle toward the back rows, the audience area should be elevated with an increasing slope (Turk, 2011: 28).

Elbas, in his 2016 study, stated that the design of reflective ceilings is one of the most important acoustic features of a theater or auditorium (Elbas, 2016: 26). Everest and Pohlmann, in their 2000 study, advised against balcony designs where the depth exceeds twice the height, as this would result in inadequate reflected sound levels for audience members seated beneath the balcony (Everest & Pohlmann, 2000: 389).

METHODOLOGY AND METHODS

The acoustic comfort situation of the chosen three performance halls will be examined first from a design perspective. Criteria such as the suitability of the volume per person, the materials used in the stage portal and the side and rear walls of the audience area, the presence of parallel walls or concave design in the audience area, the inclination of the parquet floor, the distance of the rear-most listener to the stage, the height of the stage from the ground, the ceiling material, and the balcony design will be compared with accepted standards (Long, 2006: 697-706) to make determinations. Subsequently, the empirical method, namely the Sabine reverberation time formula, will be used to calculate the reverberation time of the halls. Reverberation is defined as the time it takes for the sound intensity in a closed space to decrease by 60 dB from its original level in seconds (Everest & Pohlmann, 2009: 153). This is because the sound continues after it has decreased by 60 dB however the brain cannot analyze or process it. Nowadays, the calculation of reverberation time is a useful indicator for establishing the average acoustic properties of closed spaces and, in addition, is a value that can be easily estimated from the absorbency characteristics of the materials used in the volume and the geometry of the hall (Vergili, 2008: 10). Therefore, in this study, the reverberation times of the three selected performance halls will be calculated. Various formulas have been developed to calculate reverberation time. These include the Sabine, Norris-Eyring, Millington-Sette, and Stephens & Bate methods, as well as the Hopkins-Striker and Fitzroy methods, which are used differently from these equations. However, particularly within the scope of volume acoustics, the Sabine equation has been preferred (Kurtay et al., 2021: 2072).

RT_{Sabin}= 0.161 x V/A

RT= Reverberation time (sn)

V= Volume (m^3)

A= Absorption (m^2 sabin)

0.161= Empirical constant (sn/m)

The average absorption coefficient of each material used in reverberation time calculations will be included in the calculations based on Table 1.

Table 1. The absorption coefficients of various materials at different frequencies.

Material	125 Hz	500 Hz	2000 Hz	Average (NRC)
Parquet (Polished wood surface)	0.03	0.06	0.10	0.06
MDF (13mm)	0.11	0.22	0.30	0.21
Acoustic Panel (30 cm thick with 5cm air gap)	0.21	0.19	0.06	0.15
Linoleum	0.02	0.03	0.04	0.03
Acoustic Panel (Without air gap)	0.42	0.22	0.06	0.23
Synthetic Carpet	0.03	0.07	0.29	0.13
Rock wool perforated absorber material (5 cm thickness with 5 cm gap)	0.90	0.94	0.98	0.94
Perforated acoustic plasterboard material	0.60	0.70	0.80	0.70
Soft seat with human sitting	0.25	0.40	0.45	0.37

In the reverberation time calculations, the optimum reverberation time of the spaces will be determined by using Figure1.

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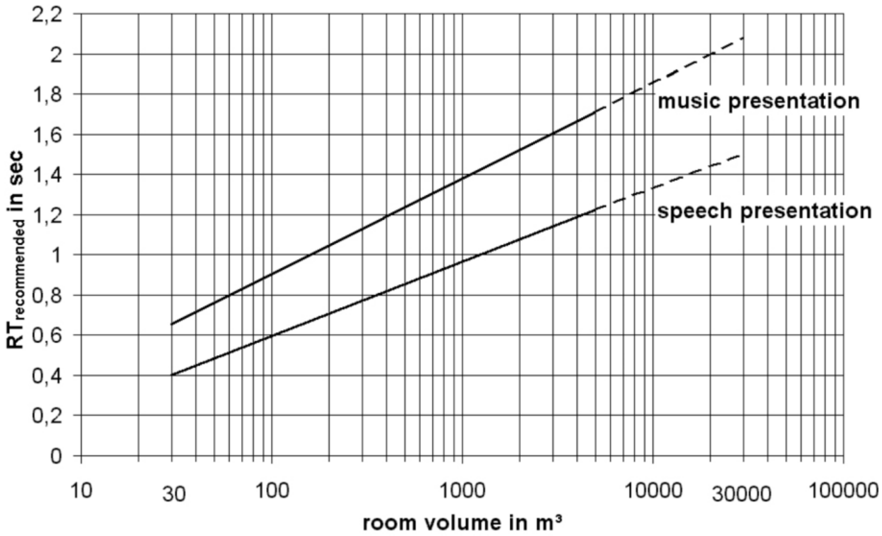

Figure 1. The Satellite Image of Recommended reverberation time for volume-dependent speech and music (Ahnert & Schmidt).

Salon volume, being directly related to the reverberation time, is one of the key variables within the design parameters that significantly influence the acoustic properties of the hall. The most suitable volume is one that does not require additional absorption beyond what the audience provides. Since the total absorption in volumes is largely influenced by the number of listeners, this ratio can be a significant measure to consider in the initial stages of design (Budak, 1994: 55). In halls intended for concerts, the optimum volume per person is typically in the range of 8-10 m^3 (Maekawa et al., 2011: 234).

