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Meeting Room Acoustic Design in the Historical Building: The Example of Istanbul University Faculty of Science and Letters Building

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ABSTRACT

In the restoration of historical buildings, the characteristics of the original period and the design decisions of the original period should be preserved. The rich interior volumes of historical buildings should not be reduced, the original ceiling height should not be changed and their original interior forms should be conserved. In addition, the requirements of current standards in the restoration of historical buildings should be met as much as possible. Providing auditory comfort conditions is also one of the important parameters in the restoration process. In this study, the meeting room in the historical building was analysed, the design decisions of the original period of the meeting room were preserved, and an acoustic improvement project was presented depending on the characteristics of the historical building. In the acoustic project proposal, the original room height, the richness of the interior volume, and the perception of the mirrored vault system were preserved to maintain original period design decisions. In the acoustic project proposal, auditory comfort conditions were improved by increasing the total absorption rate in the meeting room. Reverberation time analyses and delayed reflection analyses were performed. In addition, the homogeneous propagation of the sound in the space was examined by using the acoustic simulation program. With the acoustic project proposal, the reverberation time was controlled in line with the DIN18041 standard, the delayed reflections were greatly reduced, the homogeneous propagation of the sound in the space has been improved, and the intelligibility of speech in the meeting room has been increased.

KEYWORDS

Conservation of the historical space, Room acoustic design, Reverberation time, Speech intelligibility, Acoustic problems, Auditory comfort conditions.

INTRODUCTION

It is necessary to preserve the original forms of historical buildings and transfer them to future generations in a healthy way. In the interiors of historical buildings, the original interior forms should not be changed and the design decisions of the original period should be preserved. In addition, the requirements of current standards and current regulations should be considered in restoration processes as much as possible. The conservation philosophy and the requirements of current standards should be analysed together. In the restoration process of historical buildings, the analysis of the historical building according to current earthquake regulations, and interior requirements according to current standards should be considered important data in the preparation of restoration projects, and the integration of all disciplines should be ensured as much as possible in the preparation of restoration projects. While the restoration projects were being prepared, the requirements of all disciplines should be considered. However, satisfying current comfort conditions contrary to the conservation philosophy is a wrong solution proposal.

One of the important interior comfort conditions in historical buildings is auditory comfort conditions. Auditory problems caused by the large volume can often be observed in rooms with large indoor volumes. Especially, the problem of high reverberation time can be encountered in rooms with large internal volumes. Providing auditory comfort conditions in historical buildings should be carried out in accordance with the original design decisions of the historical building. Unfortunately, it can be observed that incorrect applications can be made in the interior design of historical buildings, the richness of the original interior can be reduced with the suggestion of suspended ceilings, the original windows can be closed and the design decisions of the original period can be damaged. Interior design decisions of historical buildings should be carried out in accordance with the design decisions of the original period and should be carried out without harming the conservation philosophy. With this perspective, interior acoustic experts and restoration experts should work together and different disciplines should make decisions together. In restoration projects that need to be carried out with the integration of different disciplines, first of all, the original period features of the historical building should not be damaged. It should be aimed to improve the auditory comfort conditions without harming the original period design decisions. In this direction, it will be useful to examine the acoustic applications in the historical buildings made in the literature and to examine what the proposed improvement decisions are.

Acoustic improvement designs carried out without damaging the original feature of historical buildings is one of the important issues to be investigated. The acoustic properties of historical buildings and the improvement of acoustic conditions are frequently investigated in the literature. In the research of Iannace et al. (2013), a classroom located in a historical building was analysed, the original vault form was preserved in the acoustic improvement proposal, and the application of portable absorbent panels on the classroom wall was suggested. Alonso et al. (2014) researched the acoustic evaluation of the cathedral of Seville. they demonstrated that covering the cathedral columns with portable velvet draperies can be improved room acoustics. It is seen that covering the cathedral columns with portable velvet draperies in concert usage cannot give damage the original period design features. Prodi & Pompoli (2016) investigated acoustics in the restoration of Italian historical opera houses. They showed that glass wool strips can be hung along the lateral walls in a historical building to decrease reverberation time. It is seen that glass wool strips are movable and do not give damage to original hall volume. Bozkurt & Demirkale (2018, 2019, 2020a, 2020b) emphasized in their research that the original dome and vault forms in historical buildings should be preserved. They stated that the richness of the historical interior should be preserved and they mentioned that the interior volumes should not be reduced in this direction. To increase the acoustic comfort conditions in the interior and to prevent acoustic problems, they investigated the improvement of the sound absorption coefficient of the plaster layers prepared with lime binder mortars in historical buildings. In the study of Bartalucci et al. (2018), the acoustic design of an auditorium in a church and of a historical theatre was researched. The authors stated that the variable acoustics of the church required to ensure optimal acoustic conditions in correspondence with the different uses is determined by the configuration of movable panels. It is observed that the variable panels do not harm the original design characteristic of the church. Iannace et al. (2019) investigated the church's acoustic condition which was built in the 1960s. The use of acoustic absorbing surfaces in accordance with the original structure of the church was suggested in the research. Berardi & Iannace (2020) investigated the acoustic of Roman theatres in Southern Italy, five different historical unroofed theatres were analysed, and they stated that the historical atmosphere makes the listener forget the acoustic limits of these theatres or the diffuse use of loudspeakers. For this reason, it has been seen that no design proposal has been presented that will negatively affect the original structure of historical theatres. Tronchin & Bevilacqua (2021) performed an acoustic analysis of the São Carlos national theatre building in Lisbon, and the acoustic conditions in the historical building were explained according to different usage scenarios. The effect of different types of stage systems on the reverberation time in the historical building was detailed. It is seen that different scenario studies have been carried out in a way that will not harm the large space perception of the historical building. Bozkurt (2022) performed an acoustic analysis of the main lecture hall on the Beyazıt campus of Istanbul University. It has been explained that the main lecture hall in the historical building was used for speaking purposes and that the volume of the hall was large. In the proposed acoustic improvement, the volume of the room was not reduced, the original windows were not closed, and the original period design decisions were preserved. In the proposed acoustic study, the absorbing surfaces have been increased and the acoustic quality of the space has been improved accordingly.

In the literature, it is observed that acoustic analysis of historical buildings is researched, and acoustic improvement suggestions can be presented in line with the characteristics of the historical building. However, it is seen that each historical building has its characteristics and acoustic improvement suggestions are presented in line with these features. It is understood that the proposed acoustic improvement proposals are not intended to damage the original period features of the historical building. However, acoustic improvement studies without damaging the original period characteristics of the historical building are a very broad subject to be investigated. It is necessary to increase the number of acoustic improvement research in historical buildings, which can be useful for acoustic experts and historical building conservation experts. Acoustic analysis studies in historical buildings can be informative for experts during the preparation of restoration projects. For this reason, in this study, the acoustic improvement project of a meeting room in a historical building was detailed.

HISTORICAL BUILDING AND MEETING ROOM

The building used by the Istanbul University Faculty of Science and Letters was designed by architects Sedat Hakkı Eldem and Emin Onat. The designed building was completed in 1952 (Günergun & Kadıoğlu, 2006). The building is located next to the Istanbul Beyazıt campus. The site plan (Fig.1a) and floor plan (Fig.1b) of the building used for the symposium held at Istanbul University in 1952 were given in Figure 1 (Günergun & Kadıoğlu, 2006). The building is registered as a cultural heritage by the IV Regional Board of Protection of Cultural Heritages. The Faculty of Science and Letters building has approximately 69200 m2 of closed area (Bozkurt et al., 2019).

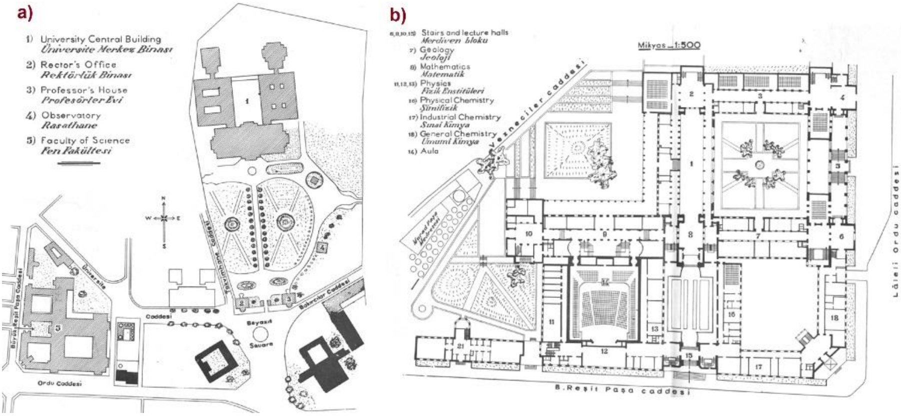

Figure 1. *The site plan and floor plan of the building used for the symposium held at Istanbul University in 1952, a) site plan, b) floor plan (Günergun & Kadıoğlu, 2006).*

The historical building, which reflects the eave forming of traditional Ottoman architecture, has a monumental appearance. Building sketches prepared by Sedat Hakkı Eldem reflecting the characteristics of traditional ottoman eaves are encountered in literature research (Fig.2).

