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COMPARATIVE ANALYSIS OF TECHNIQUES FOR THE ACOUSTIC CHARACTERIZATION OF LARGE ENVIRONMENTS FOR MUSIC AND SPEECH LISTENING: THE CASE OF THE CIVIC THEATRE OF SCHIO

ANALISI COMPARATIVA DI TECNICHE DI CARATTERIZZAZIONE ACUSTICA DI GRANDI AMBIENTI PER L'ASCOLTO DELLA MUSICA E DELLA PAROLA: IL CASO DEL TEATRO CIVICO DI SCHIO

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List of abbreviations

JND Just Noticeable Difference

C_{80} Clarity at 80 ms

D_{50} Definition at 50 ms

T_s Centre time

T_{30} Reverberation time obtained from the decay from -5 dB to -35 dB

T_{20} Reverberation time obtained from the decay from -5 dB to -25 dB

T_{10} Reverberation time obtained from the decay from -5 dB to -15 dB

EDT Early Decay Time

SNR Signal to Noise Ratio

INR Impulse response to Noise Ratio

ST Support

EEL Early Ensemble Level

STI Speech Transmission Index

RASTI Room Acoustical Speech Transmission Index

STIPA Speech Transmission Index for Public Address system

Sommario

L'acustica dei teatri storici italiani è un patrimonio culturale da studiare e preservare. Il caso di studio presentato è il Teatro Civico di Schio, inaugurato nel 1909, successivamente chiuso intorno alla metá del secolo e poi riaperto al pubblico nel 2014. Il metodo di indagine è stato diviso in una prima parte di misurazioni *in situ*, dove sono stati effettuati diversi set di misurazioni, con differenti attrezzature. Per le misurazioni, è stato fatto riferimento alle normative tecniche e alla letteratura; i descrittori sono stati utilizzati come indicato dagli standard. Successivamente, i parametri sono stati estratti dalle misure e sono stati analizzati. Come prima cosa, è stato fatto un confronto con i valori ottenuti nella caratterizzazione acustica svolta prima del restauro. In seguito, è stata indagata la riproducibilitá delle misure ed è stata eseguita un'analisi di sensibilitá dei parametri. Infine è stata fatta la caratterizzazione acustica dell'ambiente.

Abstract

The acoustics of Italian historical theatres is a cultural heritage to be studied and preserved. The case under study is the Civic Theatre of Schio, opened in 1909, subsequently closed around the middle of the century and then reopened to the public in 2014. The method of investigation was divided into a first phase of measurements *in situ*, where different sets of measurements have been done, with different equipments. For measurements, reference has been made to the technical normative and literature; descriptors as indicated by the standard have been used. Subsequently, the parameters have been extracted from the measurements and then analysed. For first, a comparison with the values obtained in the acoustic characterization done before the restoration have been carried out. Then, measurements reproducibility has been investigated and a sensitivity analysis of the parameters has been performed. Finally, the acoustic characterization of the environment has been carried out.

Introduction

The acoustics of Italian historical theatres is to be regarded as a cultural heritage, which has to be preserved and studied [25]. Italian historical theatres are characterized by a shape known as a horseshoe, a characteristic of all the theatres built in Italy in the two centuries following the 1600s. It is the synthesis of two forms: the circle resulting from the Greek amphitheatre and the rectangle of the theatre of the Renaissance court. The success of this form of theatre is certainly linked to the widespread use of opera [28]. Italian theatres are also characterized by the proscenium arch, that splits the volume of the stage house (necessary for the handling of the scenes) from the volume of the audience [16].

The case presented, the Civic Theatre of Schio (chapter 1), is an Italian historical theatre, opened in 1909 with *Mefistofele* by Arrigo Boito. It has the classical structure of many Italian historical theatres, with horseshoe shape, audience, 2 tiers of boxes and a gallery. In the second part of the twentieth century, it crossed several years of crisis and it has been reopened, after a deep restoration, in 2014. In the current configuration, the usable areas of the Theatre are the stage, the audience, the first order and the central part of the second order. The gallery and the lateral parts of the second order are not yet viable.