The geometry of performance halls is directly related to their acoustic properties, therefore the architectural plans of these spaces should be examined in congruent forms. According to the deductions made from the literature review, the architectural plan variations of halls can be categorized into seven headings. These are: rectangular (shoebox), fan-shaped, horseshoe, arena, hexagonal (diamond), terraced (vineyard), and irregular plans for those beyond the mentioned six plan types.

Rectangular plan halls are advantageous for providing rich lateral reflections, but parallel surfaces may cause the pronounced echo seen in Figure 2. Examples of rectangular plan concert halls, considered among the top three performance halls worldwide by nearly everyone in the Western world, include Het Concergebouw Main Hall, Grosser Musikvereinssaal, and Boston Symphony Hall (Beranek, 2004: 425, 47). Fan-shaped halls provide excellent sight lines and acoustics while offering a spacious audience area. An example of this design is Richard Wagner's Festspielhaus, designed to allow the composer to hear his own compositions as desired. Although the spatial form prevents pronounced echoes on side walls, sound reflected from the rear wall may reach the front of the hall with significant delay. This issue can be mitigated by covering the back wall of the audience area with absorbent material. Horseshoe-shaped halls provide good sight lines and a sense of proximity to the sound source. The presence of numerous boxes and rich interior decor contributes to distributing sound favorably, concealing possible acoustic flaws, and providing an appropriate ratio for direct reverberate sound. However, the presence of many listeners and boxes may lead to excessive sound absorption, thus achieving a relatively lower reverberation time suitable for opera (Kamisiński, 2010: 78). Halls with horseshoe plans, such as Usher Hall in Edinburgh, may suffer from adverse effects on acoustic comfort due to the concave shape of the rear wall, which causes reflected sounds to converge at a single point. This issue can be addressed by using absorbent material on rear surfaces (Ozis & Vergili, 2008: 39). The defining feature of the arena plan is that the orchestra is surrounded by seating. As evident from events held in halls like Pierre Boulez Saal, the advantage of this plan lies in fostering the greatest intimacy between the audience and performers. However, it creates a balance issue where if a listener purchases a seat facing the back of a musician positioned on stage, their spatial perception will be reversed, resulting in a loss of acoustic balance according to psychoacoustics (Teke, 2012: 7). Hexagonal plans, besides providing visual advantages, are among the useful forms due to the high level of lateral reflections. However, similar to rectangular shapes, the acoustic flaw caused by parallel walls is a disadvantage of this form. Therefore, it is advisable to avoid shapes such as regular hexagons, squares, or octagons (Long, 2006: 700). Bunka Kaikan Main Hall in Tokyo serves as an example of halls with a hexagonal plan. The terraced plan, first exemplified by the Berliner Philharmonie, opened in 1963. This plan, similar to the arena form, brings the audience closer to the performers by encircling the stage with seating, albeit offering a larger audience capacity. Moreover, instead of balconies, interconnected terraces with varying heights are preferred in this type of hall. The front and side surfaces of these terraces are carefully designed to provide early reflections to the audience. Another significant feature of these halls is the time it takes for direct sound to reach the listener. Due to the hall's form, sound reaches all points in approximately the same time, resulting in a similar initial transportation delay (ITD) throughout the hall (Ozis & Vergili, 2008: 39). Examples of halls with irregular plans, deviating from the mentioned architectural plans, include Beethoven Saal designed in the form of a grand piano (Kultur & Kongresszentrum Liederhalle, 2024) or Marian Anderson Hall designed resembling a cello body (Ensemble Arts Philly, 2024).

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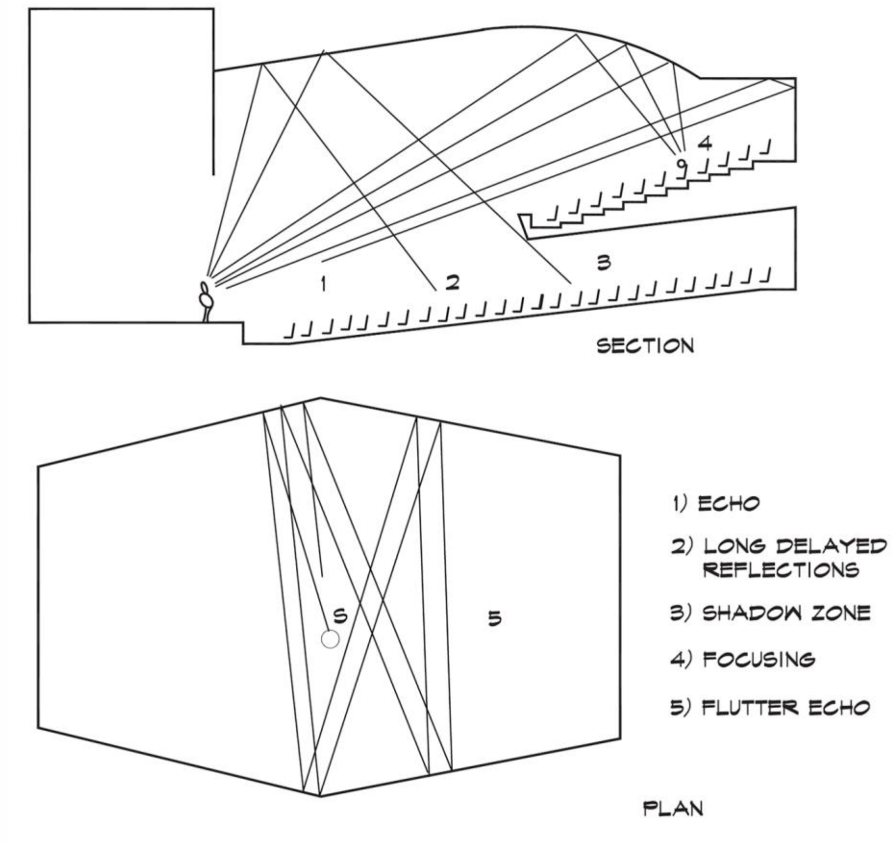

Figure 2. Acoustic flaws that may occur in performance halls (Long, 2006: 589).

