ACOUSTICAL EVALUATION OF SHOPPING MALL TYPOLOGY

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ABSTRACT

ACOUSTICAL EVALUATION OF SHOPPING MALL TYPOLOGY

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Acoustic design of shopping malls which have become very popular in recent years, has gained importance and it has been considered as an integral part of the design – construction and life cycle treatment of such complex – functional buildings. In this study, acoustic qualities of shopping malls are to be inquired by focusing on circulation areas and atrium spaces where noise is one of major disturbances. In this context, first taxonomy of shopping malls regarding their geometrical forms is to be proposed together with plan layouts, construction materials and spatial organizations. Then some of these malls in representing major characteristics of the each class in the taxonomy are to be acoustically analyzed and compared with standards by aiming to provide some guiding principles for acoustical design of such spaces.

Keywords: Acoustics of Shopping Mall, Shopping Mall Typology, Acoustical Simulation of Mall

ÖZ

ALIŞVERİŞ MERKEZİ TİPOLOJİLERİNİN AKUSTİK AÇIDAN DEĞERLENDİRİLMESİ

Çalışkan, Ekrem Bahadır

Yüksek Lisans, Yapı Bilimleri, Mimarlık Bölümü

Tez Yöneticisi: Doç. Dr. Arzu Gönenç Sorguç

Eylül 2010, 124 sayfa

Son yıllarda alışveriş merkezlerinin akustik tasarımı önem kazanarak popüler bir hale gelmiştir. Akustik tasarım bu tarz karmaşık ve işlevsel binaların tasarımının, yapımının ve yaşam süresi iyileştirmesinin ayrılmaz bir parçasıdır. Bu çalışmada gürültünün büyük bir sıkıntı olduğu dolaşım ve atrium alanlarına odaklanılarak alışveriş merkezlerinin akustik kalitesi araştırılmıştır. Bu bağlamda ilk önce alışveriş merkezlerinin geometrik formlarına göre yapılan sınıflandırma çalışması; plan yerleşimleri, yapı malzemeleri ve mekânsal düzenlemeleri ile birlikte sunulmuştur. Daha sonra her sınıfın ana niteliklerini temsil eden alışveriş merkezlerinden bazıları akustik açıdan incelenerek, söz konusu mekânların akustik tasarımına yol gösteren ilkeler oluşturmak amacıyla standartlarla karşılaştırılmıştır.

Anahtar Kelimeler: Alışveriş merkezi akustiği, Alışveriş merkezi tipolojisi, alışveriş merkezinin akustik simülasyonu

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LIST OF SYMBOLS

AI .... Articulation Index
C80 .... Objective Clarity
dB .... Decibel
D50 .... Early Energy Fraction
EDT .... Early Decay Time
Hz .... Hertz
ITDG .... Initial Time Delay Gap
RT .... Reverberation Time
SPL .... Sound Pressure Level
STI .... Speech Transmission Index
T30 .... Center Time

CHAPTER 1

INTRODUCTION

Buildings and spaces should achieve required performances regarding their functions as well as standards imposed for them. Hence design goals should be set and then design process should be considered accordingly.

A functional house which does not provide privacy, a large classroom without a light control system, a big sports centre without a properly operating ventilation system, or an exhibition hall which does not provide acoustic comfort are not considered as being well designed even if they have other good qualities. Spaces should provide all comfort conditions for the proper continuation of the physical and cerebral activities. So, the architects ought to consider all aspects of buildings[1].

Architectural acoustics is one of the important subjects and it should be considered as an integral part of any design process ranging from performance halls to classrooms, hotels to shopping malls and many other public and private spaces. Shopping malls, with remarkable increase in the number, are now one of the popular public spaces. They can be considered as "new driving forces" of

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[1] AMBROSE, James and OLLSWANG, Jeffrey. *Simplified Design for Building Sound Control.* John Wiley & Sons, New York,1995

economy as well as the new way of "socializing places" where visitors can experience different modes of interactions.

Shopping malls are products of the collection of different elements of the retailing sector in an enclosed atmosphere and under a single managerial organization in order to supply consumers with one-stop shopping[2]. Thus, in the rapid life of this century, these buildings become one of the preferred spaces for people to take part in life.

As the number of shopping malls is increasing in a competitive way, the number of users becomes an important issue for investors. So, the designers concern more about the qualities and design decisions to achieve sustainability of such public places. Therefore, optimum conditions related to indoor air quality, acoustics, circulation systems, fire safety, lightening, etc. have been explored and more efforts have been spent to determine design criteria to provide more pleasant environments.

Hence in this thesis, it is focused on the acoustical design and noise control of shopping malls that is one of the cognitive instruments for human beings to have interaction and get familiar with their environment.

There is a number of researches about acoustics of shopping malls, shopping areas and large enclosed spaces. In one of them Chen and Kang studied acoustic comfort in shopping mall atrium spaces by having measurements to evaluate acoustical quality regarding architectural design at Sheffield Meadowhall[3]. There are other studies inquiring the acoustic quality of individual malls. Demir studied acoustical quality of two malls in Ankara[4], by having sound measurements.

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[2] AKÇAOĞLU, Aksu. *The Mallification of Urban Life in Ankara: The Case of Ankamall*. Master thesis submitted at METU. August, 2008.

[3] CHEN, Bing and KANG, Jian. "Acoustic Comfort in Shopping Mall Atrium spaces: A Case Study in Sheffield Meadowhall" in: *Architectural Science Review* (Vol. 47, p. 107-114).2004

[4] DEMİR, Kader. *Noise Control and Constructual Preventions at Shopping Centers: Two Examples in Ankara.* Master thesis submitted at Gazi University. January, 2003.

Dökmeci used a 3D model of Cepa AVM and sound measurements to investigate acoustical comfort in that enclosed public areas with a central atrium[5]. Although these studies are some examples of contemporary literature, the number of the studies related to acoustical quality of malls is not adequate for further improvement. For this reason, in this study, rather than concentrating a single mall typology, major typologies encountered in contemporary practice as presented in the classification have been explored regarding acoustics. It is aimed to illustrate the effects of the architectural design decisions on acoustical qualities and to provide a matrix showing acoustics-typology relation to designers making them gain insight in acoustics at the initial design step.

In this sense, common types of materials, spatial organizations, plan layouts and geometrical forms of contemporary shopping malls are investigated for further analysis of acoustical quality of those spaces.

First, shopping malls in Ankara have been explored and a taxonomical study regarding the typologies of these malls is presented. In this taxonomical study, parameters such as material, volume, plan, dimension and etc. which affect acoustics have been taken into consideration. Then, malls exemplifying the typologies have been chosen for further acoustical analysis by AutoCAD[R] and Odeon[R].

Second chapter begins with definitions and the terms of architectural acoustics related to the topic. Then, the definition and the history of the shopping malls are briefly outlined in parallel with architectural development in the World, in Turkey and in Ankara. Finally, acoustical features of shopping malls and their importance regarding classification of mall typologies are pointed out.

The results of taxonomic study based on the typologies of shopping malls are presented in the third chapter to provide required data to prepare solid models for

[5] DÖKMECİ, Papatya Nur. *Acoustical Comfort Evaluation in Enclosed Public Spaces with a Central Atrium: A Case Study in Food Court of Cepa Shopping Center.* Master thesis submitted at Bilkent University. 2009.

acoustical analysis through simulations. The assumptions, observations and parameters that are used in the study are explained in detail.

In the fourth chapter, the data and the standards for 3D modeling and acoustic simulations prepared for the analysis are given. Necessary details for modeling and acoustic values that are assigned are clarified.

In the fifth chapter, shopping malls are evaluated with simulation program to compare with regulations and standards.

In the last chapter, study is summarized and acoustical guide aiming to help designers to relate acoustical quality with their spatial quality is presented.

CHAPTER 2

SURVEY OF THE ACOUSTICS OF ENLOSED SPACES AND SHOPPING MALLS

Acoustics have significant importance from ancient times to 21th century. Architectural acoustics explores required acoustical values in buildings in terms of intended usage. The majority of such studies in the literature focus mainly on acoustic spaces such as auditoriums, concert halls and other performance spaces; however, other enclosed spaces including large public spaces such as shopping centers and other leisure venues (restaurant, cafes and bars) still need further study since their numbers are increasing every day[6].

2.1 Modern Acoustics and Criteria

"The nineteenth century produced the beginnings of the study of the acoustics as a science and its dissemination in the published literature via technical books and journals."[7]

Establishment of modern acoustics began with sharing of the researches at nineteenth century. In 1860's Hermann von Helmholtz wrote *Sensation of Tone* in

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[6] LONG, Marshall. *Architectural Acoustics.* Elsevier Academic Press, London. 2006

[7] Ibid.

which measurement, observations and a mathematical approach could lead to significant progress. Later in the same century, John W. Strutt, Lord Rayleigh published *Theory of Sound,* which was one of the most important books ever written in the field. In the late nineteenth century, the theoretical beginnings of architectural acoustics were started by W.C. Sabine. By the time he completed his work, he had developed the first theory of sound absorption of materials, presented its relation with sound decay in rooms and a formula for decay (reverberation) time in rooms[8].

Since then acoustics has been recognized as a science, many subjective and objective parameters have been defined for evaluating the acoustics in spaces. The number of parameters used in the room acoustics is increased by the development of the sound measurement tools and audio acoustics. Acoustic parameters like; objective clarity(C80), early decay time(EDT), reverberation time(RT) and etc. are commonly used in order to evaluate performance spaces and the parameters such as early energy fraction(D50), speech transmission index(STI), articulation index(AI) and etc. are considered to evaluate the acoustics of spaces which are mostly used for speech. These are general parameters that are used acoustical behavior of spaces. In this study SPL, initial time delay gap, RT, EDT, T30, D50 and STI are taken into consideration since speech intelligibility and noise in shopping malls are mainly explored.

2.1.1 Sound Pressure Level (SPL)

The sound pressure level is the most commonly used indicator of the acoustic wave strength. It correlates well with human perception of loudness[9]. The SPL is related with hearing mechanism. For example typical conversational speech has a sound pressure level of around 50 dB, traffic noise has a sound pressure level of

[8] Ibid.

[9] Ibid.

85 dB and jet take-off at 100 meters away is about 120 dB causing pain in the ears[10]. Thus, sound pressure level is used to determine; loudness limits and ranges for octave band frequencies for all spaces including shopping malls.

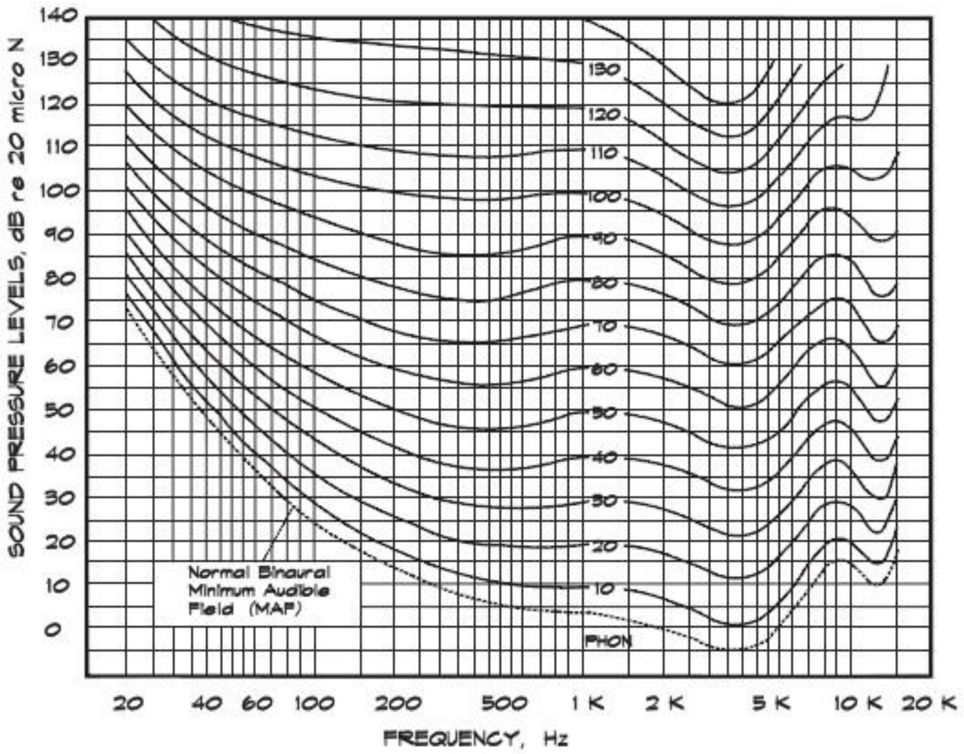

Figure 2.1 Robinson and Dadson noise level contours for pure tones[11]

[10] BARRON, Michael. *Auditorium Acoustics and Architectural Design*. Spon Press, New York. 2010

[11] LONG, Marshall. *Architectural Acoustics.* Elsevier Academic Press, London. 2006

2.1.2 Initial Time Delay Gap (ITDG)

The time delay is related to the location of sound source, reflector surfaces and the receiver. The term is considered to be a measure of acoustic intimacy[12]. Early reflections have significant effects on positioning, total sound level and perception of sound source [13]. ITDG is main acoustics parameter that relates reflection and direct sound. So, it is important in modern acoustics for accuracy of many acoustic parameters related with correlation between direct sound and reflections regarding time, sound levels and etc. As figure 2.2 shows that initial time delay gap is the time delay between direct sound and first reflections[14], it is the important main subject for defining acoustic parameters.

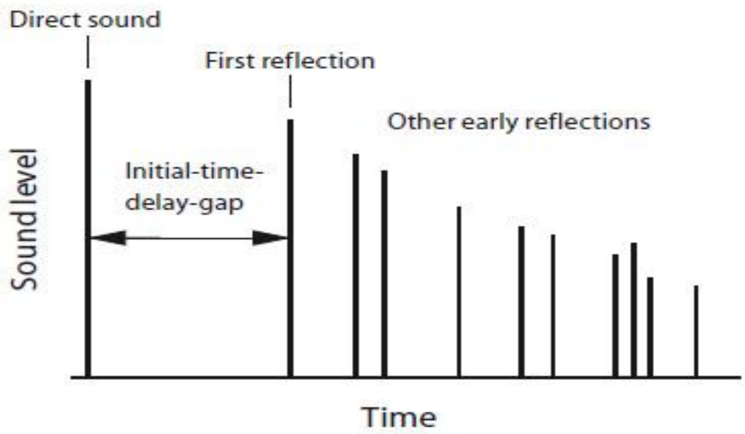

Figure 2.2 Impulse response illustrating initial time delay gap[15]

[12] BARRON, Michael. *Auditorium Acoustics and Architectural Design*. Spon Press, New York. 2010

[13] ÇELİK, Emine. *Acoustical Effects of the Position of Absorbtive Materials in a Room.* Master thesis submitted at Yıldız Teknik University. 1998

[14] BARRON, Michael. *Auditorium Acoustics and Architectural Design*. Spon Press, New York. 2010

[15] Ibid.

2.1.3 Reverberation Time (RT)

The idea that there exists characteristic time for sound to die out in a room is originated by Wallace Clement Sabine. Sabine measured the reverberation time, the time it took for the sound level to drop 60 dB, for varying amount absorptive materials[16]. Reverberation time is the fundamental concept for evaluating the sound field in an enclosed space and it is defined at a given frequency or frequency band as "the time taken for a sound to decay by 60 dB after the source is stopped".[17]

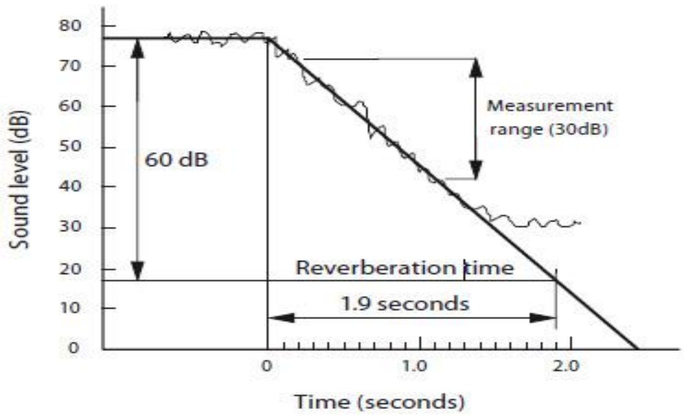

Figure 2.3 Reverberation time[18]

"*Reverberation provides the background of the decay of previous syllables or notes against which the new speech sounds or musical notes are heard.*

[16] LONG, Marshall. *Architectural Acoustics.* Elsevier Academic Press, London. 2006

[17] Lawrence, Anita. *Acoustics and the Built Environment.* Elsevier Applied Science, London. 1989.

[18] BARRON, Michael. *Auditorium Acoustics and Architectural Design*. Spon Press, New York. 2010

If the reverberation time is too long, then one sound can be rendered inaudible by and earlier louder sound. But with too short a reverberation time, the sound quality becomes too stark, like listening in the open air."[19]

Since the reverberation time is directly related to volume and total absorption, the architectural features: volume of the building and total absorption of the surfaces which is related with absorptive character and the area of them have significance effects on the reverberation. Volume and general material approaches are seem to be important for shopping mall regarding both acoustics, architectural and functional reasons. Thus, these subjects have been explored for shopping malls regarding their typologies. Optimum reverberation time is related to the acoustic quality of the spaces and it is determined to the intended usage of them. Figure 2.4 shows the recommended reverberation times for different places.

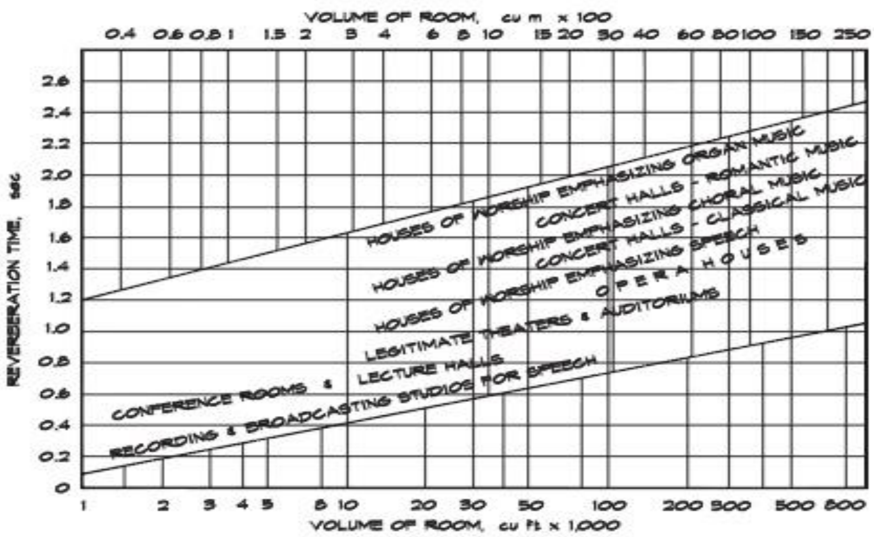

Figure 2.4 Reverberation times and room volumes[20]

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[19] Ibid.

[20] LONG, Marshall. *Architectural Acoustics.* Elsevier Academic Press, London. 2006

2.1.4 Early Decay Time (EDT)

"Early decay time is the initial sound decay in the first 10 to 20 milliseconds of drop after the initial burst that can be caused by an impulse source. After the first impulse there is a string of pulses, which are reflections from surfaces nearest the source and receiver. Thereafter follows a complicated train of pulses, which are the first few orders of reflections from the room surface."[21]

The early decay time is better related to the subjective judgment of reverberation than the traditional reverberation time[22]. High EDT values define more reverberant space and less clarity in a space. Lower values are important for the acoustical quality of spaces as well as shopping malls. In a highly diffuse space where the decay is completely linear, RT and EDT values are identical. But, in non-diffuse space like shopping malls, while RT can be considered about general reverberation in mall, EDT is related with distribution of reverberation regarding geometry of space and position of receiver. Thus, it is important for spatial distribution of reverberation in shopping malls. For example, in a dining space it can be seen that EDT increases with the increase of talker-listener distance, whereas RT is almost constant across seats[23].

2.1.5 Center Time (T30)

Center time is the center of gravity along the time axis of the squared impulse response[24]. Lower values mean that most of the energy reaches to

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[21] Ibid.

[22] BARRON, Michael. *Auditorium Acoustics and Architectural Design*. Spon Press, New York. 2010

[23] KANG, Jian. "Numerical Modelling of Speech Intelligibility in Dining Spaces" in: *Applied Acoustics* (vol. *63*, issue 12, p. 1315-1333). Dec 2002.

[24] Ibid

receiver early and the clarity of sound is high; higher values mean most of the energy reaches to receiver more after than direct sound and the space is reverberant[25]. In shopping mall there varying sound sources as music, paging or other pedestrians. The sound levels of these sources should come into balance at proper time in order to perceive source's singularity. T30 should be explored in shopping malls in order to define the distribution of sound clarity.

2.1.6 Early Energy Fraction (D50)

The early energy fraction is the fraction of the total sound energy which reaches to receiver within 50 ms of the direct sound[26]. It is related to the speech intelligibility. Measured values of D50 in excess of 0.50 are considered satisfactory for speech intelligibility[27].

2.1.7 Speech Transmission Index (STI)

Speech transmission index is a direct measure of speech intelligibility. Steeneken and Houtgast (1980, 1985) developed an algorithm to transform a set of m values into a speech transmission index by means of an apparent signal to noise ratio expressed as a level[28]. With the calculations of the STI, there can be score of speech intelligibility in a room. Speech intelligibility is an important phenomenon for shopping malls since the users form an interaction. STI and D50 should be especially explored in shopping malls, since the speech intelligibility between

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[25] ÇELİK, Emine. *Acoustical Effects of the Position of Absorbtive Materials in a Room.* Master thesis submitted at Yıldız Teknik University. 1998

[26] BARRON, Michael. *Auditorium Acoustics and Architectural Design*. Spon Press, New York. 2010

[27] Ibid.

[28] LONG, Marshall. *Architectural Acoustics.* Elsevier Academic Press, London. 2006

people and perception of paging are important for continuing of interaction and informing in these spaces.

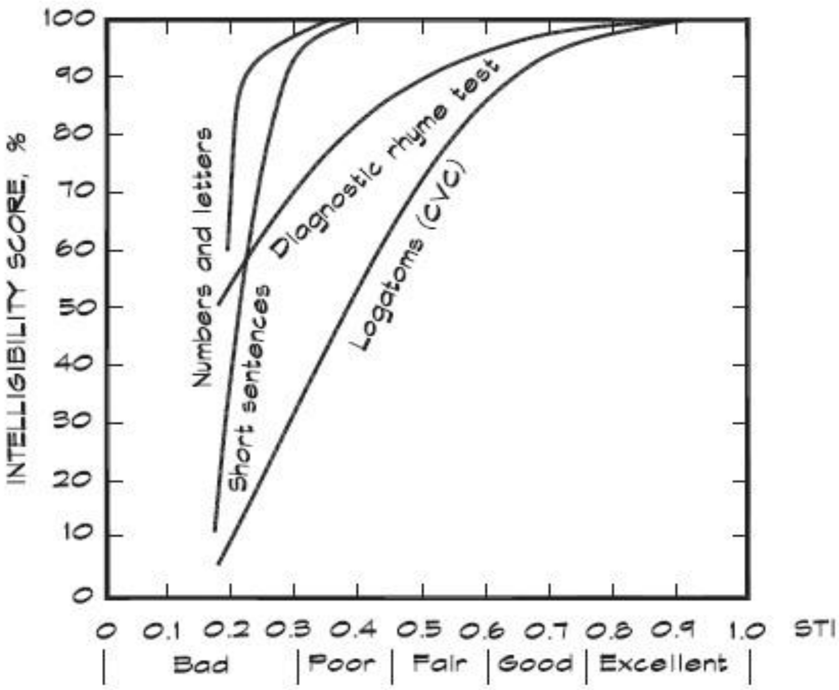

Figure 2.5 Typical Relations between the STI and Intelligibility Scores for the various types of Tests (Houtgast et al., 1985) [29]

2.2 Definition and History of Shopping Malls

Existence of the different types of shopping places and buildings can be seen in different cultures and locations throughout the history. The shopping mall has

[29] Ibid.

become the most significant and popular interface where consumers and producers meet.

Shopping activity takes place in stoas, arcades, open or closed bazaars, hans, bedestans, passages and etc. in the history. All these places have reasons for existence, disappearance or evolution. Some sources define the evolution of the arcades to malls; some define the department stores into malls. Today's shopping malls include not only the stores for shopping but also leisure areas such as cinemas, restaurants and playgrounds for social and cultural activity.

2.2.1 The First Examples of Shopping Malls

Although the Grand Bazaar in Istanbul is the ancestor of shopping malls[30] or agora in Ancient Greek, Jerusalem bazaar are ancient shopping spaces[31], in the literature Bednar[32], Kruppa[33] and Jackson[34] considered Southdale Mall in Minnesota, built in 1956 by the architect Victor Gruen, as the first example of today's shopping malls.

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[30] GOTTDIENER, M. *Postmodern Göstergeler*. İmge Kitabevi, Ankara. 2005.

[31] JACKSON, K. "All the World's a Mall: Reflections on the Social and Economic Consequences of the American Shopping Center" *in: The American Historical Review* (Vol. 101, Issue 4, p. 1111-1121). Oct 1996.

[32] BEDNAR, M. *Interior pedestrian Places.* Watson-Guptil Pub., New York. 1989.

[33] KRUPPA, F. *Mall of America: The New Town Center. 1993*

[34] JACKSON, K. "All the World's a Mall: Reflections on the Social and Economic Consequences of the American Shopping Center" *in: The American Historical Review* (Vol. 101, Issue 4, p. 1111-1121). Oct 1996.

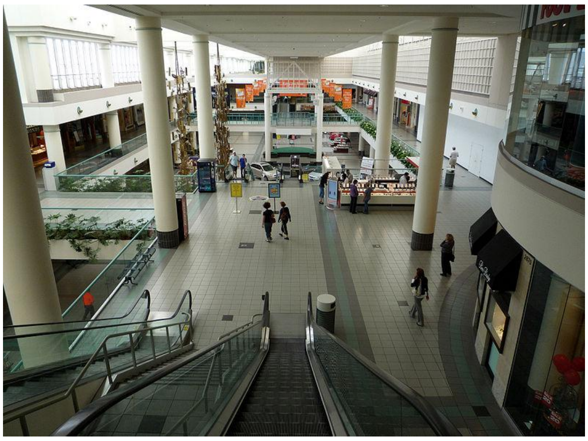

Figure 2.6 Interior view of Southdale Mall[35]

2.2.2 Shopping Malls in Turkey and Ankara

Hans, kervansarays, bedestans and bazaars are the shopping places that were used by the Turkish people throughout the history. But the contemporary examples of shopping malls in Turkey were first emerged toward the end of the 20th century in Turkey.

Galleria Ataköy in Istanbul is the first shopping mall in Turkey. In the 1980s the number of shopping malls was just 3, but in the ten-year period it starts to rise geometrically[36]. In January 2008, according to the Ampd(Alışveriş Merkezleri ve Perakendeciler Derneği), there were 186 shopping malls, and in three year period the number of malls was expected to be 350. In august 2009 there were 222 shopping malls in Turkey, %80 of them are in Istanbul and Ankara and there were not any shopping malls in 42 cities[37].

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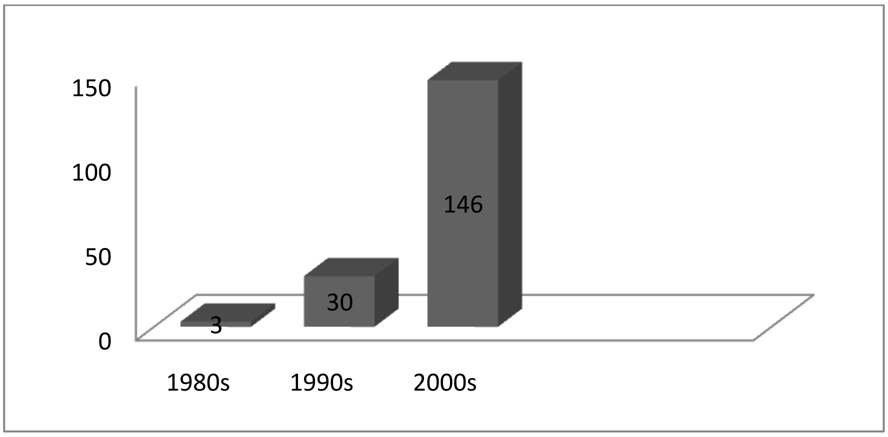
[35] http://en.wikipedia.org/wiki/Southdale_Center (May 2010)

[36] http://www.ampd.org/images/tr/arastirmalar/Sektorel_Bilgiler/organize_perakende_sektoru_ozet_Ocak2008.ppt (May 2010)

[37] LASELLE, Jones Lang. *Perakende Piyasalarına Bakış.* August 2009

Table 2.1 Shopping malls in Turkey[38]



Atakule, opened by Turgut Özal on 13 October 1989, is the first shopping mall in Ankara and the second in Turkey[39]. Karum is the second shopping mall in Ankara and it was opened in 1991. Until 2010 different types and sizes of shopping malls have been constructed and opened to the service. The timeline of shopping mall's existence in Ankara is shown figure 2.7. As it can be seen in figure, at near and far dates different architectural appearances are coming into existence, whereas the architectural features like domes, vaults and atriums are part of designing shopping malls which are explored latter sections.

[38] http://www.ampd.org/images/tr/arastirmalar/Sektorel_Bilgiler/organize_perakende_sektoru_ozet_Ocak2008.ppt (May 2010)

[39] http://www.alisverismerkezleri.gen.tr/atakule_alisveris_merkezi.asp?id=90 (April 2010)

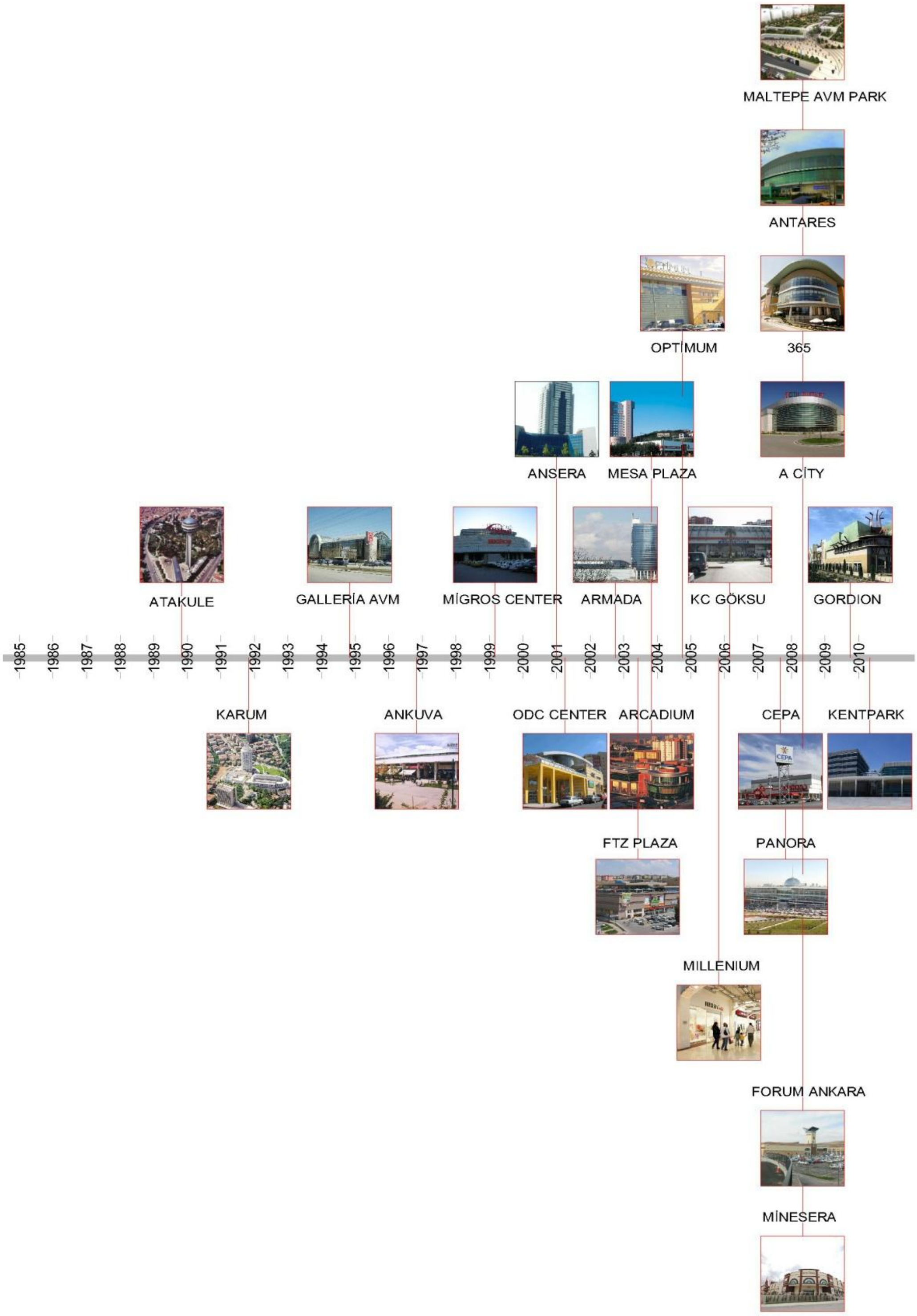


Figure 2.7 Developments of shopping malls in Ankara[40]

[40] Drawn by the author based on the internet research and in-stu observations

2.3 Acoustical Features of Shopping Malls

Since shopping malls are contemporary examples of large public spaces where acoustics plays an important role in their overall quality as well as for their sustainability, then it is necessary to evaluate their acoustical qualities regarding their materials, plan layouts, geometrical forms and etc. The common architectural features of shopping malls including atrium, vault, dome and gallery determine not only the spatial qualities of malls, but also acoustics. Hence, these architectural elements should also be investigated in relation to acoustics.

