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Acoustical design of İzmir Opera House

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Abstract

İzmir Opera House in Mavişehir, İzmir, designed by Teğet Architecture of İstanbul, faces the Aegean coastline in a high-rise residential suburban area. The project was awarded with the 1st price in the national design competition held in 2010 and is planned to be tendered in the third quarter of 2016. Over a construction area of 56.000 m^2 the opera house will be the largest opera venue in Turkey. The project aims to re-organize the relations between urban areas and the coast in terms of programmatic and morphological sense. The complex accommodates a main hall with seating capacity of 1368, a black box with a capacity of 450 and a multipurpose open-air courtyard for 400 persons, rehearsal rooms for orchestra, ballet and opera, ateliers, offices and storage areas. This paper basically introduces the acoustical design process of main hall. Sightline analysis for the main hall has been performed as the first step in acoustical design. Number of balconies, floor rakes, and wall inclinations are studied accordingly. Surface modulations are specifically designed to provide enough scattering on relevant surfaces. Resonators, suspending under the ceiling in the main hall are specifically designed to control excessive bass sound. While tuning architectural parameters as of orchestra pit and room dimensions, surface forms and textures; rigorous acoustical simulations are held for the main hall until acoustical design criteria are satisfied in accordance with the functions.

Keywords: Opera halls, room acoustics, acoustical simulation

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1 Introduction

İzmir Opera House in Mavişehir, İzmir is designed by Teğet Architecture of İstanbul. The project was awarded with the 1st price in the national design competition held in 2010 and is planned to be tendered in the third quarter of 2016. The project site faces the Aegean coastline in a high rise residential suburban area. The project aims to re-organize the relations between urban areas and the coast in terms of programmatic and morphological sense. The opera house is designed to be the largest opera venue in Turkey considering its total construction area of 56.000 m^2. The seating capacity of the main hall and black box are 1368 and 450, respectively, along with a multipurpose open air courtyard which accommodates for 400 people. The complex also houses rehearsal rooms for orchestra, ballet and opera, ateliers, administrative offices and storage areas as well.

Figure 1: İzmir Opera House, exterior view

The main objective is to design the form of interior surfaces and textures as well as to determine optimum architectural parameters and room dimensions for orchestra pit and main hall. Design process is executed with minute acoustic simulations to validate whether the acoustical design criteria for the main hall is met.

2 Acoustical design

In this section acoustical design steps of the main hall are presented. As an initial step, objective acoustical parameters and optimum ranges for opera function are set (Table 1).

Table 1: Acoustical parameters and optimum ranges for opera function (500 Hz – 1000 Hz)

Parameter	Optimum range	Just noticeable difference
T30	1.6 s – 1.8 s	5% (≈ 0.1 s)
EDT	1.5 s – 1.7 s	5% (≈ 0.1 s)
STI	> 0.6	0.05
SPL	Minimum variations in SPL <10 dB	2 dB
C80	>0 dB <+4 dB	1 dB
LF	>0.2 <0.4	0.05
G	>1 <+4 dB	1-2 dB
Bass Ratio	>1.05	
HVAC Noise	NC 15	

2.1 Main hall design

Main hall within Izmir Opera House in its concept design phase was accommodating 1260 seats and had an approximate interior volume of 11,000 m^3. In construction documentation phase, the ceiling height is increased in order to provide room for an additional balcony level. Thus, the volume is increased up to 12,500 m^3 while the hall accommodates 1368 seats in its final form. This makes a 9.14 m^3 volume per person, which is considered proper for opera use. Although this value is a little higher than those indicated in the literature [1], it is in line with old renowned opera halls as of Semperoper with a volume of 10.3 m^3 and some recent successful venues like New National Theatre in Tokyo with a volume of 9.9 m^3 and Oslo Opera House with a volume of 8.3 m^3 per person [2].

The first step of acoustical design is the sightline analysis for the main hall. Horseshoe form is preferred for providing better sightlines as well as for increasing lateral reflections. Number of balconies, floor rakes, and wall inclinations are studied accordingly. The two levels of balconies in concept design are increased to three levels so that the audience can be seated in a much proportionate room where the back seats are no more than 28m away from the apron. Seats are staggered for minimizing the floor rakes which reaches maximum to 36° at the third balcony level. Back wall is inclined towards the front of the hall as another intervention to improve sightlines with a minimum floor rake. For the same reason, side balconies as well are also raked/inclined down towards the front of the hall. Balcony parapets in section are inclined upwards in between 11-19° in order to prevent late-delayed reflections from parapet surfaces to the stage.