In performance halls, particularly the reflective design of the stage area is important for adequate early reflections in the audience area (Toktas, 2011: 9). As the distance from the source increases, according to the inverse square law, the direct sound reaching the listener will decrease inversely with the square of the distance. For instance, the direct sound level for a listener 100 meters away from the orchestra will be half as much as that for a listener 30 meters away from the orchestra. Therefore, the distance between the source and the listener are crucial for ensuring sufficient direct sound reaching the listeners. Studies have indicated that this distance should not exceed 40 meters (Turk, 2011: 28). When determining the stage floor height, it is known that having the stage at a certain height from the seating area ensures visual comfort for the audience and facilitates easier access to direct sound for the audience. For music-oriented halls, the accepted criterion for stage height is at least 50 centimeters above the ground floor level. Heights exceeding 100 centimeters may result in parts of the orchestra not being visible to the audience (Barron, 2010: 59). It is crucial for the point where the seats are located to provide a direct view of the stage. Tilting the audience area is preferred for this purpose. However, if the tilt is fixed, towards the rear seats, hearing impairment may decrease. This may cause more direct sound to be absorbed in the front rows and reach the rear rows. If the audience area is elevated with an increasing tilt, this issue can be resolved. In this case, each row of the audience will have equal viewing and hearing comfort (Turk, 2011: 28). Additionally, for providing an ideal line of sight and facilitating direct sound transmission, it is appropriate to position the seats staggered.

In a hall intended for music, the audience desires to feel enveloped by sound that comes from all directions. This sensation is not solely achieved through lateral reflections provided by side walls. In addition to lateral reflections, there is a need for reflective, diffusive, and absorptive materials to be used on the ceilings. These reflective surfaces, in wide and high rooms, work to minimize the time delay difference between indirect and direct sounds. Otherwise, reflections arriving with a significant time difference can be perceived as echoes by the audience (Ergin, 2014: 62).

Another point to consider in performance halls is the design of the balconies. Balcony designs should avoid depths exceeding twice their height (Everest & Pohlmann, 2000: 389). Otherwise, individuals in the audience areas beneath the balconies may not feel adequately enveloped by sound or may not receive sufficient reflected sound. Alternatively, as indicated in Figure 2, acoustic shadowing, a flaw in the balcony area, may occur.

IDENTIFICATION OF EXPERIMENTAL AREAS

According to the 2022 data from the Turkish Statistical Institute (TUIK), Kocaeli ranks among the top 10 most populous cities in Turkey and is one of the fastest-growing provinces, particularly in terms of industrialization (TUIK, 2024). One of the most significant industrial establishments in Izmit, which has hosted numerous industrial facilities throughout the Republican era, is the Izmit Paper Factory, which was established in 1934. The factory was completely closed in 2005 and transferred to the ownership of Kocaeli Metropolitan Municipality, after which a transformation project called 'Seka Park' has been in progress (Oral Aydin & Comlekcioglu Kartal, 2020: 23). The formation of the Kocaeli Congress Centre, one of the performance spaces examined in this study, is related to this transformation. The other two venues are the Sabanci Cultural Centre, constructed by the Sabanci Foundation, one of the leading actors in the country's industry, and the Suleyman Demirel Cultural Centre, located within the Yahyakaptan Housing Complex, a project similar to the mass housing initiatives implemented in every industrial city, carried out by Emlak Bank.

Sabanci Cultural Centre

One of the largest cultural centres provided by the Sabanci Foundation, the Sabanci Cultural Centre was designed by architect Hayati Tabanlioglu, with architectural drawings completed by architects Mehmet Tepeler, Levent Atay, and Mete Tepeler. The Cultural Centre opened on December 3, 1988, but was closed in March 2020 to prevent the spread of the COVID-19 pandemic. In September 2020, activities at the Sabanci Cultural Centre were suspended due to collapses detected in the foyer area of the building. The hall, which has a seating capacity of

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606, five backstage areas, and a single balcony, has not been given a specific name. However, it is referred to as the 'Grand Hall' in posters and ticket sales for concerts, theater performances, and similar events. For convenience in this study, the hall will also be referred to as the 'Grand Hall.' The plan for the Grand Hall at the Sabanci Cultural Centre was obtained from the website of the Kocaeli Provincial Directorate of Culture and Tourism, while the section drawing was provided, with permission, from the archives of Mete Yapi Incorporated.

Suleyman Demirel Cultural Centre

The Grand Hall, with a seating capacity of 514, located in the Suleyman Demirel Cultural Centre, which was opened on September 22, 1998, and for which Prof. Dr. Selma Kurra (dB-KES Engineering, 2022) provided acoustic consultancy, will be examined within the scope of this study. There is no digital plan or section available for the Grand Hall; only the visual representation of the plan and sections shown in Table 3 and the AA section scanned into a computer format exist. The plan and section show 602 seats, but after renovations carried out in 2022, the number of seats was reduced to 475. No plan or section drawing depicting the renovation process or its outcome has been produced. The drawings used in this study were obtained from the Directorate of Building Control of the Kocaeli Metropolitan Municipality.