2.3.1 Acoustical Characteristics of Atrium Spaces

Atrium space is a popular architectural element that provides visual and aesthetic relations with different levels, rooms and locations at public and private buildings. The use of atrium spaces in shopping malls serves to provide visual relation with shops and to control the perception of spaces. In such large atrium spaces, acoustics is an important factor affecting the overall physical comfort[41].

Atrium voids allow the sound to be transmitted from one level to another. Therefore, the concerning sound sources are not only the sources that are at the same level with receivers, but also sound sources situated at other levels. Since the use of atrium spaces are observed in many shopping malls significantly effecting acoustics, it should be considered as one of the parameters defining the typology.

[41] CHEN, Bing and KANG, Jian. "Acoustic Comfort in Shopping Mall Atrium spaces: A Case Study in Sheffield Meadowhall" in: *Architectural Science Review* (Vol. 47, p. 107-114).2004

2.3.2 The Effect of Volume and Shape in Acoustics

Volume, shape and size of a room or a space have crucial importance for the acoustical formations within the space[42]. Large volumes of spaces increase reverberation times and ambient noise, resulting a decrease in speech intelligibility. Generally, shopping malls have large volumes and thus longer reverberation times.

Geometries of surfaces are also crucial for reflection patterns which determine noise, RT and other sound parameters resulting in different acoustical properties. The concave surfaces tend to concentrate or focus the reflected sound, and the convex surfaces lead to diffuse reflection[43]. The main geometrical features of the walls and ceiling of the shopping malls not only affect the users in architectural terms, but also have effects on acoustical quality of these spaces. Hence, surface geometries should be examined in terms of acoustics.

2.3.3 Acoustical Characteristics of Domes and Vaults

Vaults and domes are architectural elements that are used for structural reasons in the past, but today they are rather used as design elements. Spaces surrounded by smooth concave surfaces such as domes are often considered unsuitable for effective presentation of speeches or music performances because the reflected sound from concave surfaces do not diffuse properly in a room and may create sound foci and dead spots under certain geometrical conditions[44]. In shopping malls, these architectural elements are used to close top of the circulation areas

[42]MEISSNER, M. “Influence of Wall Aborption on Low-Frequency Dependence of Reverberation Time in Room of Irregular Shape” in : *Applied Acoustics* (Vol. 5, Issue 3, p. 293-312). 2007.

[43]MAEKAWA, Z. and Lord, P. *Environmental and Architectural Acoustics*. E&FN Spon, London. 1994.

[44]INOUE, Satoshi; SUGINO, Kiyoshi; KATOU, Masahiro and IMAIZUMI Hiroyuki. “ Speech Transmission Performance and the Effect of Acoustical Remedies in a Dome” in: *Applied Acoustics* (Vol. 70, Issue 1, p. 221-230). Jan 2009.

providing an aesthetical solution, yet they also have potentials to affect the acoustics adversely because of the concave geometry.

2.3.4 Acoustical Requirements in Shopping Malls

Studies about the architectural acoustics aim to guide the designers to obtain comfortable spaces for the users. The studies about the enclosed spaces can generally be classified in two: regarding function of the space as 'acoustic space' and 'non-acoustic' space[45]. Auditoriums, concert halls, theatres opera houses, religious buildings (churches, cathedrals, mosques) and recording studios are examples of acoustic spaces as the main function in such spaces are related to the music and or perception of special acoustical indices that require serious acoustical designs and treatments[46].

There are some standards and regulations concerning noise that countries should follow in public spaces. TSE and ISO standards, Noise Control Regulation[47], Environmental impact and evaluation regulations[48] and Environment noise and control[49] are some of these sources that can be used for evaluation of sound in enclosed public spaces and shopping malls. The major criterion indicated in these directives/standards is mostly related to sound pressure so does in the case of malls. Other parameters and design standards that are related with overall acoustical quality for shopping malls as many other public spaces are not

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[45]KANG, Jian. (2003). "Acoustic Comfort in Non-Acoustic Spaces: a Review of Recent Work in Sheffield" in: *Proceedings of the Institute of Acoustics* (vol. *25,* p. 125-132). 2003

[46]DÖKMECİ, Papatya Nur. *Acoustical Comfort Evaluation in Enclosed Public Spaces with a Central Atrium: A Case Study in Food Court of Cepa Shopping Center.* Master thesis submitted at Bilkent University. 2009.

[47]*Gürültü Kontrol Yönetmeliği.* Republic of Turkey Ministry of Environment and Forest. 11 December 1986

[48]*Çevresel Gürültünün Değerlendirilmesi ve Yönetimi Yönetmeliği.* Republic of Turkey Ministry of Environment and Forest. 4 Jul 2110.

[49]Kurra, Selma. *Çevre Gürültüsü ve Yönetimi.* Butech, Istanbul. 2009.

included. Considering complex functional programs, structural necessities and architecture of shopping malls, the studies about sustaining proper comfort conditions in architectural design have become important. This study aims to provide guiding principles for acoustical quality of shopping malls at initial architectural design step by exploring acoustical behaviors of malls regarding their typologies.

CHAPTER 3

CLASSIFICATION OF THE SHOPPING MALLS

As it is pointed out in the previous chapter, today shopping malls are public spaces where many people frequently spend time. Due to this heavy use, malls are one of the building types where comfort conditions have major importance. Shopping malls are the buildings which are designed in such a way that they confine commercial, social, and cultural areas in a single building. There, users are expected to spend maximum time, resulting in higher turnover rates as the primary objective determining the design/architecture of shopping malls. There are other factors such as environmental conditions, cultural and social structures affecting and diversifying the design and plans of shopping malls.

Although there appears to be various set of criteria taken into account in shopping mall designs, it is still possible to provide a taxonomical matrix based on typologies/design schemas and on sizes of these spaces for further inquiries of comfort conditions of such spaces.

The taxonomy proposed within the context of the present study is to be employed to investigate acoustical qualities/problems of shopping malls regarding geometrical form, plan layouts and materials, and size of such buildings. It is seen that there are typical design schemas in all over the world applied to malls allowing integration of architectural programs, mall standards and commercial requirements. Hence, it is possible to classify these schemas for further studies.

3.1 Analysis of Shopping Malls Included in the Study

It is necessary to explore geometrical forms, materials and functional features, i.e., typical design schemas of shopping malls in order to provide a concise classification. Here it is important to note that; none of the malls included in this study is either criticised or advertised, because the study is related general acoustical behaviours of shopping malls. They are just accepted as the cases representing the typologies.

3.1.1 Analysis of Typical Design Schemas: Cases in Ankara

Ankara is one of the most appropriate cities for this study due to the fact that almost half of the shopping centres in Turkey exist in Ankara and in Istanbul[1]. Although this typological study can be extended to examine the shopping malls in Turkey and in the world, the general similarities in the design schemas allow to be focused on malls in a specific place where observations and examinations in-stu become possible.

The mall list has been prepared upon individual in-stu observations, publications and documentations related with these malls. Although these data have been specifically obtained to examine acoustical features, it is possible to extend it further to inquire other features.

[1]LASELLE, Jones Lang. *Perakende Piyasalarına Bakış.* August 2009

Table 3.1 Shopping malls in Ankara[2]

No	Name	Location	Year
1	Atakule	Çankaya	1989
2	Karum	Çankaya	1991
3	Galleria Ankara	Ümitköy	1995
4	Ankuva	Bilkent	1997
5	Ankamall	İvedik	1999-2006
6	Ansera	Çankaya	2001
7	ODC Center	Çukuranbar	2001
8	Armada	Söğütözü	2002
9	Arcadium	Ümitköy	2003
10	FTZ Plaza	Keçiören	2003
11	Mesa Plaza	Ümitköy	2003
12	Optimum Oulet Center	Sincan	2004
13	Millenium Outlet Park	Batıkent	2005
14	Kc Göksu AVM	Eryaman	2006
15	Cepa AVM	Eskişehir R.	2007
16	Panora AVM	ORAN	2007
17	A City Outlet Center	Batıkent	2008
18	Minasera AVM	Ümitköy	2008
19	365 AVM	Birlik	2008
20	Antares AVM	Etlik	2008
21	Maltepe Park AVM	Maltepe	2008
22	Forum Ankara	Etlik	2008
23	Gordion AVM	Ümitköy	2009
24	Kentpark AVM	Eskişehir R.	2010

3.1.2 Data Inquiry

Since detailed data related to finishing materials, design schemas and etc., of shopping malls are not available, in-stu observations/measurements , aerial photographs and Google Earth[3] have been used to prepare plans and simulation models used in the study. Therefore, measurement sensitivity in these studies is mainly based on observations, the dimensions defined in municipality regulations

[2]Listed by the author based on the internet research and in-stu observations

[3]Google Earth, http://earth.google.com/

and the information obtained from satellite photos rather than a precise measurement.

Here it is important to clarify that, precise measurements are not required within the scope of the study since the aim is to show the relation between acoustical quality and the common architectural solutions employed in malls like general design schemas, typical geometrical forms as encountered in majority of malls, rather than, architectural details like fine finishing materials, decorative elements, fine spatial variations in dimensions and etc.

3.2 Elements of the Study

Before, during and following observations and examination, determination of criteria used in the classification study for acoustical analysis is crucial for the coherency of mall taxonomy as well as to avoid any bias related definitions/assumptions.

Shopping malls are generally defined as enclosed public spaces thus; some examples which have semi-open or open configurations are excluded in this study.

Via observations and documentations, it is seen that shopping malls are multi storey buildings in general. Moreover, as mentioned in previous chapter architectural elements such as atria, curved, domed vaulted ceiling geometries and etc. are commonly observed in those spaces. Hence, the taxonomical study based on typology and the acoustical evaluations of them are mainly focused on the multi storey shopping malls.

3.2.1 Major Features Included in the Study

Constructing of the malls as single or multi storey is a critical decision in terms of acoustical qualities and architectural design. Moreover, the circulation structure is directly related with vertical relations as well as physical connections of levels which are important to evaluate impact architectural form on acoustics. Table 3.2 shows the major features regarding acoustics of shopping malls in Ankara.

Table 3.2 Analysis of shopping malls

Malls	Central Gallery	Central Gallery Ceiling	Circulation except central gallery	Circulation type	Circulation Ceiling
Atakule	Existing	Vault	Existing	Without Gallery	Flat
Karum	Existing	Vault	Existing	Without Gallery	Flat
Galleria Ankara	Existing	Vault	Non E.	N.A.	N.A.
Ankuva	Existing	Vault	Non E.	N.A.	N.A.
Ankamall	Non E.	N.A.	Existing	With Gallery	Flat-Vault
Ansera	Existing	Vault	Non E.	N.A.	N.A.
ODC Center	Non E.	N.A.	Existing	Without Gallery	Flat
Armada	Non E.	N.A.	Existing	With Gallery	Flat
Arcadium	Existing	Dome	Existing	With Gallery	Vault
FTZ Plaza	Existing	Flat	Non E.	N.A.	N.A.
Optimum O. C.	Existing	Flat	Existing	Without Gallery	Flat
Millenium O. Park	Non E.	N.A.	Existing	one storey	Flat
Cepa AVM	Existing	Cone	Existing	With Gallery	Flat
Panora AVM	Existing	Dome	Existing	With Gallery	Flat-Vault
A City O.Center	Non E.	N.A.	Existing	With Gallery	Flat
Minesera AVM	Existing	Vault	Non E.	N.A.	N.A.
365 AVM	Non E.	N.A.	Existing	With Gallery	Flat
Antares AVM	Existing	Dome	Existing	With Gallery	Vault
Maltepe Park	Non E.	N.A.	Existing	With Gallery	Flat-vault
Forum Ankara	Non E.	N.A.	Existing	With Gallery	Flat
Gordion AVM	Existing	Cone	Non E.	N.A.	N.A.
Kentpark AVM	Existing	flat-do	Existing	With Gallery	Flat-vault
Non E.	Non Existing				
N.A.	Not Applicable				

Atrium spaces which are designed between shopping mall floors and their relation with circulation areas determine the architectural schema of the building. Although they are designed mostly for architectural reasons, they have a crucial role in acoustical quality of these spaces. General observations have shown that the majority of malls are multi storey buildings and they have at least one atrium.

Another group of shopping malls are characterized by having central gallery space. All circulation areas are designed to connect galleries with shops. Though visual connections are successfully established between all floors and areas, the existence of sound transmission paths created by those components may cause “noise” problem.

Galleries are important architectural tools that provide buildings with natural day light. Therefore, on the ceilings of these spaces or in the side frontages, there should be light holes providing connection to the outside. These light holes are formed by using architectural elements such as domes, vaults and flat surfaces. Since it is known that those components are effective in the overall acoustical quality of enclosed spaces, they are taken into consideration while determining the mall typologies.

There are also some examples where circulation areas are built out of central gallery and circulation areas built without central gallery. These circulation plans provide vertical and horizontal connections among commercial areas in shopping malls. The classification of shopping malls is made regarding their typologies considering the architectural features of them affecting acoustics which are listed and explained above.

3.2.2 Assignments of Materials Used in Malls

It is neither possible to determine precise specifications or brands of materials used in shopping malls nor required within the context of this study. Rather generic materials are assigned by in-stu observations and documentations which is available. The table given below illustrates the general types of materials used in the finishing of the shopping malls. The acoustical features like absorption coefficients, scattering values, and etc. are assigned based on generic values found in the literature related with acoustics which is coherent with precision expected in the analysis.

Table 3.3 Surface materials of shopping malls

Malls	Gallery Ceiling	Ceiling	Walls	Floor
Atakule	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Karum	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Galleria Ankara	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Ankuva	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Ankamall	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Ansera	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
ODC Center	Plastic	Plastic	Glass-plastic	Ceramics, Granite
Armada	Plastic	Plastic	Glass-plastic	Ceramics, Granite
Arcadium	Glass-plastic	Metal	Glass-plastic	Ceramics, Granite
FTZ Plaza	Plastic	Plastic	Glass-plastic	Ceramics, Granite
Optimum O. C.	Plastic	Plastic	Glass-plastic	Ceramics, Granite
Millenium O. Park	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Cepa AVM	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Panora AVM	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
A City O.Center	Plastic	Plastic	Glass-plastic	Ceramics, Granite
Minesera AVM	Plastic	Plastic	Glass-plastic	Ceramics, Granite
365 AVM	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Antares AVM	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Maltepe Park	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Forum Ankara	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Gordion AVM	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite
Kentpark AVM	Glass-plastic	Plastic	Glass-plastic	Ceramics, Granite

As seen in the tables, shopping mall surfaces are completed by using similar materials. Therefore, materials have been considered as the same in main areas without causing any bias in the analysis. Because of the similarity of surface materials, materials are considered as ineffective feature while defining the typologies of shopping malls, whereas they are thought to be important about acoustical quality/problem of the shopping mall building type regarding their acoustical features.

3.3 Major Typologies in Ankara

Typologies are determined according to the types of circulations areas, number of storey and types of the gallery elements. The classification of shopping malls is done by this study for acoustic modeling and simulations. Figure 3.1 shows the typical design schemas of shopping malls in Ankara. Main features of each group that will be used to develop acoustical model have been explored in detail in the section below.

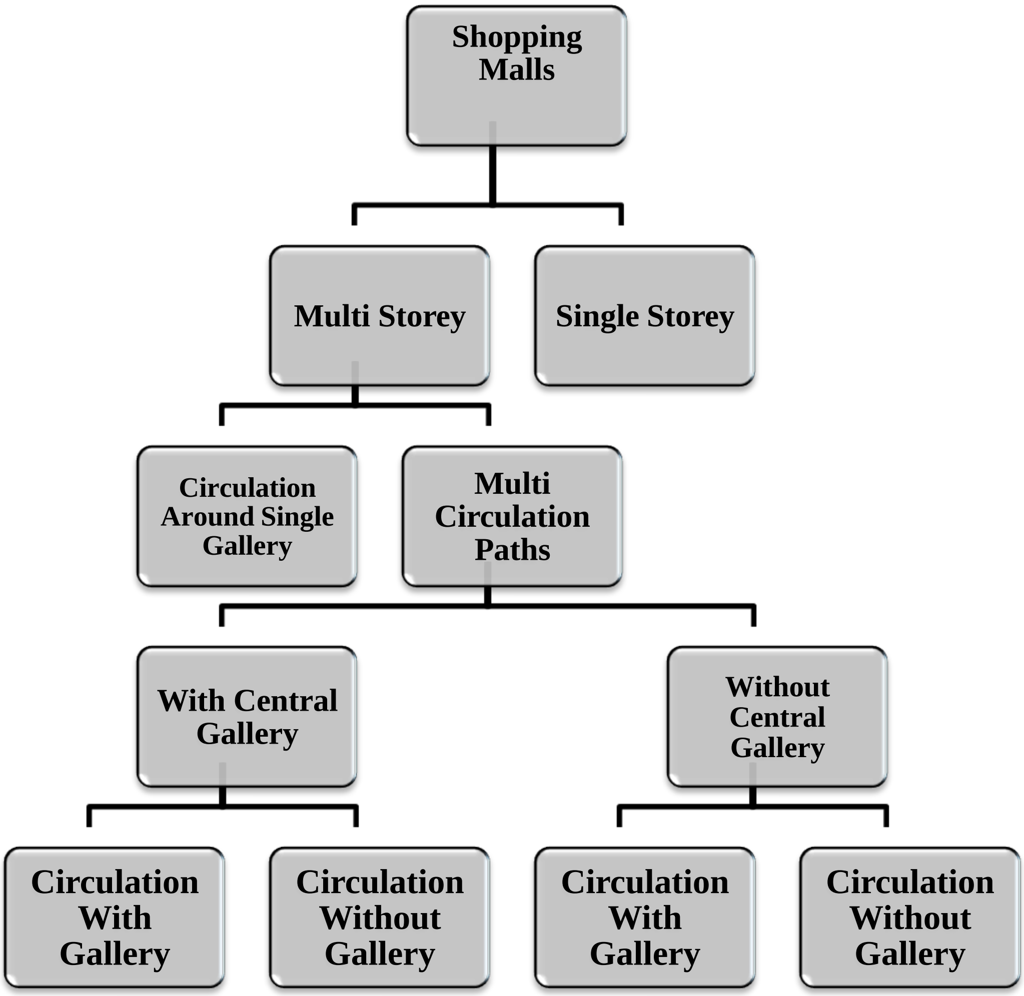


Figure 3.1 Major typologies in Ankara

3.3.1 Main Features of Typologies Used in the Analysis

Single Storey Shopping Malls

Single storey shopping malls are built according to the preferences of investors and in the case of availability of land. In these malls, access to shops is easier in comparison with multi storey malls provided that horizontal distances are kept at reasonable levels. Individual shops are located around circulation areas and some dining areas and shops are located at mezzanine. Commercially named outlet centers mostly use this schema. ‘Millennium Outlet Park’ shown in figure is given as an example.

Figure 3.2 Interior view of Millennium Outlet Park[4]

Since single storey malls do not include critical architectural elements such as atriums and vertical circulations effecting acoustics, they are decided to be excluded in the study. Hence, no evaluation study is carried out for such mall types.

Multi Storey Shopping Malls

These shopping malls have more than one storey (excluding car parking and service) and shops are arranged at these levels and connected horizontally and

[4] http://www.alisverismerkezleri.gen.tr/millennium_outlet_alisveris_merkezi.asp?id=61 (May 2010)

vertically by various circulation systems which also cause sound/noise transmission from one level to another. Therefore, such forms have to be investigated in terms of their acoustical qualities.

Multi storey buildings are the most common mall type. There are different surface geometries, circulation plans and galleries in these buildings.

Circulation around Single Gallery

A single major gallery, circulation paths around it, shops that can be accessed from, and food-court at the basement or upper part of the gallery are the main features of such malls. Galleries with different geometries and sizes, their ceilings influence the acoustic of these buildings. The use of dome, vault, flat roof and different geometries are considered under sub groups of this typology. Galleria Ankara, Ankuva, Ftz Plaza, Minasera AVM, Ansera and Gordion AVM can be given as examples belonging to this group. Galleria Ankara is a small sized and an early constructed example; on the other hand, Gordion AVM is a large sized and recently built one of this group. Hence, these two extreme malls exemplifying this typology are investigated for further acoustical evaluation.

Figure 3.3 Interior view of Galleria Ankara[5]

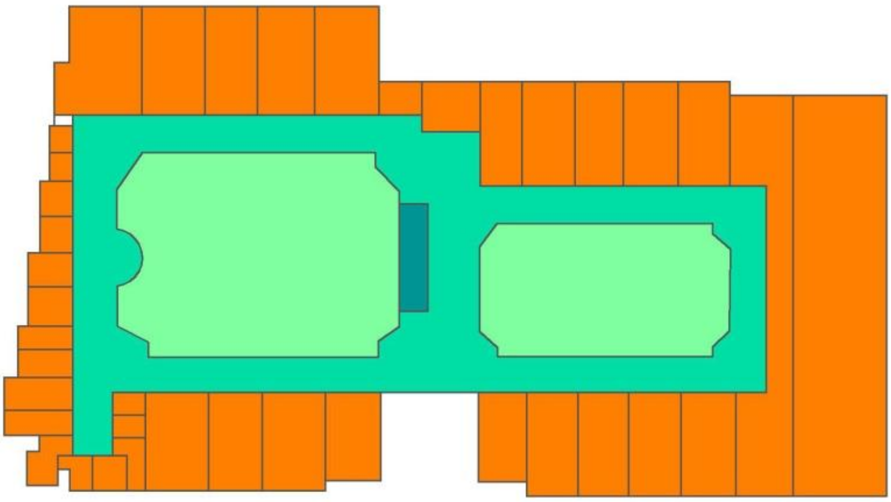


Figure 3.4 Plan layout of Galleria Ankara

[5] http://www.alisverismerkezleri.gen.tr/galleria_ankara_alisveris_merkezi.asp?id=71 (May 2010)

Figure 3.5 Interior view of Ankuva[6]

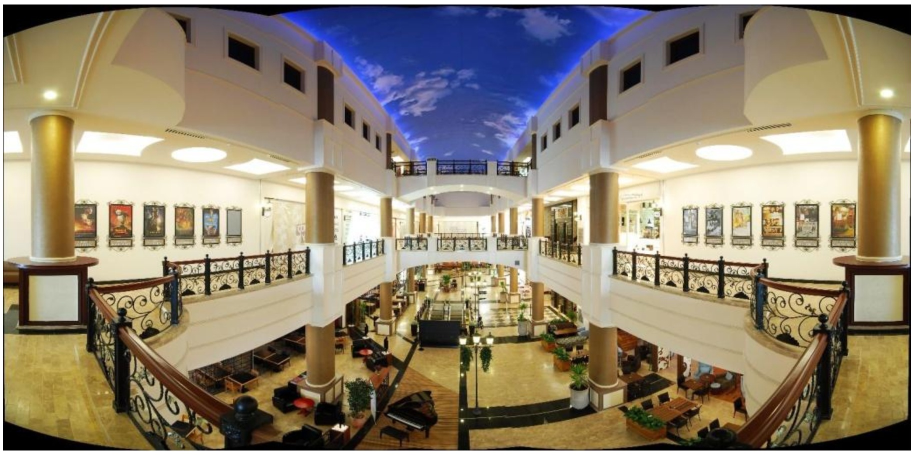


Figure 3.6 Interior view of Minasera[7]

6 http://www.tepeinsaat.com.tr/tepe.html (May 2010)

7 http://www.avmgazette.com/avm/minasera.aspx (May 2010)

Figure 3.7 Interior view of Gordion AVM

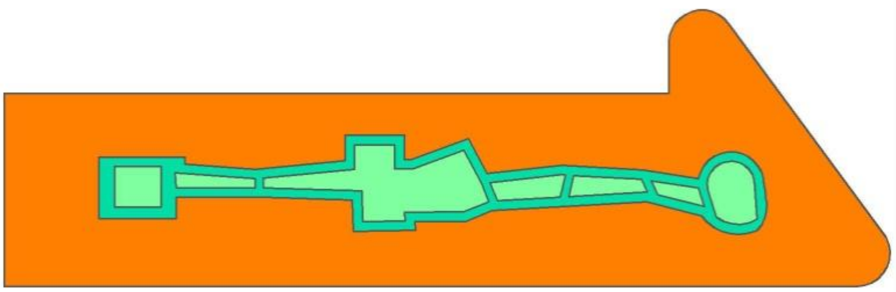


Figure 3.8 Plan layout of Gordion AVM

Multi Circulation Paths

In the majority of shopping malls included in this study, there are plan schemas formed by the combination of different circulation axes. Circulation schemas designed in order to provide access to many shops, have different galleries, geometries and dimensions. It is possible to divide this group into two: shopping malls with central gallery which is important in terms of architectural acoustics and shopping malls without a central gallery.

With Central Gallery

Even if there are circulation areas in shopping malls, the presence of a central gallery linked to the dining, entrance or any other important areas are the main features of these malls. Ceilings of these areas have been observed to be designed as domes, flat roofs and different geometric shapes. Circulation axes that provide access to other areas of the building can be with or without galleries.

Circulation with Gallery

Shopping malls having circulation areas connected with gallery spaces rather than their central galleries define this type of shopping malls. Circulation areas are also in physical connection verticaly with storeys in these malls. Gallery ceilings are mostly finished as vaults or flat surfaces. Arcadium, Cepa, Panora, Antares and Kentpark Shopping Centers are some examples belonging to this group.

Gallery ceilings of Antares and Panora are vaulted; and others listed above in this category either have flat surfaces or vaults at the top of the galleries. Antares Cepa are chosen as the examples representing this typology for further acoustic analysis.

Figure 3.9 Circulation gallery of Cepa AVM

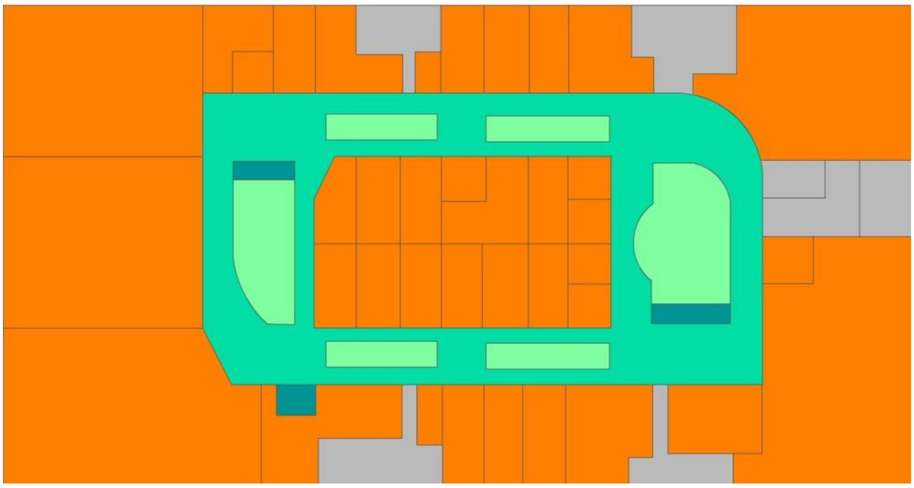


Figure 3.10 Plan layout of Cepa AVM

Figure 3.11 Circulation gallery of Panora AVM

Figure 3.12 Circulation and central gallery of Antares AVM

Figure 3.13 Plan layout of Antares AVM

Circulation without Gallery

In some shopping malls, it is observed that, there are not any gallery spaces in circulation areas except for in central gallery. Atakule, Karum and Optimum Outlet Centers are the shopping malls that take part in this group.

These types of buildings seem to be similar with single gallery shopping malls regarding their architectural and acoustical properties. Since other studies have considered single gallery shopping malls, simulations for these malls are not examined.

Figure 3.14 Interior view of Karum[8]

Figure 3.15 Interior view of Optimum Outlet Center

[8] http://www.koray.com.tr (May 2010)

Without Central Gallery

Unlike the examples discussed previously, some shopping malls which do not have a central gallery area have been observed. Again, within this group there are examples with or without gallery spaces in circulation areas.

Circulation with Gallery

Existing galleries may be small or large in size and their ceilings can be formed by vaults or flat surfaces. Ankamall, Armada, A City Outlet, Forum Ankara and 365 Shopping Centers are the examples in this group.

Armada Shopping Center having a very systematic gallery schema and circulation pattern is explored as an example of this category as well 365 shopping center which is the smallest example of this group.