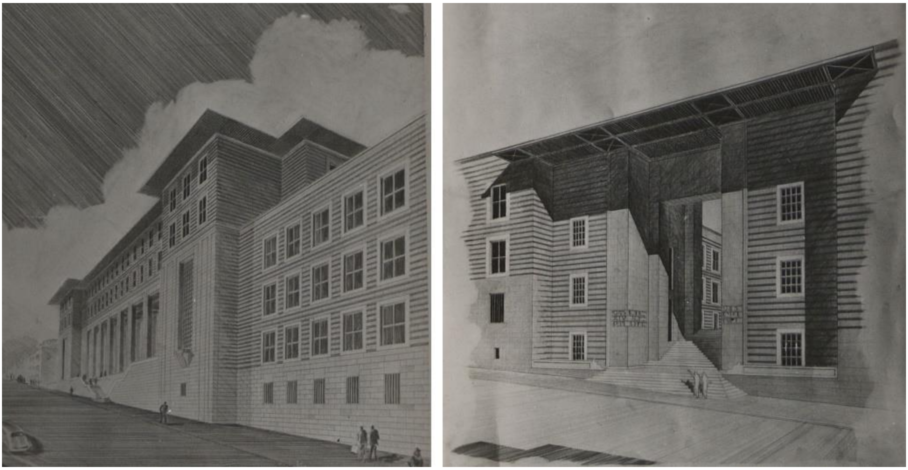

Figure 2. *Prepared building sketches in the early design process by Sedat Hakkı Eldem (URL-1).*

Figure 3. *Facade and indoor photographs of the building at the Faculty of Science and Letters of Istanbul University (Bozkurt et al., 2019).*

The building, designed by architect Sedat Hakkı Eldem, has rectangular and square courtyards surrounded by stone facades (Bozkurt et al. 2019). Inside the building, there are qualified corridors and rooms which have high ceiling heights and interior richness (Bozkurt et al., 2019). In addition, the vault form, which is frequently encountered in Ottoman architecture, can be seen in the interior of the building (Fig.3). It is understood that the building forms and design styles used in the history of Turkish architecture are especially emphasized in the building (Fig.3) (Bozkurt et al., 2019).

The meeting room, which is used by the Faculty of Science, was renovated according to the restoration project. The interior pictures of the meeting room belonging to the Faculty of Science before the renovation carried out in 2015 were presented in Figure 4. It is understood in Figure 4 that the ceiling height of the meeting room is high and there is a mirror vault system on the ceiling.

Figure 4. *Meeting room photographs before the renovation carried out in 2015.*

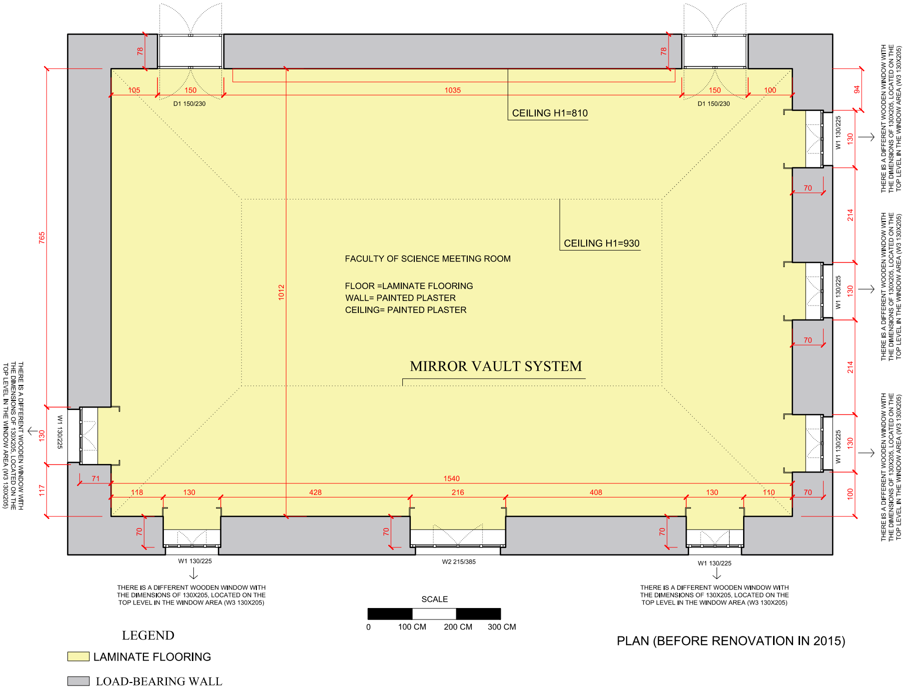

Figure 5. *Meeting room plan before the renovation carried out in 2015.*

The plan of the meeting room before the renovation is given in Figure 5., It is seen that the ceiling height is too high, and the floor height is 9.3 meters. Before the renovation, it was shown in Figure 5 that the floor covering was laminate flooring, and the ceiling and walls were painted plaster surfaces. It is understood from the drawing that the meeting room is approximately 156 m^2. It is observed that the volume of the room is approximately 1380 m^3. It is necessary to offer solutions to acoustic problems that may arise from the large volume of the meeting room. It is aimed to present an acoustic project proposal that will preserve the historical identity of the building and will not harm the perception of the mirror vault system, and it is detailed in the 4th section.

METHODOLOGY

The calculation of the reverberation time varies depending on the total volume and the total absorption in the room. If the total absorption in the room increases without changing the room volume, the reverberation time decreases. If the total absorption does not increase while the volume of the room increases, the reverberation time increases. In this direction, the problem of reverberation time is frequently observed in rooms having large volumes.

In the literature, it is observed that two different methods are frequently used in calculating the reverberation time. The most widely used reverberation time calculation method in the literature is the Sabine method. With the help of the Sabine method, it is understood that the sound absorption coefficient of the materials is obtained by the ISO 354 standard. It is stated in EN ISO 354 standard that "*The average reverberation time in the reverberation room is measured with and without the test specimen mounted. From these reverberation times, the equivalent sound absorption* *area of the test specimen, A_T, is calculated by using Sabine's equation*". Many acoustic researchers can prefer to use the Sabine method during the reverberation time analysis since the sound absorption coefficient results measured in a reverberation room are obtained with the Sabine method. In the book prepared by Everest & Pohlman (2009), the authors stated that commonly available coefficients apply only to Sabine and for this reason, authors prefer to use the Sabine equation for some analyses. The second widely used reverberation time calculation method in the literature is the Eyring-Norris Equation method. Everest and Pohlman mentioned that the Eyring-Norris method can be used in more absorptive rooms and they defined that the other equations are generally equivalent to the Sabine equation during the average absorption coefficients of 0.25 or less. In the literature, it is seen that the Eyring-Norris method can be used in more absorbent spaces (such as small-volume rooms and studios). In this study, primarily the Sabin method was preferred to be used in the reverberation time analysis. However, in the acoustic improvement proposal, it was observed that the average absorbency of the room was quite high, and for this reason, it was decided to use the Eyring-Norris method separately in the reverberation time analysis. In this study, the reverberation time was analysed by using both the Sabine method and the Eyring-Norris method, and the properties of the wall surfaces were determined accordingly. The equation of the Sabine method for reverberation time analysis was given in Equation 1. (Long, 2006; Demirkale, 2007; Everest & Pohlmann, 2009).

$$\mathrm{RT_{sabine}} = 0.161\ \frac{\mathrm{V}}{\sum \mathrm{A}} \tag{1}$$

$\mathrm{RT_{sabine}}$= reverberation time of a room calculated with sabine method (sec.)
V= volume of room (m^3)
∑A= total absorption in the room (Eq. 2) (metric sabins). ∑A includes absorption provided by room boundaries, audience, furnishings, air, etc.