Kocaeli Congress Centre

The construction of the congress centre, designed by Ozer/Urger Architecture, began on November 19, 2017, and was completed in 2020. The Akcakoca Auditorium, which will be evaluated for its acoustic comfort in this study, has a seating capacity of 1,301 and was designed to host concerts and theater performances. The auditorium features two backstage rooms and a single balcony. The drawings used in this study were obtained from the Izmit Metropolitan Municipality Directorate of Building Control.

DATA ANALYSIS, CASE STUDY, DISCUSSION

In this section, the reverberation times of the performance venues located within the Sabanci Cultural Centre, Suleyman Demirel Cultural Centre, and Kocaeli Congress Centre will be calculated based on their opening dates. The calculations will be conducted using Table 1 and the Sabine formula, aiming for the acceptable reverberation time as shown in Figure 1, according to the volume of each venue.

Sabanci Cultural Centre

The volume of the Grand Hall is 2568 m^3. Utilizing the optimum values from Figure 1, the acceptable reverberation time for a concert hall of this volume appears to be ~1.55 seconds.

There are 9 panels on each side wall, and each panel is made of reflective material with a wooden surface and polished finish. The length of these panels is approximately 1.70 m and the width is measured 1.65 m. Therefore, the area of one reflective panel is calculated as 1.70 m x 1.65 m = 2.8 m^2. When calculating the total area of the panels on opposite walls, considering 9 panels on each side, the total area is 2.8 m^2 x 9 panels x 2 walls = 50.4 m^2.

Out of the 9 panels with a length of ~1.70 m on each side wall, 3 panels have reflective panels installed on them. The length of these panels is 5,5 m, and the width is 1.65 m. Hence, the area of one reflective panel is calculated as 5.5 m x 1.65 m = 9.075 m^2. When considering the area covered by 3 panels on opposite walls, the total area of the reflective surface for 6 panels is 9.075 m^2 x 3 panels x 2 walls = 54.45 m^2.

The total reflective area on the side walls, denoted as $S_{\text{wall reflective panels}}$, is calculated as 104.85 m^2, which is the sum of 50,4 m^2 and 54,45 m^2. The absorbing material on the side walls consists of MDF covered with acoustic fabric. To calculate the area of the absorbing panels on the side walls, subtract the area of the reflective panels from the total area of the side walls:

$S_{\text{wall absorbing panels}} = 222.75\ m^2 - (50.4\ m^2 + 54.45\ m^2) = 117.9\ m^2$.

A sound-reflective surface treatment is applied to the ceiling. Aluminum-covered wooden panels with voids are used for this purpose. The area of the ceiling is determined to be 320 m^2, denoted as S_{ceiling}. The absorption coefficient αceiling is assumed to be 0.15 Sabins. The product of S_{ceiling} and α_{ceiling} is calculated as follows:

$S_{\text{ceiling}} \times \alpha_{\text{ceiling}} = 320\ m^2 \times 0.15 = 48\ m^2$ Sabins.

Hence, the absorbing area on the ceiling, denoted as A_{ceiling}, is 48 m^2 Sabins.

The total number of seats in the auditorium is 606. Assuming each seat occupies an area of 1 m^2, denoted as S_{seats}, and considering the presence of 606 occupants during full occupancy, the absorption coefficient per person, denoted as αseat, is assumed to be 0.37 Sabins. The product of S_{seats} and αseat is calculated as follows:

$S_{\text{seats}} \times \alpha_{\text{seat}} = 606\ m^2 \times 0.37 = 224.22\ m^2$ Sabins.

Thus, the absorbing area due to the seats, denoted as A_{seats}, is 224.22 m^2 Sabins

The area of the circulation axis outside the seating area on the floor is approximately 60 m^2, denoted as $S_{\text{circulation axis}}$. Considering that the linoleum material used on the floor has an absorption coefficient of 0.03 Sabins, denoted as αcirculation axis, the absorbing area due to the circulation axis, denoted as $A_{\text{circulation axis}}$, is calculated as follows:

$S_{\text{circulation axis}} \times \alpha_{\text{circulation axis}} = 60\ m^2 \times 0.03 = 1.8\ m^2$ Sabins.

Hence, $A_{\text{circulation axis}}$ is equal to 1.8 m^2 Sabins.

The six boxes located on the audience rear wall, positioned on the right and left sides, with heights ranging from 1.10 m and widths varying from 1.40m to 1.78 m to 1.10 m outward from the center, will act as resonators across a wide frequency band. A resonator, in this context, connects to the cavity surrounding it through a narrow opening

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called a neck within the wall, forming an airspace where sound waves propagate. While primarily serving decorative purposes, or acting as sound absorbers at very low frequencies, they can also behave as sound absorbers in volumetric applications. By virtue of their ability to behave as sound absorbers at low frequencies, they help eliminate the need for absorption surface treatments in volume applications, thus economically facilitating reverberation control (Erol, 2006: 83). Consequently, they will neither positively nor negatively affect the reverberation time in the volume and will not be included in the absorption calculations.