In this Theatre, measurements of acoustic qualification of the hall has been carried out (chapter 3). The aim of this study was to qualify the current acoustics of this Theatre (chapter 7) and to compare it with the previous situation, characterized before the restoration (chapter 4). The main parameters used to characterized large environments for music and speech listening have been analysed: energy parameters, reverberation parameters and speech intelligibility parameters.

Measurements reproducibility has been also investigated (chapter 5), performing 2 sets of measurements with 2 different equipments with omnidirectional source. In addition, a sensitivity analysis of the parameters has been performed (chapter 6), comparing the results obtained with different techniques. In the fist 2 comparisons, 2 types of source have been compared respectively: in the first, omnidirectional dodecahedron and directional loudspeaker have been compared, while, in the second, omnidirectional dodecahedron emitting a sine sweep and balloons have been compared. The third comparison has regarded the type of acquisition, with Dirac software and with Tascam digital recorder. The last comparison deals with 2 different settings of the source used to characterize the speech intelligibility in the hall.

Chapter 1

The city and the Civic Theatre

1.1 The city of Schio

Schio is an Italian town of the province of Vicenza, in the Veneto region (figure 1.1). It has about 40000 inhabitants. It is the third town in the province by population, after the capital and Bassano del Grappa.

Schio is situated at the mouth of Val Leogra and it is crossed by several rivers with torrential character: Leogra, Timonchio, Livergon and several other smaller tributaries. The town of Schio is surrounded by a mountainous amphitheatre that has disadvantaged the development of rural cultures and trade, thus promoting industrial development (especially the art of wool) as a means of livelihood. The ancient rural culture, however, is evidenced mainly by the presence of many districts in its hills and mountains. The territory is characterized by a large presence in the underground mining, attracting numerous populations and favouring the settlement. These people reclaimed the territory and planted many crops, as vegetables, grains and fruits [35] [33].

1.1.1 History

The name "Schio" comes from scledum, Medieval Latin term meaning a plant of the family of the oak (the "ischi", which is a vulgar term to indicate the white oak) or a site planted with oaks. The name of its inhabitants, "scledensi", also comes from scledum.

Despite the name is relatively recent, Schio is not a city of recent foundation. The earliest traces of human presence in this area date back to prehistoric times,

(a) Schio.　(b) Position of Schio

Figure 1.1: Position of Schio [46].

documented by a large number of archaeological finds. At the end of Val Leogra and not far from the Astico Valley, Schio is found always in a convenient location, close to transport links, such as the Pista dei Veneti, a track that crossed all the Veneto from the Adige to the Piave and beyond, along the slopes of the hills that surround the north of the Veneto plain [38].

The Romans arrived in the Veneto plain in the second century BC. The Roman presence is documented by a stone, marble and bronze object found at San Martino [19]. At the border between Schio and Santorso in Contra Rio there is a vast artificial raising, a square of about 400 meters wide, which is claimed to be an ancient Roman entrenchment.

Little or nothing is known of late antiquity and the early Middle Ages. In 568 the Lombards came to Italy. Numerous finds testify their presence in the area of Schio, which was part of the Duchy of Vicenza. The old town of Schio grew up around a crossroads formed from the intersection of major trade routes around the castle and the cathedral. It is not clear the moment when the Municipality was born, perhaps already in 1228, but the first documents found are dated 1275 [11]. However, the excavation of the Maestra Canal dates back to this period. The medieval period was much troubled by a political point of view, as it followed several dominants. During the Middle Ages, Schio followed the fate of Vicenza: Maltraversi with the lordship of Ezzelino III da Romano (1236-1259), then the Scrovegni and the Lemici, when Vicenza was subject to Padua (1266-1311), then the Scala (1311-1387) and the Nogarola [20]. The lordship of Nogarola had nothing to do with the old feudal: the Nogarola could not interfere with public life of Schio and they were fully subject to the municipal authority. Then, during the long period of domination of the Republic of Venice, Schio experienced a great economic and social development: the city became with time the main place of wool production of the Venetian Republic.