One disadvantage of the horseshoe shape is the concave surfaces at the corners of both enveloping walls and balconies. Surface modulations are specifically designed to provide enough scattering on these surfaces as shown in Figure 2. Apart from that, wall and ceiling surfaces of the hall are designed to be reflective that are made out of 25 to 50 mm solid wood in order to enforce reflections and provide desired reverberation. Different modules of Helmholtz resonators, suspending under the ceiling in the main hall are specifically designed to control excessive bass sound. One of those modules is presented in Figure 3 below.

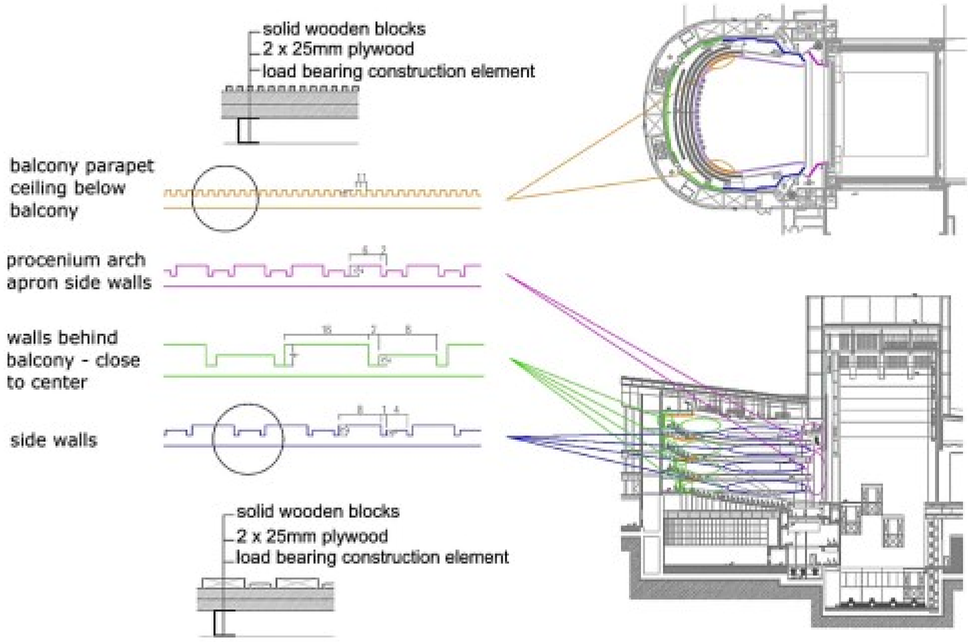

Figure 2: Sound scattering surface details applied on walls and balconies

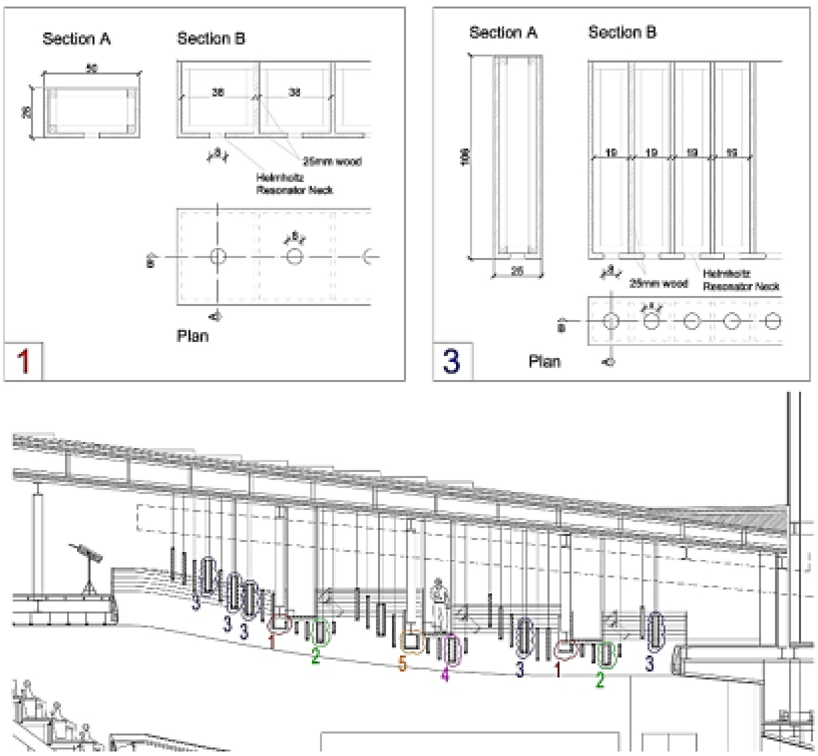

Figure 3: Detail of a typical Helmholtz resonator applied underneath ceiling (a), section view of the ceiling with Helmholtz resonators (b)

2.2 Apron and orchestra pit design

Apron design in opera halls is important for good distribution of music and sounds of performers in to the hall, and for providing the communication/balance in between orchestra and opera singers/performers. For that reason it is beneficial that the walls and ceiling above apron have a reflective surface and a form that is expanding towards the main hall, helping the transfer of early sound reflections into the audience area [2, 3]. The reflective surfaces are designated as of 50 mm solid wood. Some scattering is applied in proper amounts on side walls of apron for providing good/even distribution of sound inside the hall (Figure 2).

Orchestra pit design is crucial for the balance in between music from orchestra and opera singers on the stage. The pit should be located in a lower level and surrounded by walls in such a way that the music from orchestra should not dominate opera singers' sounds, while the music should sufficiently be distributed towards the audience area. The depth of orchestra pit of the main hall/auditorium is designed to be 1.8m and the average width is 6.5m to fit 78-musician orchestra as required by the opera company, i.e., İzmir State Opera. The height between orchestra floor and stage floor is 2.7m. In order to control excessive sound build up from the orchestra inside the pit, perforated wood is applied over concave walls on the audience side (front wall) up to 1 m height from the floor. Retractable velour curtains are advised at the back wall of the pit for tuning of the sound by musicians playing different instruments. Orchestra pit has a 100 cm height parapet wall on the audience side, 30 cm of which is out of glass. The parapet wall has an inclination of 15° towards the audience area.