The rear wall is equipped with reflective and absorptive panels in equal proportions and in a rhythmic pattern. The width of the rear wall is calculated as 24.6 m, with a height of 7.2 m. Therefore, the total area of the rear wall, denoted as $S_{rear\ wall,}$ is 177.12 m^2. Since half of this area is covered with reflective material and the other half with absorptive material:

$S_{rear\ wall\ reflective} = 88.56\ m^2$

$S_{rear\ wall\ absorptive} = 88.56\ m^2$

Considering these values, the calculation of the full occupancy scenario of the hall, without considering air absorption as a significant variable, will be as follows:

Total Reflective Material:

$S_{side\ wall\ reflective\ panels} + S_{rear\ wall\ reflective\ panels} = 104.85 + 88.56 = 193.41\ m^2$

$A_{reflective} = 193.41\ m^2$ $\alpha_{reflective} = 0.06$ Sabins

$A_{reflective} = 193.41\ m^2 \times 0,06 = 11.6\ m^2$ Sabins

Total Absorptive Material:

$S_{side\ wall\ absorptive\ panels} + S_{rear\ wall\ absorptive\ panels} = 117.9 + 88.56 = 206.46\ m^2$

$A_{absorptive} = 206.46\ m^2$ $\alpha_{absorptive} = 0.21$ Sabins

$A_{absorptive} = 43.3566\ m^2$ Sabins

$A = A_{reflective} + A_{seats} + A_{ceiling} + A_{circulation\ axis} + A_{absorptive}$

$= 11.6 + 224.22 + 48 + 1.8 + 43.3566$

$= 328.9766\ m^2$ Sabins

$RT = 0.161 \times V / A$

$RT = 0.161 \times 2568 / 328.9766$

$RT = 1.25$ sec.

Suleyman Demirel Cultural Centre

The volume of the Grand Hall is 3150 m^3. Utilizing the optimal values of reverberation time from Figure 1, the acceptable reverberation time for a concert hall of this volume appears to be ~1.6 seconds.

Due to the preference for a sloped floor but a flat ceiling, the side walls form a trapezoidal shape. Accordingly, the area of one side wall is 157.5 m^2, and since there are two side walls, a total area of 315 m^2 is calculated. Both side walls are designed with a portion being reflective and a portion absorptive. For the reflective material on the side wall, an area of 65 m^2 is chosen. The reflective coefficient of the polished surface of smooth wood used as the reflective material is 0.06 Sabins.

A_1 (For the reflective portion of the side walls): S_1=65 m² α_1=0.06 Sabins

$S_1 \times \alpha_1 = 65 \times 0.06 = 3.9$ m² Sabins

$A_{\text{side walls reflective}}$ = 3.9 m² Sabins.

The area of the portion of the side walls chosen for absorption is 250 m². The selected absorptive material is seamless acoustic paneling, with an absorption coefficient of 0,23 Sabins.

A_{1-1} (For the absorptive portion of the side walls): S_{1-1}=250 m² α_{1-1}=0.23 Sabins

$S_{1-1} \times \alpha_{1-1} = 250 \times 0.23 = 57.5$ m² Sabins

$A_{\text{side walls absorptive}}$ = 57.5 m² Sabins

In the ceiling area, from the region up to the lighting fixtures, absorptive material was used, while reflective material was employed from the point where the lighting fixtures begin to the stage boundary. In this case,

A_2 (Ceiling Absorptive): S_2=145 m², α_2=0.23 Sabins

$S_2 \times \alpha_2 = 145 \times 0.23 = 33.35$m² Sabins

$A_{\text{absorptive ceiling}}$ = 33.35m² Sabins

$A_{2\text{-}1}$(Ceiling reflector) $S_{2\text{-}1}$=330 m2 $\alpha_{2\text{-}1}$=0.06 Sabins

$S_{2\text{-}1}$ x $\alpha_{4\text{-}1}$= 330x 0.06=19,8 m² Sabins

$A_{2\text{-}1}$ = 19.8 m² Sabins

$A_{\text{reflective ceiling}}$ = 19.8 m² Sabins

The total number of seats in the hall is 475. Each seat is assumed to occupy an area of 1 m². Since the examination is based on a full occupancy scenario, the absorption coefficient per person will be taken as 0.37 Sabins.

A_3 (For Human and Seat Absorption): S_3=475 m², α_3=0.37 Sabins

S_3 x α_3= 475x0.37=175.75 m² Sabins

A_{seats} = 175.75 m² Sabins

On the floor, the area of the circulation axis, including the stairs and corridor outside the seating area, is 400 m². The absorption coefficient of the carpet used here is 0,13 Sabins.

$S_{\text{circulation axis}}$ x $\alpha_{\text{circulation axis}}$ = = 400x0.13=52 m² Sabins

$A_{\text{circulation axis}}$ = 52 m² Sabins

On the wall behind the audience, there are 6 windows belonging to the sound and light room, each measuring 1162 cm in width and 80 cm in height. Since 4 of these windows are completely open, without glass, they will act as resonators over a wide frequency band range, and therefore, they will not have a positive or negative effect on the reverberation time in the volume. Therefore, their absorption will not be included in the calculation.

On the back wall, absorbent material has been used. The absorption coefficient of the air used is 0.23 Sabins.

A_4 (Back Wall) S_4= 120 m² α_4 =0.23 Sabins

S_4 x α_4=120x0.23= 27.6 m² Sabins

$A_{\text{back wall}}$ = 27.6 m² Sabins

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According to these values, the calculation of the condition when the Grand Hall is fully occupied will be as follows, without taking air absorption as a significant variable:

$A = A_{side\ walls\ reflective} + A_{side\ walls\ absorptive} + A_{absorptive\ ceiling} + A_{reflective\ ceiling} + A_{seats} + A_{circulation\ axis} + A_{back\ wall}$

= 3.9+ 57.5+33.35+19.8+175.75+52+27.6

= 369.9 m^2 Sabins

RT = 0.161 V/A

RT = 0.161 x 3150/369.9

RT = 1.37 sec.