Figure 3.16 Interior view of Armada[9]

[9] http://www.gezi-yorum.net (May 2010)

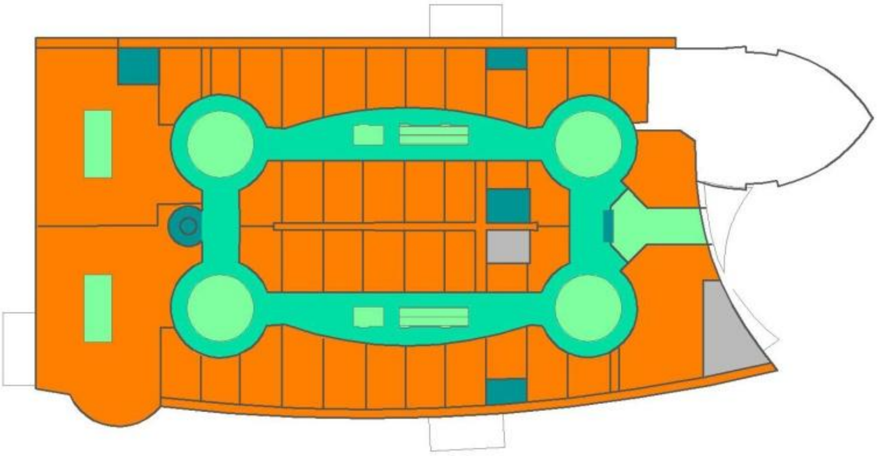


Figure 3.17 Plan layout of Armada

Figure 3.18 Interior view of A City Outlet Center

Figure 3.19 Interior view of 365 AVM

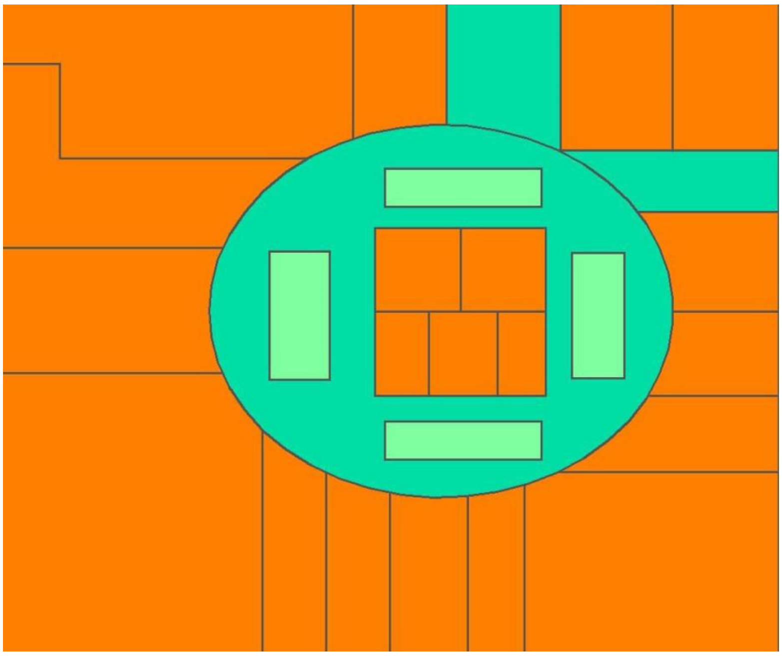


Figure 3.20 Plan layout of 365 AVM

Circulation without Gallery

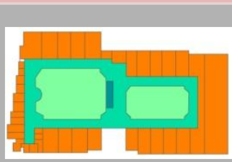
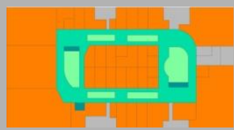
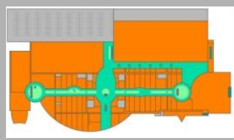
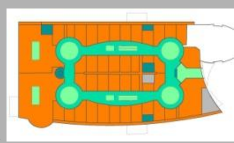
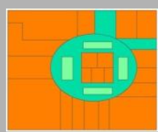
There are examples which do not have either a central gallery or gallery spaces between other circulation areas. Ankara ODC center is an example representing this group. Although it has the qualifications defining a shopping mall, it has not been examined in terms of acoustics due to its small size.

Figure 3.21 Outside view of ODC Center

3.3.2 Typologies Included in the Acoustical Evaluation

Table 3.4 shows the malls studied in this thesis. These malls are chosen not only as the examples well demonstrating the types/classes included in taxonomy but also the ones used by large populations.

Table 3.4 Typologies which are examined

Galleria Ankara……..	
Gordion AVM…………………………….........	
Cepa AVM…..………………………………	
Antares AVM…..……...……………………...	
Armada…...…..………………………………….	
365 AVM………………………………………….......	

These schemas are used to make 3D models that are used in acoustical simulations for further analysis. As discussed previously, models are reflecting basic design schema and material configurations which are adequate to show general acoutical propeties of malls considered in the study. These models and their acoustical analysis are then used to illustrate the effect of mall typolgy on the acoustical quality experienced in.

CHAPTER 4

3D MODELLING AND SIMULATION

Most commonly used typologies in the mall design presented in the previous chapter are then evaluated through simulations rather than acoustic measurements in order to illustrate the relation with design of malls and acoustics in design process, AutoCAD for 3D models and ODEON 9.2 software licensed in Middle East Technical University in simulations are employed. AutoCAD is computer aided design program and ODEON is commonly used acoustical simulation program.

Face models created by employing 3D modeling techniques are required in order to make analysis with ODEON program. These models can be created either with ODEON or with any other modeling programs.

4.1 Assumptions and Precision of 3D Modeling

3D models used in the analysis are constructed regarding plan schemas obtained in previous chapter. In the models, fine finishing details and decorative elements are not included. As it is stated before, the study is focused on general acoustical behaviors of malls, thus it is not required more precise models.

The typical modeling process is composed of aerial photographs, in-stu observations and measurements.

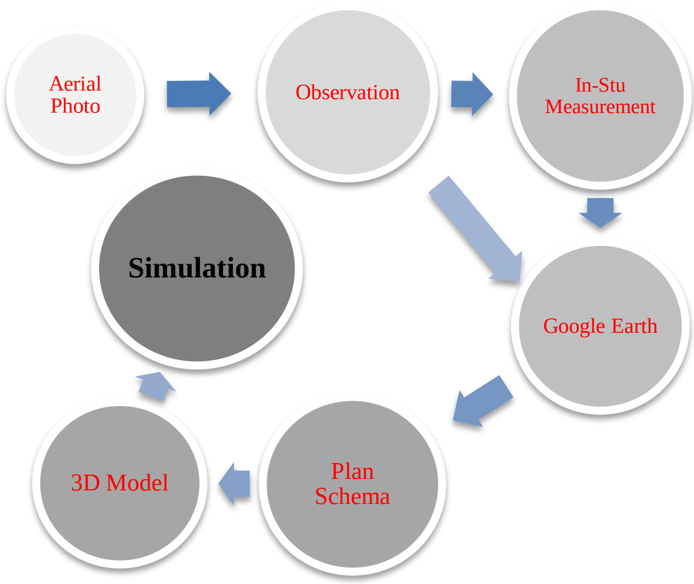


Figure 4.1 The process of analysis of a mall typology

In the models, in order to compare different typologies, basic assumptions related with materials and material distributions, the error in dimensioning in constructing the models are kept the same to avoid any bias related to precision.

Assumptions:

a) Measurement unit in all drawings is in cm,
b) Models include ceiling, walls and floors and other architectural components and ornaments are approximated by these components.
c) Solid surfaces of 100cm height above the floor have been used to model gallery railings,

d) Outdoor spaces have been closed as the inner volumes of models have to be closed,
e) Entrances of shops have been closed as no study about the sound levels within shops was carried out, but proper absorption values are assigned,
f) Parking volumes have not been modeled,
g) Decorative elements at the shops wall have not been modeled,
h) Distance between floor level and suspended ceiling is taken as 150 cm,
i) Steel or concrete support elements on ceiling surfaces have not been modeled since their area is negligible compared with the size of main surfaces and thus their effect on absorption.

4.2 Adjustments of Simulation

Buildings modeled in AutoCAD have been inserted into ODEON. This process has been made with the same settings for each building. The improper adjustments can result in differences in surface characteristics and scales of models resulting in bias.

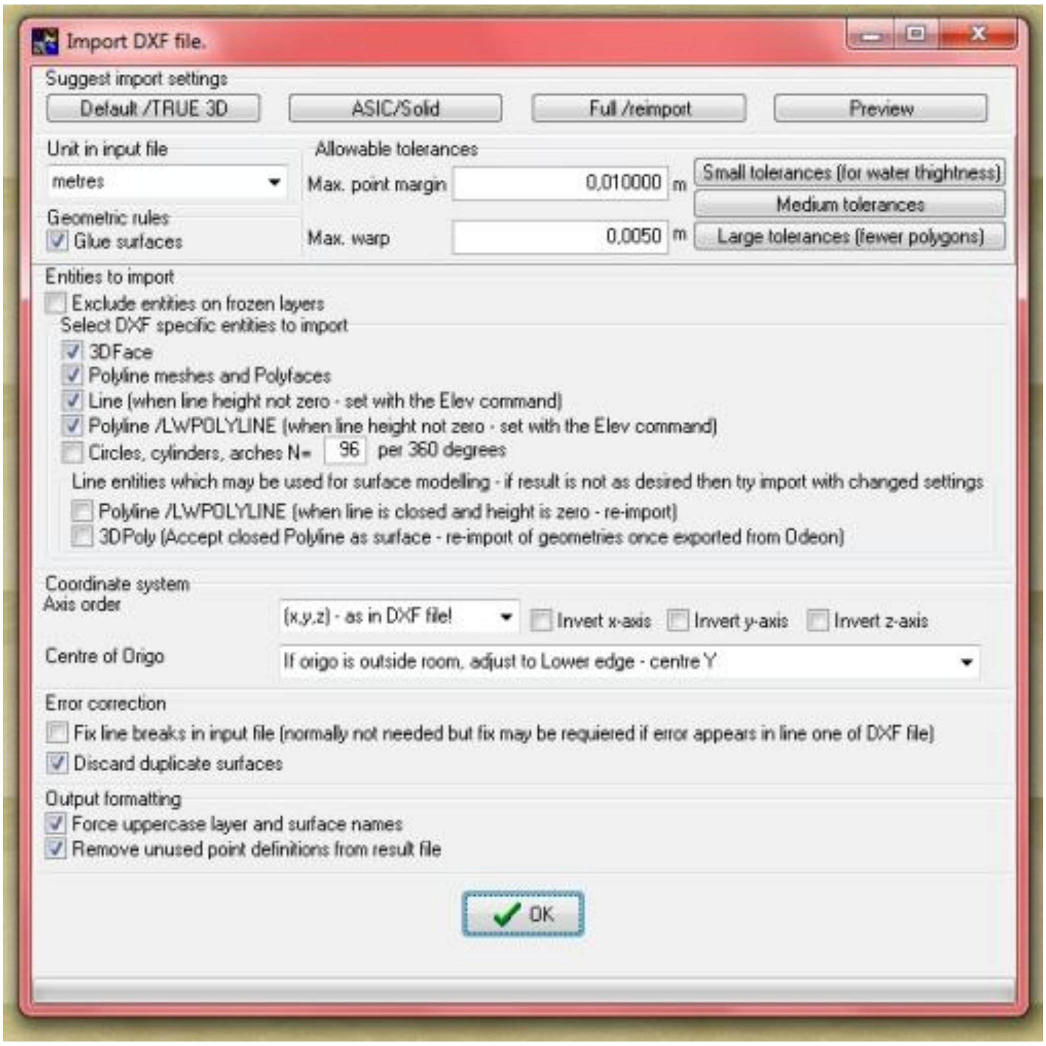


Figure 4.2 Inserting 3D Models

It has to be ensured that all the models are airtight in order to have proper acoustical analysis. 3D *investigate ray* command has employed for each model and checked if shop volumes are closed. The program creates rays from the source(s) and rays investigate that there is any hole in the model by reflections with this command. Figures below show the air tightness of the models used in the acoustical analysis.

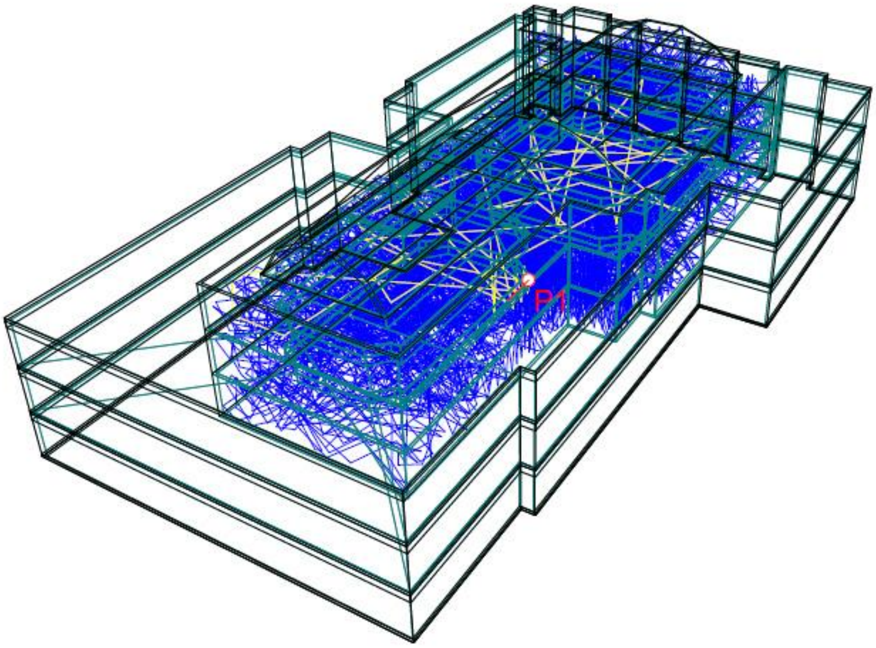


Figure 4.3 Investigate rays of Galleria Ankara

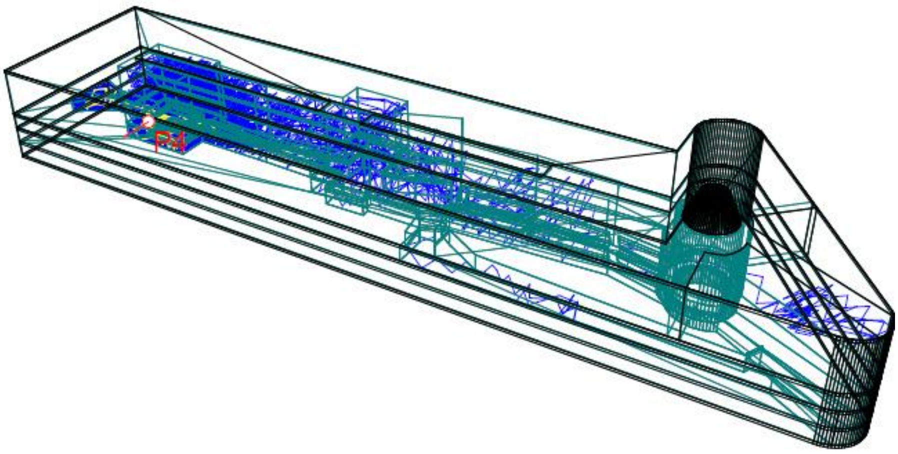


Figure 4.4 Investigate rays of Gordion AVM

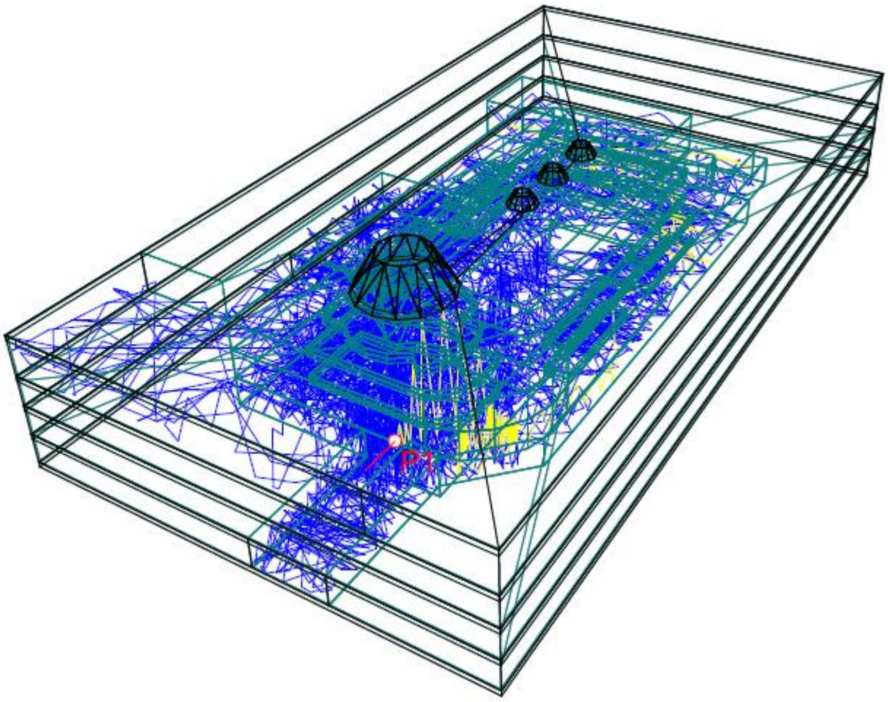


Figure 4.5 Investigate rays of Cepa AVM

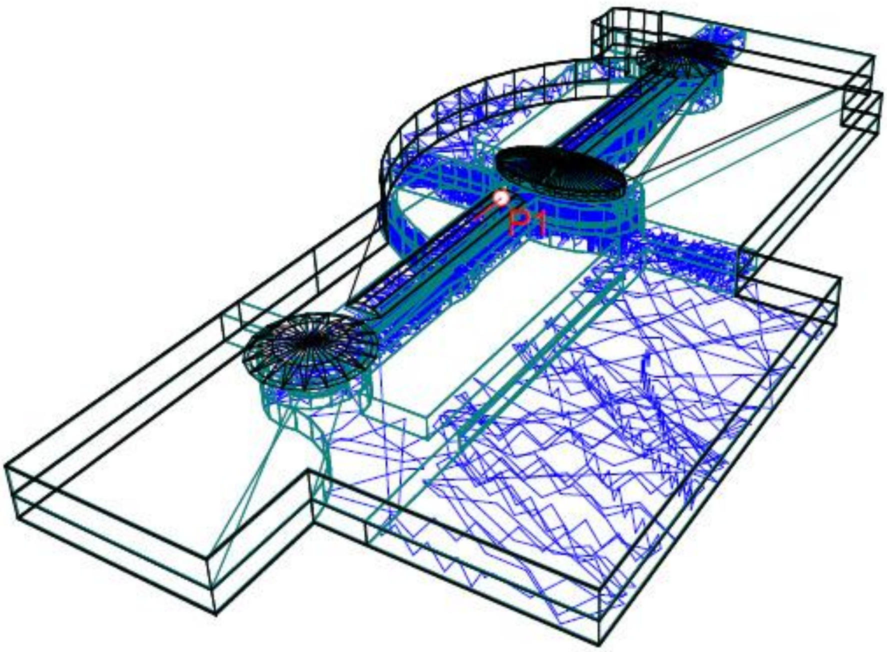


Figure 4.6 Investigate rays of Antares AVM

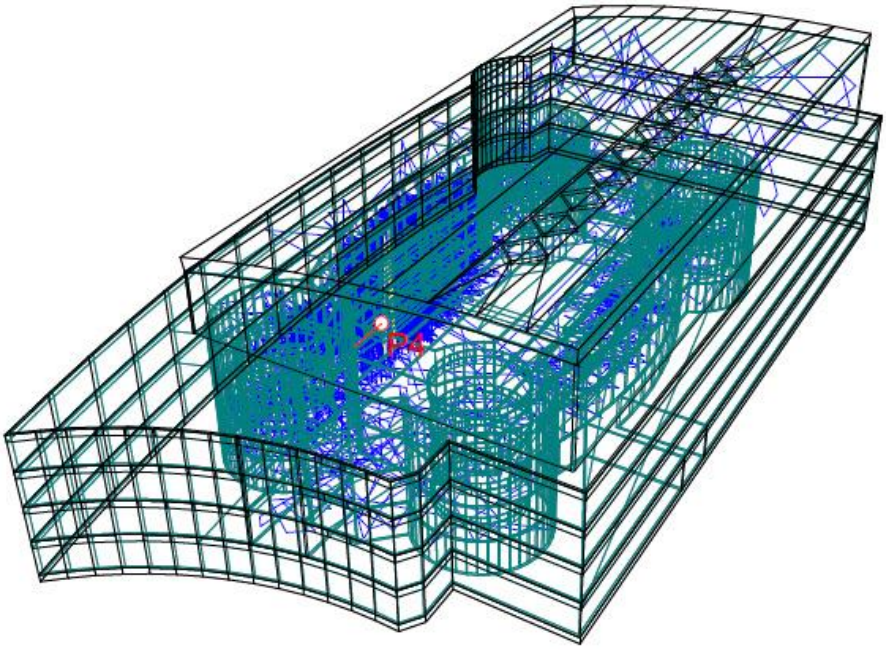


Figure 4.7 Investigate rays of Armada

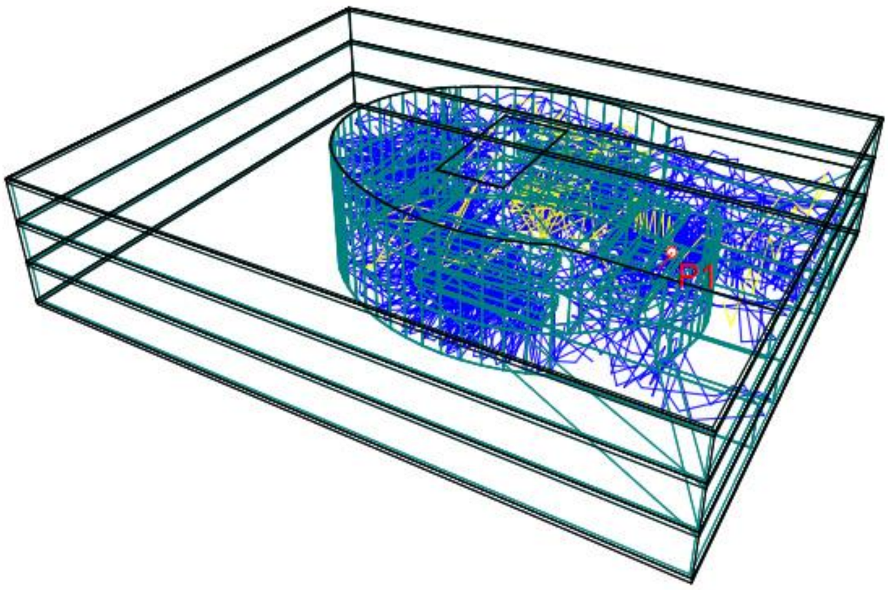


Figure 4.8 Investigate rays of 365 AVM

After the completion of these steps, 3D models have been examined and worked on. Similar approaches and values have been chosen in the models to obtain coherence between simulations. The subjects are listed below:

a) Program settings
b) Sound reflection settings
c) Surface material characteristics,
d) Sound sources and locations,
e) Sound receivers and locations.

4.3 3D Modeling

Six shopping centre buildings have been selected for acoustical analysis and their 3D modeling are prepared by using AutoCAD 2010. During the formation of these 3D models, the assumptions and methods that are defined previously are taken into consideration

The 2D plans and section drawings obtained by the methods explained in Chapter 3 have been drawn by employing AutoCAD 2010 to provide data for modelling. Figure 4.9 shows the 2D drawings of CEPA building as an example of this process.

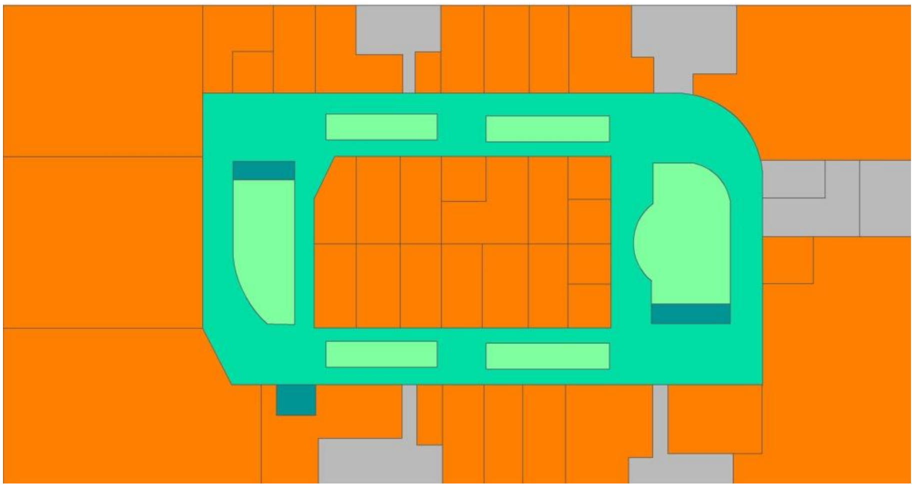


Figure 4.9 Drawing of CEPA

Elements such as internal and outer walls, windows, hand rails and floors are separated by layers. These elements are reduced to a closed polygon by *polyline* command. Then, these closed polygons are raised to 3D layer by layer depending on their section heights by *extrude* command. Figures below illustrate the modelling stages of CEPA building.

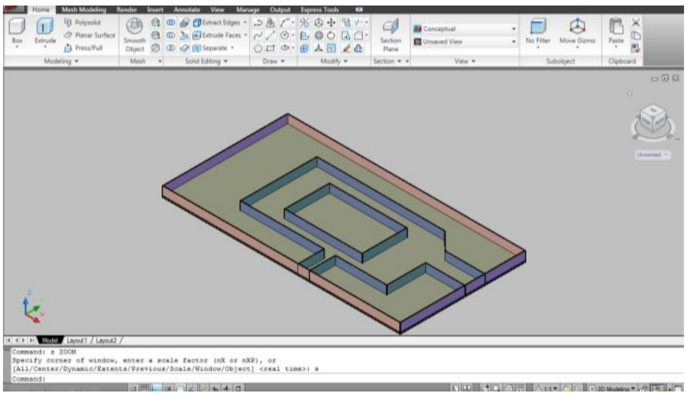


Figure 4.10 Modeling Process of CEPA 1

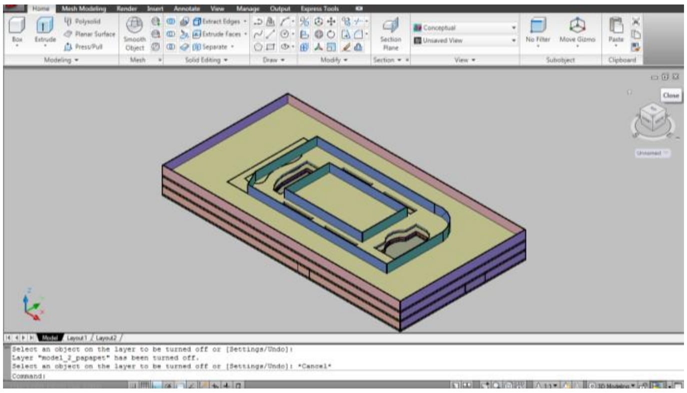


Figure 4.11 Modeling Process of CEPA AVM 2

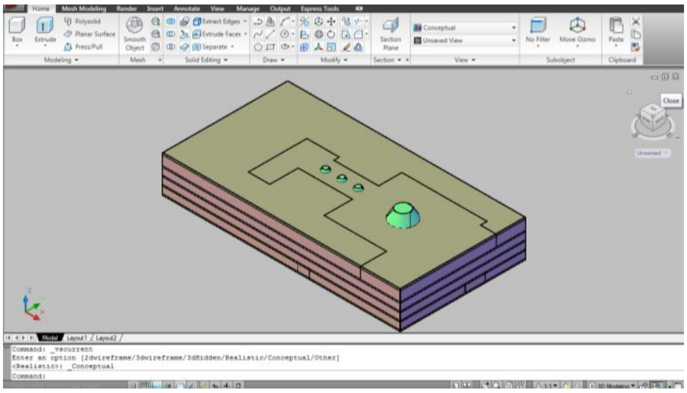


Figure 4.12 Modeling Process of CEPA AVM 3

A building modeled as 3D solid can be inserted into ODEON 9.2 as explained and the required studies can be conducted before simulation. This process is applied to all examining malls in order to have 3D Models for simulations. The results of the simulations are presented in the next chapter.

CHAPTER 5

ACOUSTICAL EVALUATION OF THE SELECTED MALLS

In this chapter, acoustical behavior of shopping malls representing the major architectural typologies explained in previous chapters is investigated through simulations. In this study a well known room acoustics software, namely, ODEON is employed and the results are presented for the selected cases.

5.1 Preparation of a Typical Model

In chapter 4, preparation of 3D models of shopping malls for the acoustical analysis through simulations is explained in detail. Assumptions/decisions regarding solid models and their material configurations to be employed in the analysis are explained in detail. Solid models that are developed strengthen out that gross acoustical behavior of malls is the subject matter of the study. Yet it is necessary to validate the efficacy of these models in terms of their precisions in order to evaluate the relation between architectural forms and acoustics in such large scale public spaces. Hence the analysis is performed in two folds;

Evaluation of 3D acoustic models on CEPA case for which there is a qualitative and quantitative study taken as benchmark. Then, acoustical analysis of the malls included in the thesis, consisting of the following steps.

1- Modeling
2- Decisions of Source Locations
3- Material Assignments (absorption coefficients, scattering coefficients, acoustic transparency)
4- Simulation/Evaluations

Figure 5.1 given below illustrates the analysis process from physical data to development of 3D solid model in one of the malls explored in the study.

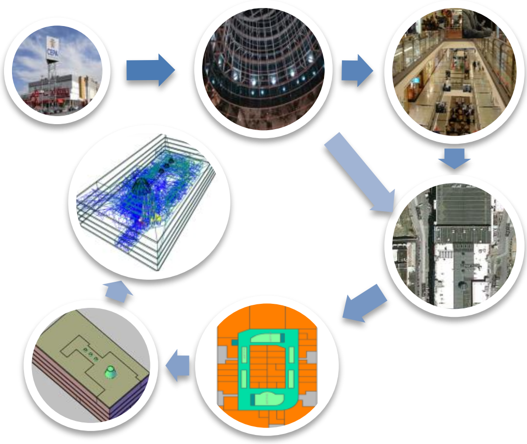


Figure 5.1 Analysis procedure of a Cepa AVM

5.2 Validation of the 3D Models

It is known that precision in computational studies is an important issue that researchers should take into account and should propose models precise enough in relation with the requirements, context and scope of the study as in this case.

Malls are very complex enclosed spaces having diverse fine details, yet it is possible to classify them according to major/gross architectural features which bring in the question of precision of the models and thus degree of the accuracy of the results for further discussions to be based on.

In this study, CEPA AVM which has been already analyzed by Dökmeci[10] in a quantitative and qualitative way by measurements, simulations and interviews is considered as the benchmark for the validity analysis and for the precision of the 3D models. Because in this study, the simulation results are checked with noise measurements for accuracy. The result of Dökmeci's study is compared to analysis results obtained in this study, using the resulting model of the process shown in Figure 5.1. Material assignments and decisions about the detailing as explained in Chapter 3 and Chapter 4 are also plausible for the validity evaluation of the model. The table below illustrates the analysis results of Cepa AVM and the results of Dökmeci's study.

Table 5.1 Comparison of analysis results of Cepa AVM

Parameters	**SPL at 1000 Hz**		**EDT at 1000 Hz**		**T30 at 1000 Hz**		**STI**	
	Worse Location	Best Location	Worse Location	Best Location	Worse Location	Best Location	Worse Location	Best Location
Present Study with Proposed Solid Model	59.6	72.7	3.1	7.0	7.9	9.8	0.24	0.65
Dökmeci's Results as the Benchmark	56.1	73.5	3.8	8.1	6.5	9.2	0.27	0.69

[10] DÖKMECİ, Papatya Nur. *Acoustical Comfort Evaluation in Enclosed Public Spaces with a Central Atrium: A Case Study in Food Court of Cepa Shopping Center.* Master thesis submitted at Bilkent University. 2009.

As it is seen in table 5.1, the values of parameters that are stated to evaluate speech intelligibility and noise are quiet similar in both of the studies with a percentage difference of % 7.25 and % 15 for the best and worst locations respectively. This percentage deviation which practically negligible between these two analysis results may have several reasons ranging from the type of the materials assigned to the surfaces to number of rays, in broader sense the initial settings of the software process as well as the construction of 3D model itself . Hence this 3D model prepared in the present context of the study questioning gross acoustical behavior of malls and the model prepared for a very specific case analysis, namely Cepa AVM have shown very similar results. Therefore it is possible to state that in such large scale enclosed spaces, the precisions of the proposed models are adequate for further studies. Since similar modeling attitudes are kept for modeling of the other malls included in the study, then it can be concluded that 3D models presented here will exhibit very similar results with a deviation of order of % 7.25-15 with fine detailed models which is negligible in practice.

5.3 General Overlook to Shopping Malls

Assumptions and decisions related to the choice of materials and the level of detailing in solid models have been explained in the previous chapters. Since the gross acoustical behavior of malls regarding their architectural design rather than specific or local one, has been concerned, such decisions on the use of material properties, finishings and ornaments will negligibly affect the results. Source locations and numbers are determined similarly in all the malls included in the study based on circulations and entrances. Omni directional point sound source(s) with 90 dB overall gain are used in the analysis as it is general practice in room acoustics and in the evaluation of such speech based enclosed public spaces. Number of point sound sources used in the analysis varies 2 to 3 regarding their locations: located under and/or near the galleries and the area of malls.