2.3 Stage tower design

Stage tower architectural characteristics are directly affecting the acoustical conditions within the hall. The acoustics of the stage/stage tower is predominantly depicted by the height of the stage tower and stage curtains applied for different functions. Different curtains and décors have different sound absorption performance. The stage decors and some of the curtains change in different opera plays. Although these uncertainties, specific curtains are always utilized in each play such as backdrop and leg curtains. Thus, a rough estimate for the stage tower acoustics can be made. Stage tower walls and ceiling are also a part of the stage acoustics' design. These surfaces and curtains are considered in simulations while tuning the balance in between stage tower and main hall acoustics. In Izmir Opera House main hall, leg curtains are advised to be 300 gr/m^2 dense cotton curtain and backdrop is advised to be 200-300 gr/m^2 polyester curtain. For additional sound absorption and reverberation control within the stage tower, underneath the main ceiling of stage tower, 100 mm thick 50 kg/m^3 mineral wool application is suggested. Detailed material definitions and sound absorption coefficient information of materials applied in stage, main hall and orchestra pit are given in following section (Table 2).

3 Acoustical simulations

3.1 Room and material information

Acoustical conditions within the auditorium are analyzed by simulations over the given geometry and estimated material input data. A simplified acoustical model comprising 17,705 plane surfaces is developed for use with ODEON version 12.12. Estimated acoustical volume for the main hall is 21171m³, excluding stage tower. The 3D OpenGL view of the main hall is given in Figure 4. Ray tracing view of the model is shown in Figure 5. Sound absorption coefficient data of materials applied within main hall, stage tower and orchestra pit are listed in Table 2.

In simulations a point source is defined over the main stage representing opera singer (h: 1.5 m) and a surface source (h: 1.2 m) is defined inside the pit representing the orchestra. Audience area at a height of 1.2 m from floor is divided into 100x100 cm grids in order to obtain distribution maps. Number of late rays is defined to be 200,000.