Kocaeli Congress Centre

The volume of the Akcakoca Auditorium is 11.074.986 m^3. Utilizing the optimal values from Figure 1, the acceptable reverberation time of a concert hall in this volume appears to be approximately 1.85 seconds.

The total area of the side wall panels is 551 m^2. The back of these panels consists of perforated material made of 5 cm spaced rock wool, with an absorption coefficient of 0.94 Sabins.

$A_{side\ walls}$= 551x0.94= 517.94 m^2 Sabins

For the ceiling, 4 circular perforated acoustic plaster panel materials are preferred. The total area of these reflective ceiling panels is 654.73 m^2. The absorption coefficient of the material is 0.70 Sabins.

$A_{ceiling}$ = 654.73 x 0.70= 458.311 m^2 Sabins

The total number of seats in the hall is 1300. It is assumed that each seat occupies an area of 1 m^2. Since the examination is conducted during full occupancy of the hall, the absorption coefficient per person will be taken as 0.37 Sabins for the 1300 seated individuals.

Total area for absorption due to audience:

A_{seats}= 1300 x 0.37= 481 m^2 Sabins

The area of the circulation axis on the ground floor is 56 m^2. The absorption coefficient of the carpet used here is 0,13 Sabins.

$A_{circulation\ axis}$= 56 x 0.13= 7.28 m^2 Sabins

The area of the rear wall located behind the audience is 95.475 m^2. Since the same material as the reflective side walls is used, the absorption coefficient is 0.94 Sabins.

$A_{back\ wall}$= 95.475 x 0.94= 89.7465 m^2 Sabins

According to these values, the calculation of the reverberation time of the auditorium when fully occupied, without considering air absorption as a significant variable, would be as follows:

$A = A_{side\ walls} + A_{ceiling\ +\ Aseats} + A_{circulation\ axis} + A_{back\ wall}$

= 517.94+458.311+481+7.28+89.7465

= 1554.2775 m^2 Sabins

RT = 0.161 V/A

RT = 0.161 x 11074.986/1554.2775

RT = 1.147 sec.

ICONARP – Volume 12, Issue 2 / Published: 31.12.2024

In this case, the current reverberation time of the three performance venues and the expected reverberation time are represented in Table 2:

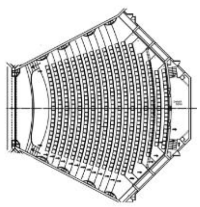
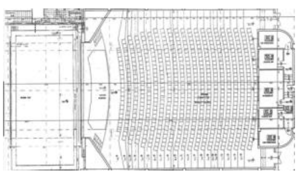
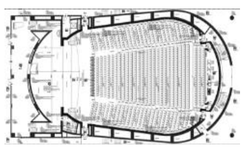
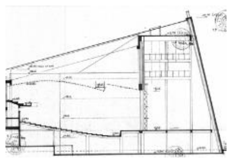
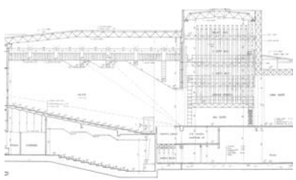
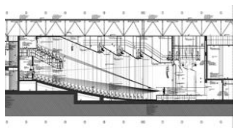
Table 2. Current RT and optimum RT values of three selected performance halls

Halls	Current RT values of halls	Optimum RT values
Sabanci Cultural Centre Grand Hall	1.25 s	1.55 s
Suleyman Demirel Cultural Centre Grand Hall	1.37 s	1.6 s
Kocaeli Congress Centre Akcakoca Auditorium	1.147 s	1.85 s

EVALUATION OF PERFORMANCE HALLS IN TERMS OF DESIGN FEATURES

For the evaluation based on the architectural features of the three selected performance venues, an analysis of each venue's architectural plan, seating capacity, acoustic design considerations, audience area, stage height, balcony features, area and nature of surface materials used in the hall, and other design characteristics has been examined in light of the theoretical information provided in Section Two. These have been presented comparatively in Table 3.

Table 3. Investigation of Three Performances Halls in Terms of Design Features

Performance Halls / Design Criteria	Sabanci Cultural Centre Grand Hall	Suleyman Demirel Cultural Centre Grand Hall	Kocaeli Congress Centre Akcakoca Auditorium
Plan			
AA Section			
Format	Hexagon (Diamond)	Rectangular (Shoe box)	Horseshoe
Session Capacity	606	475	1300
Volume per capita (V/N) ratio	4.23 m^3 NOT SUITABLE for concert purpose.	6.63 m^3 NOT SUITABLE for concert purpose.	8.5 m^3 SUITABLE for concert purpose.
Stage portal	Covered with reflective material: The listener area will receive sufficient early reflection.	Covered with absorbing material: The listener area will not receive sufficient early reflection.	Covered with reflective material: The listener area will receive sufficient early reflection. SUITABLE