$$\sum \mathrm{A} = \left((\alpha_1\,.S_1 + \alpha_2\,.S_2 + \ldots + \alpha_n\,.S_n) + x.V\right) \tag{2}$$

α_1, α_2, α_n= sound absorption coefficients (For different surface based on material properties)

S_1, S_2, S_n = respectively different room surfaces
x = air absorption coefficient

The reverberation time can be calculated using the Eyring-Norris method with the help of the Equation 3 (Everest & Pohlmann, 2009).

$$RT_{Eyring-Norris} = 0.161 \frac{V}{-S\ \ln(1-\alpha_{average})} \quad (3)$$

$RT_{Eyring\text{-}Norris}$ = reverberation time of a room calculated with Eyring-Norris method (sec.)
V= volume of room (m^3)
S = total surface area of room (m^2)
In = natural logarithm (to base "e")
$\alpha_{average}$ = average absorption coefficient ($\Sigma S_i \alpha_i$ / ΣS_i)

Optimum values of indoor reverberation time vary according to the function of the room and the volume of the room. In the DIN 18041 standard, the determination of the required reverberation time according to the function types and indoor volume was clarified. In this research, the analysis of the reverberation time was made in accordance with the DIN 18041 standard, and the acoustic improvement proposal for the space was presented in this direction. In the DIN 18041 standard, it is stated that the optimum reverberation time for speech-purpose rooms can be obtained with the help of Equation 4 when there is a sound system in the room.

$$T_{TARGET} = [0{,}32 \times \log[V] - 0{,}17]\ s \quad (4)$$

V= room volume (m^3)

Since the volume of the meeting room is approximately 1380 m^3, the optimum reverberation time of the meeting room is equal to 0.835 (according to Equation 4). The required maximum and minimum reverberation time values, which vary according to the frequencies, can be obtained with the help of Figure 6. The required maximum and minimum reverberation time values are calculated according to the frequencies, considering the optimum reverberation time.

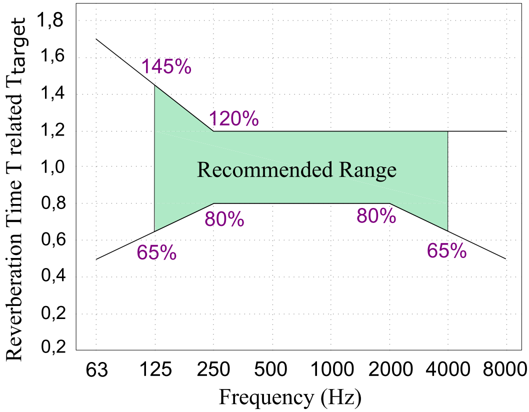

Figure 6. *Required reverberation time range according to the DIN 18041 standard (Nocke,2016; Bozkurt, 2022).*

According to octave band frequencies, the maximum and minimum reverberation time values required in the meeting room to provide auditory comfort conditions are given in Table 1. Table 1 was prepared using Figure 6 and was accepted as the limit level in this study. In the acoustic improvement proposal, limit levels have been determined in Table 1 to provide acoustic comfort conditions in line with the DIN 18041 standard. The reverberation analyses were carried out by not only the Sabin method and by the Eyring-Norris method.

Table 1. *The meeting room required reverberation time ranges (minimum and maximum values).*

Required reverberation time ranges	Frequency (Hz)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Maximum reverberation time	1.21	1.00	1.00	1.00	1.00	1.00
Minimum reverberation time	0.54	0.67	0.67	0.67	0.67	0.54

One of the important parameters in room acoustic is the prevention of delayed reflections. If there is a difference of 30 milliseconds between the reflected sound and the direct sound, it can cause delayed reflections

(Maekawa et al., 2011; Jaramillo, 2015). Initial time delay gap analyses were performed according to Equation 5.

$$\text{ITDG} = \frac{(R1+R2)-D}{0{,}344} \tag{5}$$

ITDG= Initial time delay gap (30 ≥ ITDG)
R1= Distance between source and reflective panel (meter)
R2= Distance between reflector panel and receiver (meter)
D= Direct distance between receiver and source (meter)

Reflected sound reaching the receivers after 30 milliseconds may damage the auditory comfort conditions. Delayed reflection analysis has been considered an important parameter in the determination of room surface properties. Surfaces that may cause delayed reflections are designed to be absorbent.

In speaking halls, the intelligibility of speech can be examined with AI (Articulation Index). This parameter takes into account the signal/background noise ratio as well as the reverberation time. In terms of speech intelligibility, the AI value was determined as very good between 1 and 0.7, and good between 0.5 and 0.7 (Mehta et al., 1999). A receiver point, which is the farthest point from the source, was selected in the AI calculation and AI calculation was performed in this direction. While performing the AI calculation, the sound pressure level at the receiver point is calculated according to the sound pressure level at the source. It is calculated separately according to the frequencies and the total signal level is taken into account, including the reflections at the receiver point. According to Equation 6, the sound pressure level difference between the source and the receiver is acquired. AI (Articulation Index) can be calculated by using Equation 7 (Mehta et al., 1999). The AI calculation process was detailed in the acoustic project proposal section.

$$SPL_2 = SPL_1 - 20\log\frac{D_2}{D_1} \tag{6}$$

SPL_2= Sound pressure level (source) (dB)
SPL_1= Sound pressure level (listener) (dB)
D_2= Distance from receiver (meter)
D_1= Distance of source (reference distance 1 meter)

$$\text{AI} = \text{Sum of ((S-N ratio) x weighting factor)} \tag{7}$$

AI= Articulation Index
S-N ratio = Signal Level -Noise Level (dB)

Acoustic problems in the space can prevent the homogeneous propagation of sound in the room. Among acoustic problems, concave surfaces can cause focusing. Since the ceiling structure of the historical place is vaulted, it may cause focusing problems. In this research, surfaces that may cause acoustic problems are designed to be absorbent, and acoustic problems have been tried to be reduced in this direction. In addition, flutter echo problems, echo problems, whispering galleries, and shadow areas can be defined as acoustic problems and these problems can damage the homogeneous propagation of the sound. After the acoustic project proposal is presented, the homogeneous propagation of the sound can be examined in acoustic simulation programs. In this study, a similar method was determined, and it was examined in detail whether the sound spread homogeneously in the proposed project using acoustic software. It can be seen that many different types of acoustic software are used in the literature. In this study, open-source I-SIMPA software was used as acoustic software. It is seen that the I-SIMPA software can be used in acoustic research prepared recently (Ribeiro et al., 2021; Pillai et al., 2022; Bozkurt, 2022). Acoustic model analysis prepared in the I-SIMPA software was presented in detail in the discussion section, and the homogeneous propagation of the sound was examined.

Reverberation time (RT) is defined as the time required for the sound to decrease by 60 dB after the source has stopped emitting. Also, similarly to reverberation time analysis, EDT and T_{15} can be investigated in an acoustic simulation program instead of the reverberation time (RT). EDT is defined as six times the time it takes sound to decay by 10 dB after the source has stopped emitting. T_{15} is defined as four times the time after the source has stopped emitting. In the I-SIMPA software, EDT and T_{15} results were analysed in this study. The homogeneous propagation of the sound was examined over the EDT and T_{15} results in the acoustic software.