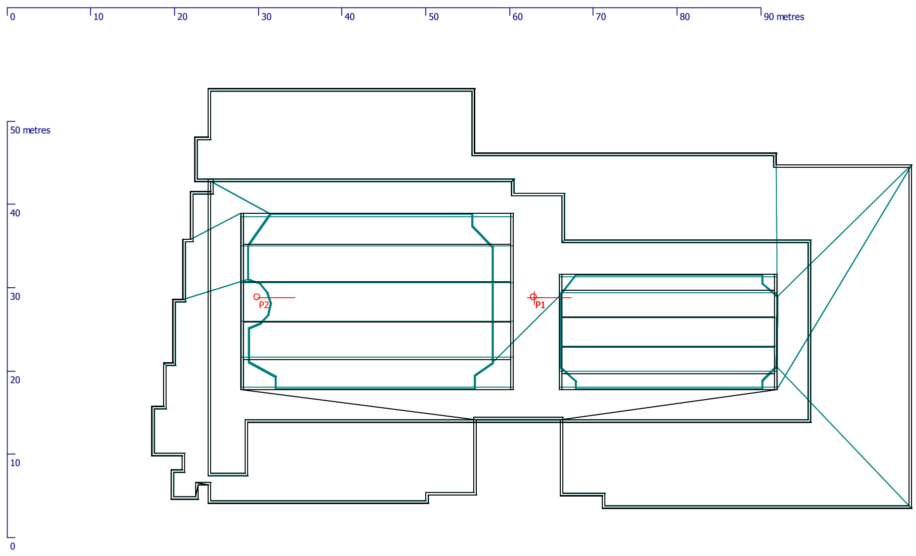


Figure 5.2 Plan showing source positions (Galleria Ankara)

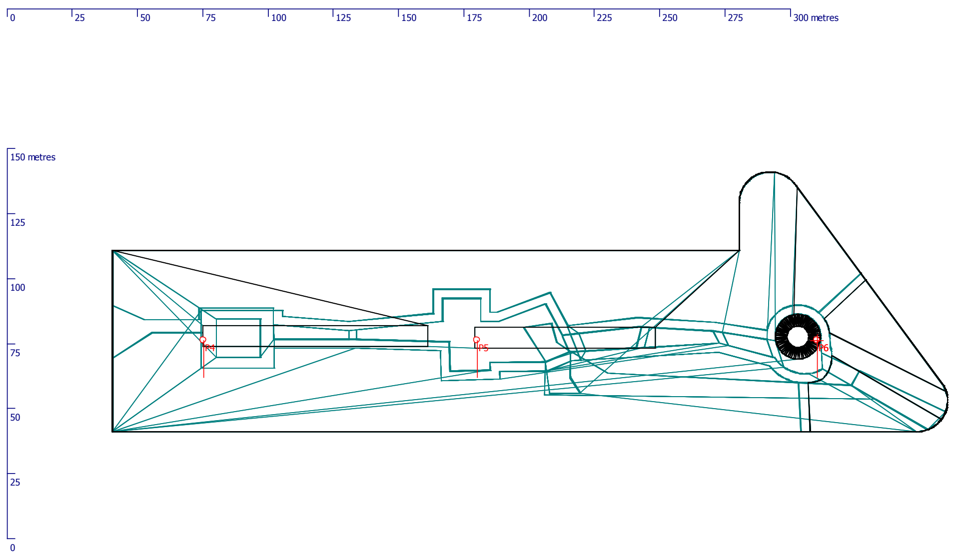


Figure 5.3 Plan showing source positions (Gordion AVM)

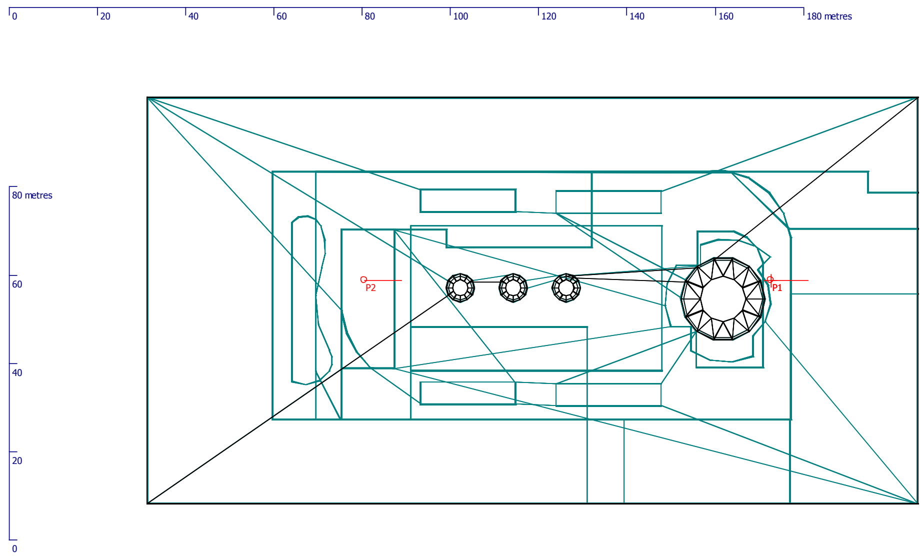


Figure 5.4 Plan showing source positions (Cepa AVM)

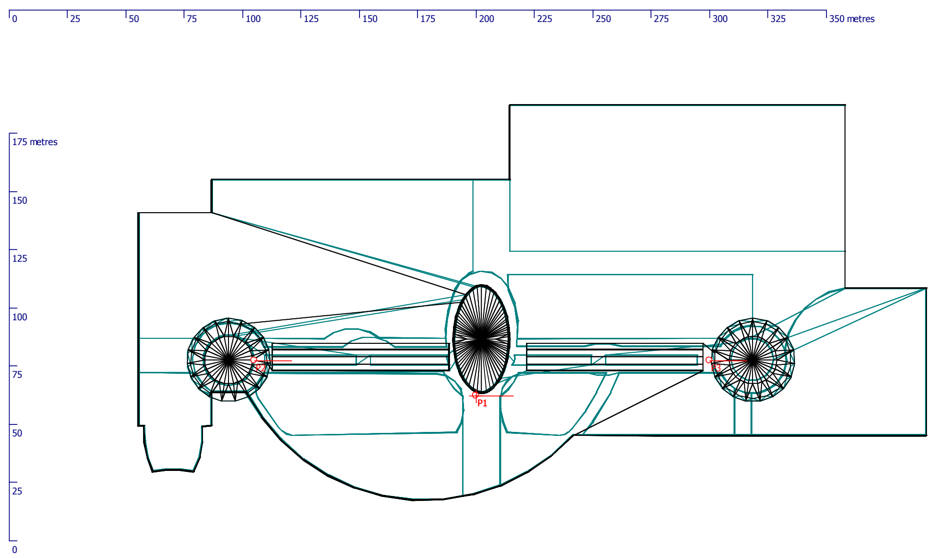


Figure 5.5 Plan showing source positions (Anteras AVM)

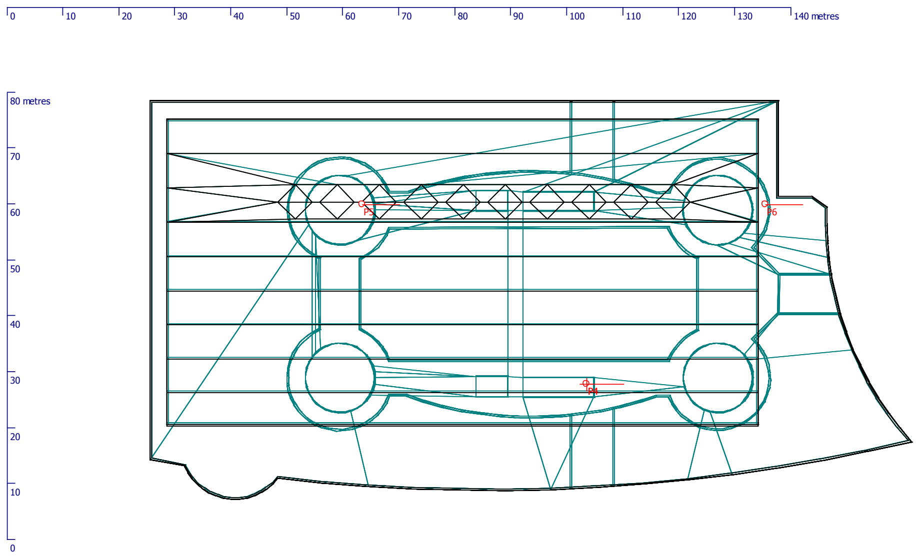


Figure 5.6 Plan showing source positions (Armada)

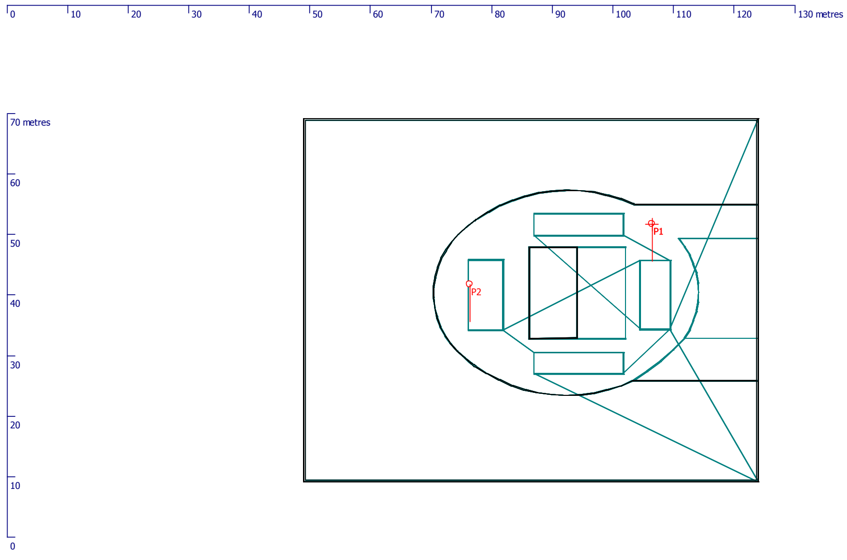


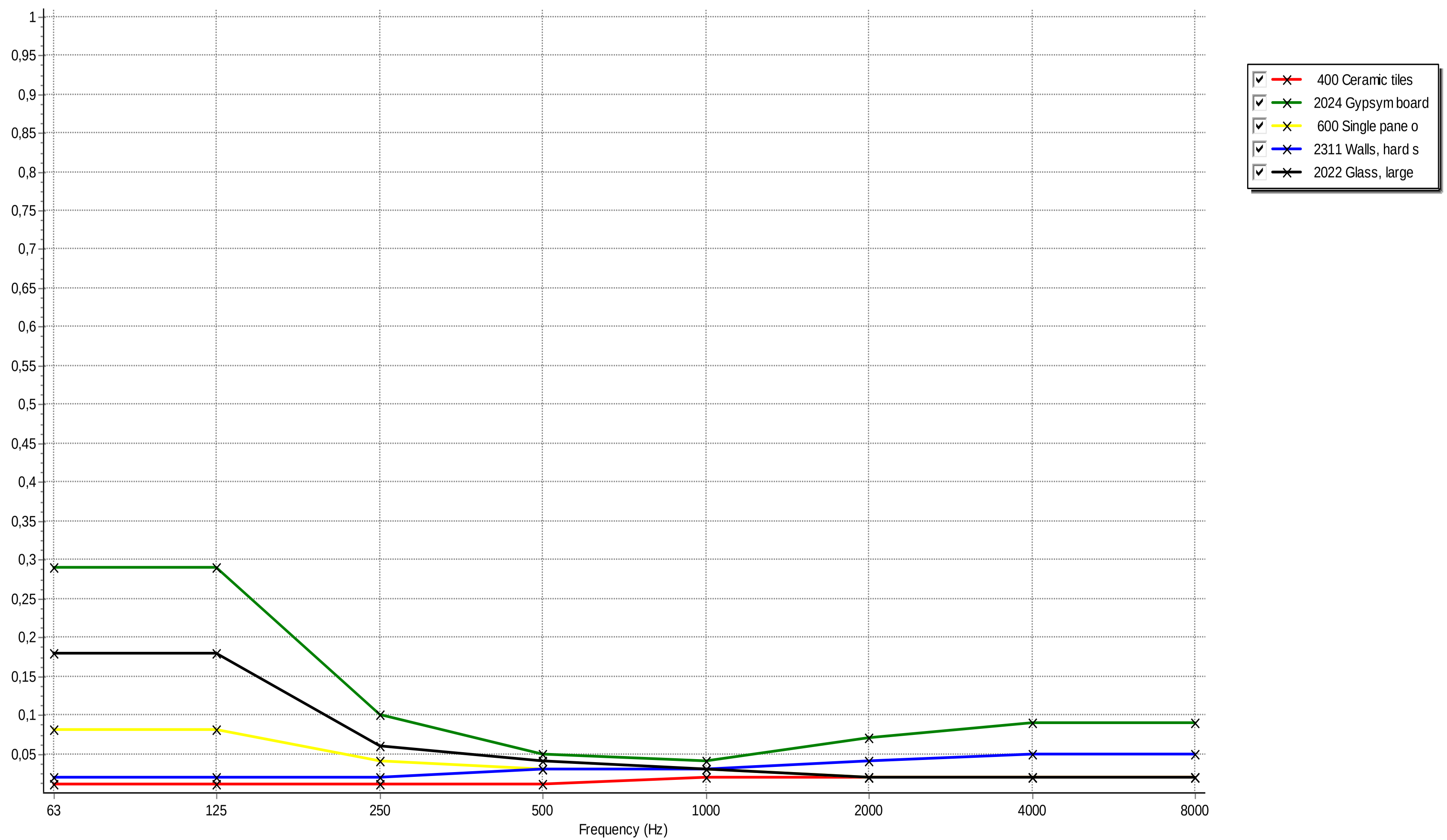
Figure 5.7 Plan showing source positions (365 AVM)

Since this study focuses on the general acoustical behaviors of the malls rather than a specific location, grid responses which cover all the accessible exposed areas are calculated. *Grid response* command calculates the parameters by sound receivers which are located according the distance between them on the plan surface. The distance between the grids are chosen as 8-10 meters in the analysis process.

As explained before, surface materials of the shopping malls are similar. As principal acoustic properties of these materials are available in data banks and acoustical literature, they are assigned to all the surfaces in the solid models.

Table 5.2 shows the absorption coefficients of materials that are assigned to the surfaces of all shopping malls. In general, the materials that were observed have significant reflective features that indicate the potentials of long and excessive reverberation in the shopping malls considered here. It is seen that in low frequencies the absorption coefficients and thus absorption performances are rather higher than in mid and high frequencies; as a result panel effects that are encountered in large suspended surfaces as in the case of suspended ceilings.

Table 5.2 Absorption coefficients of materials



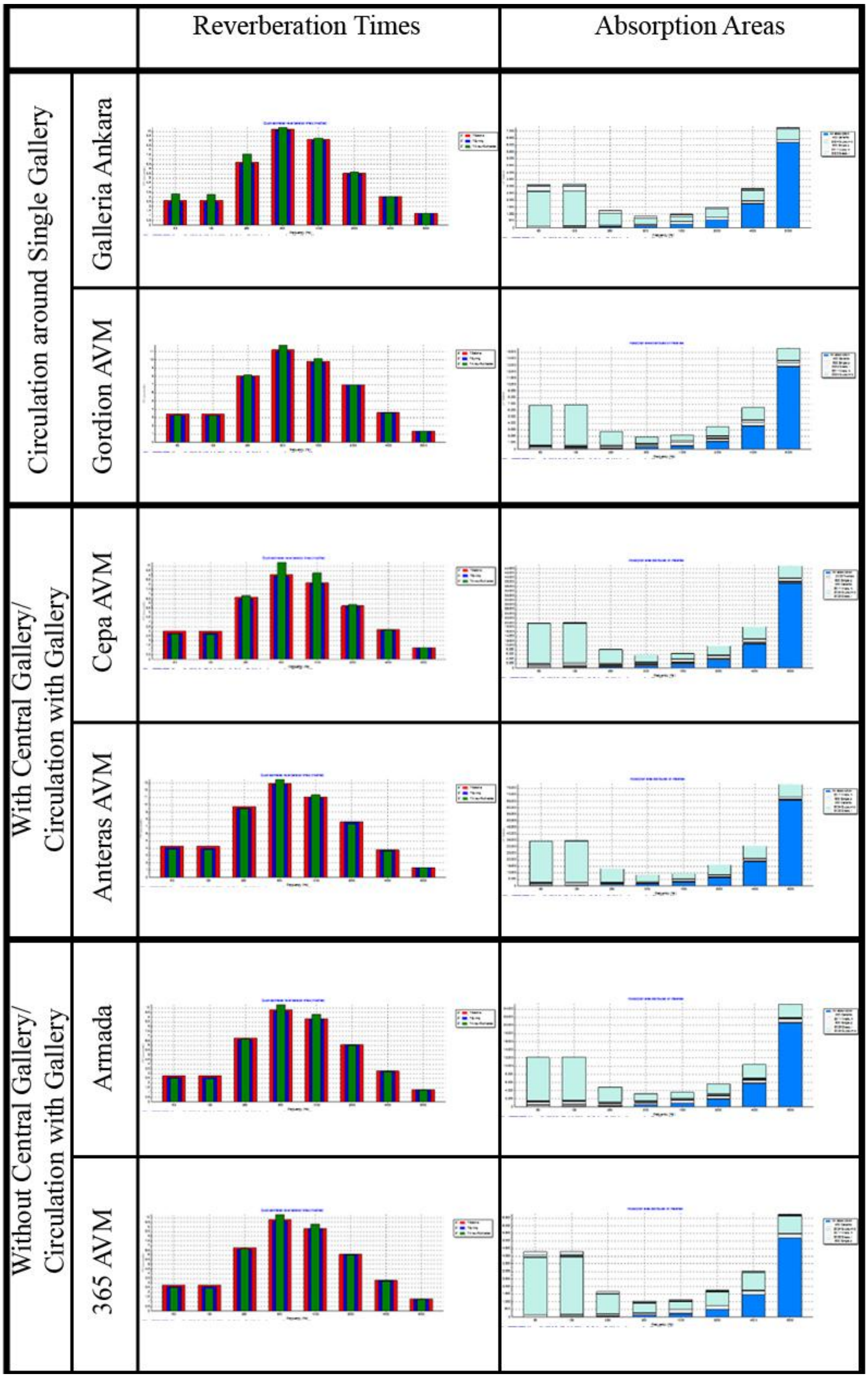


Figure 5.8 Reverberation times and absorption areas of shopping malls

Figure 5.8 shows the quick reverberation time estimations and distribution of absorption regarding the areas on which they are effective. Detailed figures showing these can be found in appendices. Reverberation times as defined by Sabin, Eyring, or others are only related to the total amount of absorption as a function of surface areas and volumes of shopping malls without any function indicating spatial distribution. Hence RT does not vary from one position to another unlike other acoustical parameters based on acoustic energy which is a function of cartesian space and time. Yet RT is a very valuable tool to assess the general acoustical behavior of the rooms and gives an insight about initial design decisions defining the acoustic quality. Although there is no proposed reverberation time range for shopping malls, they should exhibit similar acoustical qualities and RT defined for other enclosed public spaces where speech and noise are important for the comfort of users. As reverberations time is a function of absorption, it is necessary to determine the distribution of RT over the frequency spectrum of interest. It can be seen in the graphics showing RT distributions reverberations times are shorter in low frequencies as a result of absorptive properties of materials used in these malls as well as panel effect related to their use in the space. At high frequencies on the other hand, air in the room contributes to the overall absorption starting from 2000Hz. This contribution is more emphasized in large volumes as in the case of malls. This fact has been depicted in RT distributions given in Figure 5.8. Although materials have very low absorption coefficients, RTs are not that long due to air absorption which gives a clue for further discussions on acoustical performance of the malls.

Materials used in contemporary mall examples have similar acoustical properties as a part of requirements/ standards of malls and as a part of other standards related to function, use and safety. Therefore, designers should assign/choose their materials within these limits which restrict their choices and thus the possibility of much better acoustics just by using different set of materials.

It should be noted that the frequencies which designers specifically take care of, are the mid frequencies which is one of the determinants of speech intelligibility, for which neither air absorption nor panel effect come into play. Reverberation times in 365 AVM and Armada are slightly shorter than other malls in the order of % 25. The exposed volumes of those malls to wave phenomenon i.e. acoustic propagation are relatively smaller and thus shorter reverberation times are observed. This shows the importance of the use of optimum volumes for circulation areas and atriums in order to provide recommended reverberation times at mid and high frequencies for further acoustical qualities.

Mid frequencies are mostly reckoned for the assessment of speech quality/intelligibility in room acoustics. Analysis results of malls included in the study show that reverberation times are much longer than RT values suggested for speech based spaces. Main reason of such long reverberation times is firstly the large exposed volume of the malls, and the use of acoustically reflective materials. It is obvious that, suggesting the use of absorptive materials in all the surfaces is nor realistic nor feasible. Yet analysis also shows that ceilings play crucial roles in the acoustics allowing designers to experience new materials improving reverberation response. Therefore, even in the very first stages of the design process, architect should consider ceilings as very flexible tools to tune the acoustics to the required values. Even the use of ordinary gypsum boards on the ceilings, as seen in the analysis, contributes acoustics considerably. The use of special acoustic boards which are specially designed and developed to satisfy other building codes will definitely improve the acoustics of these malls and even other surfaces which are very reflective.

Although the reverberation times and absorption areas give the idea of acoustical quality of shopping malls, other acoustical parameters showing spatial variation of acoustics have a prime importance in the assessment of building typologies regarding acoustics.

5.4 Acoustical Analysis of Malls through Simulations

There are a set of acoustical parameters indicating different acoustical features of spaces depending on their function, and use. Since shopping malls are enclosed public spaces where the number of users is high, noise and speech intelligibility have prime importance for the acoustical comfort. Hence, acoustical parameters SPL, EDT, T30, D50 and STI indicating these features are to be taken into account for the acoustical evaluations of malls included in the study.

5.4.1 Sound Pressure Level

Sound pressure level indicates the sound energy distribution in shopping malls derived by geometrical form and spatial organizations. Omni directional point sound source(s) with 90 dB overall gain are used in the analysis as it is stated in the previous section. The background noise is assigned 50 dB overall gain for all shopping malls as it is considered in the level of ventilation system. According to the location of source(s), some values are simulated lower than they have to be. However, it is not considered as a bias because the general distribution of sound pressure levels is explored. Figure 5.9 illustrates the distributions of sound pressure levels throughout shopping malls.

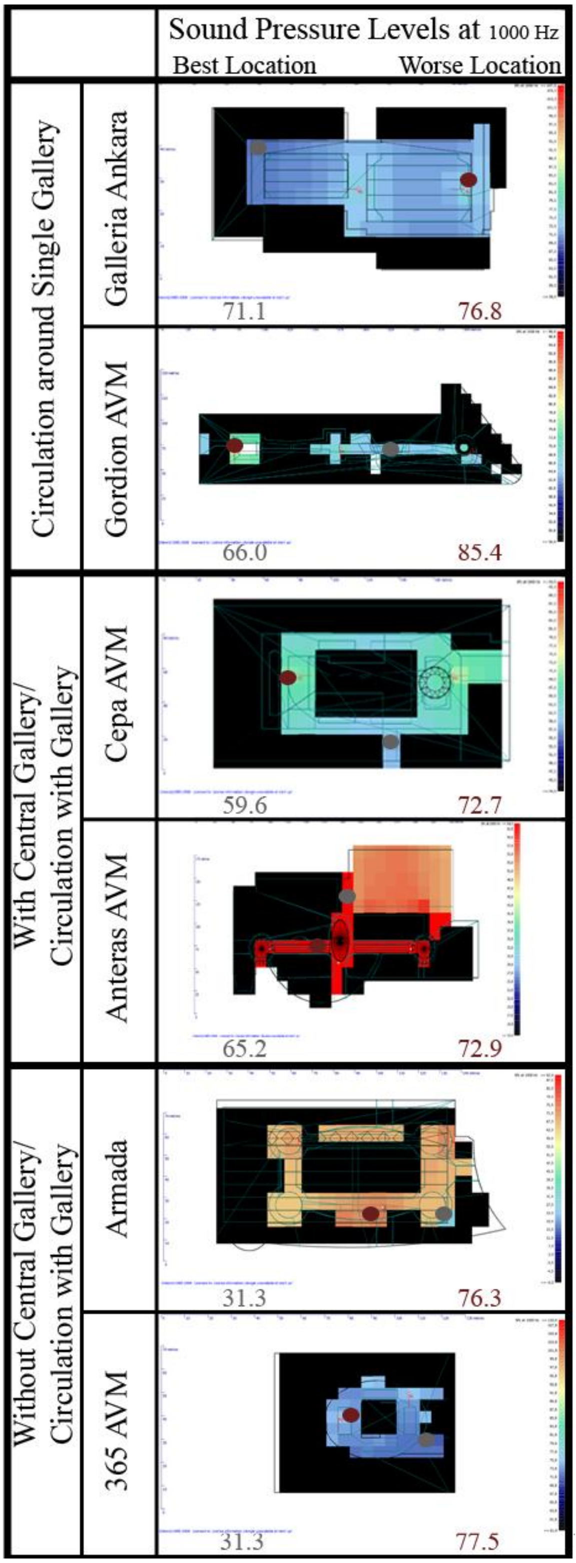


Figure 5.9 Sound pressure levels distribution in shopping malls

SPL is distributed between 70-80 dB in Galleria Ankara and between 65-70 dB in Gordion Ankara. Sound pressure levels have higher values in the close neighborhood of the sources as expected and, have lower values far from the sound sources. The central gallery has significant importance in this homogenous distribution. The volume of atrium and non-existence of ceilings at storeys that create absorption results as parallel ambient noise level throughout malls. Although both malls have similar distribution, Gordion AVM has more similar values around narrower atrium, because of lateral reflections and less volume. Consequently, shopping malls with single gallery tends to have higher SPL than other malls regarding ambient noise.

SPL distributions are homogenous in Cepa AVM and Anteras AVM similar to typologies exemplifying malls with circulation around single gallery. The atriums and circulations that are directly connected with central gallery are important for sound to transmit over the malls. Anteras AVM has lower sound pressure levels than Cepa AVM because of fewer storeys in terms of the volume. The absorption of air has significance effects on acoustics regarding SPL and reverberation. It is important for designers to use absorptive materials and geometrical relations in order to prevent the sound coming from atriums to circulations

SPL distributions in Armada and 365 AVM are similar and more homogenous than shopping malls explored above. Although there is not central gallery in Armada and 365 AVM, the circulations connected to each other and related to the storey with atriums are significant architectural features to sustain similar distributions. The SPL is around 75 db at 1000 Hz for two malls and this is also close to the levels simulated in other.

SPL distributions are simulated quiet similar in all examples; however there are some differences between them. It is important to state that the inner spaces of shopping malls are connected to each other with galleries and corridors regarding functional schema. Thus, this composes the transmission of sound waves throughout malls. The designers should use reflector surface to control sound waves in which the levels are considerably high like central gallery, food courts and main entrances and also should use absorptive surface to decrease sound pressure levels in these spaces.

5.4.2 Early Decay Time and T30

The position of receiver and the sound energy at this position directly affect early decay time values observed in rooms. EDT shows the reflections that affect reverberation time according to position and SPL. The diffusion of sound field is related to proximity between EDT and reverberation time. Thus one of the important parameters used together with EDT is T30 whose reverberation time is calculated with 30 dB drop of sound pressure level at a specified receiver positions.

Thus, the two acoustical parameters are important to understand general acoustical behavior of shopping malls with distributions regarding reverberation and sound energy. Figure 5.10 shows the distributions of EDT and T30 throughout shopping malls.

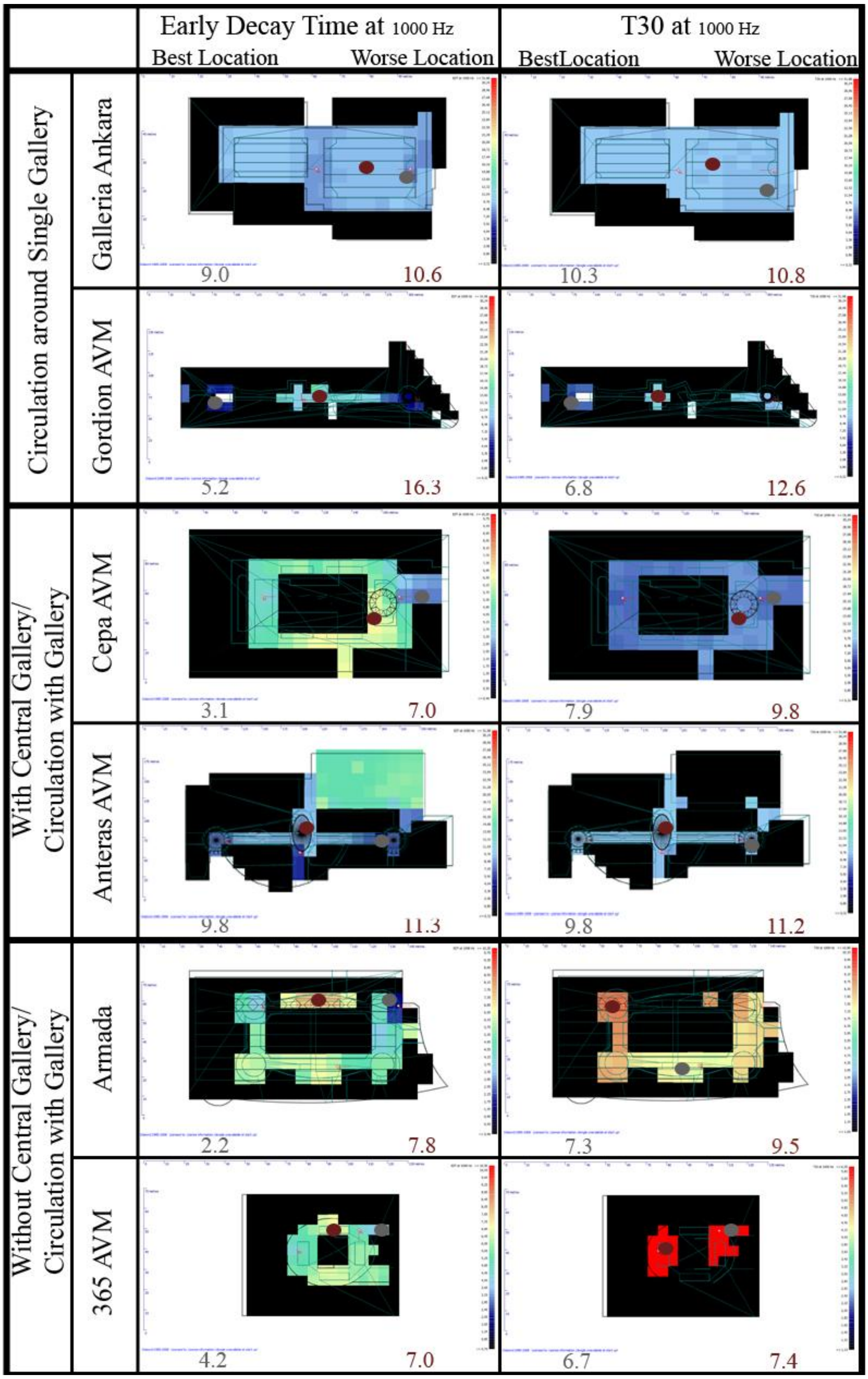


Figure 5.10 EDT and T30 distribution in shopping malls

EDT and T30 get similar distribution throughout Galleria Ankara and Gordion AVM. The single central atrium and circulation surrounding the result in this characteristic behavior of sound wave. The values are identical in Galleria Ankara which means high diffused sound field.

There are not any reflecting surface or layout that can result in reflection which have significant effects to vary distribution by reflections. EDT is between 9.0-11 s in Galleria Ankara and 12-13 s in Gordion Ankara, T30 is between 10-11 s in first malls and 11-13 s in Gordion Ankara. Although central atrium has significance importance for such enclosed public space in architecturally manner, it results in highly reverberant field throughout the malls regarding the high volume of atrium and direct connection of circulation and food-court to gallery. Designers can decrease the reverberation and sound levels by applying convex surface to the top of the atrium regarding diffusion of sound waves, and by using reflective surface around the circulation facade to gallery in order to disconnect the circulation from gallery considering acoustics.