Under Napoleonic rule, this industry declined and industries and commerce were almost completely cancelled. The economic depression persisted even during the period of Austrian domination.

In the early decades of the century, some oldest mills were in the city, the one of Garbin and Conte and the one of Francesco Rossi (Alessandro's father). Alessandro Rossi was the person who grew the wool factory of his father and made it the largest wool company in the world at that time ("Lanerossi"). Rossi, a man of great intelligence and culture, gave a decisive contribution to make to Schio an extraordinary urban and industrial centre. First he created a modern and pioneering textile industry, focusing on the production worker. He financed the construction in town of a large number of institutions for the workers of his factory. He changed the city's urban, with the construction of new housing for workers (the new working class district) and new social structures (such as kindergartens for the children of workers, schools, the theatre, gardens). He dedicated a statue to the weaver, the first monument dedicated to the workers in Italy. He promoted and financed the construction of rail links, now abandoned, with Torrebelvicino, Rocchette, Asiago and Arsiero. Nevertheless in 1891, especially after the unfortunate strike took place in February and April, some families of textile workers went to Brazil.

With the economic boom after World War II, Schio was affected to a significant population growth: the resulting housing boom, often took place in a chaotic way, due to the fact that the city was able to draw up a master plan actually operational only in 1977, determined the saturation of construction areas adjacent to the old town and the urbanization of suburban areas. In the late sixties, the creation of the Industrial Zone in the vast countryside east of the town took place [21] [33].

(a) External view. (b) Internal view.

Figure 1.2: Civic Theatre of Schio [33] [42].

1.2 The Civic Theatre

1.2.1 History

At the beginning of the last century, from a modest town of about six thousand inhabitants, Schio become an urban center with over sixteen thousand citizens. This population explosion was due the flourishing industrialization process of the area. These significant changes in the social and economic situation of the city required the construction of new and modern public works, including the construction of a new theatre. The old theatre (Teatro Sociale) was inadequate to accommodate productions of operas that require great scenes, highly complex organic orchestral and large choirs.

The construction of the new theatre didn't start from an initiative of the Municipality, but it started from the willingness and the musical passion of a group of citizens. On 8 October 1906 the Cooperative for the new theatre was founded, with a single purpose: the construction of a theatre that met modern requirements, was accessible to all classes of citizens, had about 1500 seats and was equipped with a conference room. The design competition was won by the project of the architect Ferruccio Chemello, coming from Vicenza. The construction of the theatre began in the summer of 1907. The theatre was designed and built with all the features of the Italian theatre. The orchestra pit can accommodate an orchestra of 50 elements. The capacity of the Civic Theatre (1200/1300 places, divided between stalls, boxes and gallery) was remarkable and certainly adequate to meet the new needs of the public.

For the opening night, 9 June 1909, a modern melodrama was staged, *Mefistofele* by Arrigo Boito. The performances at the Civic Theatre continued until 1915, when the theatre was used as a warehouse by the military. On 5 August 1916 the central part of the theatre caught fire. The theatre reopened in December 1919; the first show staged was *Cavalleria Rusticana* by Pietro Mascagni.

In the twentieth century, the spread in Italy of a new art, the cinema, marked for the Civic Theatre, like many Italian theatres, years of crisis, that were not resolved even with the construction of a cabin film and the projection of sound films. On 29 April 1956 the Civic Theatre hosted for the last time an opera: *Rigoletto* by Giuseppe Verdi. In 1968 it closed also as cinema, continuing until the seventies only as ballroom in the foyer.