(a) (b)

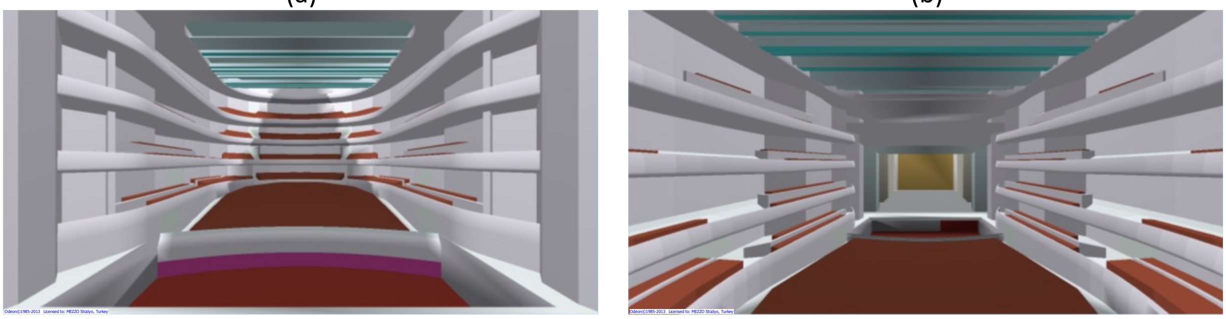

Figure 4: 3DOpenGL views of main hall, towards the back wall (a), towards the stage (b)

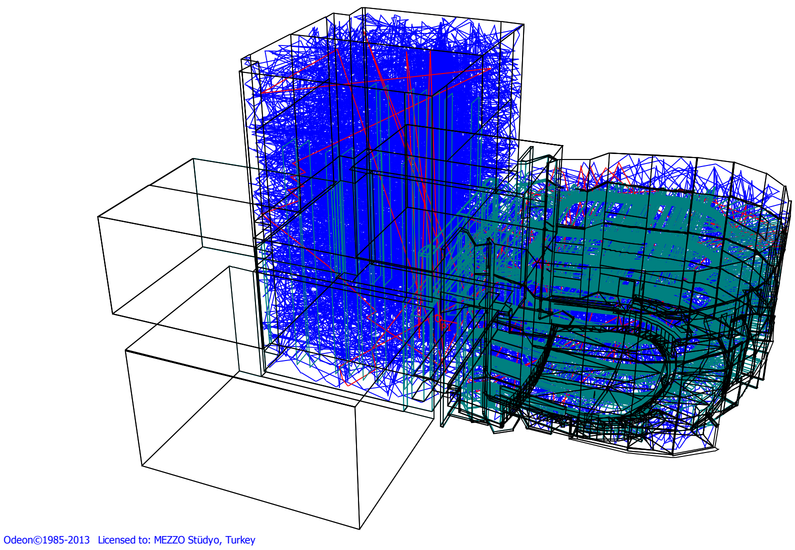

Figure 4: Ray tracing view of the acoustical model

Table 2: Material list with sound absorption coefficient data per octave bands

Location	Material name	Frequency [Hz]					
		125	250	500	1000	2000	4000
Stage painted concrete walls	Painted concrete	0.01	0.01	0.01	0.02	0.02	0.02
Orchestra pit front wall up to 1 m. concave surfaces	Slotted-perforated wood (perforation ratio 7.5 %) with 50 mm 50 kg/m³ mineral wool behind	0.17	0.50	1.00	0.80	0.40	0.42
Wall and suspended ceilings. apron ceiling	50 mm thick wooden panel with 50 mm 50 kg/m³ mineral wool behind	0.08	0.13	0.12	0.09	0.06	0.06
Audience floor	2 layers of 33 mm wood platform	0.09	0.06	0.05	0.05	0.05	0.04
Stage floor	25 mm beech + 18 mm pine massive wood flooring with 15 cm air gap behind	0.10	0.07	0.06	0.06	0.06	0.06
Stage gypsum walls	2x13 mm gypsum board with 50 mm 50 kg/m³ mineral wool behind	0.15	0.10	0.06	0.04	0.04	0.05
Main hall ceiling	3x13 mm gypsum board with 50 mm 50 kg/m³ mineral wool behind	0.28	0.12	0.10	0.07	0.13	0.09
Metal surfaces within the stage tower	Sheet metal	0.05	0.10	0.10	0.10	0.07	0.02
Backdrop	200-300 gr/m^2 polyester curtain	0.28	0.22	0.34	0.45	0.55	0.71
Projection screen	500 gr/m^2 cotton stretched fabric	0.09	0.33	0.45	0.52	0.50	0.44
Proscenium curtain	500 gr/m^2 wool curtain	0.20	0.55	0.90	1.00	1.00	1.00
Orchestra pit back wall curtain	500 gr/m^2 molton curtain	0.10	0.40	0.85	0.95	0.80	0.85
Leg curtains	300 gr/m^2 cotton curtain	0.17	0.19	0.18	0.19	0.21	0.26
Doors	Solid wood	0.14	0.10	0.06	0.08	0.10	0.10
Parapet	6 mm glass	0.10	0.06	0.04	0.03	0.02	0.02
Orchestra	Orchestra with instruments. 1.5m^2 per musician	0.27	0.53	0.67	0.93	0.87	0.80
Seating	lightly upholstered with audience	0.36	0.53	0.65	0.79	0.83	0.78
Underneath stage tower ceiling	100 mm 50 kg/m^3 mineral wool	0.65	1.00	1.00	1.00	1.00	1.00