Although EDT and T30 values are high enough to state reverberant field in Cepa AVM and Anteras AVM, the distributions of them give clue about behaviors of central gallery, circulation connected to it, gallery ceilings and volume. In Cepa AVM, EDT in central gallery with non flat ceiling and narrower secondary entrance is higher than EDT in galleries which have flat ceiling surrounded circulations and wider primary entrance. Early reflections are affected by the difference between volume, ceiling geometries and lateral reflections, accordingly. In parallel with Cepa AVM, EDT values are distributed similarly in Anteras AVM. Contrary to EDT, T30 values are in the same range for two shopping malls with single gallery shopping malls because the circulations have galleries and connected to the central gallery regarding volume connections. The reverberation in Cepa AVM is less than Anteras AVM, because Cepa AVM has flat atrium ceilings, wider circulations and lower volume regarding area compared to Anteras AVM.

EDT values are around 5 s in Armada, 6 s in 365 AVM and T30 values are around 7 s in Armada and 6 s in 365 AVM. The values indicate reverberant space and less clarity; however, the occupied values are less than the other two typologies. It is important to note that the typologies that belong to this group have inclination to create more diffuse and comfortable spaces in terms of acoustics regarding not having central atrium and better volume-area relation. It can be seen in the distribution graphic of EDT in two malls that there are difference in getting higher values at some locations. The locations in which the atrium has a food court and the atrium is existed through more storeys are considerably more reverberant. Thus, it is important to note that the food-court position according to atrium and the number of storeys connected to same galley affect the reverberation in a positively and negatively way.

5.4.3 Speech Transmission Index and D50

It is known from the literature, that Speech transmission Index (STI) is related to speech intelligibility differing to positioning and D50 is related to useful sound obtained in the first 50 ms. Although reverberation times indicate the quality of space regarding acoustics, STI and D50 should be evaluated in shopping malls because of speech intelligibility and perception of paging. Figure 5.11 shows the distributions of STI and D50 through shopping malls.

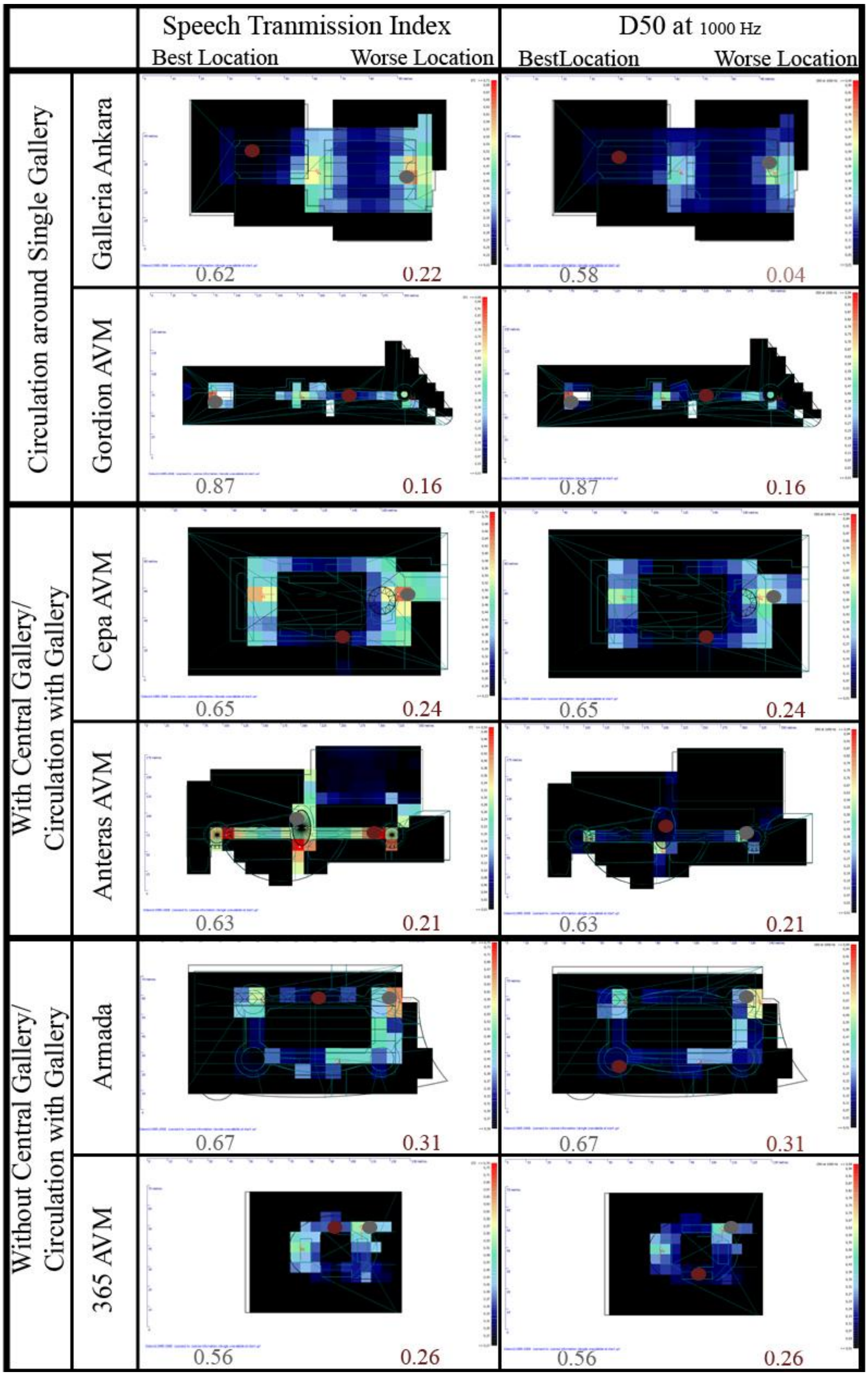


Figure 5.11 STI and D50 distribution in shopping malls

STI get poor values between 0.2-0.4 in Galleria Ankara and 0.3-0.4 in Gordion AVM except the locations that are indicated in grey color. Values below 0.5 show poor speech in intelligibility which is in correlation with the reverberant times as mentioned above. On the contrary, the dark red color indicates values of 0.7 which is good for speech intelligibility and transmission. Moreover D50 is in excess of 0.50 in same locations. This is satisfactory for speech intelligibility. Existence of wall and ceiling surfaces that are close to these points can be effective for this situation. These examples express that reflecting surfaces located according to intended design may be practical elements to control the atrium spaces regarding acoustics. It is important to design location and reflective surfaces by not corrupting the perception and aesthetics of atriums considering architecture. Except for the specific locations explained above, D50 get values lower than 0.5 in malls with central gallery which is unsefficient.

STI get values between 0.4-0.6 in Cepa AVM and 0.2-0.3 in Anteras AVM except the locations that are near source and far from the galleries. The grey color in Cepa indicates values of 0.7 and the color in Anteras AVM indicates 0.5. Simlar to STI, D50 is in excess of 0.50 in same locations showing satisfactory for speech intelligibility. The case is related to the same reasons which are expressed for single gallery malls. Getting higher values of STI and D50 in Cepa AVM than Anteras AVM are correlated with reverberation times of those spaces and shows that flat surfaces, wider corridors and less connection with central gallery have important effects on sustaining more comfortable environment, although two malls are not good enough for speech intelligibility and noise.

STI levels are affected by the wall surface geometries and atriums in Armada and 365 AVM. STI values are higher than other shopping malls. The values are around 0.3-0.6 in Armada and around 0.4-0.6 in 365 AVM. D50 values are not in excess of 0.5 however they are around 0.4 in Armada and around 0.3 in 365 AVM which are also in relation to reverberation times and STI in a good manner. Smaller and separated galleries have good effects on speech intelligibility. It sustains homogenous distribution of sound within volumes rather than focusing effects of central galleries.

The simulated parameters can be discussed for further evaluation of acoustics in shopping mall regarding architectural features as geometrical form, spatial organizations and plan layout. As it is mentioned in previous chapters, objective is to explore gross acoustical behavior of shopping malls by focusing on atrium and its locations, circulation and its physical connection with atriums, absorption areas, volume and geometry of surfaces. In the conclusion part, general recommendations are given to designers about initial design step of shopping malls regarding acoustics and expectations are mentioned orderly.

5.5 Evaluation of Architectural Features

Simulated analysis results and their evaluations are explored in detail in the previous section. It is important to evaluate the analysis results considering architectural features such as volume, area, central gallery and circulation. With the help of this evaluation, it can be possible to state the effects and consequences of spatial organizations, geometrical forms and plan layouts of shopping malls in acoustic quality.

Volume-Surface Area Relation

As it is mentioned in the previous chapters, the reverberation times and other analysis parameters are directly related to volume and surface areas of spaces. The table 5.3 illustrates the volume-area relation of shopping malls.

Table 5.3 Volume-area relation of shopping malls

Shopping Mall	**Volume (m^3)**	**Surface Area (m^2)**	**Volume/Area**
Galleria Ankara	59.732	46.627	1,281
Gordion AVM	643.178	321.863	1,998
Cepa AVM	362.672	214.937	1,687
Anteras AVM	633.967	320.237	1,980
Armada	197.954	140.516	1,409
365 AVM	50.267	50.988	0,986

The values shown in the table are calculated in terms of active volume and surface areas by ODEON program. Volume/area ratio shows the amount of volume per total active surface area of ceilings, wall and floors. They can be calculated in a different way according to architectural points of view, but here it is important to state the relation between simulated volume and surfaces in order to discuss the gross acoustical behaviors of shopping malls.

As it is stated at the beginnings, according to reasons and approaches related to designing shopping malls, by considering economic purposes, architecture and aesthetics, higher storey height is obtained in these buildings. It naturally results in higher volumes. Although volume is considerably important for architectural aspects, it has effects on acoustical quality of shopping malls.

365 AVM, Galleria Ankara and Armada have lower volume/area ratio in atriums and circulations than rest of the malls. The good effects of this are checked out with analysis results mentioned in the previous section. The shopping malls that

have lower ratios tend to be more proper for speech intelligibility regarding reverberation. Shopping malls which higher volume/area ratio have longer reverberation times affecting the acoustic comfort. Thus, it is crucial for architects to decide the proper volume/ratio in shopping malls at the initial designing step considering the value of volume in an architectural manner. Similar acoustical models for basic design of shopping malls can be prepared as it explained in the thesis and analyses results of simulation can be discusses for further improvements of building.

Central Gallery

In order for volume, central gallery has a great importance for shopping malls regarding architecture. The acoustical effects of central gallery are examined in literature and are checked out for shopping malls in the analysis results. In both malls with single central gallery and central gallery/circulation with gallery, poor acoustical values are simulated for speech and noise in, near and around the galleries. The geometrical form, location, surface material and physical connection of atrium spaces cause acoustical problems.

365 AVM and Armada that do not have a central gallery have better values for acoustical parameters. Also between these two, 365 AVM has shorter reverberation times and higher STI values that state quality for acoustics, because of lower Volume/area ratio. Thus, it can be noted that lower volumes without central gallery are good for acoustics.

Galleria Ankara and Gordion AVM have single central gallery and circulation around it. They have longer reverberation times affecting acoustics negatively. Also, Gordion AVM is worse because of its volume. The sound that grow out of and is transmitted by atriums should be controlled and should be prevented from circulations in order to decrease reverberations. The convex geometry of ceilings, size of atrium, absorptive surfaces around atriums and reflection panels located at façade of circulation to atriums can be effective to sustain acoustical quality.

It is seen in analysis that Cepa AVM and Anteras AVM which have circulations except for circulations in central gallery are better in terms of acoustics than those that have only single central gallery, because this kind circulation organization tends to break the space relation of gallery and so its effects.

Gallery-Circulation Relations

It is indicated in analysis that physical connections and their form of circulations to galleries have effects on acoustics in shopping malls. The shopping malls in which the circulation is directly connected to central gallery have longer reverberation times in the shopping malls. In Anteras AVM, the reverberation and speech parameters get lower values than Cepa AVM in which circulations are partially connected to central gallery. Therefore, the connection ratio and geometry should be taken into account by designers to decrease reverberations.

Another important thing is the location of wider spaces such as food-court according to gallery and circulations. In Armada, the two atriums that have food-court have poor values than other similar atriums. Also in Cepa AVM, the food-court located above the central gallery is affected negatively in terms of acoustics. The physical relation of food-courts with gallery should be designed in less a connected way in order to prevent the effects of atrium on food-court and the effects of food-court on atrium.

CHAPTER 6

CONCLUSION

6.1 General Evaluation and Observation of Typologies

Further methods or designs related to materials, surfaces and geometric relations can be developed to deal with the existence of architectural features which affect acoustics in a negative way. This study is mainly focused on evaluating the acoustical behavior of shopping malls by exploring spatial organizations, plan layouts and geometrical forms in order to indicate the existence of architectural features mentioned throughout thesis. Table 5.4 illustrates the acoustical effects of existent features such as volume, gallery and circulation in a more systematic way.

In this study, the decisions that should be made for further steps are considerably taken into account. The information, obtained from the process of the classification study, modeling and simulation, is optimized and verified in order to evaluate the gross acoustical behaviors of shopping malls. As it stated in the previous chapter, the optimization of the precision level of modeling is check out with study that have detailed model and noise measurement. Thus, with this performance of study it can be noted that architects can use computational tools by optimizing the architectural features affecting acoustics at the initial step in order to shape their design accordingly.

Table 6.1 Chart showing the effects of architectural features

	Negative effect	Positive Effects
Higher Volume/Area Ratio	**X**	
Lower Volume/Area Ration		**X**
Circulation Around Single Gallery	**X**	
Convex Surface Geometry of Atrium		**X**
Existence of Central Gallery	**X**	
Circulation Connected to Central Gallery	**X**	
Closeness of Entrance to Central Gallery	**X**	
Less Connection with Central Gallery		**X**
Circulation with Narrow Gallery		**X**
Close Positioning of Food-Court to Gallery	**X**	
Absorptive Surface Materials		**X**

In-stu observations and taxonomical study based on the typologies have developed an insight for acoustical problems regarding the architectural elements and material applications used in malls. This study is checked out and compared with the analysis results of simulations. Although acoustics of these malls seem to be insufficient for speech intelligibility and noise, there are similarities and differences between shopping malls regarding architectural features that affect acoustic comfort in these spaces. It can be possible to sustain more pleasant environment by considering the architectural decisions as materials, area, volume, spatial organizations, circulation composition, location and geometrical form of atriums regarding acoustical behaviors of them.

In all shopping malls, absorption areas of surface materials are lower at mid-frequencies and higher at low and high frequencies. The quick estimate reverberation times are long for any public space as it is mentioned and they show that the absorption areas and absorptions are not enough to obtain in most of the parts of the shopping malls. The ceilings materials can be assigned to increase absorption. It is stated in chapter 2 that there is a similar approach to inside material decisions of malls. Designers can make decisions about materials considering the criteria of aesthetics, cleanup, sustainability and etc. but at the same time, they should think of the absorptive qualities of material in order to create less reverberant spaces.

It is seen that the atrium spaces in all typologies, especially central galleries without flat surfaces tend to form more reverberant spaces. EDT and T30 values are high and D50 values are below 0.5 in such places. There is significant number of researches about the atriums spaces. Considering the acoustics, there should be more interest in reflecting and absorptive surfaces at the side, top and bottom of the atrium spaces and in design solutions which can break the connections between circulations and galleries.

At single gallery shopping malls, it is impossible to avoid direct connection of gallery and circulations because the circulation is inside the gallery. An approach in which established surfaces are effective to prevent circulations from reflections growing out of the gallery can be thought by not corrupting the relation between circulation and gallery in an architectural manner. The results related to this typology give the hint that some locations that are close to the atrium spaces can be more appropriate for speech considering that there are some reflective geometries by them. Moreover, railings of corridor arranged by the atriums can be used for reflective and absorptive surfaces.

Shopping malls with central gallery/circulation with gallery indicates some different points considering the typology above. The width of circulation, ceiling geometries of circulation and connection with central gallery are effective in acoustics. Flat ceilings in circulations and wide corridors result in less reverberation and more clarity. In accordance with the connection design and geometry, central gallery has different effects on circulations. By fully interrupting the connections in terms of acoustics circulations can be prevented from bad acoustic behavior of gallery. Besides, for the central gallery there is significant decrease of sound sources which can sustain lower sound pressure levels and reverberations.

Although shopping malls, without central gallery/circulation with gallery, do not have appropriate acoustical quality for speech intelligibility and noise, they have plentiful parameters in terms of acoustics which results from architectural features such as smaller volume-area ratio, and decomposed galleries. Absence of central gallery and the problems of it are explored through the chapters and flat geometries of gallery surfaces are effective to sustain acoustical quality. It is seen in two examples that belong to this typology, reverberation and D50 values get worse near the galleries which ended up with food courts and non-flat ceiling surfaces. Wider corridors and reflection panels that break the acoustical relation between the circulations and the galleries can be effective to have acoustical quality.

6.2 Expectations and Concluding Remarks

The simulations of the shopping malls considering their taxonomical classifications based on typologies present general acoustical quality/problems resulting from their design schema, spatial organizations and material applications. Throughout this research, observations and the case studies, architectural features that affect both determining typologies and acoustics have been explored. A vocabulary consisting of elements such as gallery, volume, circulations organizations, ceiling geometry and etc. has been tried to be defined between architecture and acoustics for stating the acoustics-typology relation of enclosed public space such as shopping malls. Designers can use this acoustics-typology relation to see how general architectural design decisions affect the acoustical qualities with gaining insight in acoustics at initial design step. Also it is possible for further studies as detailed analysis, for noise measurements and for experimentations to develop and define the acoustical features, designs and qualities of such enclosed public spaces.

Although there are many buildings types and many criteria about places that architects should consider to obtain sustainable and comfortable spaces, shopping malls are popular buildings with remarkable increase in the number and acoustics is more recognized and important science related to the quality of space. They should be taken into consideration more in order to create more proper "socializing places" for human beings.

It can be seen that the unscripted performance through this study is considerably related to the performative architecture regarding optimization of the parameters that grow out of the process which have to be envisaged, annotated and verified in order to sustain productivity of the study. It is also expected that the architects of shopping malls or any other buildings can regard the design step as a process itself that should be designed and developed considering both architectural and acoustical issues rather than regarding the design step only as a way to end: building.

REFERENCES

Akçaoğlu, Aksu. *The Mallification of Urban Life in Ankara: The Case of Ankamall*. Master thesis submitted at METU. August, 2008.

Ambrose, James and Ollswang, Jeffrey. *Simplified Design for Building Sound Control.* John Wiley & Sons, New York,1995

Ankuva, Tepe. *http://www.tepeinsaat.com.tr/tepe.html*, last visited; 20/05/2010

Armada,Gezi-Yorum. *http://www.gezi-yorum.net*, last visited; 20/05/2010

Atakule, Alışveris Merkezleri. *http://www.alisverismerkezleri.gen.tr/atakule_alisveris_merkezi.asp?id=90*, last visited; 10/04/2010

Barron, Michael. *Auditorium Acoustics and Architectural Design*. Spon Press, New York.

Bednar, M. *Interior pedestrian Places.* Watson-Guptil Pub., New York. 1989.

Chen, Bing and Kang, Jian. "Acoustic Comfort in Shopping Mall Atrium spaces: A Case Study in Sheffield Meadowhall" in: *Architectural Science Review* (Vol. 47, p. 107-114).2004.

Demir, Kader. *Noise Control and Constructual Preventions at Shopping Centers: Two Examples in Ankara.* Master thesis submitted at Gazi University. January, 2003.

Dökmeci, Papatya Nur. *Acoustical Comfort Evaluation in Enclosed Public Spaces with a Central Atrium: A Case Study in Food Court of Cepa Shopping Center*. Master thesis submitted at Bilkent University. 2009.

Çelik, Emine. *Acoustical Effects of the Position of Absorbtive Materials in a Room.* Master thesis submitted at Yıldız Teknik University. 1998.

Çevresel Gürültünün Değerlendirilmesi ve Yönetimi Yönetmeliği. Republic of Turkey Ministry of Environment and Forest. 4 Jul 2110.

Galleri Ankara, Alışveris Merkezleri. *http://www.alisverismerkezleri.gen.tr/galleria_ankara_alisveris_merkezi.asp?id=71*, last visited; 10/05/2010

Gottdiener, M. *Postmodern Göstergeler*. İmge Kitabevi, Ankara. 2005.

Gürültü Kontrol Yönetmeliği. Republic of Turkey Ministry of Environment and Forest. 11 December 1986.

Inoue, Satoshi; Sugino, Kiyoshi; Katou, Masahiro and Imaizumi Hiroyuki. "Speech Transmission Performance and the Effect of Acoustical Remedies in a Dome" in: *Applied Acoustics* (Vol. 70, Issue 1, p. 221-230). Jan 2009.

Jackson, K. "All the World's a Mall: Reflections on the Social and Economic Consequences of the American Shopping Center" *in: The American Historical Review* (Vol. 101, Issue 4, p. 1111-1121). Oct 1996.

Kang, Jian. "Acoustic Comfort in Non-Acoustic Spaces: a Review of Recent Work in Sheffield" in: *Proceedings of the Institute of Acoustics* (vol. *25*, p. 125-132). 2003.

Kang, Jian. "Numerical Modelling of Speech Intelligibility in Dining Spaces" in: *Applied Acoustics* (vol. *63*, issue 12, p. 1315-1333). Dec 2002.

Karum, Koray. *http://www.koray.com.tr*, last visited; 10/05/2010

Kruppa, F. *Mall of America: The New Town Center. 1993*

Kurra, Selma. *Çevre Gürültüsü ve Yönetimi.* Butech, Istanbul. 2009.

Laselle, Jones Lang. *Perakende Piyasalarına Bakış.* August 2009

Lawrence, Anita. *Acoustics and the Built Environment.* Elsevier Applied Science, London. 1989.

Long, Marshall. *Architectural Acoustics.* Elsevier Academic Press, London. 2006

Maekawa, Z. and Lord, P. *Environmental and Architectural Acoustics*. E&FN Spon, London. 1994.

Meissner, M. "Influence of Wall Aborption on Low-Frequency Dependence of Reverberation Time in Room of Irregular Shape" in : *Applied Acoustics* (Vol. 5, Issue 3, p. 293-312). 2007.

Millenium Outlet Park, Alışveris Merkezleri. *http://www.alisverismerkezleri.gen.tr/millennium_outlet_alisveris_merkezi.asp?id=61*, last visited; 12/05/2010

Minasera, Avmgazette. *http://www.avmgazette.com/avm/minasera.aspx*, last visited; 12/05/2010

Research done at 2008, AMPD. *http://www.ampd.org/images/tr/Arastirmalar/Sektorel_Bilgiler/organize_perakende_sektoru_ozet_Ocak2008.ppt*, last access at May 2010

Southdale Mall, Wikipedia. *http://en.wikipedia.org/wiki/Southdale_Center*, last visited; 18/05/2010

APPENDIX A

ANALYSIS RESULTS OF GALLERIA ANKARA

Table A.1 Reverberation time Estimation (Galleria Ankara)

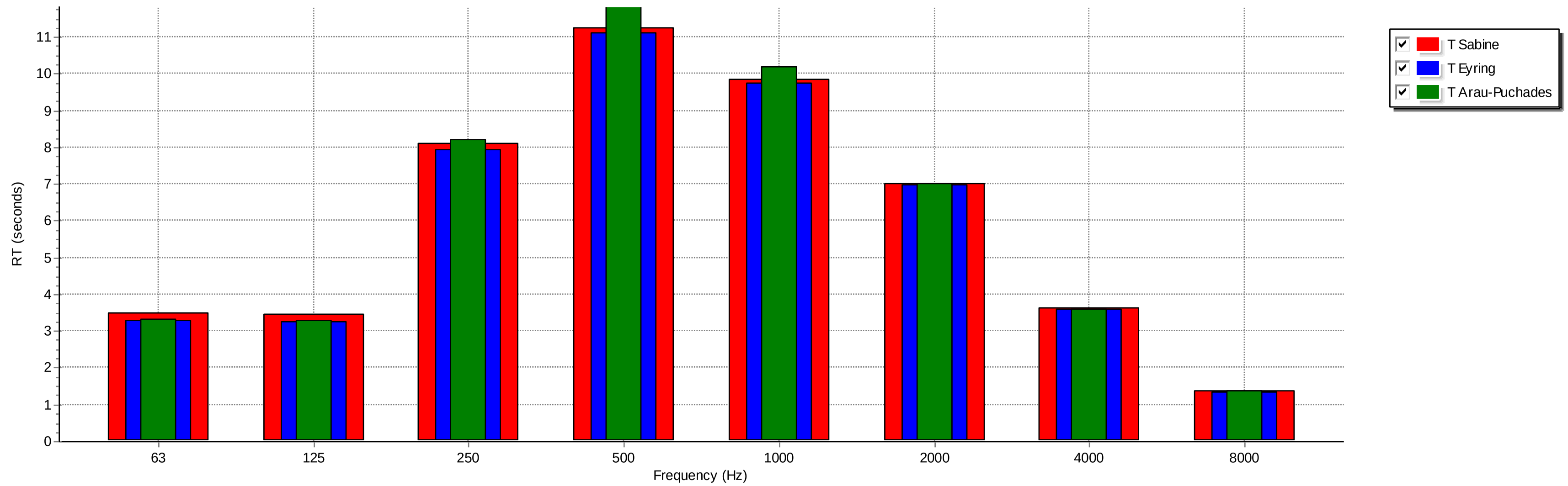
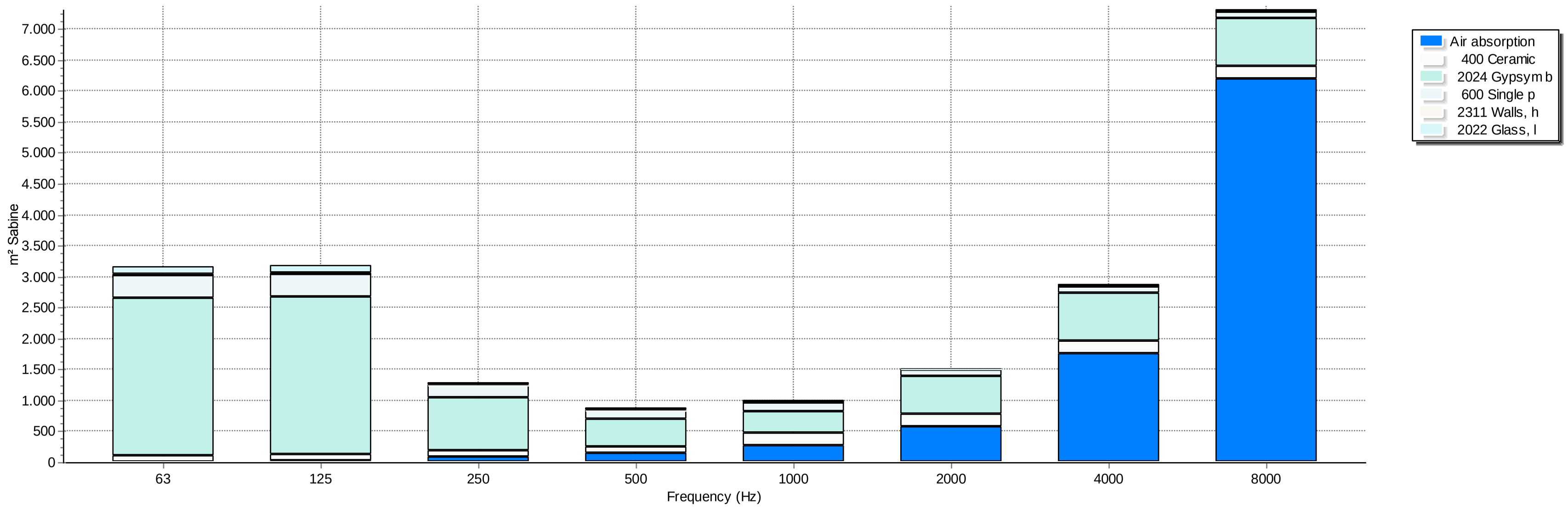


Table A.2 Absorption area distributed on materials (Galleria Ankara)



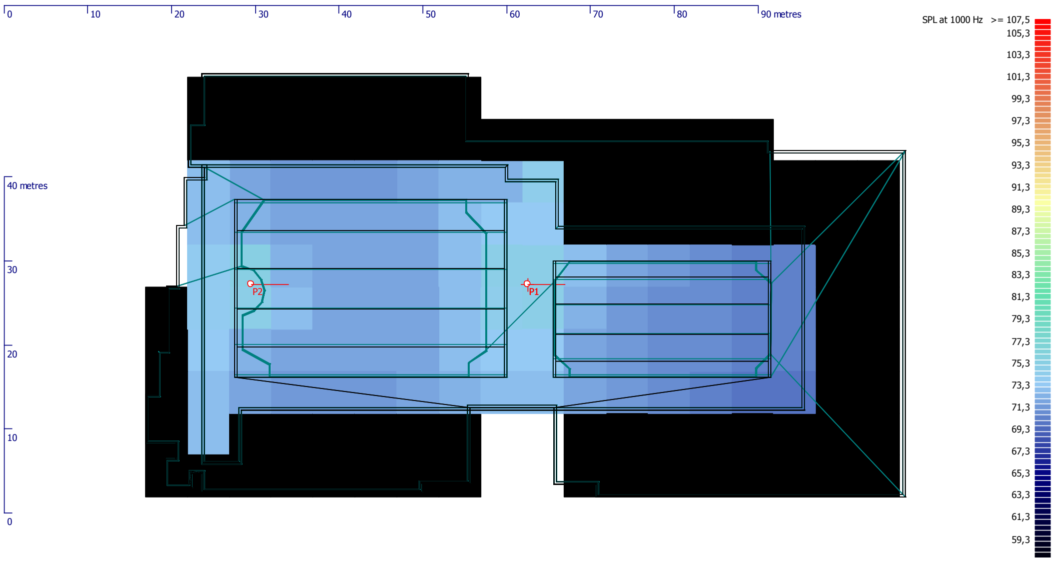


Figure A.1 Distribution of SPL at 1000 Hz (Galleria Ankara)