In 1994 the Foundation of the Civic Theatre was founded in order to promote the recovery of theatre structure [32]. In 2014 the Civic Theatre (figure 1.2) has return to the city of Schio [33].

Locality	Schio (VI)
Address	Via Pietro Maraschin 19
Type	Italian theatre
Orchestra pit	Present (closed)
Opening	1909
Reopening	2014
Shape	Horseshoe
Internal structure	Stage, audience, two orders, gallery
Original number of seats	1500
Number of seats in 2014	350
Stage space width	13,80 m (useful 13,22 m)
Stage space depth	14,60 m
Stage space height	12,73 m
Curtain	No

Table 1.1: Characteristics of the Civic Theatre of Schio [33].

1.2.2 Architecture and restoration

The building is one of the few buildings in the city to be built in the Art Nouveau style. The main structure is in reinforced concrete, a material that allowed it to remain intact after fire. The internal structure is shaped like a horseshoe and it was able to accommodate 1500 people [33].

The architect, Ferruccio Chemello (Sestri Levante 1862 - Montecchio Maggiore 1943) attended inferior schools in Liguria and completed his training in Padua and graduated in 1881 in land surveyor. The following year he was hired by the Office of Civil Genius of Vicenza. In 1883 he accepted the chair of geometric design offered by the Olympic Academy of Vicenza. Starting from 1892 he began to work as a draftsman, activities that allows him to have the first contacts with the representatives of the business families Rossi, Conte and Dal Brun, his future clients [34].

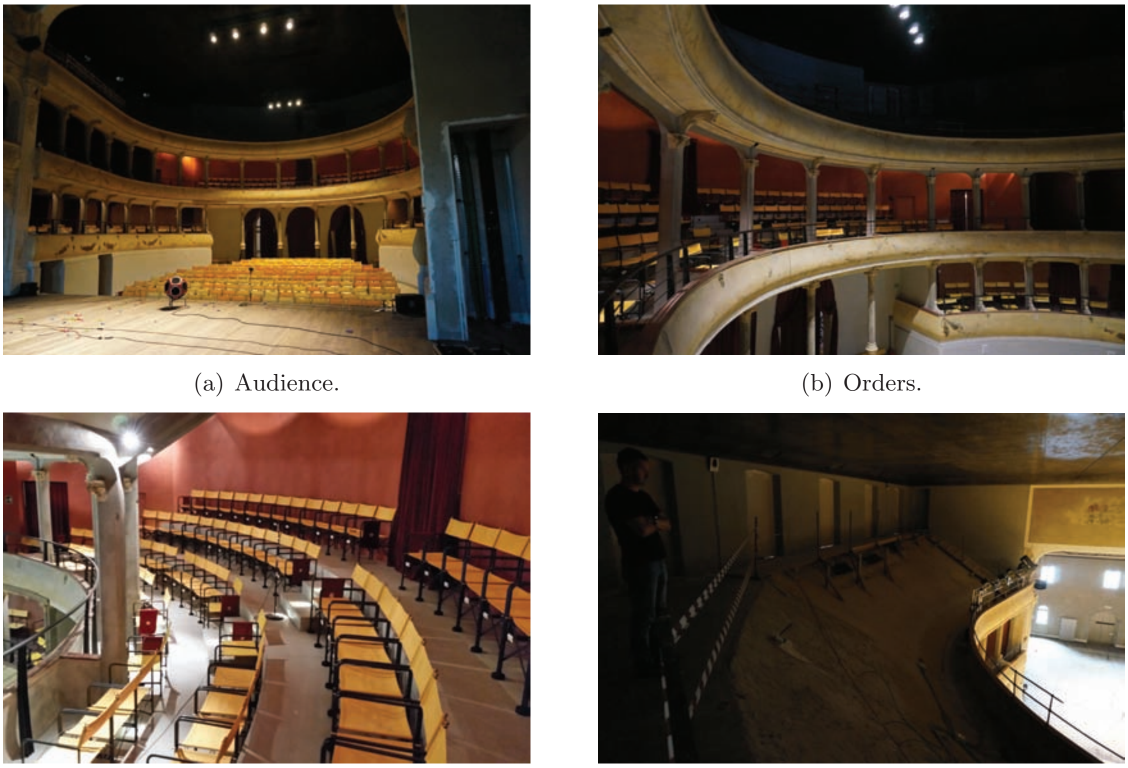
The Civic Theatre of Schio, built in 1907, consists of three buildings placed side by side (the stage, the audience and the Ridotto or foyer), with wood roofs. The elevated structure consists of bearing walls (blocks of stone and gravel) with reinforced concrete bridge decks. Around the stalls, the boxes have a characteristic structure with pillars and slabs ribbed concrete.