3.2 Simulation results

In this section acoustical simulation results of the main hall with proposed materials and final acoustical design are presented. Global reverberation times over octave bands are presented in Figure 5. Reverberation time (T30), early decay time (EDT), lateral fraction (LF80), clarity (C80) distribution maps are presented for 500Hz octave band in Figure 6 along with the STI and SPL(A) distribution maps.

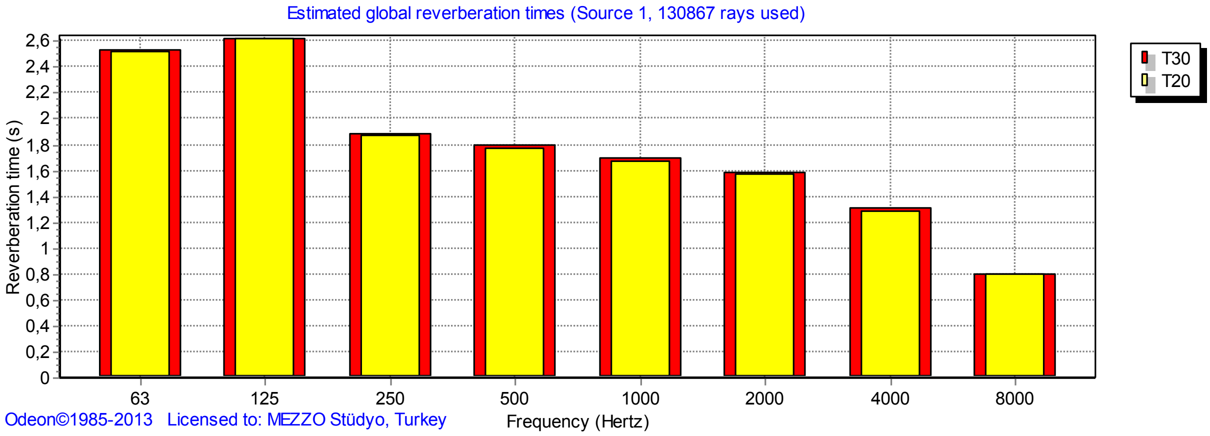

Figure 5: Reverberation times (T30) over octave bands of the main hall

T30 average for low frequencies is 2.25s as can be observed in Figure 5. The mid frequency reverberation time average is 1.75s. This indicates a bass ratio (BR) of 1.28. In overall seating locations, EDT ranges in between 1.3 s – 1.6 s for mid frequencies. The EDT values observed for the seating positions close to stage are lower than the ones at the rest of audience area. LF varies in between 0.22 to 0.45 and C80 is in between 0 to 4dB in overall audience area, which are all within acoustical parameter limits given in Table 1. For 500 Hz 10 m away from the over stage source, sound strength (G) is estimated to be 4.6dB. A-weighted sound pressure level variations do not exceed 10 dB(A) within the audience area. STI values are above 0.57 at the 50% of audience area.

4 Concluding remarks

The acoustical design of the main auditorium/hall within Izmir Opera House is held in coordination with architectural design team. Several scenarios of use are considered in the acoustical design process. Simulation results indicate that acoustical comfort limits are satisfied for the basic functions of the main hall, which are opera and ballet. In addition to the opera use, the auditorium is occasionally planned to be used for symphonic music and recitals for annual Music Festival in İzmir. In that case additionally an orchestra shell over main stage shell is proposed, for providing better ensemble of the orchestra by enhancing the early reflections from the reflective close-by wooden surfaces. In case of conference use, retractable wool curtains are proposed at the back walls for reverberation control. These curtains are designed to be collected/retracted during standard use of the hall.