DOI: 10.15320/ICONARP.2024.309

	SUITABLE	NOT SUITABLE	
Side wall material	Of the 9 panels on a single wall, 6 of them are covered with acoustic fabric on MDF, i.e., absorptive; 3 of them are covered with lacquered material on wood, i.e., reflective. SUITABLE	One of the two materials used is a treated wood reflective panel, the other is a hollow acoustic panel. SUITABLE	Highly absorbent material with 5 cm hollow back and 5 cm stone wool perforations. NOT SUITABLE
The presence of parallel side walls	None, so there is no problem of emphatic echo. SUITABLE	None, so there is no problem of emphatic echo. SUITABLE	None, so there is no problem of emphatic echo. SUITABLE
Concave form presence	None, so there is no acoustic focusing or sound creep. SUITABLE	None, so there is no acoustic focusing or sound creep. SUITABLE	None, so there is no acoustic focusing or sound creep. SUITABLE
Feature of ceiling panels	Reflective material SUITABLE	The area up to the lighting elements is absorptive, and reflective material is used from the beginning of the lighting elements to the stage portal. SUITABLE	Reflective material SUITABLE
Parter	Constant inclination: The hearing angle towards the rear seats will be reduced. NOT SUITABLE	Constant inclination: The hearing angle towards the rear seats will be reduced. NOT SUITABLE	Increasing slope: The hearing angle towards the rear seats will not be reduced. SUITABLE
Seating position	Surprising: FIT for providing an ideal field of view and direct sound transmission. SUITABLE	Surprising: FIT for providing an ideal field of view and direct sound transmission. SUITABLE	Surprising: FIT for providing an ideal field of view and direct sound transmission. SUITABLE
Stage height	111 cm NOT SUITABLE	114 cm NOT SUITABLE	90 cm SUITABLE
Source – farthest listener distance	18.5 m: FIT for adequate direct sound reaching the listener. SUITABLE	23.3 m: FIT for adequate direct sound reaching the listener. SUITABLE	35 m: FIT for adequate direct sound reaching the listener. SUITABLE
Balcony Depth D ≤ 2H	300 cm ≤ 500 cm No sound shadow is created. SUITABLE	No Balcony	760 cm ≤ 710 cm Sound shadow occurs. NOT SUITABLE

CONCLUSIONS AND RECOMMENDATIONS

This study highlights the importance of designing multipurpose halls with attention to acoustic criteria from both musician and audience perspectives. The reaction of audiences in a concert hall that was opened in Hamburg in 2017, who expressed dissatisfaction with the acoustics, supports this notion (Mischke, 2024). Similarly, the remarks of Serdar Yalcin, the resident conductor of the Istanbul State Opera and Ballet, about a private multipurpose hall in Istanbul provide another supportive example: “Everything has been well thought out acoustically. There is no 90-degree angle; the sound hits the boards and reflects. The acoustic feature is very suitable for performances such as choir, chamber music, and recitals. It is especially suitable for chamber theater, so much so that even whispers can be heard by the audience. It is important for the sound to be evenly distributed throughout the hall; thus, for small to medium-sized performances, the acoustics of this hall meet all the desired qualities. Another supportive comment comes from violinist Seda Subasi: "... it has suitable acoustics for classical music performances with small ensembles. The performer can better control their voice because the sound is heard at the same volume from every part of the hall (including above the stage). This acoustic provides great comfort in nuance making. This, in turn, strengthens the communication between the performer and the audience. Thus, it creates a warm atmosphere." (Talayman, 2024).

As seen in Table 2, since the reverberation time of the venues is below the optimum values, it is evident that the selected venues will not perform well for the intended purpose. Therefore, none of the three venues will provide a lively, rich music experience to the audience.

When evaluated in terms of design characteristics, the outcome for the three performance venues is shown in Table 3. Accordingly, it is evident that there are deficiencies in the design criteria for leveraging natural acoustics in the musical use of the examined venues.

The suggestions for addressing these deficiencies are presented in Table 4 for the Sabanci Cultural Centre, Table 5 for the Suleyman Demirel Cultural Centre, and Table 6 for the Kocaeli Congress Centre. These tables were created based on the optimal reverberation time specified in Table 2 and improvement recommendations tailored to the design characteristics outlined in Table 3 for each hall.

In Table 4, improvement suggestions are provided for the Grand Hall of the Sabanci Cultural Centre regarding the optimal number of attendees, audience area, back wall material, parterre slope, stage height, and reverberation time.

Table 4. Current situation and improvement suggestions for the Sabanci Cultural Centre Grand Hall

Sabanci Cultural Centre Grand Hall	Admissions	Current Status	Suggestions for improvement
Volume/ Person m^3	The optimum volume per person determined for venues to be used for concert purposes is in the range of 8-10 m^3 (Maekawa et al., 2011: 234).	4.23 m^3	In order to make is suitable for concert purposes, the number of seats should be maximum 320 and minimum 255.
Listener Area Back Wall Material	In order to prevent echo in the volumes, the reflection distance should be shortened; especially the back wall of the hall should be absorptive (Turk, 2011: 33).	Hall of the 177.12m^2 rear wall is covered with reflective and half with absorbing material.	The entire back wall should be covered with thick fabric with a coefficient of 0.45 Sabins.
Parter	It is important that the audience area is comfortable enough to see the stage directly. For this, it is preferable to slope the area. However, if it is raised with a constant slope, the hearing angle towards the back rows in the audience area will be	Constant slope.	In order not to reduce the hearing angle, the slope should be destabilized and listening seats should be placed on the increasing slope.

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	reduced. This will cause direct sound to be absorbed more in the front rows and reach the back rows. This problem is solved if the listening area is raised with increasing slope. In this case, listeners in each row will have equal visual and auditory acuity (Turk, 2011: 28).		
Stage – Floor Height	The accepted criterion for stage height in halls to be used for music purposes is at least 50 cm in relation to the ground floor slab. At heights exceeding 100 cm, the middle and back parts of the orchestra may not be seen by the audience (Barron, 2010: 59).	111 cm, high.	The stage height should be reduced to at least 100 cm.
RT	According to Figure 1, 1.55 s or 1.39 s which is the minimum 10 percent.	1.25 s	When 320 seats are used and the entire back wall is covered with a thick fabric with an absorption coefficient of 0.45 Sabins the desired reverberation time range of 1.48 s will be achieved.