Structural measures implemented have achieved the seismic improvement, obtained by: the restoration of masonry piers, the inclusion of chains and braces groundwater on the shell, the reinforcement of the existing wooden roofs, the restore and the increase of the scope of concrete structures with the use of fibre-reinforced composites and reinforcing bars integrative and, finally, the addition of new steel structures for certain functional adjustments. The project involved finally the creation of a new "graticcio" above the stage and a portion of technical ceiling for the housing of the air handling units at the foyer. The adaptation of the systems has also required the creation of a central technological inground outside the building and a technical compartment below the stage [42].

Characteristics of the Theatre are shown in table 1.1 [33]. The area for the public is composed by the audience, two orders and a gallery (figure 1.3). Some parts of the Theatre are not yet viable: the lateral parts of the second order and the gallery.

1.2.3 Citizen participation

The project of the restoration of the Civic Theatre has been carried out with particular attention to the citizens' and artists' opinions and to the value of the relationship between this place and the community. The "Lotto Zero" project was born to create



(a) Audience. (b) Orders.

(c) Second order. (d) Gallery.

Figure 1.3: Views of the Civic Theatre of Schio.

a partecipatory debate to choose the way to recover the Theatre. The concern of the Municipality and the Foundation of the Civic Theatre was that, now, the identification of the arts and the place where they are performed is missing out; in fact the arts can be accessible through the television, the computer and the smartphone. Contrary, they believed in the fact that "the theatre needs the theatre", so, the theatre needs the relationship with the actors and the performers and the emotions have to be shared between performers and public. The theatre is a place where people can create relationships. It get use to leave the house and meet other people [13].

1.2.3.1 Lotto Zero

The "Lotto Zero" project promoted a work group composed by many people from different areas, as architecture, technology, direction, and also, in addition to the experts, by a group of audience, to make a shared project for the future of the Civic Theatre. Between June and September 2005, a program of events take place in order to "test" the Theatre:

- *Terra di latte e miele*, a "one woman drama" by Ottavia Piccolo;
- *Concerto*, a concert with music of Giovanni Bonato;
- *Le cittá invisibili*, a reading from the book of Italo Calvino;
- *Un teatro per Jules*;
- *Un curioso accidente*, the comedy by Carlo Goldoni;
- *Polvere ovvero la storia del teatro*;

- *L'uomo delle dodici colombe.*

To understand the emotions of the audience, a questionnaire has been distributed to the public of these events. The questionnaire was divided in 5 sections:

- judgement on the performance, on the influence of the place on the perception of the show and on the most important characteristics that a theatre should have to enhance the show;
- indication between 3 possible ways to recovery the Theatre;
- judgement on the acoustic comfort and the visibility of the hall;
- indication of the preferred typology of performance for the Civic Theatre;
- personal data, as age, sex and cultural attitude.

The answers of the people have been analysed and, on the base of these opinions, the restoration was planned, planning a capacity of 450 places [13].

Chapter 2

Room acoustics

2.1 Standard UNI EN ISO 3382

The UNI EN ISO 3382 [1] [2] [3] is the international reference for the definition of the acoustic parameters which are able to uniquely define an environment and the related methods of measurement.