Clarity (C_{50}), which is an objective measure of the intelligibility of speech, is indicated in dB. C_{50} can be used to analyse late reflections which are unfavourable for understanding speech. Late reflections cause speech sounds to merge making speech unclear. However, if the delay does not exceed 50 ms (milliseconds) limit, the reflections can contribute positively to the intelligibility. In the C_{50} analyse, the ratio of the energy of the sound reaching the receiver before 50 ms to the sound energy reaching the receiver after 50 ms is considered. The formula for the C_{50} analysis was presented in Equation 8 (Laura et al., 2020). In addition, it can be observed that the Definition (D_{50}) analysis can be used as a similar analysis of the Clarity (C_{50}) term in the literature. D_{50} (Definition) is indicated in %. D_{50} (Definition) is the ratio between the energy arriving during the first 50 ms and the total energy. The formula for the D50 analysis was shown in Equation 9 (Patania et al., 2014). The homogeneous propagation of the sound in the meeting room was investigated in the I-SIMPA software, considering the D_{50} and C_{50} parameters.

$$C_{50} = 10\log\left(\frac{\int_0^{50\ ms} p^2 t(dt)}{\int_{50\ ms}^{\infty} p^2 t(dt)}\right)\ dB \tag{8}$$

C_{50} = Clarity term for the first 50 ms
p(t)= Sound pressure of the impulse response measured at the measurement point

$$D_{50} = \frac{\int_0^{50\,ms} p^2 t(dt)}{\int_{50\,ms}^{\infty} p^2 t(dt)} \quad \% \tag{9}$$

D_{50} = Definition term for the first 50 ms
p(t)= Sound pressure of the impulse response measured at the measurement point

ACOUSTIC PROJECT PROPOSAL

In the restoration process of historical buildings, reducing the original room volumes and reducing the ceiling height by making suspended ceilings can damage the richness of the space. In this direction, it is not preferred to reduce the room volume by making suspended ceilings in historical buildings (Bozkurt & Demirkale, 2018). In particular, if there are high-quality handmade coatings on the ceiling or forms such as vaults or domes that reflect the original period feature, the suspended ceiling system should not be preferred. In the analysed room, closing the mirrored vault system on the ceiling by using the suspended ceiling may damage the richness of the meeting room. However, acoustic problems that may arise due to its high volume are also encountered as an important parameter. In this context, it is a more accurate way to find solutions to acoustic problems without reducing the volume of the room and without damaging the perception of the vault system.

During the preliminary design phase, the design proposal given in Figure 7 was examined for acoustic improvements. It is foreseen that the proposed study will improve the acoustic environment conditions, but it is clear that it will damage the identity of the historical building and the perception of the mirrored vault system in the room. It was suggested to use acoustic absorbing panels with a suspended ceiling system. However, it is very difficult to visually perceive the vault system on the ceiling. In addition, it was suggested that the two windows in the historical place should be closed completely. The perception of the windows on the upper level is difficult. Since the suspension systems on the ceiling are very dense, the perception of the high floor height of the room is damaged. In this direction, it was decided to hang only artificial lighting with the suspension system and to reduce the acoustic panels in the ceiling system. The perception of the mirrored vault system, which was designed by Sedat Hakkı Eldem, was aimed to be preserved. For this reason, the proposed acoustic project in Figure 7 was not applied.

Figure 7. *Meeting room project suggestion which is not applied (Istanbul University Construction and Technical Department, meeting room design suggestion, 2014).*

The photos after the renovation of the meeting room are presented in Figure 8. In the photographs of 2015, it is seen that the original windows were not closed. In addition, it is observed that the perception of the vault was not impaired and the suspension systems were not used densely. Only artificial lighting systems were applied by hanging. According to the request of the Faculty of Science, the carpet covering, which can be easily installed and dismantled, has been made on the floor surface. The original floor height has been preserved. In addition, the windows on the upper levels are easily perceived and the windows on the upper levels contribute to natural lighting. The visual perception of the vault system, which is frequently observed in the history of Turkish architecture, has been conserved, and the design decisions made in its original period have been preserved accordingly. The ceiling system given in Figure 7 was not applied and accordingly, the design decisions of Sedat Hakkı Eldem, the architect of the building, were respected. In brief, the perception of the original vault form has been preserved and the inner richness of the space has been preserved.

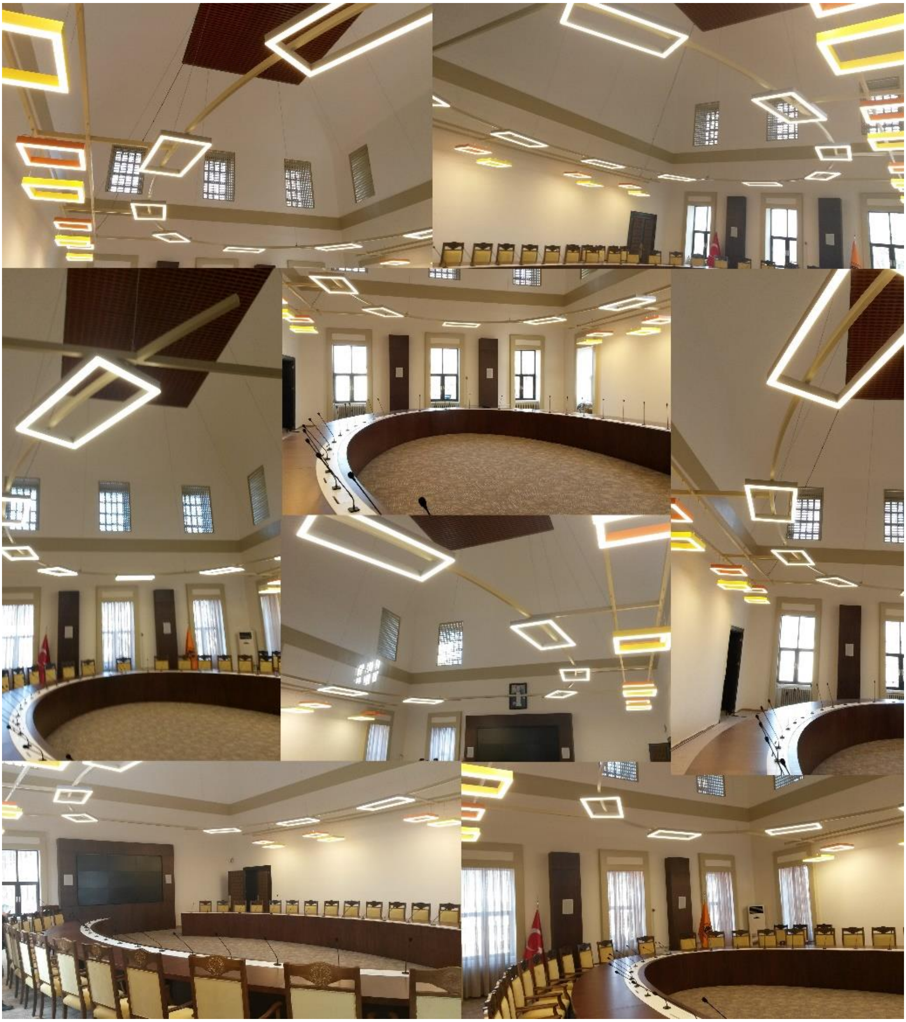

Figure 8. *Meeting room after renovation (Photos from 2015).*

It is observed that the renovation work carried out in line with the budget has improved the acoustic comfort conditions by using carpet covering. However, the absorbency of the room is still not at a sufficient level. The total absorption value calculated according to Equation 2 in the meeting room was presented in Table 2.

Table 2. *Total absorption results of the meeting room after renovation.*

PROPERTIES OF SURFACES		FREQUENCY (Hz)											
		125 Hz		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz	
SURFACE TYPE	Area (m^2)	α	S. α	α	S. α	α	S. α	α	S. α	α	S. α	α	S. α
Carpet	155.85	0.02	3.12	0.06	9.35	0.14	21.82	0.37	57.66	0.60	93,51	0.65	101.30
Solid wooden door	6.90	0.14	0.97	0.10	0.69	0.06	0.41	0.08	0.55	0.10	0,69	0.10	0.69
Curtain	48.84	0.04	1.95	0.16	7.81	0.19	9.28	0.17	8.30	0.20	9,77	0.25	12.21
Painted plaster surface	515.28	0.02	10.31	0.02	10.31	0.02	10.31	0.02	10.31	0.02	10,31	0.02	10.31
Air (not surface, volume-m^3)	1380.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	13,80	0.02	27.61
Total absorption, ∑A			16.34		28.16		41.82		76.82		128.08		152.12

In line with the total absorption results given in Table 2, Equation 1 was used to calculate the reverberation time based on the Sabin method. Similarly, the reverberation time was calculated according to the Eyring-Norris method by using Equation 3 in line with the total absorption values given in Table 2. The results of the reverberation time calculations were presented in Table 3.

Table 3. *Reverberation time calculation results of the meeting room after renovation (without acoustic project suggestion).*

Reverberation time calculation results	Frequency (Hz)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sabine method	13.60	7.89	5.31	2.89	1.74	1.46
Eyring-Norris method	13.45	7.74	5.16	2.74	1.58	1.30
Required maximum value	1.21	1.00	1.00	1.00	1.00	1.00
Required minimum value	0.54	0.67	0.67	0.67	0.67	0.54

Although the carpeting could improve the reverberation time at high frequencies, it did not greatly increase the overall absorption level of the low frequencies. The reverberation time values calculated by the Sabin method and the Eyring-Norris method did not meet the requirements of the DIN 18041 standard. It was understood that the reverberation time calculation results are much higher than the required levels.