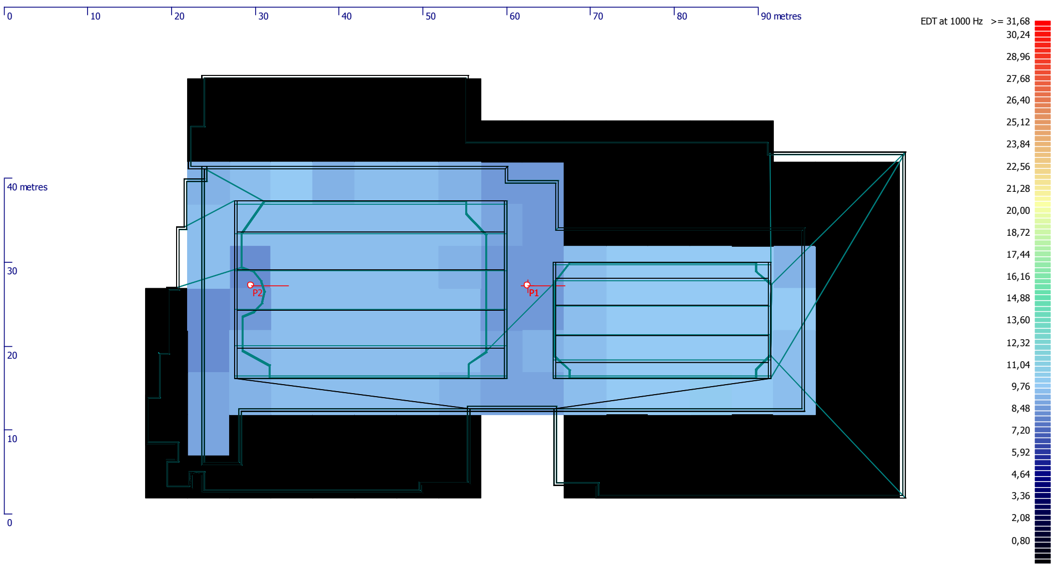
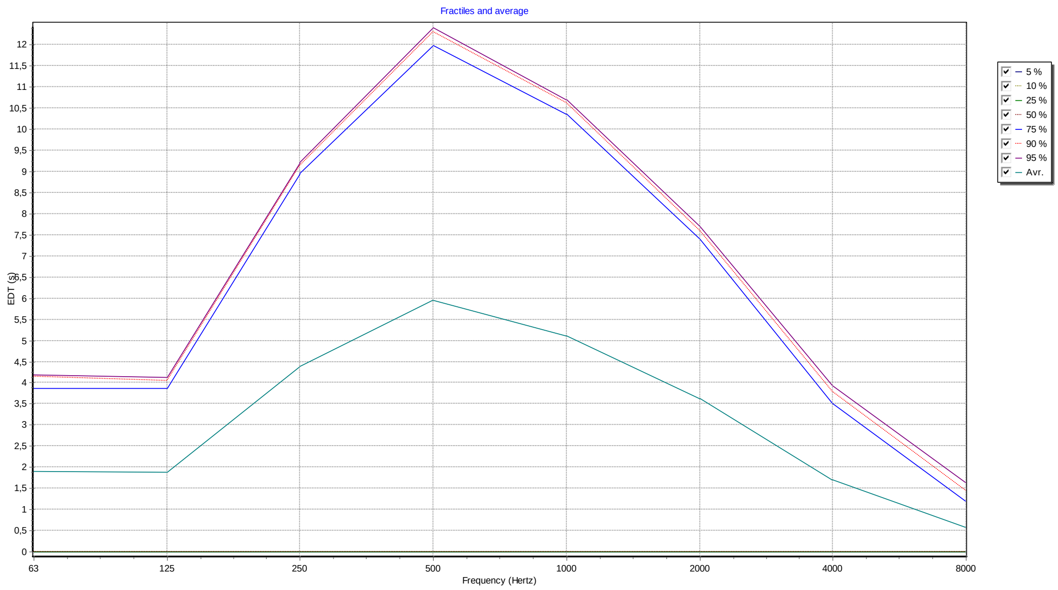


Figure A.2 Distribution of EDT at 1000 Hz (Galleria Ankara)

Table A.3 EDT values for octave band frequencies (Galleria Ankara)



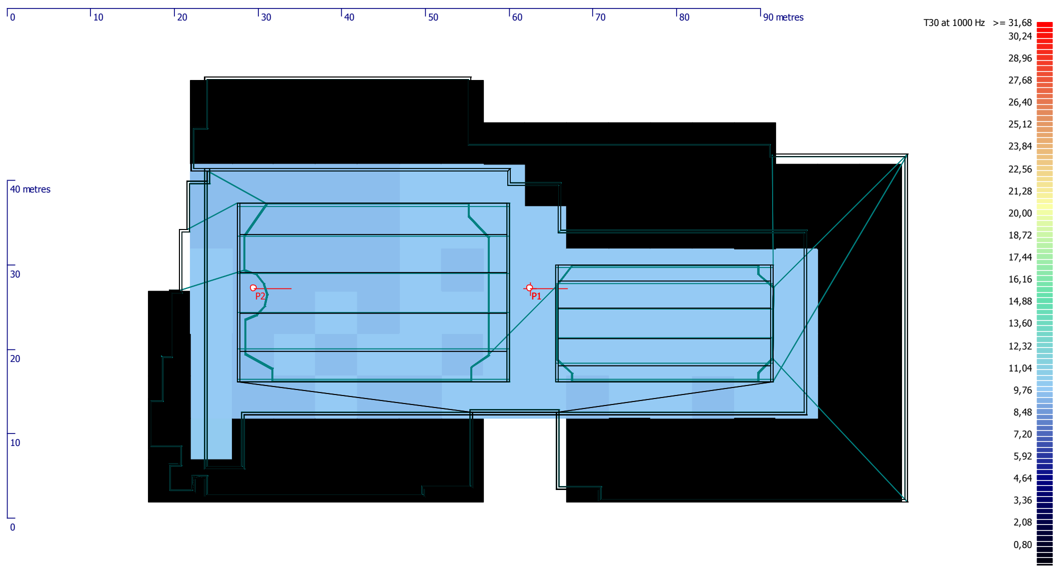


Figure A.3 Distribution of T30 at 1000 Hz (Galleria Ankara)

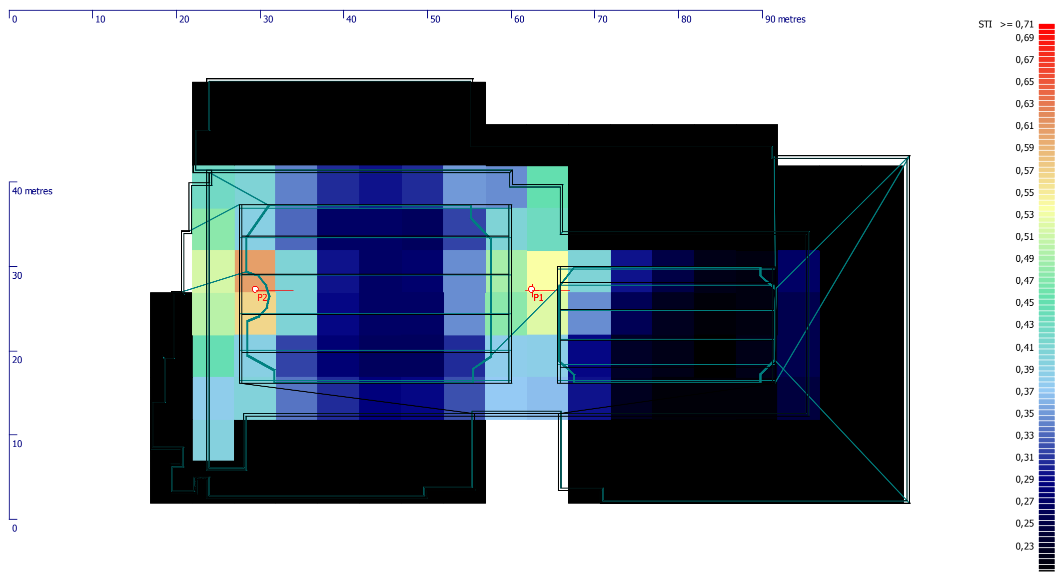


Figure A.4 Distribution of STI (Galleria Ankara)

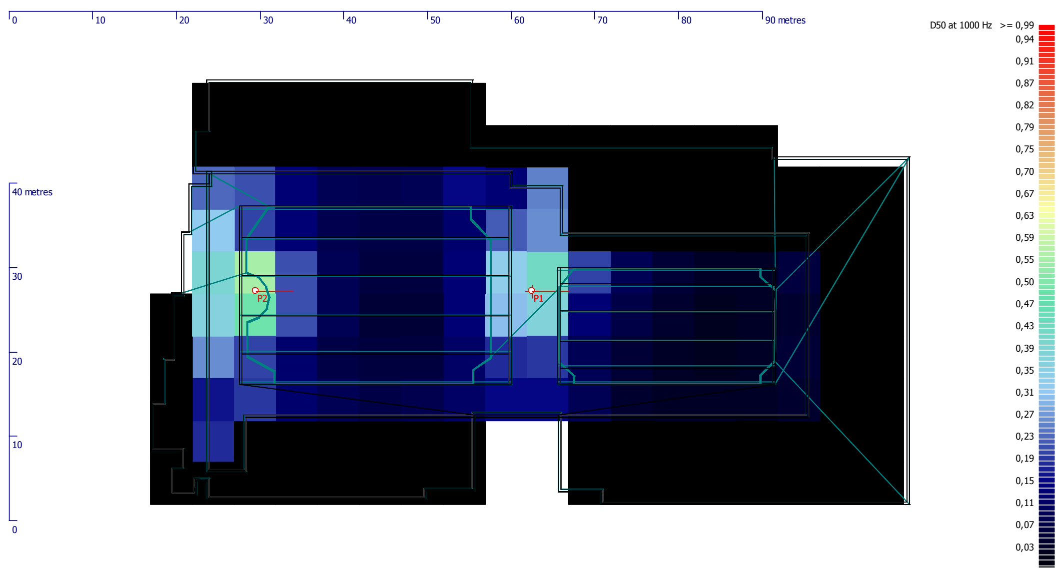


Figure A.5 Distribution of D50 at 1000 Hz (Galleria Ankara)

APPENDIX B

ANALYSIS RESULTS OF GORDION AVM

Table B.1 Reverberation time estimation (Gordion Ankara)

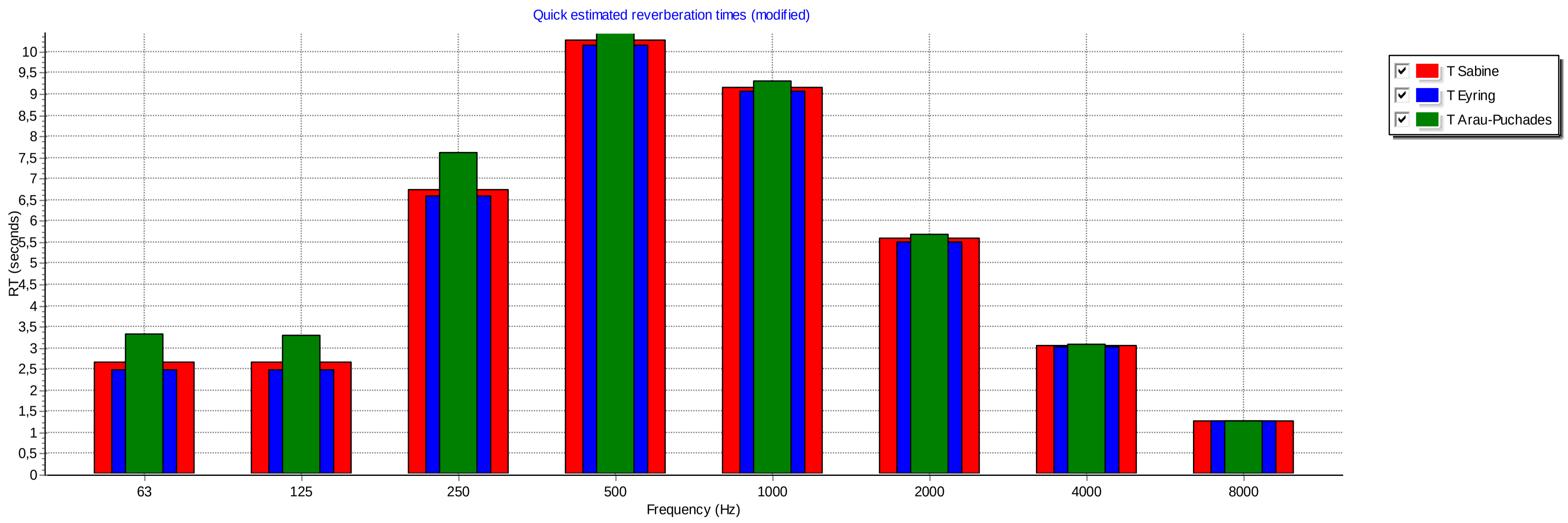
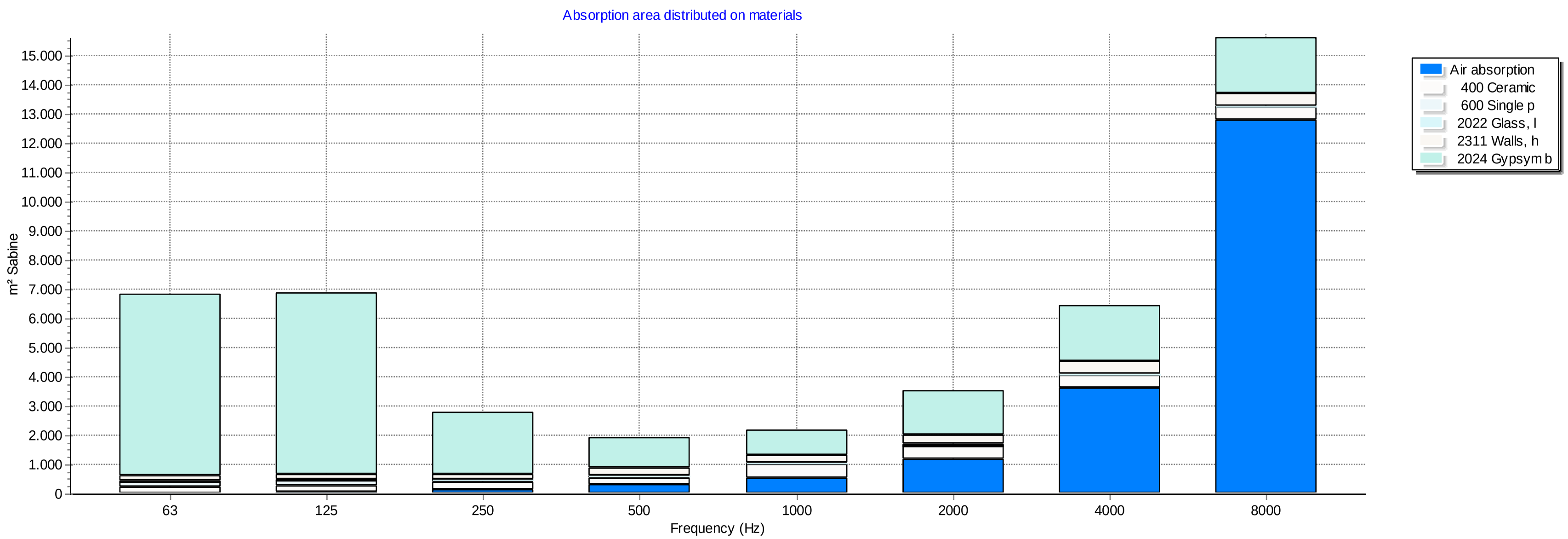


Table B.2 Absorption area distributed on materials (Gordion AVM)



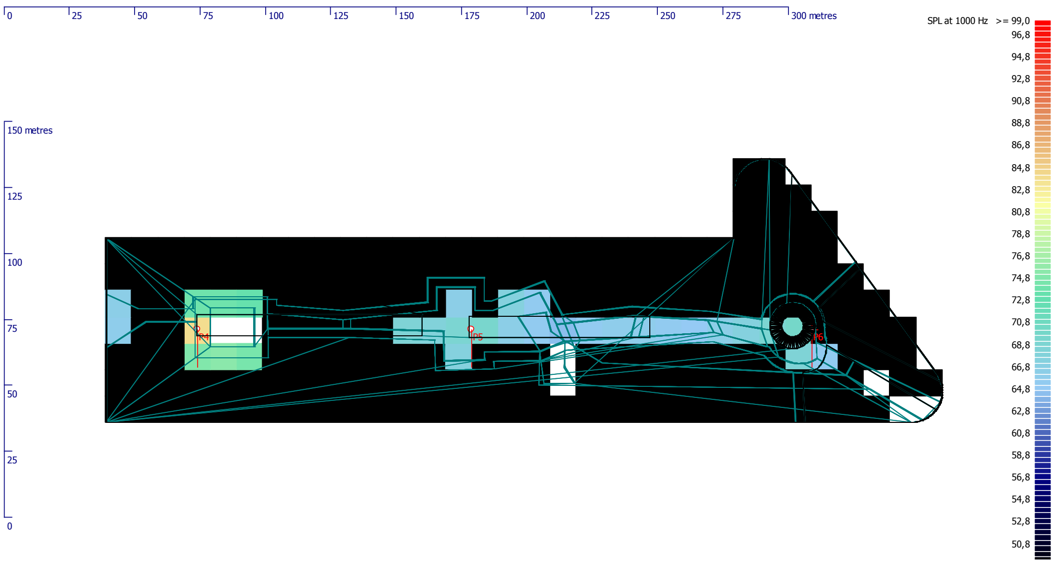


Figure B.1 Distribution of SPL at 1000 Hz (Gordion AVM)

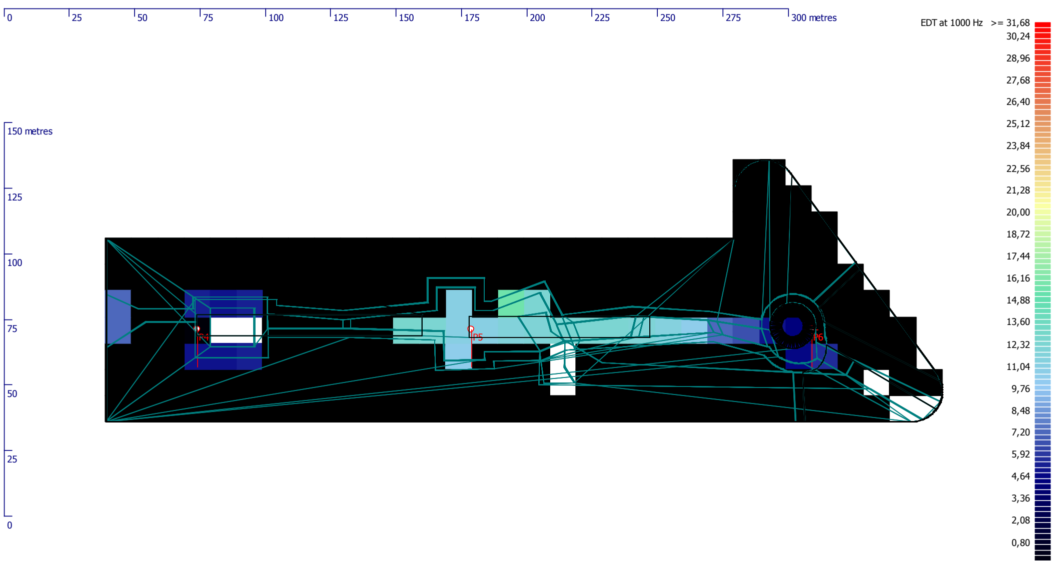
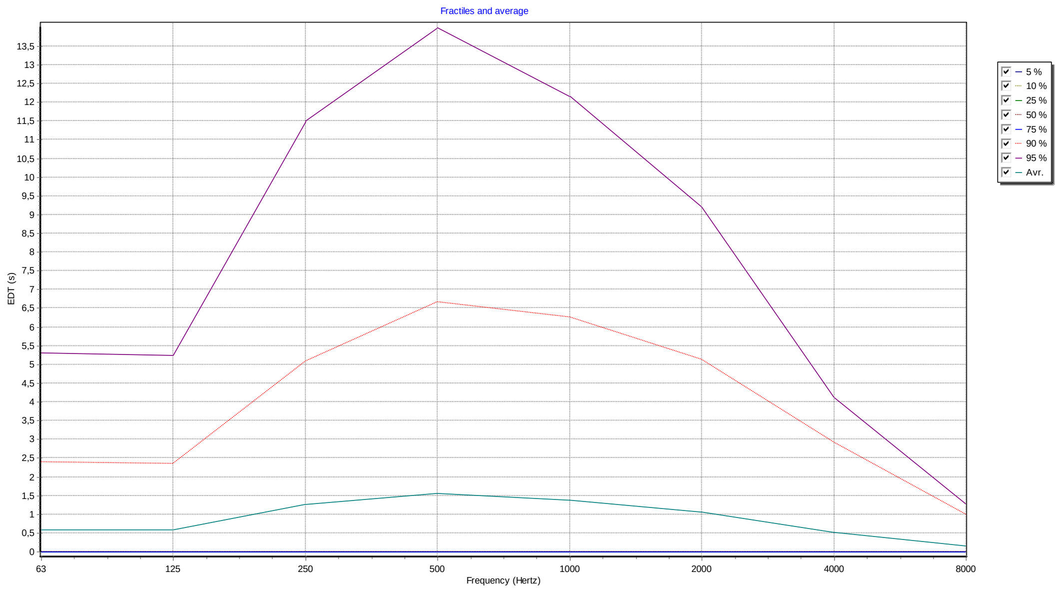


Figure B.2 Distribution of EDT at 1000 Hz (Gordion AVM)

Table B.3 EDT values for octave band frequencies (Gordion AVM)



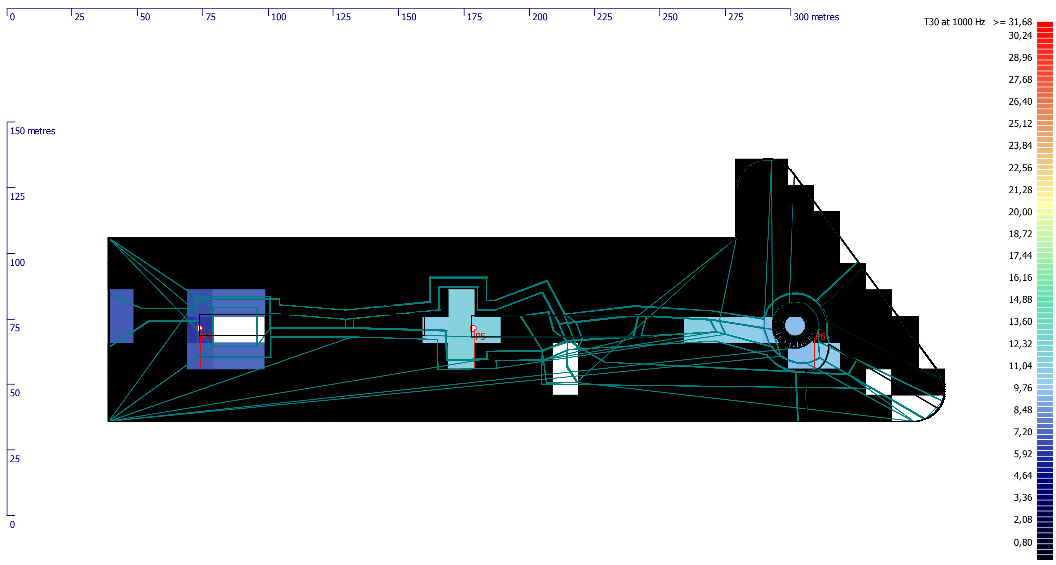


Figure B.3 Distribution of T30 at 1000 Hz (Gordion AVM)

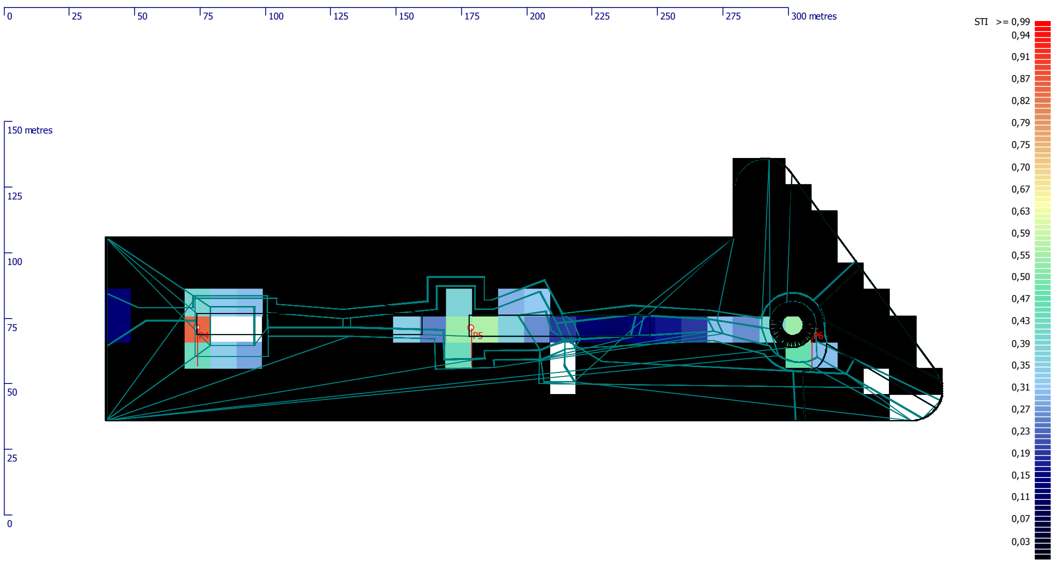


Figure B.4 Distribution of STI (Gordion AVM)

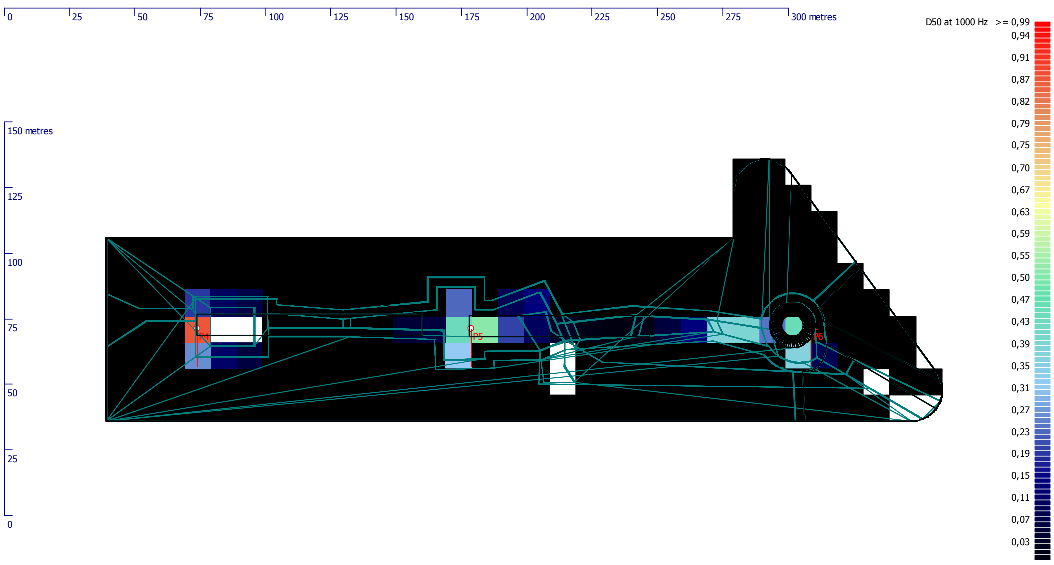


Figure B.5 Distribution of D50 at 1000 Hz (Gordion AVM)

APPENDIX C

ANALYSIS RESULTS OF CEPA AVM

Table C.1 Reverberation time estimation (Cepa Ankara)

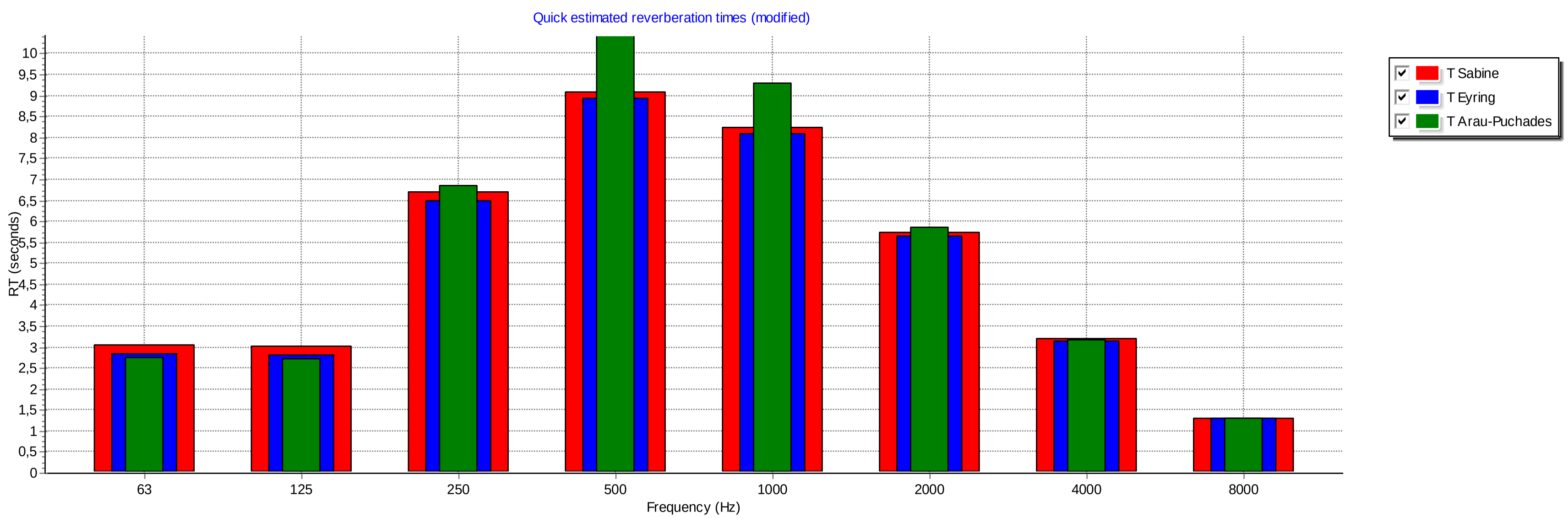
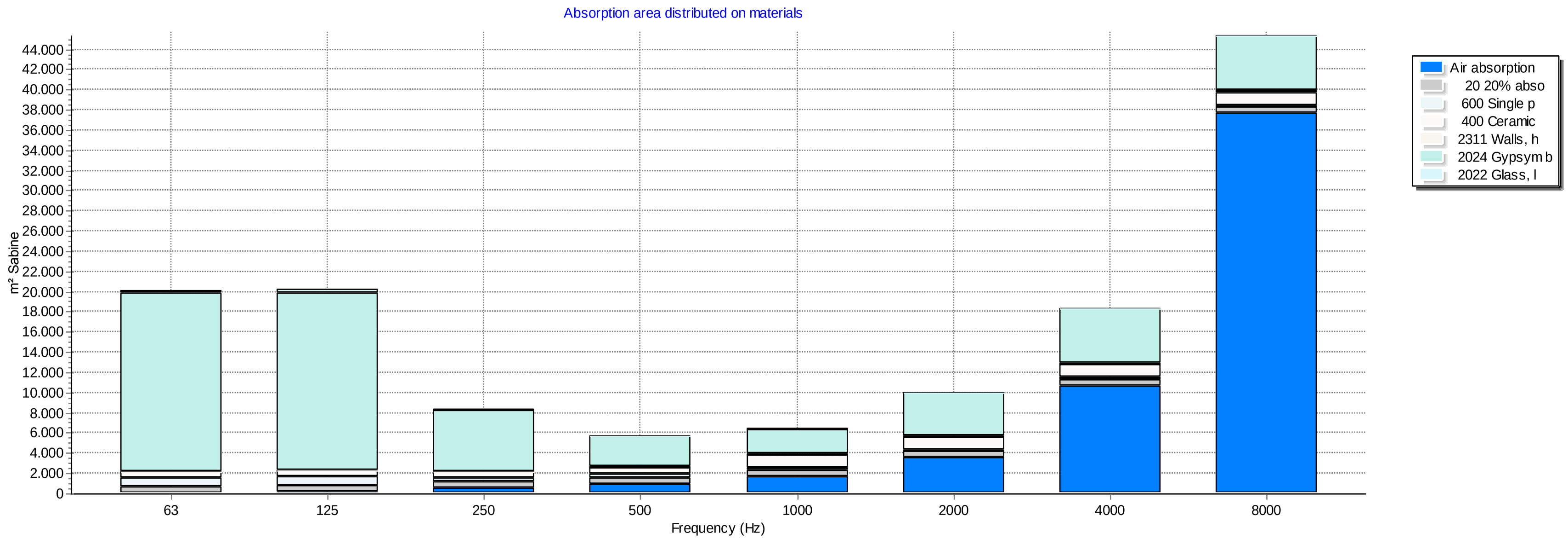


Table C.2 Absorption area distributed on materials (Cepa AVM)