All the parameters that describe the behaviour of a room can be obtained from the impulse response. The impulse response of a room is composed of many single impulses, the first of which represents the direct sound (the one that runs the minimum distance between source and receiver and does not undergo the influence of the boundaries of the environment) while the others are the later reflections (due to the interaction of the sound wave with the boundary surfaces or objects in the room). Among the following reflections, early reflections, which are a useful signal together with the direct sound, are distinguished from the reverberant field, which is instead a masking signal.

The first part of ISO 3382 [1] is referred to performances spaces. This part of ISO 3382 establishes a method to obtain reverberation time from impulse responses and from interrupted noise. The annexes introduce the concepts and details of measurement procedures for some of the newer measures, but these do not constitute a part of the formal specifications of this part of ISO 3382. The intention is to make it possible to compare reverberation time measurements with higher certainty. Annex A presents measures based on squared impulse responses: a further measure of reverberation (early decay time) and measures of relative sound levels, early/late energy fractions and lateral energy fractions in auditoria. Within these categories, there is still work to be done in determining which measures are the most suitable to standardize upon; however, since they are all derivable from impulse responses, it is appropriate to introduce the impulse response as the basis for standard measurements. Annex B introduces binaural measurements and the head and torso simulators (dummy heads) required to make binaural measurements in auditoria. Annex C introduces the support measures that have been found useful for evaluating the acoustic conditions from the musicians point of view. This part of ISO 3382 specifies methods for the measurement of reverberation time and other room acoustical parameters in performance spaces. It describes the measurement procedure, the apparatus needed, the coverage required and the method of evaluating the data and presenting the test report [1].

The second part [2] is referred to reverberation time in ordinary rooms, while the third part [3] is referred to open plan offices.

Height of the sources above the floor	1,5 m
Height of the receivers above the floor	1,2 m
Frequency range	125 ÷ 4000 Hz in octave bands
Distance between microphones	about 2 m
Distance between microphones and reflecting surfaces	1 m
Safety curtain	up/down
Orchestra pit	open/closed

Table 2.1: Prescriptions of ISO 3382 [1].

2.1.1 Measurement indications

For the measurements of reverberation time, the temperature and relative humidity of the air in the room should be measured to an accuracy of 1 Celsius degree and 5%, respectively. An accurate description of the state of occupancy of the room is of decisive importance in assessing the results obtained by measuring the reverberation time. In theatres, a distinction shall be made between "safety curtain up" and "safety curtain down", between "orchestra pit open" and "orchestra pit closed".

The sound source shall be as close to omnidirectional as possible. It shall produce a sound pressure level sufficient to provide decay curves with the required minimum dynamic range, without contamination by background noise. Omnidirectional microphones shall be used to detect the sound pressure. Source positions should be located where the natural sound sources in the room would typically be located. A minimum of two source positions shall be used. The height of the acoustic centre of the source should be 1,5 m above the floor.

Microphone positions should be at positions representative of positions where listeners would normally be located. For reverberation time measurements, it is important that the measurement positions sample the entire space. Microphone positions shall be at least half a wavelength apart (a distance of around 2 m for the usual frequency range). The distance from any microphone position to the nearest reflecting surface, including the floor, shall be at least a quarter of a wavelength, normally around 1 m. No microphone position shall be too close to any source position, in order to avoid a too-strong influence from the direct sound. In rooms for speech and music, the height of the microphones above the floor should be 1,2 m, corresponding to the ear height of average listeners in typical chairs.

Where there is no requirement for specific frequency bands, the frequency range should cover at least 250 Hz to 2000 Hz for the survey method. For the engineering and precision methods, the frequency range should cover at least 125 Hz to 4000 Hz in octave bands, or 100 Hz to 5000 Hz in one-third octave bands (table 2.1). For the engineering and precision methods, the duration of excitation of the room needs to be sufficient for the sound field to have achieved a steady state before the source is switched off. The decay curve for each octave band is generated by a backward integration of the squared impulse response [1].