In the literature, it was stated that delayed reflections of 30 milliseconds from reflective surfaces can affect auditory comfort conditions negatively (Demirkale, 2007; Makeawa et al., 2011; Jaramillo & Stell, 2015). Reflection analyses were examined according to the flat surface of the mirrored vault system in the historical building. The ceiling reflections of three different receiver points were investigated, and the positions of three different receiver points were shown in Figure 9. It was calculated whether there is a delayed reflection at three different receiver points (Eq.5). The reflection results of three different receiver points, calculated according to Equation 5, were presented in Table 4. It was determined that there is a delayed reflection caused by the ceiling height at the first receiver point. According to the results of Table 4, it can be understood that delayed reflection problems may occur at many receiver points.

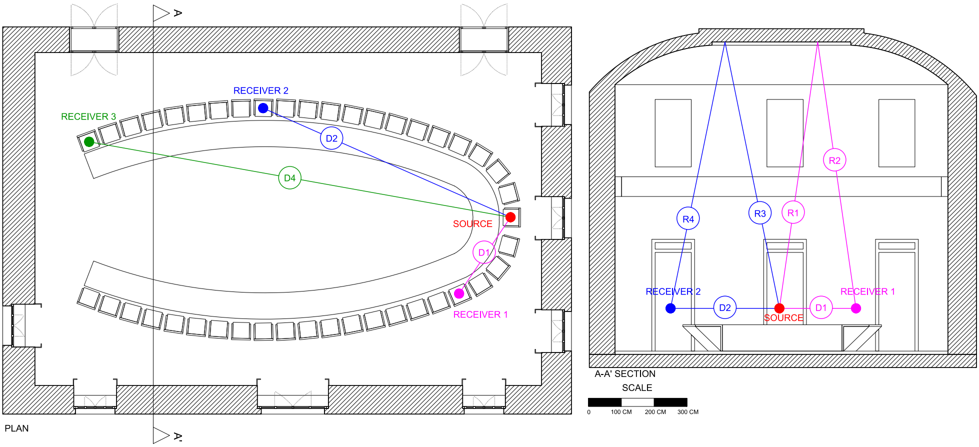

Figure 9. *Analysis of reflections (initial time delay gap).*

Table 4. *Analysis of reflections (initial time delay gap).*

RECEIVER	EQUATION	CALCULATION RESULTS
Receiver 1	$\frac{(R1+R2)-D1}{0,344} \leq 30\ ms$	$\frac{(8.22+8.22)-2.8}{0.344} = 39.65 \qquad 39.65 \nleq 30\ ms$

Receiver 2	$\frac{(R3+R4)-D2}{0,344} \leq 30\ ms$	$\frac{(9.08+9.08)-8.23}{0.344} = 28.87 \quad 28.87 \leq 30\ ms$
Receiver 3	$\frac{(R5+R6)-D3}{0,344} \leq 30\ ms$	$\frac{(10.39+10.39)-13.01}{0.344} = 22.58 \quad 22.58 \leq 30\ ms$

Due to the high ceiling height, delayed reflections can be observed in the meeting hall. It has been determined that the delayed reflection problems caused by the ceiling height negatively affect the acoustic comfort conditions. However, reducing the ceiling height with the suggestion of a suspended ceiling will also harm the richness of the space. For this reason, in this research proposal, the ceiling height was not changed and the decisions of the original design period were preserved. It has been suggested that ceiling surfaces be designed as absorbers to reduce delayed reflection problems. In addition, vault ceiling systems can cause the focusing problem in room acoustic. Designing such concave surfaces having a sound-absorbing character reduces the focusing problem in room acoustic. Hence, the sound-absorbing feature of the surface of the vault system is beneficial for improving acoustic comfort conditions. For the stated reasons, it was recommended to cover the surfaces of the vault with materials with a high sound absorption coefficient.

To adjust the required reverberation time, it is necessary to increase the total absorption in the meeting room (Metha et al., 1999; Jaramillo & Stell, 2015). In Figure 10, the positions of the surface coatings in the acoustic project were shown in the plan and section. In the floor covering of the hall used by the science faculty, the carpet was requested to be used in line with the faculty's request, and the reverberation time was improved. However, it is observed that the floor coverings of the historical building are generally terrazzo. It is also difficult to clean the carpet covering. Since a comprehensive acoustic project has been prepared and the sound absorption coefficient of all frequencies has been reconsidered, the replacement of the floor covering has been suggested in the acoustic project (Fig.10).

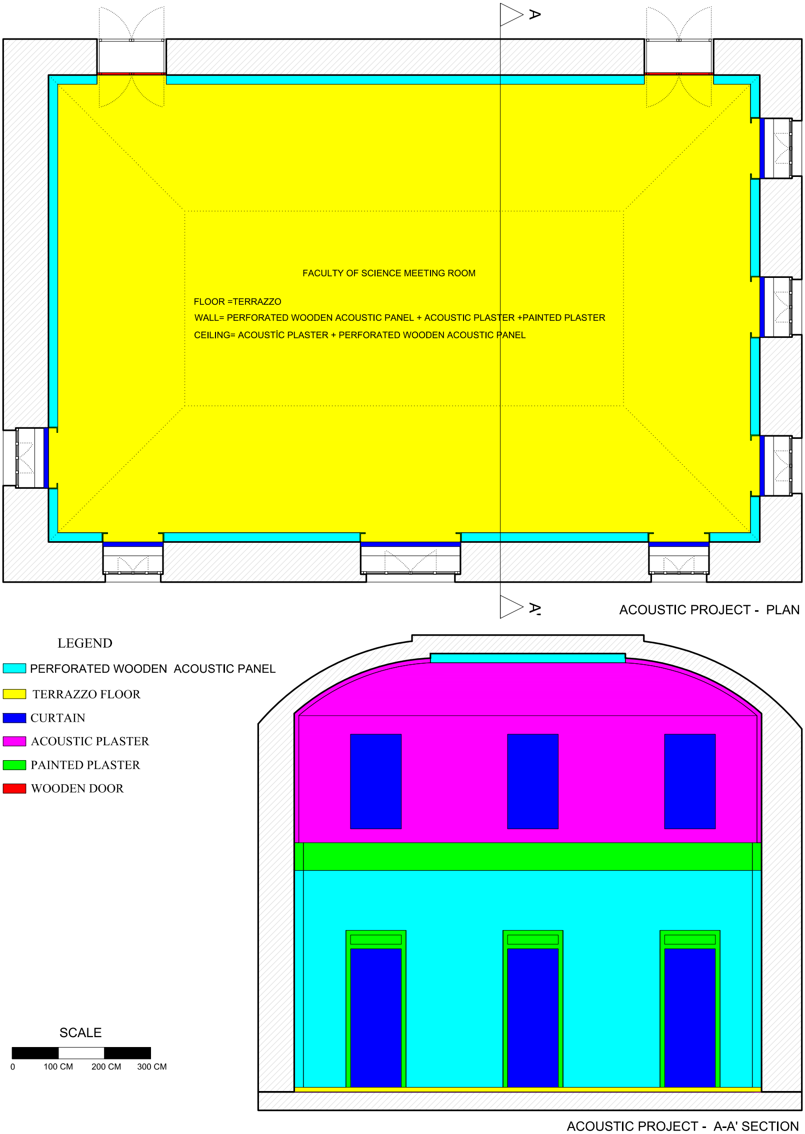

Figure 10. *Meeting room acoustic project proposal.*

The perception of the vault form was not intended to be changed in the acoustic project. For this reason, acoustic plaster coating was recommended for the upper elevations. The perforated acoustic wood cladding was proposed only on the flat surface of the mirrored vault system (Fig.10). In the photographs given in Figure 4 and Figure 8, wooden material was used in the flat part of the mirrored vault and the perception of the vault system was emphasized. The same design idea was continued in the acoustic project proposal (Fig.10).

It was suggested to use curtains in front of the windows in the acoustic project. In addition, the molding on the upper level of the room and the window moldings, shown in Figure 8, has been preserved in the acoustic project. It was suggested to paint the room and window moldings. It was suggested to paint the room and window molding coverings (Fig.10). It was recommended to use a perforated wooden acoustic panel coating in the area between the floor covering and the upper-level room molding. It was suggested that wooden acoustic panel coatings should be a removable system (Fig.10). In addition, it was recommended to assemble it in a way that will not damage the historical building. The materials used in the reverberation time calculation and the references from which the sound absorption coefficients were obtained were detailed in Table 5.