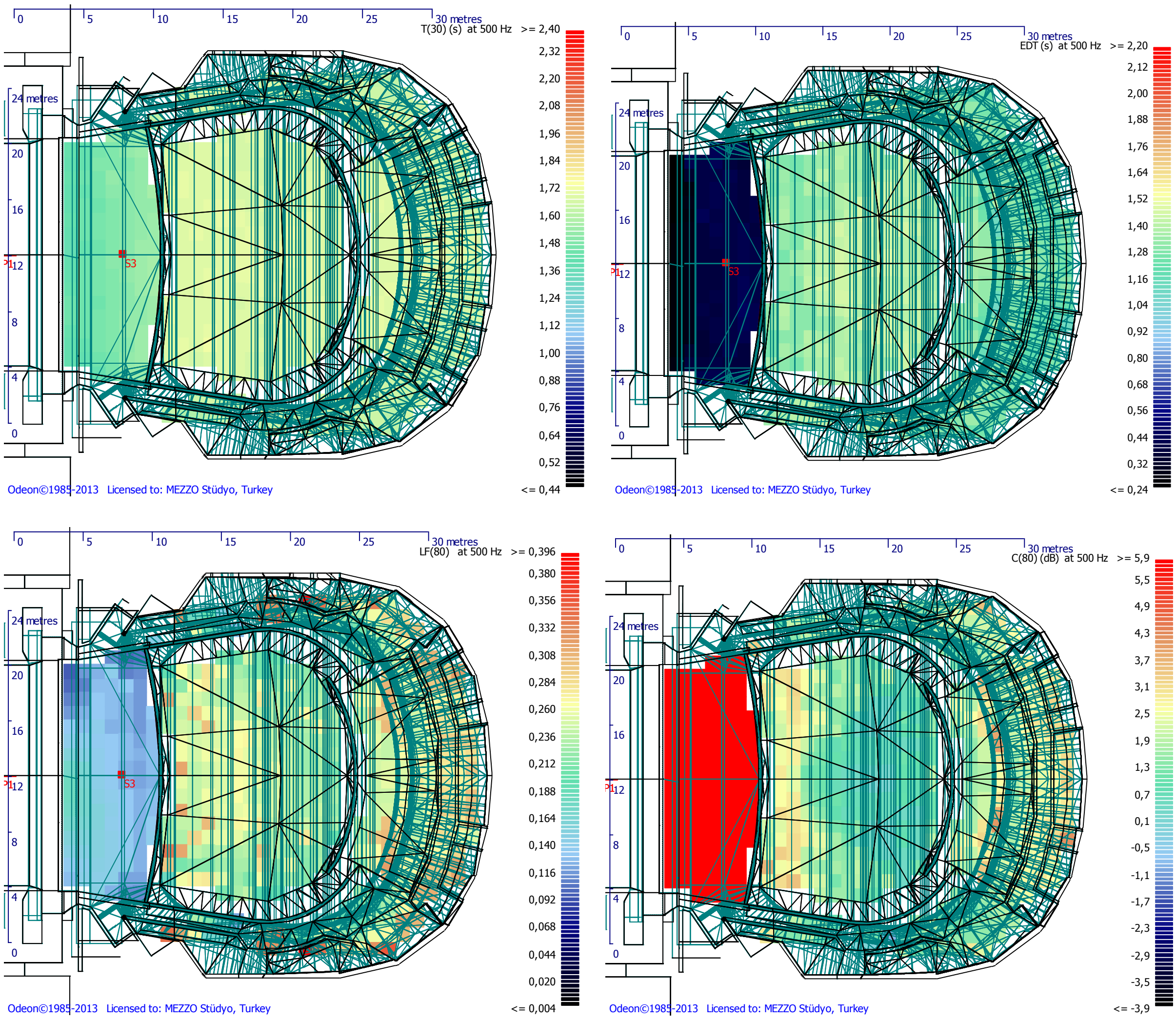

Figure 6: T30$_{500Hz}$. EDT500$_{Hz}$. LF(80)500$_{Hz}$ and C(80)500$_{Hz}$ distribution maps

Acknowledgement

Teğet Architecture of Istanbul is gratefully acknowledged for permission of the release of visual material.

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