2.2 Ferrara Chart

The Ferrara Chart [25] is a set of indications given by a research from Pompoli and Prodi [25], which give the guidelines for acoustical measurements inside historical opera houses. This research came from the necessity of adapting the acoustical measuring techniques to the architectural typology of historical theatre and the need of standardizing the measurement sessions to make the results comparable. The research analysed two kinds of theatres: the Baroque theatres and the Renaissance theatres.

Height of the omnidirectional sources above the floor	1,2 m
Height of the directional sources above the floor	1,5 m
Height of the receivers above the floor	1,1 m

Table 2.2: Prescriptions of Ferrara Chart [25].

The sound sources and the receivers are positioned in order to characterize the acoustical environment for the audience and for the performers. In the zone of the theatre occupied by the performers (that is orchestra pit and stage) both sources and receivers are positioned, whereas in the hall, where only the audience is supposed the be accomodated, only receivers are placed.

As regard Baroque theatres (figure 2.1), the sound sources are omnidirectional (unless otherwise stated) and each position of a sound source which is marked in the plan corresponds to a complete set of measures of the grid of receivers. All the positions of sound sources, except one (A2), lie along a line which is parallel to the longitudinal axis of symmetry of the theatre at a distance of 1 m from it. The off-axis positioning of the sound sources avoids that spurious effects due to the symmetry of the hall, that might contaminate the data.

The sound sources, in the condition of hall and stage coupled, are placed as follows (figure 2.1):

- two positions in the orchestra pit, one named first violin (A1) and another in the covered part of the pit, in the usual position of double-basses or trombones (A2);
- two positions on the stage, one at 2 m from the line of the fire-curtain (A3) and the second at least three meters behind (A4);
- one position for a directional source (A5).

The sound sources are placed at 1,2 m from the floor except for the directional source (A5), that can be placed at 1,5 m heigh. The grid of receivers consists of 22 points: 9 in the stalls, 3 in each order of boxes, 3 in the gallery, 2 in the orchestra pit and 2 on the stage. If the time available to make the measurements limits the possibility of going trough the complete grid, it is possible to use a reduced grid of receivers, made up of 12 points. The receivers numbered 19, 20, 21 e 22 (figure 2.1) are to be taken in any case. Due to the supposed acoustical symmetry of the hall the receives are positioned only on one half of the hall at 1,1 m above the floor facing the sound source (table 2.2). The position 19, corresponding to the conductor, the position 20, corresponding to the front singer and the position 22 of the back singer lie on the symmetry axis while position 21 (deep instruments) is at 1,5 m from the lateral wall and at 1 m from the back wall of the orchestra pit (figure 2.1). The grid of receivers in the hall, though maintaining the indicated form (figure 2.1), has to be adapted to the conformation of the stalls (number or rows) and to that of the boxes (number of boxes for each order [25])

2.3 Parameters

Subjective studies of the acoustical characteristics of auditoria have shown that several quantities that can be obtained from measured impulse responses are correlated with particular subjective aspects of the acoustical character of an auditorium. While reverberation time is one fundamental description of the acoustical character of an