Table 5. *Properties of the surfaces.*

TYPE AND PROPERTIES OF COVERING	REFERENCE
Acoustic panel with aligned holes, (Pitch(mm): 32x32, Hole diameter(mm): Ø8, Perforated area: 4.9%, panel thickness:16 mm, plenum 200mm, 40 mm thick rock wool with 30 kg/m^3 density in the cavity)	Decustik company catalog, URL-2
Terrazzo	Cox& D'Antonio ,2004
Carpet	Cox& D'Antonio ,2004
Curtain (Hung straight)	Cox& D'Antonio ,2004
Painted plaster surface	Cox& D'Antonio ,2004
Acoustic plaster	Cox& D'Antonio ,2004
Solid wooden door	Cox& D'Antonio ,2004

In line with the acoustic project proposal, the total absorption results of the meeting hall were calculated with the help of Equation 2, and the total absorption results according to the octave band frequencies were given in Table 6. According to the calculated total absorption results given in Table 6, reverberation time was calculated according to the Sabine method using Equation 1, and reverberation time was calculated according to the Eyring-Norris method using Equation 3. The reverberation time calculation results of the new acoustic project proposal calculated separately according to the Sabin method and the Eyring method were presented in Table 7.

Table 6. *Total absorption results of the meeting room (according to the acoustic project suggestion).*

PROPERTIES OF SURFACES		FREQUENCY (Hz)											
		125 Hz		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz	
SURFACE TYPE	Area (m^2)	α	S. α	α	S. α	α	S. α	α	S. α	α	S. α	α	S. α
Terrazzo	155.85	0.01	1.56	0.01	1.56	0.015	2.34	0.02	3.12	0.02	3.12	0.02	3.12
Solid wooden door	6.90	0.14	0.97	0.10	0.69	0.06	0.41	0.08	0.55	0.10	0.69	0.10	0.69
Curtain	48.84	0.04	1.95	0.16	7.81	0.19	9.28	0.17	8.30	0.20	9.77	0.25	12.21
Painted plaster surface	40.32	0.02	0.81	0.02	0.81	0.02	0.81	0.02	0.81	0.02	0.81	0.02	0.81
Acoustic panel with aligned holes	230.00	0.75	172.50	0.55	126.50	0.44	101.20	0.36	82.80	0.19	43.70	0.08	18.40
Acoustic plaster	242.75	0.30	72.83	0.35	84.96	0.50	121.38	0.70	169.93	0.70	169.93	0.70	169.93
Air (not surface, volume-m^3)	1380.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	13.80	0.02	27.61
Total absorption, ∑A			250.61		222.33		235.41		265.50		241.81		232.76

Table 7. *Reverberation time calculation results of the meeting room after renovation (according to acoustic project suggestion).*

Reverberation time calculation results	Frequency (Hz)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sabine method	0.89	1.00	0.94	0.84	0.92	0.95
Eyring-Norris method	0.72	0.84	0.78	0.67	0.76	0.79
Required maximum value	1.21	1.00	1.00	1.00	1.00	1.00
Required minimum value	0.54	0.67	0.67	0.67	0.67	0.54

It is understood in Table 7 that the reverberation time results calculated by both the Sabin method and the Eyring-Norris method are in accordance with the range defined in the DIN 18041 standard. The total absorption rate of the meeting room has been increased with the proposed new acoustic project, and the auditory comfort conditions have been improved accordingly. It has been seen that the results of the reverberation time calculation are in accordance with the requirements of the DIN 18041 standard.

In the analysis of speech intelligibility, there are different parameters besides reverberation time. One of the important parameters in evaluating speech intelligibility is the Articulation Index (AI). The distance value between the source and the receiver is effective in the AI (Articulation Index) calculation. The higher the sound energy that reaches the receiver from the sources, the higher the AI value. In the AI calculation, the background noise level of the room is effective in the calculation. In addition, the value of the reverberation time of the space is also considered in the AI calculation. An AI value between 1 and 0.7 means that the speech intelligibility level is very good in the room. Also, it was stated that speech intelligibility was good when the AI value was between 0.7 and 0.5 (Metha et al., 1999). In this study, the listener at the farthest point from the speaker was analysed (It will be sufficient for the receiver point with the least AI level to meet the required level). For this reason, the AI value of the Receiver 3 point shown in Figure 9 has been calculated. While calculating the AI value, the sound pressure level of the direct sound reaching the listener was considered. Reflections were not taken into account in the AI calculation, since the total absorption level is high in the proposed acoustic improvement study and only the floor covering has a reflective character. The values of the sound pressure level 1 meter away from the speaker were given in Table 8 according to the changing frequencies (Metha et al., 1999). The sound pressure level of direct sound calculated according to Equation 6 was shown in Table 8 according to frequencies (Mehta et al.,1999). The interior noise level of the meeting hall was defined according to the NC30 noise curve which can be accepted as the maximum interior noise level of the meeting hall function. Moreover, WF (weighting factor) was acquired from the book prepared by Mehta et al.

(1999) and was shown according to the frequency in Table 8. The result of the AI value calculated in accordance with Equation 7 was given in Table 8.

Table 8. *Articulation Index calculation at the receiver 3 which is the farthest point from the source (Receiver 3 was shown in Figure 9).*

Frequency (Hz)	SPL at 1m (dB)	Signal Level (dB)	Noise Level (NC 30)	S-N ratio	WF (weighting factor)	(S-N) x WF
250	72.5	50.2	41	9.2	0.0024	0.0221
500	74	51.7	35	16.7	0.0048	0.0802
1000	68	45.7	31	14.7	0.0074	0.1088
2000	62	39.7	29	10.7	0.0109	0.1167
4000	57	34.7	28	6.7	0.0078	0.0523
AI = 0.0221 + 0.0802 + 0.1088 + 0.1167 + 0.0523 = **0.38**						

The calculated AI value is analysed separately in indoor areas. Correction should be performed in the reverberant room. The level that should be subtracted from the AI value was defined in the book of Metha et al. (1999) according to the calculated reverberation time values. In the book, it is recommended to decrease approximately the 0.7 value from the AI result when the reverberation time is approximately 0.7 seconds. The calculated AI value was 0.31 after the reverberation time correction was done. It was determined that if the listeners see the speaker, the calculated AI value and the effective AI value can be different, and it was clarified that the effective value was higher in this case (Mehta et al., 1999). While the calculated AI value is approximately 0.31, the effective AI value is approximately 0.50 (Mehta et al.,1999).

It was seen that the calculated AI value was between 0.5 and 0.7. This range can be defined as good according to Metha et al. (1999). Since the effect of reflections was ignored in this calculation, the AI value is expected to be higher in the real situation. In addition, the calculations are calculated for the human voice speaking without shouting. There is a loudspeaker system in the meeting room and the speaker's voice can be increased with the help of the electroacoustic system. In this case, it is clear that the AI value will be much higher.

DISCUSSION

Within the scope of the study, an acoustic project proposal was presented to improve auditory comfort conditions and it was aimed to control the reverberation time in line with the DIN 18041 standard. The calculation results of the reverberation time and the required reverberation time values (maximum and minimum) were shown in Figure 11. Moreover, the reverberation time calculation results without the acoustic project proposal and the reverberation time calculation results with the acoustic project proposal were compared in Figure 11.