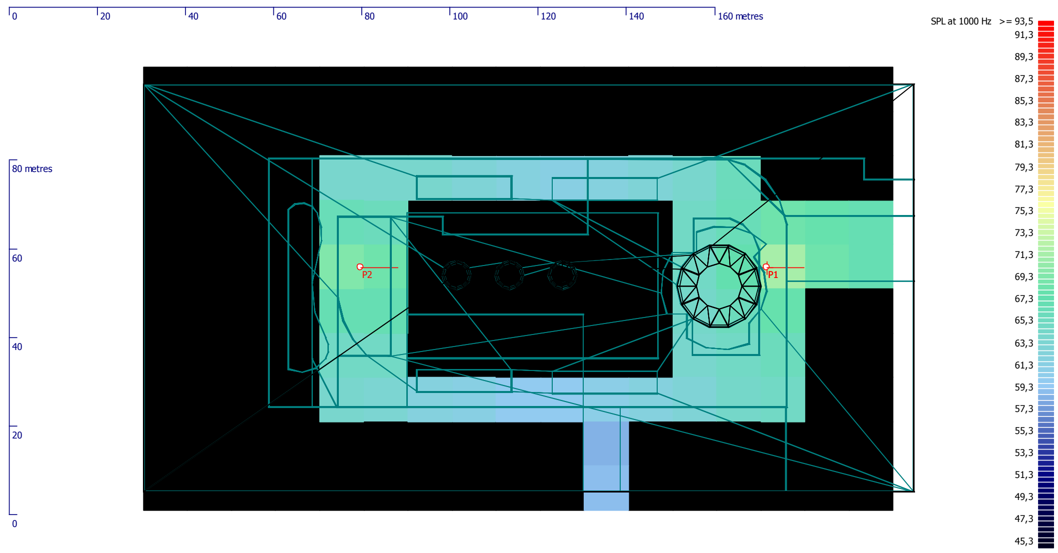


Figure C.1 Distribution of SPL at 1000 Hz (Cepa AVM)

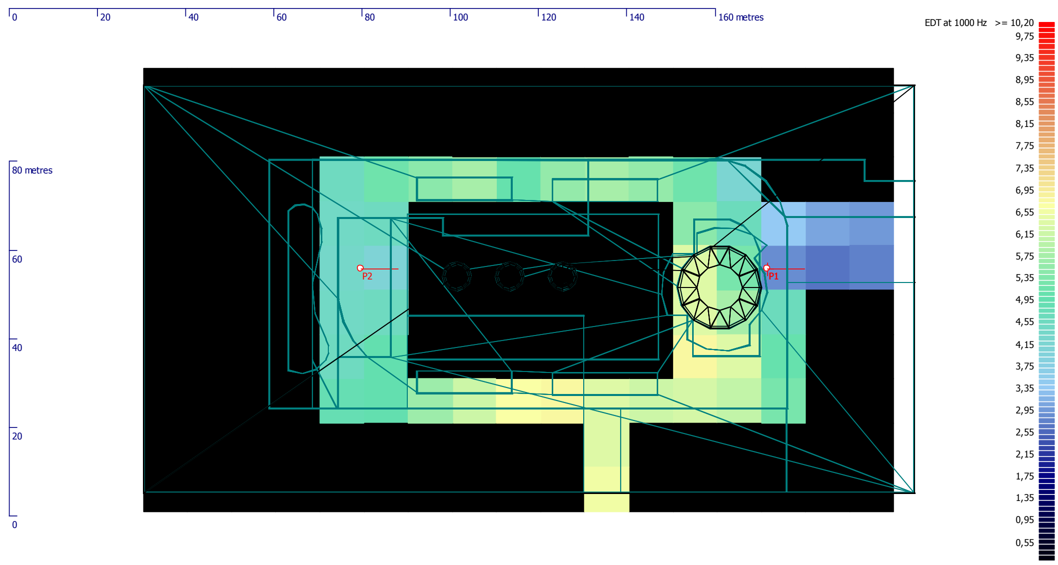
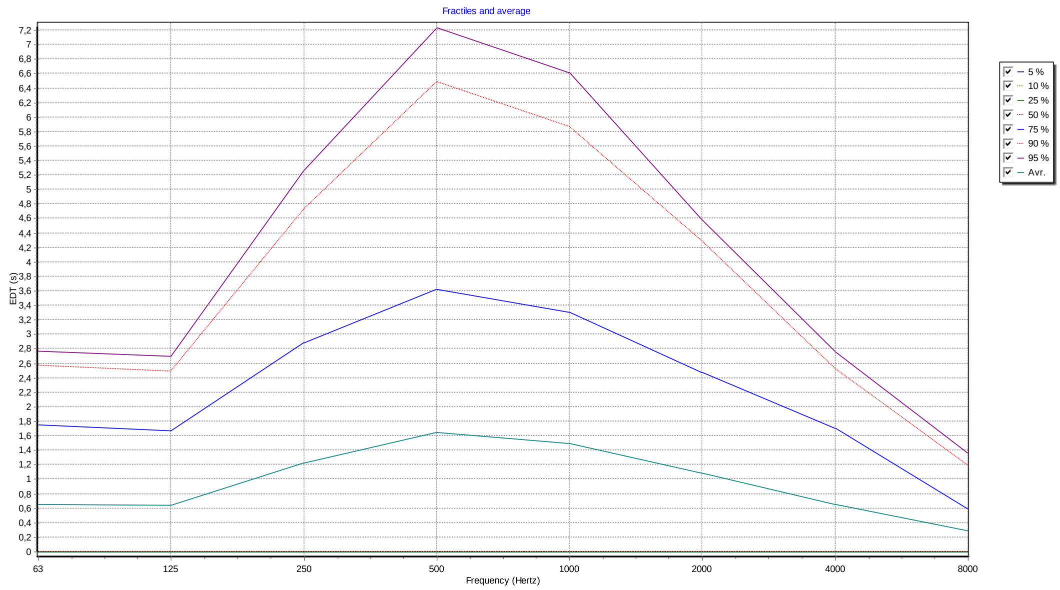


Figure C.2 Distribution of EDT at 1000 Hz (Cepa AVM)

Table C.3 EDT values for octave band frequencies (Cepa AVM)



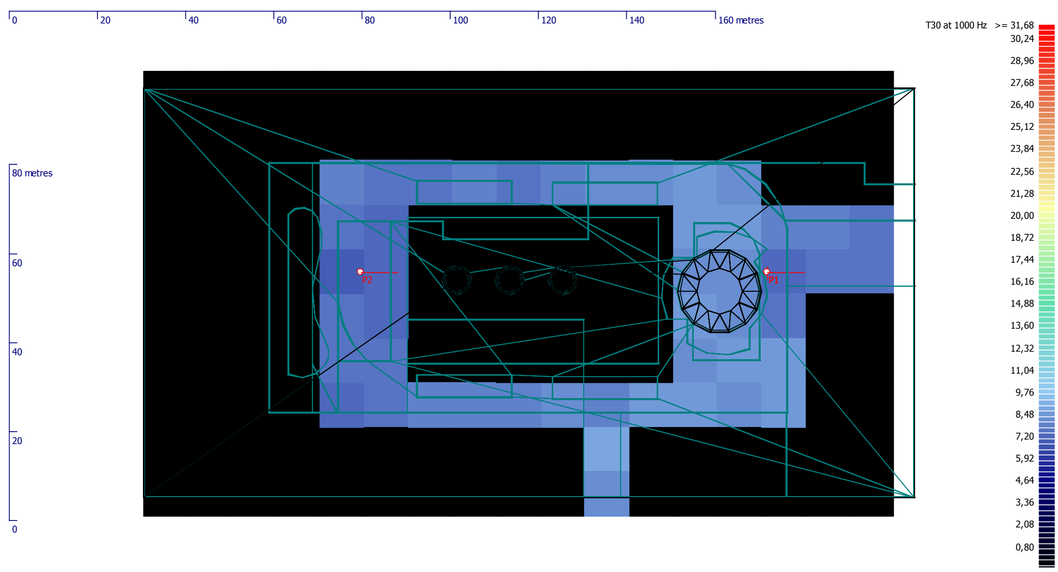


Figure C.3 Distribution of T30 at 1000 Hz (Cepa AVM)

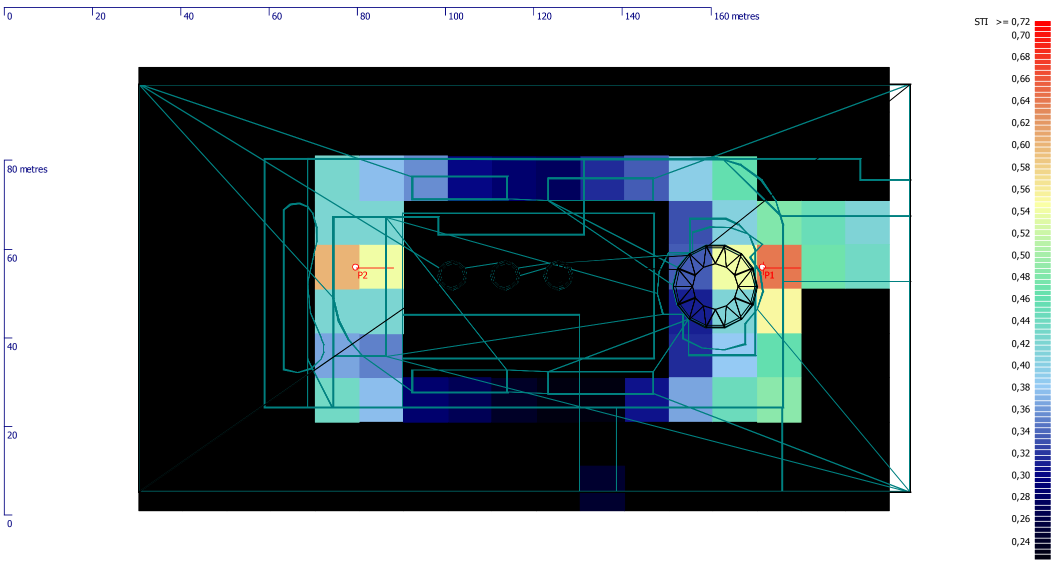


Figure C.4 Distribution of STI (Cepa AVM)

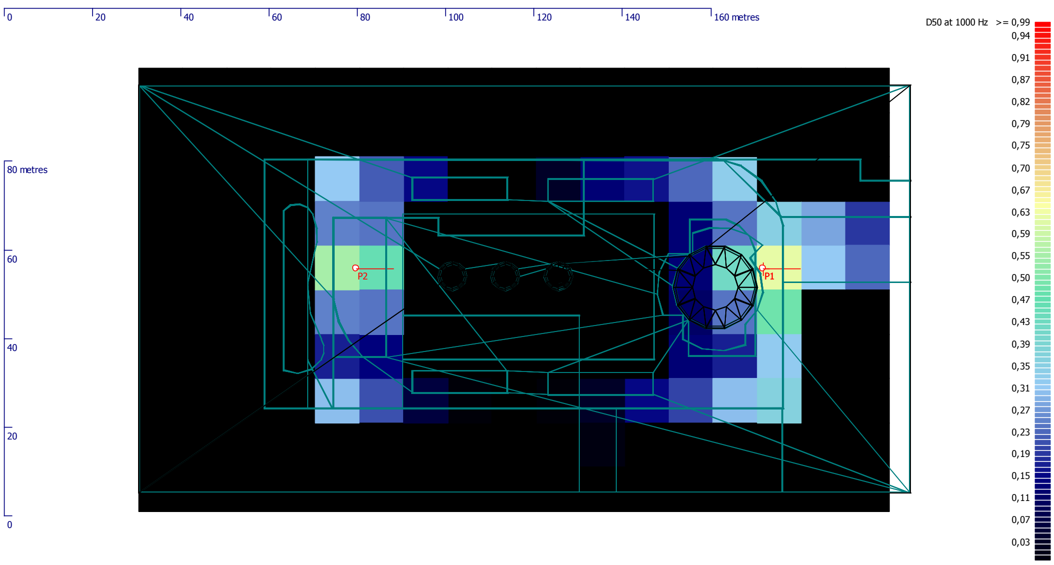


Figure C.5 Distribution of D50 at 1000 Hz (Cepa AVM)

APPENDIX D

ANALYSIS RESULTS OF ANTARES AVM

Table D.1 Reverberation time estimation (Antares Ankara)

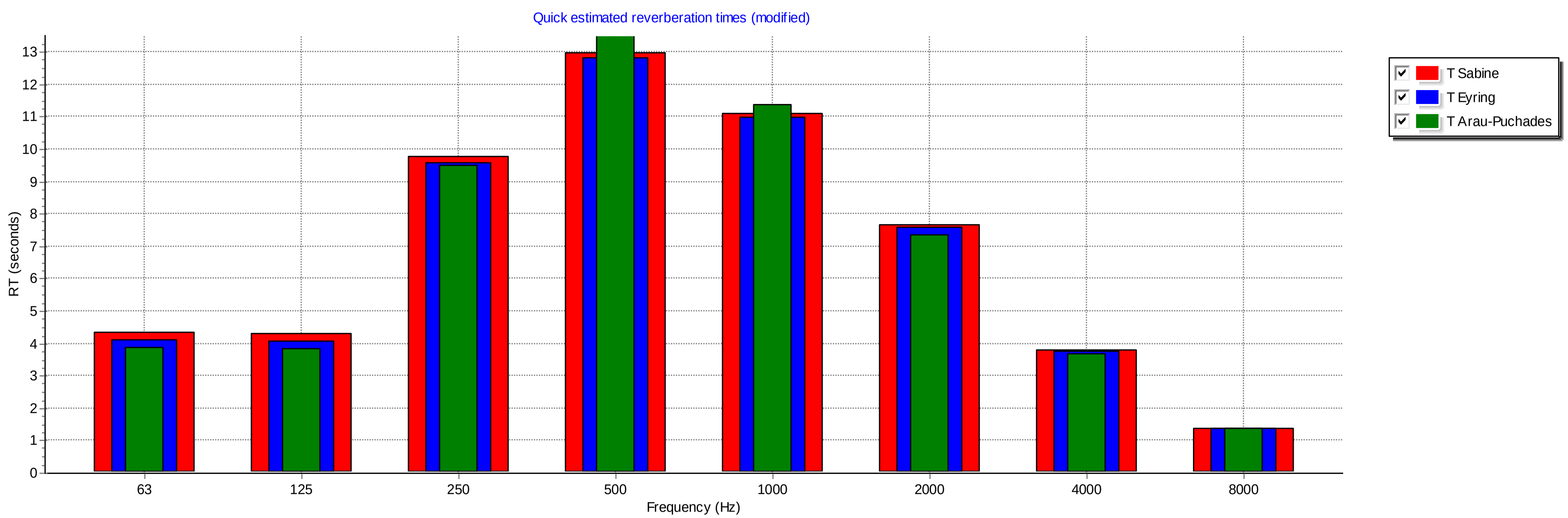
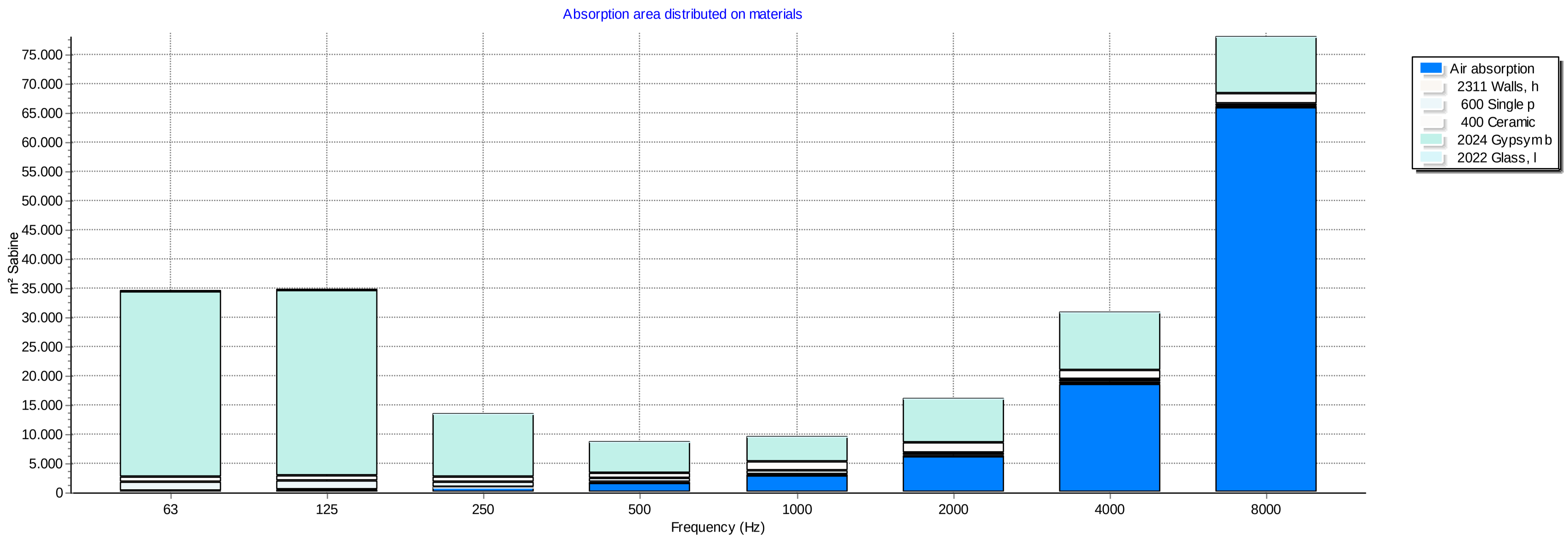


Table D.2 Absorption area distributed on materials (Antares AVM)



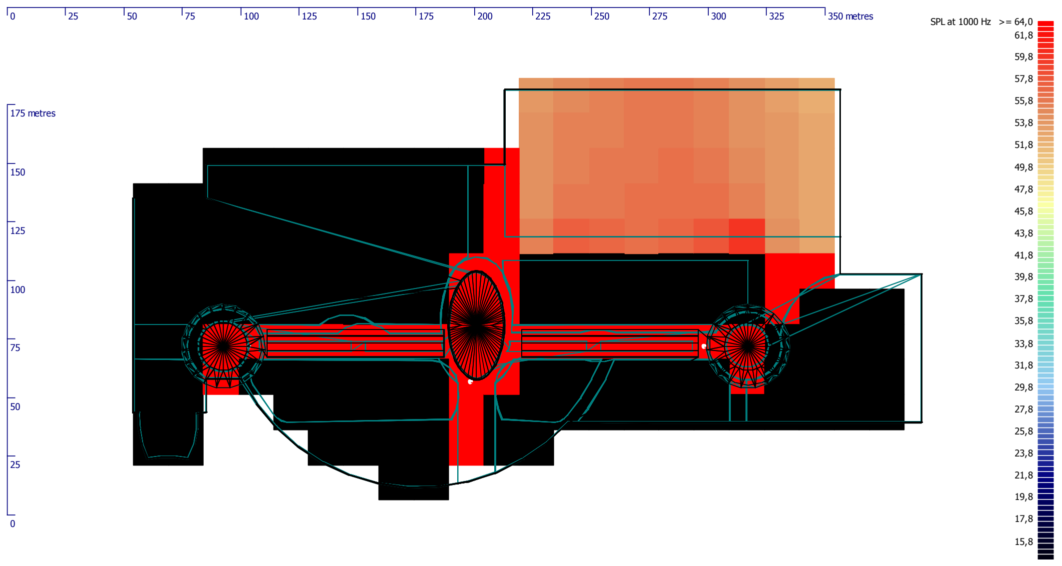


Figure D.1 Distribution of SPL at 1000 Hz (Antares AVM)

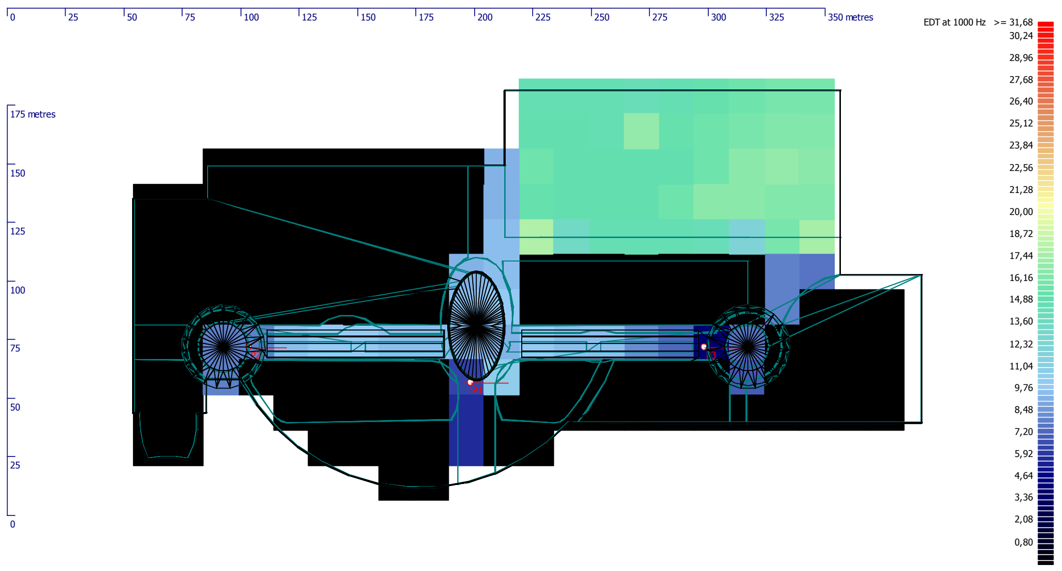
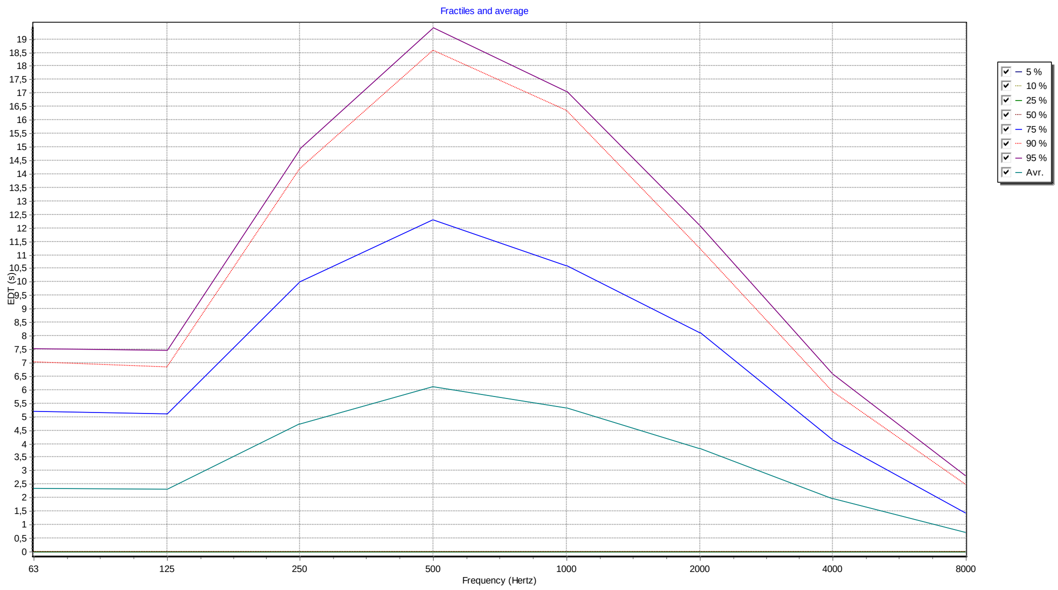


Figure D.2 Distribution of EDT at 1000 Hz (Antares AVM)

Table D.3 EDT values for octave band frequencies (Antares AVM)



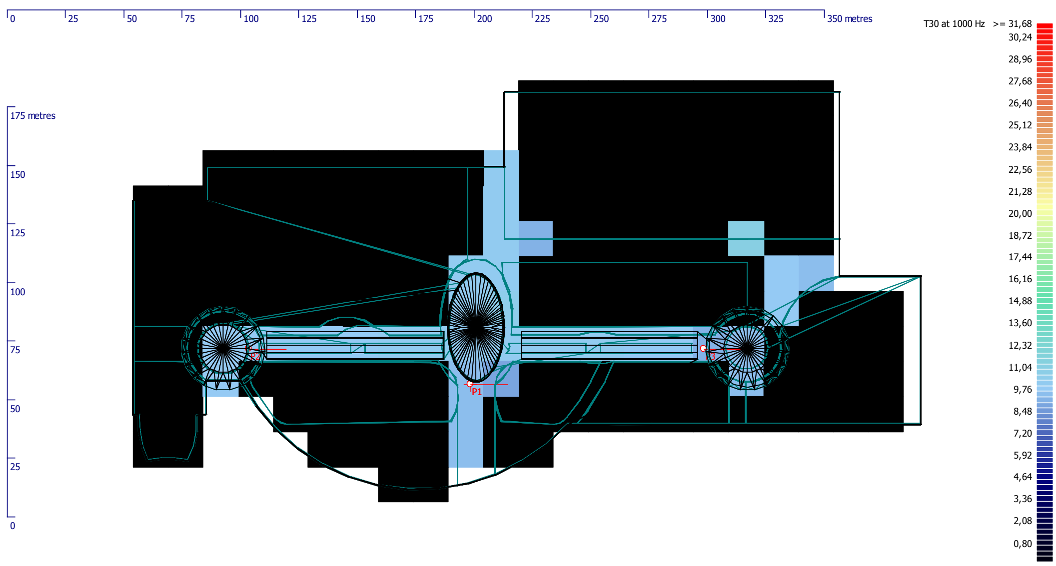


Figure D.3 Distribution of T30 at 1000 Hz (Antares AVM)

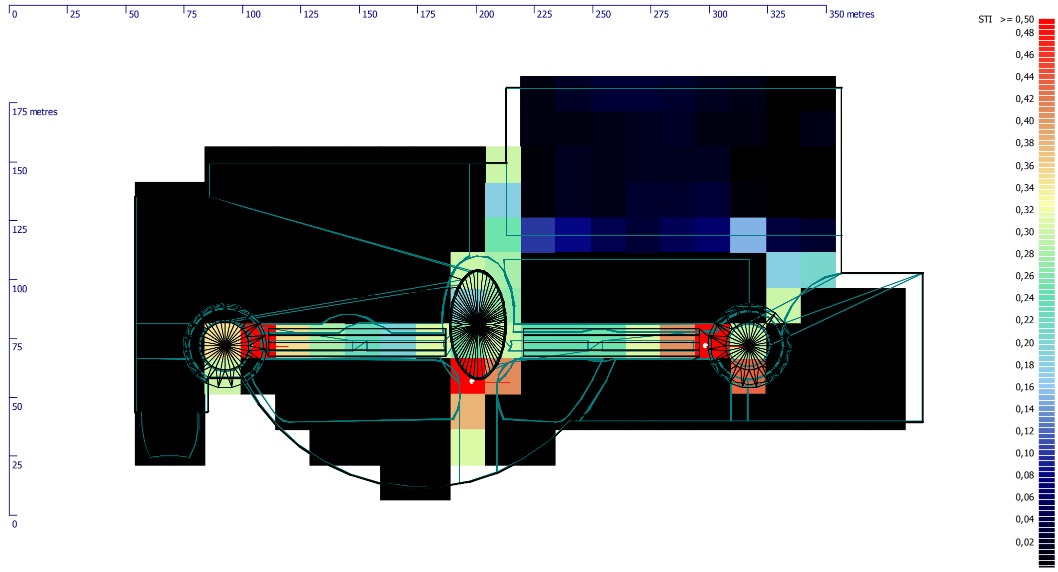


Figure D.4 Distribution of STI (Antares AVM)

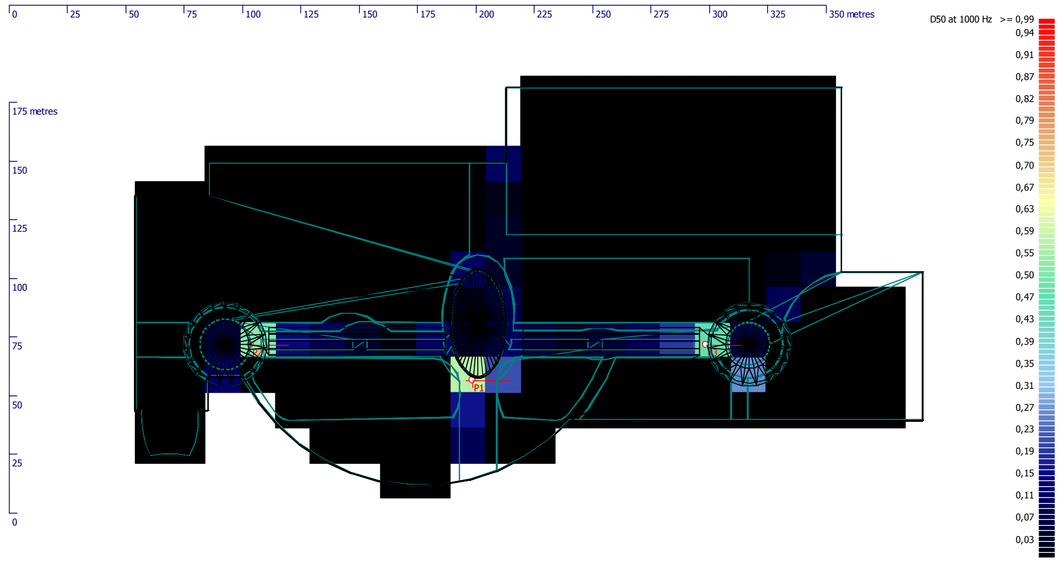


Figure D.5 Distribution of D50 at 1000 Hz (Antares AVM)

APPENDIX E

ANALYSIS RESULTS OF ARMADA

Table E.1 Reverberation time estimation (Armada)

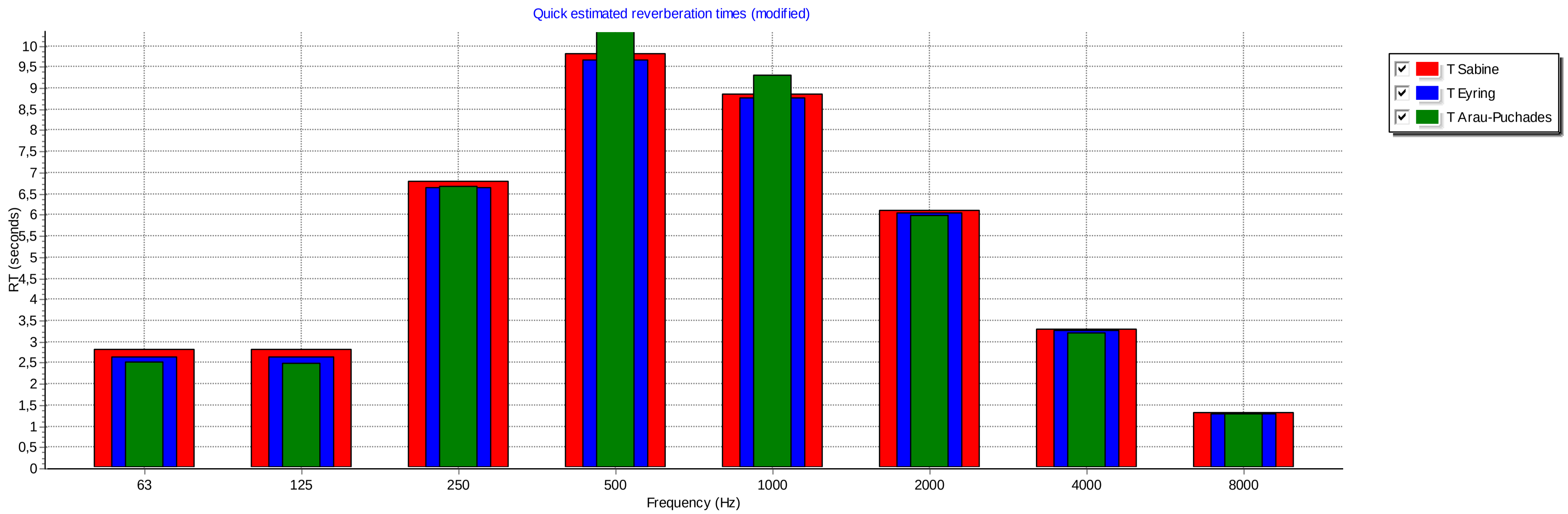
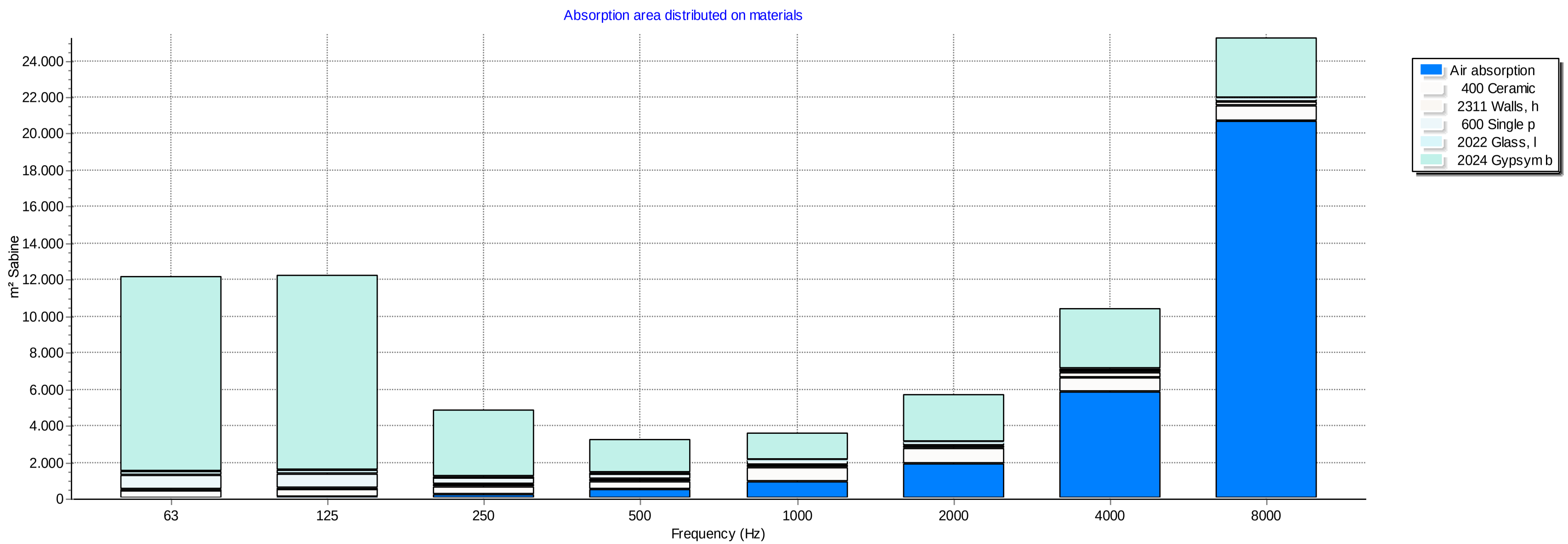