In the table 5, the optimum number of people, stage portal, parter slope, stage height and reverberation time are suggested for the Suleyman Demirel Cultural Centre Grand Hall.

Table 5. Current situation and improvement suggestions for Suleyman Demirel Cultural Centre Grand Hall

Suleyman Demirel Cultural Centre Grand Hall	Admissions	Current Status	Suggestions for improvement
Volume / Person m^3	The optimum volume per person determined for halls to be used for concert purposes is in the range of 8-10 m^3 (Maekawa et al., 2011: 234).	6.63 m^3	In order to make it suitable for concert purposes, the number of seats should be maximum 390 and minimum 310.
Stage Portal	The listener area should be covered with reflective material to ensure sufficient early reflection.	Covered with absorbent material	The absorption coefficient is less than 0,20 Sabins; it should be covered with reflective material.
Parter	Ensuring that the audience area provides comfort in directly viewing the stage is important. For this purpose, inclining the seating area is preferred. However, if the incline is fixed and elevated, the auditory discomfort diminishes towards the back rows. This leads to a situation where direct sound is more absorbed towards the front rows, reaching the back rows less effectively. If the audience area is	Constant slope.	To prevent auditory discomfort, the stability of the incline should be disrupted, and the listener seats should be placed on an increasing slope.

	elevated with an increasing incline, this issue can be resolved. In this case, each row of the audience will have equal viewing and auditory comfort. (Turk, 2011: 28).		
Stage – Floor Height	When determining the stage floor height, it is known that having the stage positioned at a certain height above the seating area contributes to the audience's visual comfort and facilitates the direct transmission of sound to the audience. For music-oriented venues, the accepted criterion for stage height is a minimum of 50 centimeters above the ground floor level. Heights exceeding 100 centimeters may result in parts of the orchestra not being visible to the audience. (Barron, 2010: 59).	114 cm	The stage height should be reduced to a minimum of 100 cm.
RT	According to Figure 1, either 1.6 seconds or the minimum of 10%, which is 1.44 seconds.	1.37 s	With the use of 390 seats, the desired reverberation time range can be achieved within 1.49 seconds without the need for any other structural changes.

In Table 6, improvement recommendations are provided for the audience area, side wall material, ceiling panel material, balcony design, and reverberation time for the Akcakoca Auditorium at the Kocaeli Congress Centre.

Table 6. Current Situation and Improvement Recommendations for Akcakoca Auditorium in Kocaeli Congress Centre

Kocaeli Congress Centre Akcakoca Auditorium	Admissions	Current Status	Suggestions for improvement
Listener area side wall	The design of side wall surfaces as sound reflective is directly related to subjective acoustic parameters such as balance and blending. The objective criterion of Clarity is associated with its subjective counterpart, spaciousness, through the design of side walls. If a sense of spaciousness is desired, it is necessary to ensure the characteristics of early sound arrival and sufficient lateral reflection.	The absorptive material consisting of perforated stone wool with a 5 cm air gap behind it has an absorption coefficient of 0.94 Sabins, indicating its absorptive rather than reflective quality.	Covering the side wall panels with solid gypsum panels with an absorption coefficient of 0.50 Sabins will contribute to an increase in the reverberation time in the space.
Ceiling panels	The reflective ceiling is one of the most important acoustic features of a theater or auditorium. (Elbas, 2016: 26)	The absorption coefficient of perforated acoustic plasterboard material is 0.70 Sabins, therefore it has an	The material preferred for use on the ceiling should be air-gap MDF with a coefficient of 0.28 Sabins.

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		absorptive rather than reflective quality.	
Balcony Depth D ≤ 2H	Balcony under designs that exceed twice the height of the depth should be avoided. (Everest & Pohlmann, 2009: 389).	760 cm ≤ 710 cm A sound shadow is created.	Reducing the number of seats in the balcony from 239 to 139 will help to decrease the depth of the balcony.
RT	According to Figure 1, 1.85 seconds or the minimum of 10%, which is 1.66 seconds.	1.147 s	When the number of seats is reduced to 1200, and the side wall panels are covered with solid gypsum panel material, and the ceiling panels are chosen as air-gap MDF, the desired reverberation time range of 1.78 seconds will be achieved.

People's need to hear, understand, and enjoy is as important as their need to see in every space and time. Regardless of the purpose for which a performance venue is programmed, it should provide the audience with auditory comfort. This is an indication of the importance given to culture, art, and the human beings nourished by them. According to the results, none of the three performance venues will satisfy the audience from the listener's perspective; and from the performer's perspective, they will not allow the performer to showcase the desired performance.

Ultimately, it is evident that the common issue to be addressed in the three venues is the number of seats. Among the three venues, Kocaeli Congress Centre Akcakoca Auditorium lacks the most in reverberation. Kocaeli Congress Centre, Suleyman Demirel Cultural Centre, and Sabanci Cultural Centre are multipurpose performance venues, and in terms of acoustic comfort and volume size, the existing facilities are unable to meet the needs of the city's residents. This study has identified a clear requirement for multipurpose performance venues or music-functioning halls with a seating capacity of over 1000, which provide optimal auditory comfort, to be constructed in the city.

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Resume

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