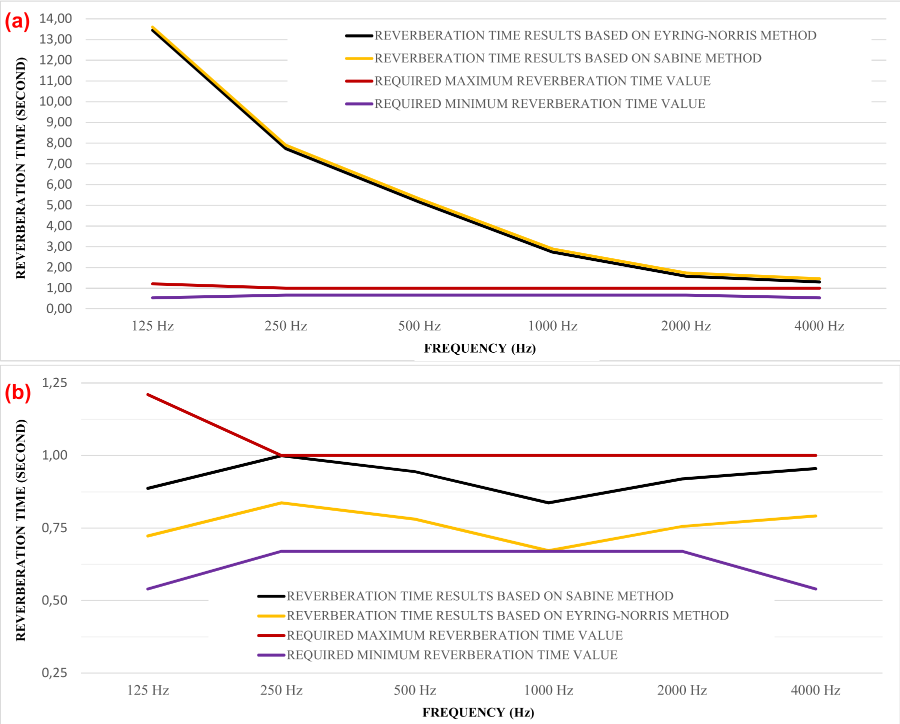

***Figure 11**. Reverberation time results of the meeting room a) without acoustic project suggestion, b) with acoustic project suggestion.*

In Figure 11a, it can be seen that the reverberation time results are very high compared to the required range. It was observed that the reverberation time should be controlled to increase the auditory comfort conditions. The reverberation time results of the proposed acoustic project were shown in Figure 11b. Reverberation time values were improved by increasing the total absorbency in the room. Reverberation time results calculated according to both the Sabine method and Eyring-Norris method meet the required values. It has been determined that the reverberation time results calculated in line with the acoustic project are in accordance with the reverberation time intervals specified in the DIN 18041 standard (Fig.11b). In addition, designing the vault ceiling surfaces with sound-absorbing characteristics was suggested in the acoustic project study. In this way, it was aimed to reduce the focusing problem, which can often be observed on concave surfaces. In addition, the reduction of delayed reflections caused by ceiling reflections was intended with the acoustic project proposal. The auditory comfort conditions of the meeting room were improved with an acoustic project proposal.

Everest & Pohlmann (2009) stated that if the average absorption level in the room is below 0.25, the results of the Sabin method reverberation time calculation will be close to the Eyring-Norris method reverberation time calculation. A similar situation can be seen in Figure 11a. In the acoustic improvement project proposal, the total absorption ratio in the room was increased and the average absorption value exceeded 0.25. For this reason, the reverberation time calculation results of the Sabin method and the Eyring-Norris method can be different in Figure 11b.

It has been determined that the AI (Articulation Index) value is suitable for all listener points as a result of the analyses made. However, it could not be recommended to reduce the plan size of the room by dividing it with a partition wall, even if the AI value was calculated as insufficient. It would be advisable to reduce the number of listeners simply by reducing the table size. It is essential to preserve the original room forms in the restoration of historical buildings.

In literature research, it is seen that acoustic suggestions are presented in accordance with the original form of historical buildings. Iannace et al. (2013) examined the vaulted classroom and offered practical suggestions. They could not present the concave vault surfaces as absorbent. However, in this study, there was no budget constraint as there was no field measurement and there was no obligation to implement the proposed project. Hence, the vault surfaces are designed as absorbent. Alonso et al. (2014) investigated the cathedral in Seville and they suggested covering the cathedral columns with portable velvet draperies to improve acoustic comfort conditions. However, the visual perception of the original stone columns was changed. In the acoustic project proposal, the original period perception of the vault form was preserved with the acoustic plaster proposal. It is predicted that the visual perception of the vault surfaces does not change significantly in this acoustic project suggestion. Prodi & Pompoli (2016) and Bartalucci et al. (2018) analysed the improvement of the room acoustic using portable surfaces. Similarly, in the proposed acoustic project study, it has been suggested to use removable acoustic absorbers on the lower surfaces of the wall coverings.

Homogeneous propagation of sound is targeted in indoor acoustic designs. In interior design, if the sound spreads homogeneously, the occurrence of interior acoustic problems is prevented. Homogeneous propagation of sound can be examined in acoustic simulation programs. The reverberation time values calculated in the 4th section provide information about the average approximate levels for the meeting room. However, the reverberation time results, which vary according to the receiver points in the space, can be obtained with the help of acoustic simulation programs. For this reason, the reverberation time in acoustic research was also examined in the I-SIMPA acoustic software. Version 1.3.4 of the I-SIMPA software was used, the meeting room was modelled in a 3D model, and the 3D model was transferred to the I-SIMPA software. The coating properties of the surfaces were defined in line with the acoustic project after the 3D model was transferred to the I-SIMPA software. The images of the model obtained from the I-SIMPA software were given in Figure 12.

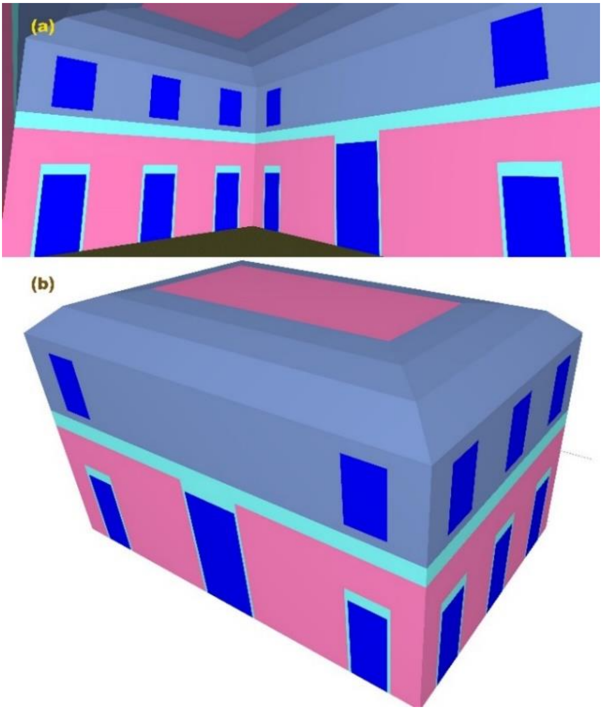

Figure 12. *The meeting room model in the I-SIMPA software, a) Interior image of the room, b) exterior image of the room.*

The location of the speakers used in the meeting room is shown in Figure 8. The location of the loudspeakers was approximately entered into the simulation program and 4 different loudspeakers were defined as sources during the analysis process. Analyses were carried out with the loudspeakers 3 meters above the ground. The loudspeakers are defined as omnidirectional in the acoustic software to analyse the reflections of the loudspeakers on all wall surfaces. Receivers were defined as a plane, and the plane receiver grid system was located 1.6 meters above the floor. Grid solution was defined as 30 cm x 30 cm in a plane receiver grid system. The acoustic analysis was performed by choosing the SPSS calculation method in I-SIMPA software.

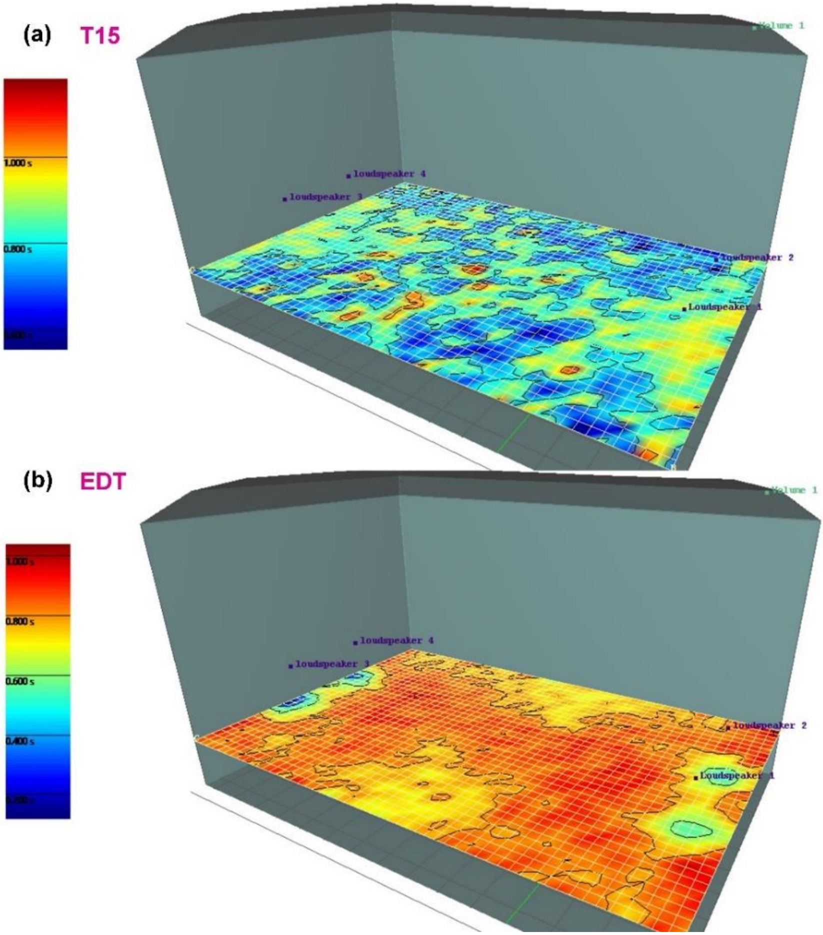

Figure 13. *Acoustic software results at 500 Hz, a) T15, b) EDT.*

The simulation program calculation results at 500 Hz related to the reverberation time were given in Figure 13. It is seen that the T15 results and the results of the reverberation time calculated in the 4th section approximately overlap with each other (Fig.13a). Likewise, The EDT simulation results at 500 Hz and the calculated reverberation time results at