Table E.2 Absorption area distributed on materials (Armada)



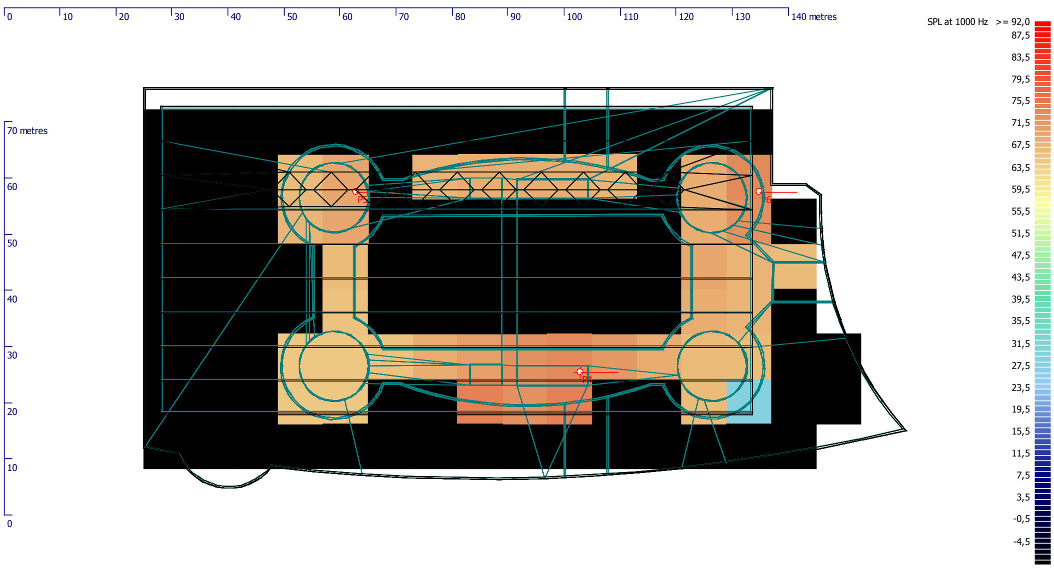


Figure E.1 Distribution of SPL at 1000 Hz (Armada)

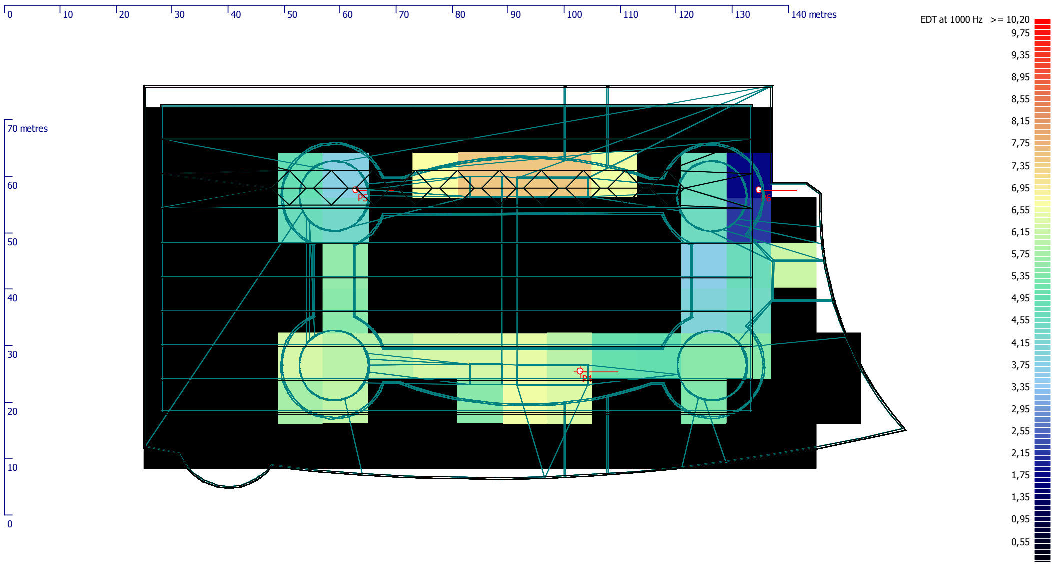
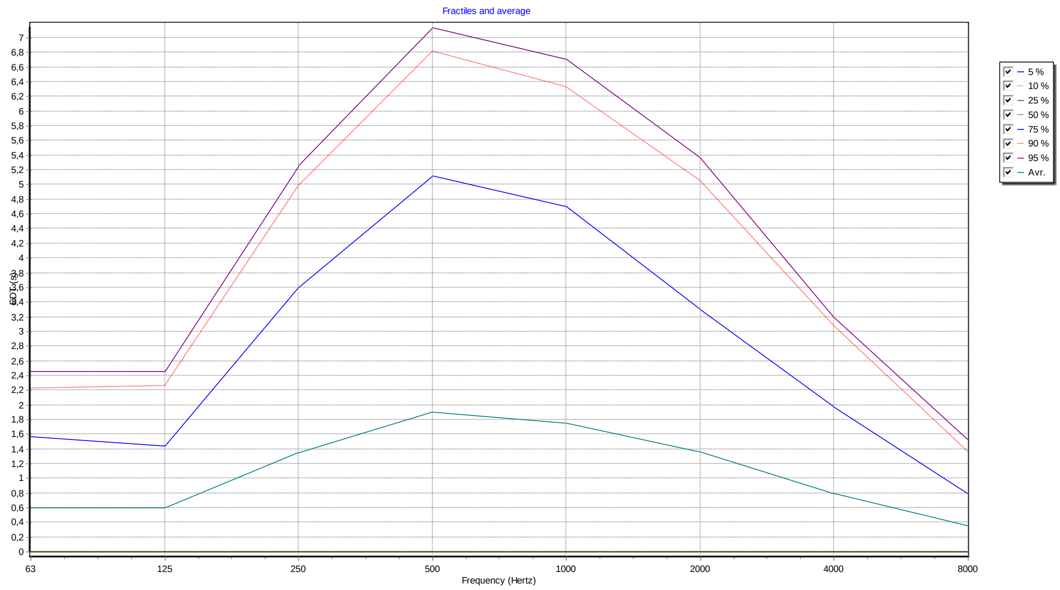


Figure E.2 Distribution of EDT at 1000 Hz (Armada)

Table E.3 EDT values for octave band frequencies (Armada)



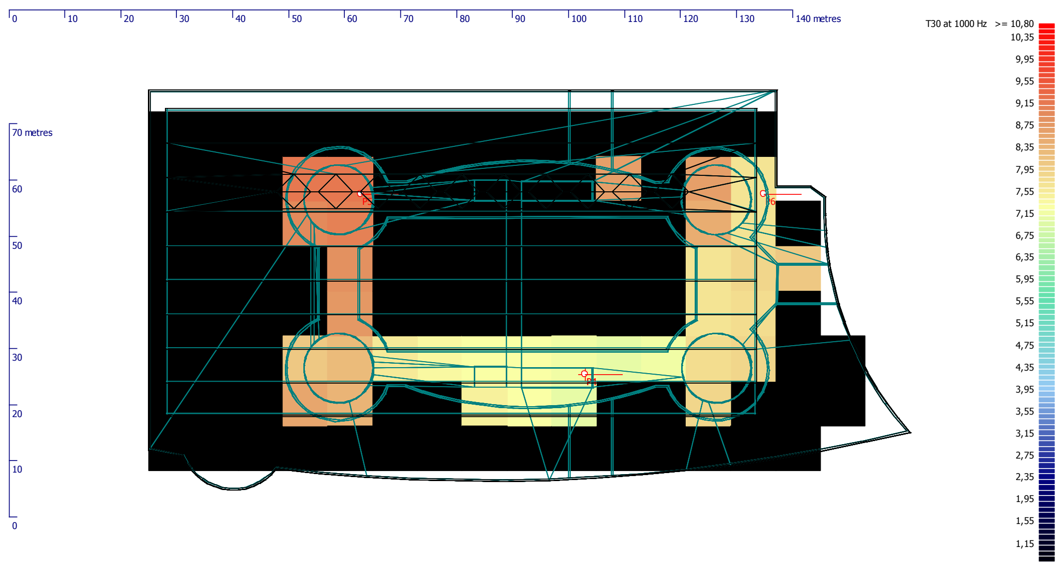


Figure E.3 Distribution of T30 at 1000 Hz (Armada)

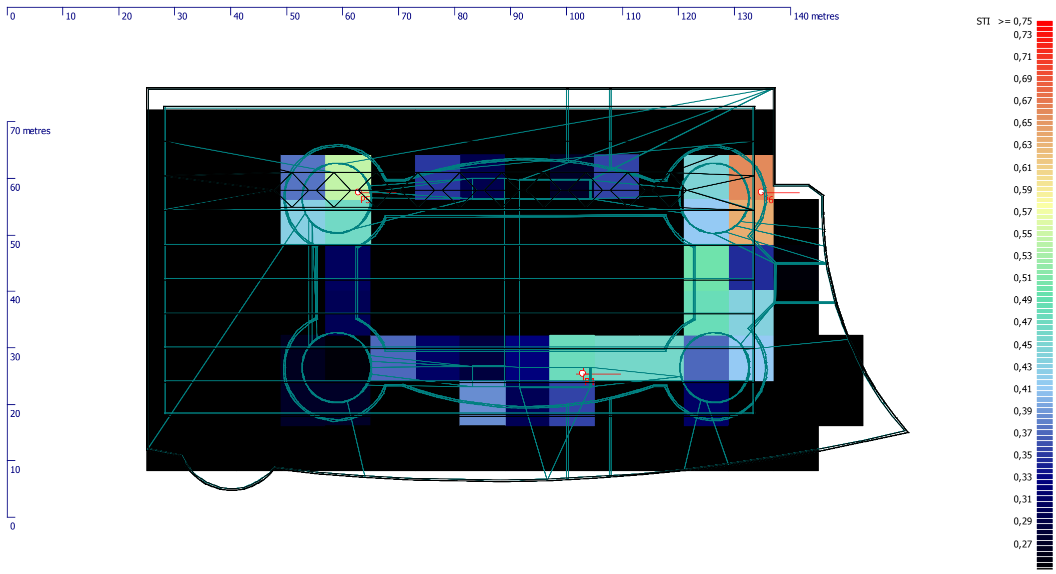


Figure E.4 Distribution of STI (Armada)

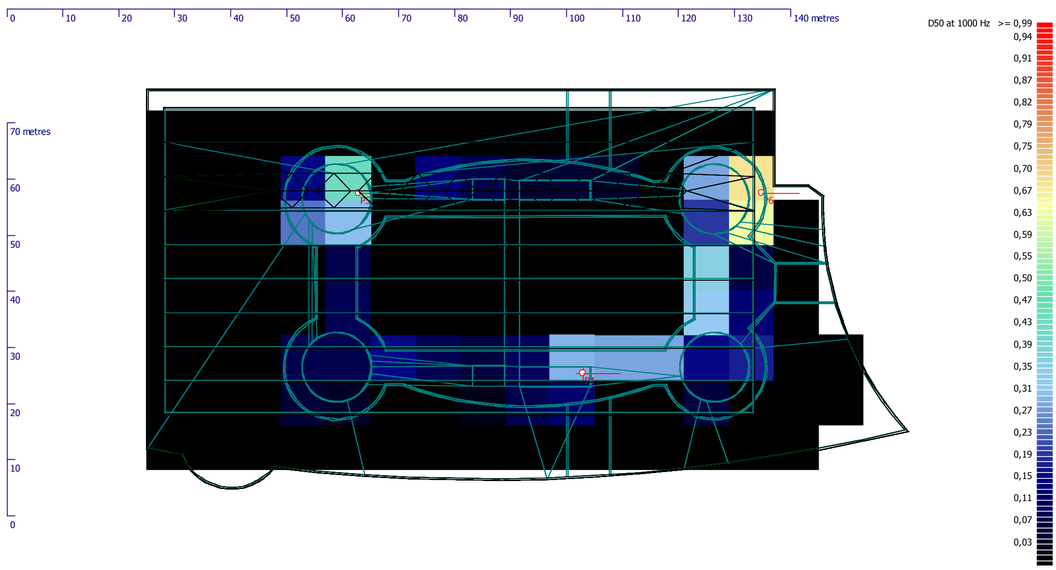


Figure E.5 Distribution of D50 at 1000 Hz (Armada)

APPENDIX F

ANALYSIS RESULTS OF 365 AVM

Table F.1 Reverberation time estimation (365 AVM)

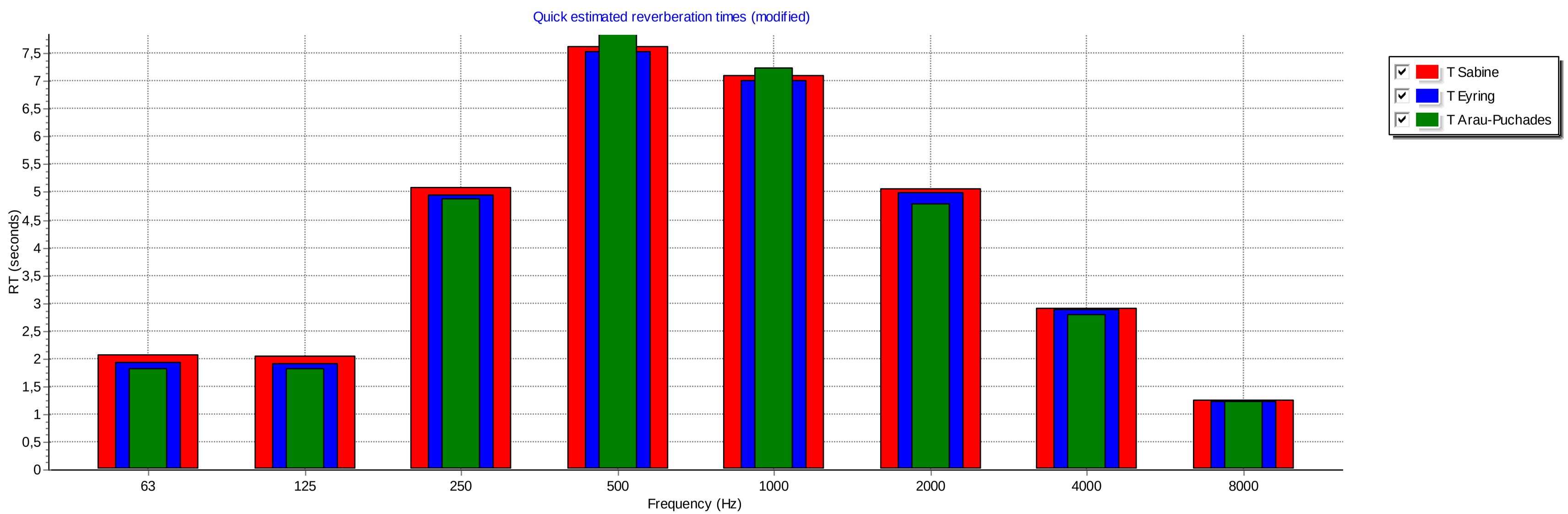
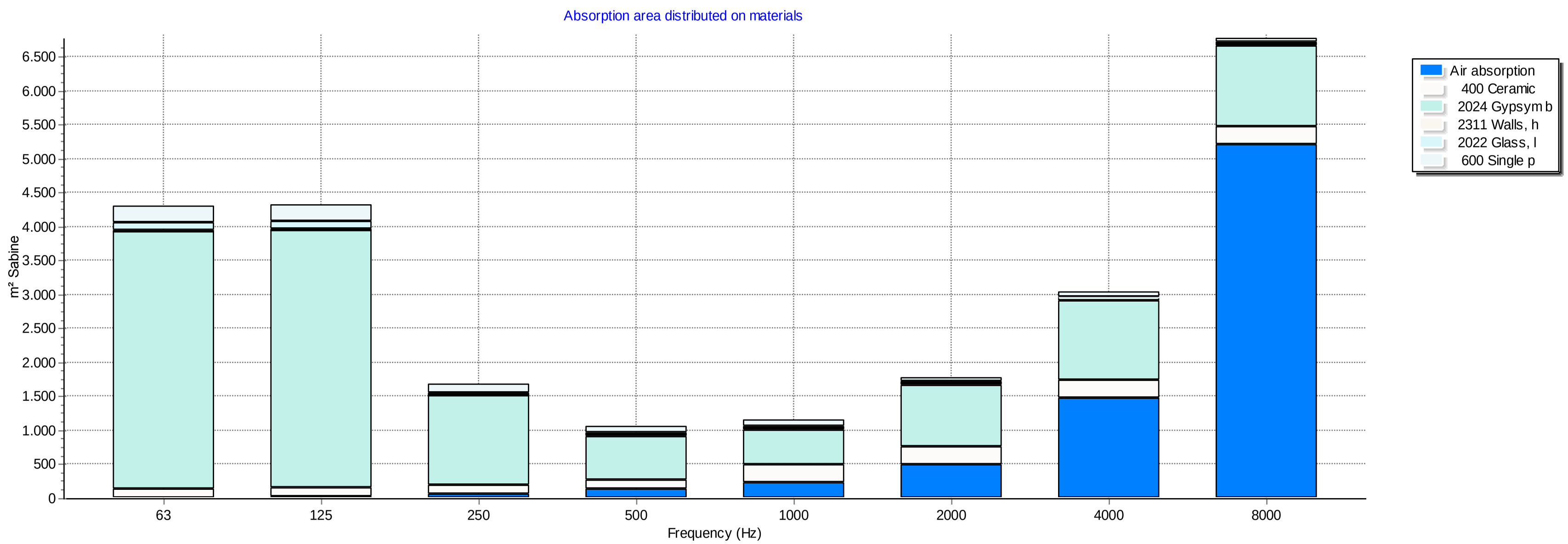


Table F.2 Absorption area distributed on materials (365 AVM)



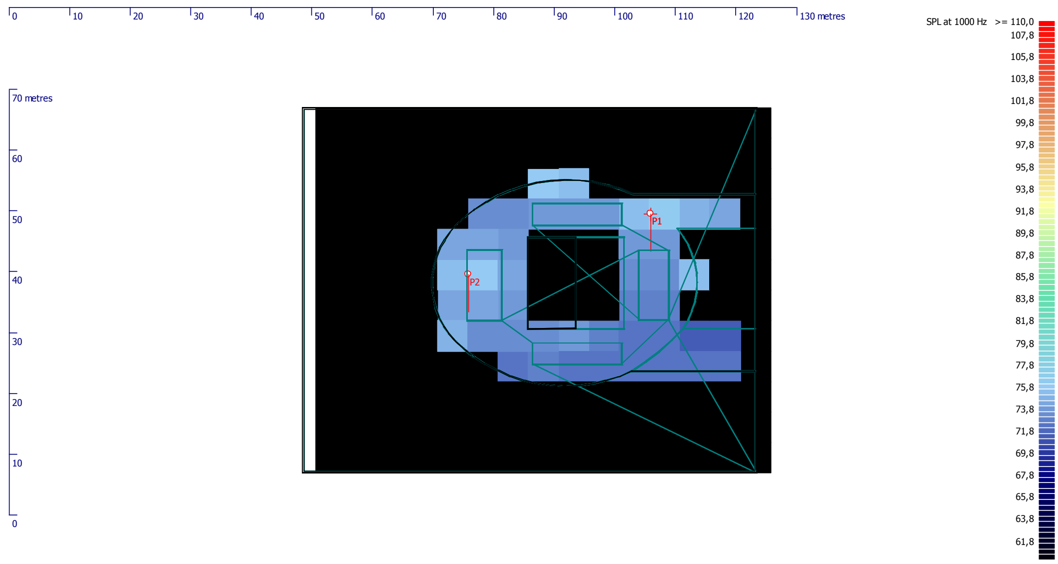


Figure F.1 Distribution of SPL at 1000 Hz (365 AVM)

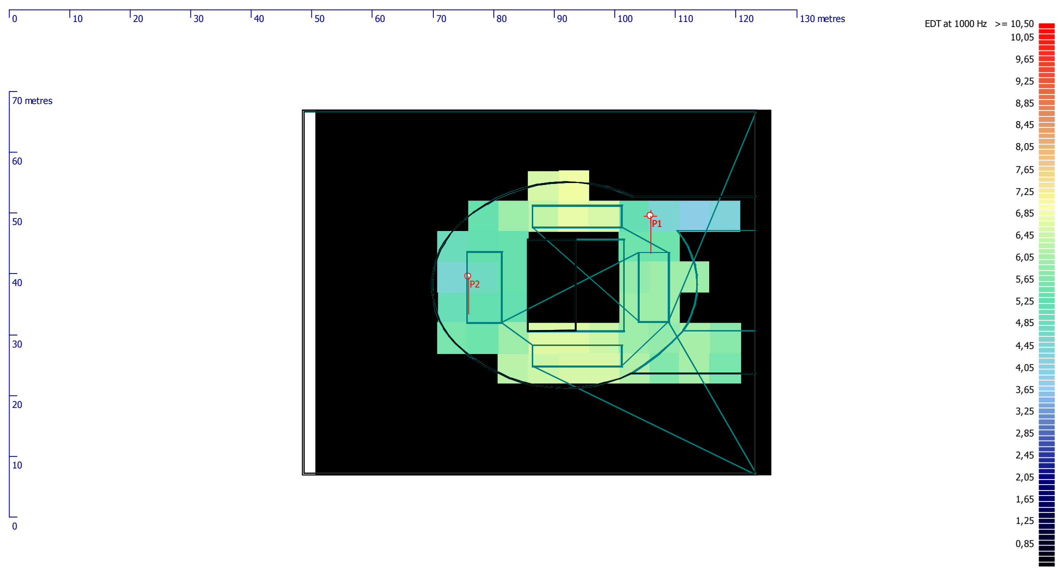
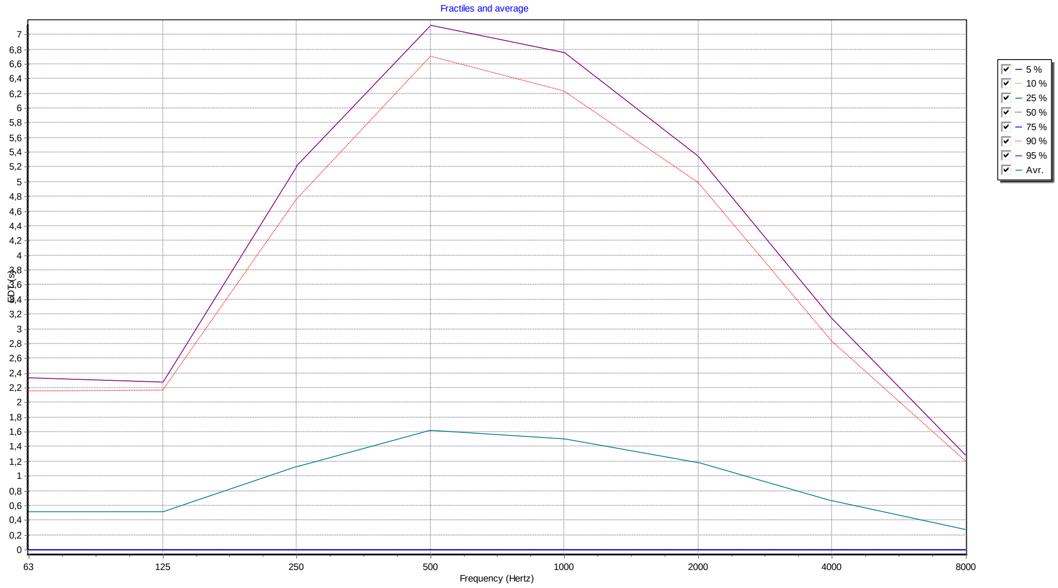


Figure F.2 Distribution of EDT at 1000 Hz (365 AVM)

Table F.3 EDT values for octave band frequencies (365 AVM)



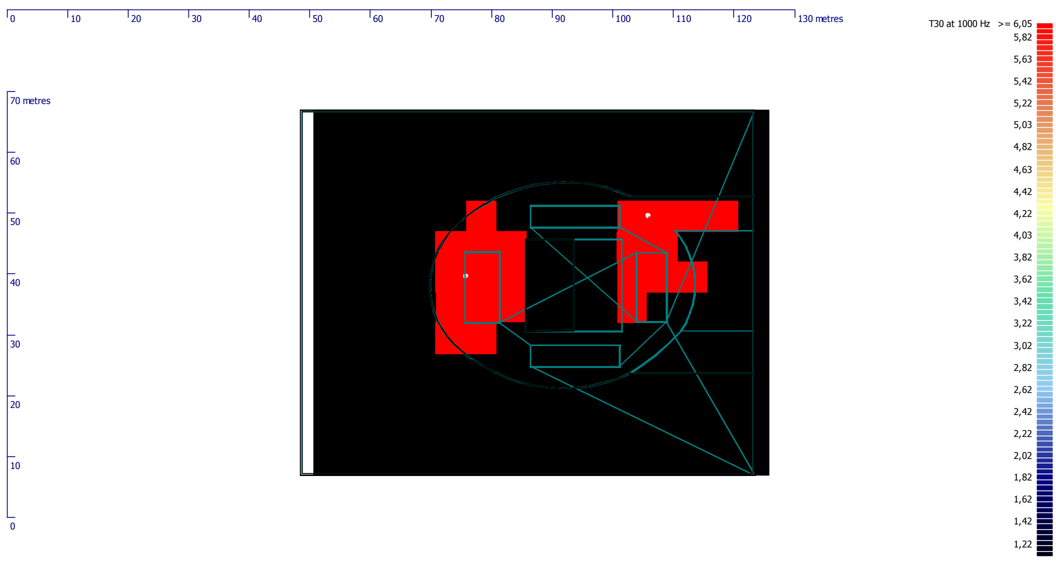


Figure F.3 Distribution of T30 at 1000 Hz (365 AVM)

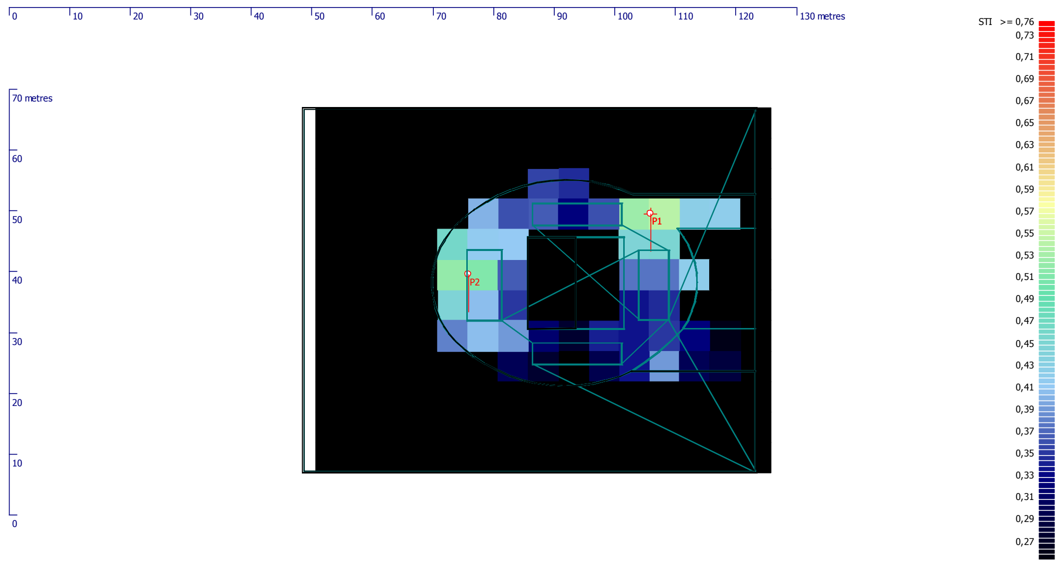


Figure F.4 Distribution of STI (365 AVM)

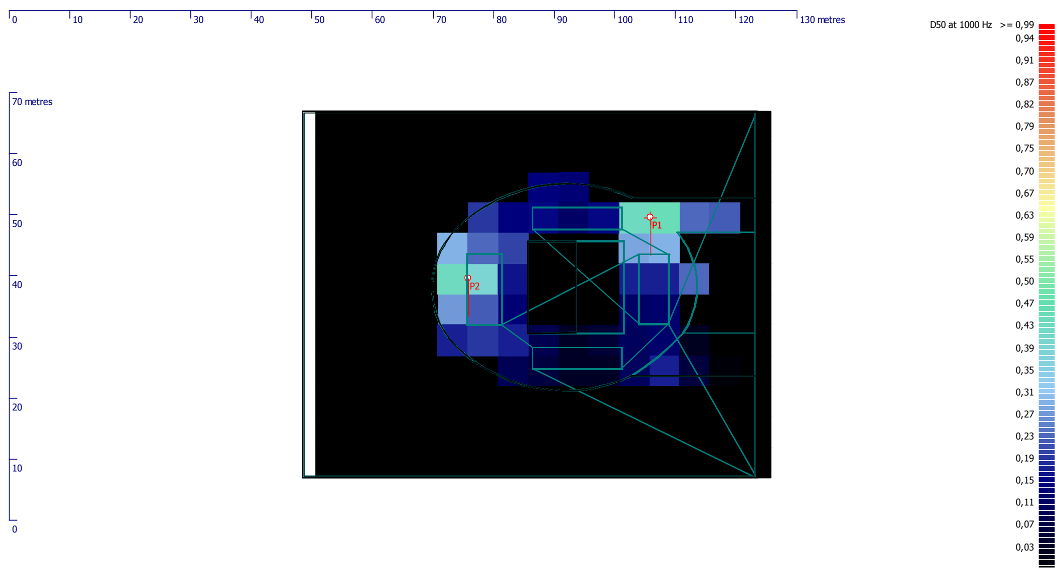


Figure F.5 Distribution of D50 at 1000 Hz (365 AVM)