500 Hz (calculated in the 4th section) are approximately similar at the receiver points (Fig.13b). In general, it is observed that the results of the reverberation time in the grid system are close to each other. It slightly differs the reverberation time values of 4 different points where only the loudspeakers are located. It can affect the homogeneous spread of the loudspeakers. Apart from this situation, no significant differentiation was observed in the grid system in the results of the reverberation time. For this reason, it can be said that the sound spreads homogeneously in the meeting room at 500 Hz in general. It has been found that surface coatings can reduce acoustic problems in general.

It is possible to analyse the delayed reflections on the results of the simulation program. An acoustic project was proposed so that the ceiling surfaces would be absorbent, delayed reflections were improved, and these issues were detailed in the 4th chapter. In this section, the results of the simulation program are examined over the parameters clarity (C_{50}) and definition (D_{50}), and the results of the C_{50} and D_{50} at 500 Hz were given in Figure 14. Llorca et al. (2018) suggested that the clarity (C50) value should be above 1 dB in the halls used for speech purposes. It was seen in Fig 14a that the C_{50} results are above the value of 1 dB in general, and it was observed that most of the sound energy reaches the receivers before 50 milliseconds. In the D_{50} analysis, it was understood in Figure 14b that more than 50% of the sound energy generally reaches the receivers before 50 milliseconds. In the C_{50} and D_{50} analyses, it was determined that the delayed reflections occurred less. It has been noticed that absorbent surface recommendations reduce delayed reflections.

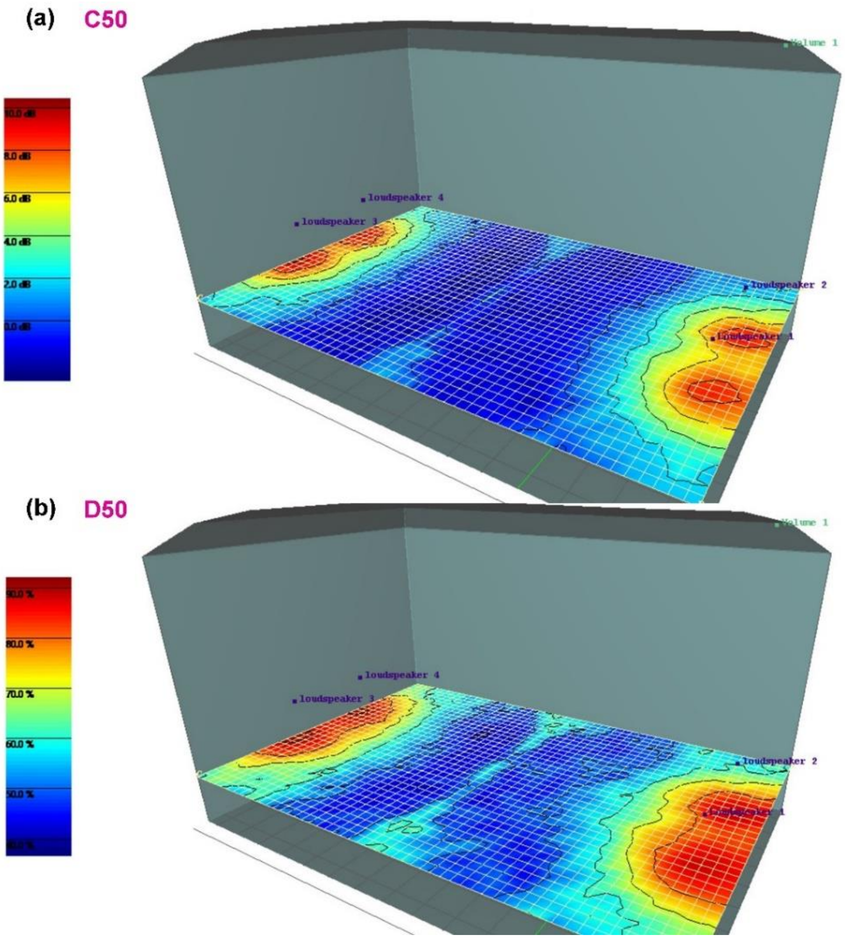

Figure 14. *Acoustic software results at 500 Hz, a) C50, b) D50.*

In this study, field measurements could not be made because there was no calibrated sound measurement system and sufficient budget could not be found. In the literature, it can be observed that firstly the field measurements are made for the existing hall, then the acoustic model analysed in acoustic software is calibrated in line with the field measurements, and finally, the acoustic simulation results are examined by acoustic improvement suggestions. The lack of field measurements can be considered the biggest weak point of this research.

The proposed acoustic project does not harm the perception of the large volume of the historical place. In the acoustic project, the original design decisions were conserved, the ceiling height was not reduced by the suspended ceiling proposal and the perception of the vault in the interior was preserved. The sound absorption performance of the surfaces was improved. Accordingly, the total absorption in the room has been increased. In summary, with the proposed acoustic project, the original period decisions of the historical building were preserved and the interior acoustic comfort conditions were improved at the same time. The research provides information about the acoustic project preparation process in the restoration of historical buildings. In historical building restorations, this study may be useful to define appropriate intervention decisions for the improvement of acoustic comfort conditions.

CONCLUSION

In the restoration of historical buildings, the design decisions made in the original period should be preserved. In addition, restoration decisions should be made in accordance with user comfort conditions. In this research, the meeting room of a historical building was examined and acoustic design suggestions were presented in accordance with its historical structure. It has been aimed to improve the auditory comfort conditions without harming the design decisions of the original period of the historical space. In this direction, an acoustic project proposal has been presented. In the acoustic project suggestion, the design decisions of the original period were preserved, the ceiling height was not changed, and the richness of the interior and the vault form, which was the characteristic of the original period, were preserved.

In the acoustic project proposal, the total absorbance of the room has been increased and the auditory comfort conditions have been improved accordingly. Within the scope of the research, reverberation time, delayed reflections, and articulation index were examined in detail. Acoustic improvement decisions were presented in line with all parameters in the acoustic project proposal. In addition, the meeting room was analysed with the help of an acoustic simulation program and the homogeneous propagation of the sound was investigated in detail. The results of the T_{15} parameter, EDT parameter, C_{50} parameter, and D_{50} parameter obtained in the acoustic simulation program were analysed and compared with the calculated results. In addition, according to the results of the acoustic simulation program, it was questioned whether the sound spreads homogeneously or not. As a result, it has been determined that the reverberation time has been improved in line with the DIN 18041 standard with the acoustic project proposal. It has been ensured that the results of the reverberation time calculated in line with the acoustic project proposal are compatible with the DIN 18041 standard. It has been understood that delayed reflections are largely prevented. It has been understood that the sound can generally spread homogeneously. Due to the homogeneous spread of the sound, acoustic problems in the space were reduced (focusing, whispering gallery, etc...). In summary, with the proposed acoustic project, indoor auditory comfort conditions have been increased.

Restoration of each historical building should be carried out in accordance with its own unique design decisions. For this reason, acoustic improvement designs should differ depending on the character of the historical building. With this point of view, acoustic improvement project works of historical buildings may differ in each historical building. For this reason, acoustic improvement project studies are a very broad research topic in the literature.

It is anticipated that this research can be beneficial to inform the experts working on restoration issues. In addition, it is estimated that the prepared study can give an idea to academic studies.

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