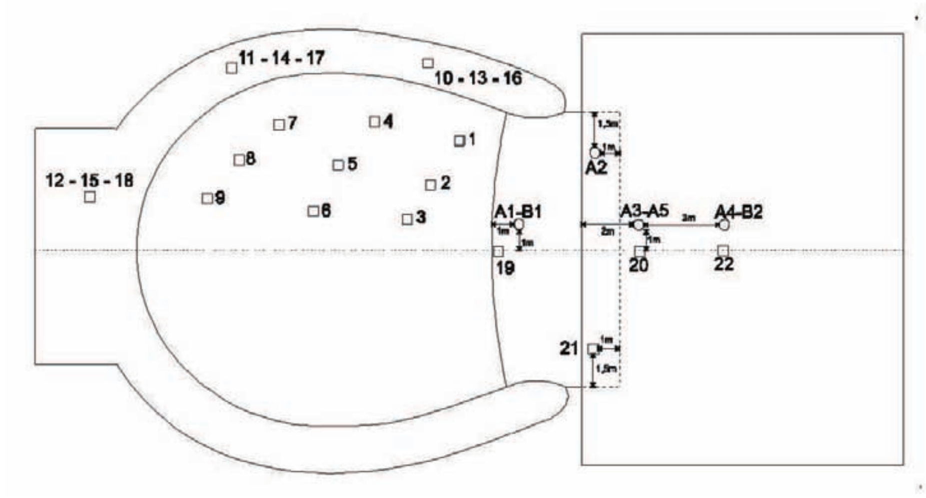


Figure 2.1: Plan of the baroque theatre with the positioning of sound sources and receivers (Ferrara Chart) [25].

Subjective aspect	Acoustic quantity	JND	Typical range
Perceived reverberance	EDT (s)	Rel. 5%	1,0 s; 3,0 s
Perceived clarity of sound	C_{80} (dB)	1 dB	-5 dB; +5 dB
Perceived clarity of sound	D_{50}	0,05	0,3; 0,7
Perceived clarity of sound	T_s (ms)	10 ms	60 ms; 260 ms

Table 2.3: Table from UNI EN ISO 3382-1:2009, Appendix A, Auditorium measures derived from impulse responses [1].

auditorium, the addition of values of these newer quantities gives a more complete description of the acoustical conditions in the auditorium [1].

Some acoustic quantities are reported in table 2.3, grouped according to listener aspects. In this table, subjective listener aspects, acoustic quantities, just noticeable differences (JND) and typical ranges are reported. Quantities as clarity, definition and centre time are related to perceived definition, clarity, or the balance between clarity and reverberance, as well as to speech intelligibility. Speech intelligibility can also be determined by measuring the speech transmission index (STI), as explained later [1].

2.3.1 Clarity

The index of *clarity* at 80 ms (C_{80}) expresses the possibility for the listener to distinguish sounds that follow one another in time or that arrive simultaneously from different instruments; it is defined as the ratio between the energy that comes within the ear during the first 80 ms (directed energy and early reflections) and the energy that comes in the immediate aftermath (energy of successive reflections) (equation 2.1).

$$C_{80} = 10log\frac{\int_0^{80\,ms} p^2(t)dt}{\int_{80\,ms}^{\infty} p^2(t)dt} \qquad (dB) \tag{2.1}$$

Where $p(t)$ is the instantaneous sound pressure of the impulse response measured at the measurement point and 0 ms is the instant of direct field arrival [1].

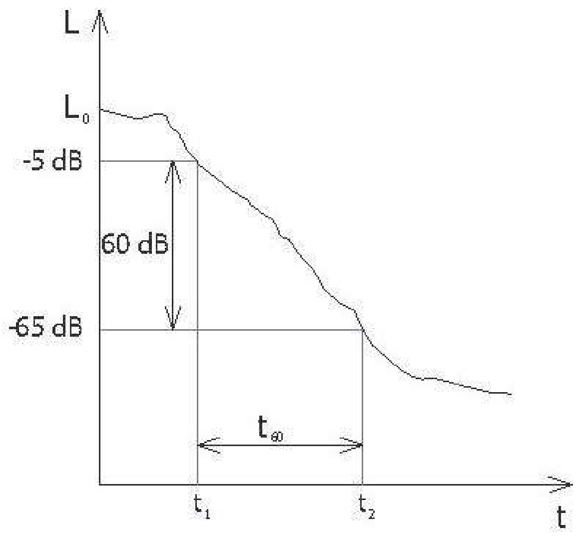


Figure 2.2: Example of extraction of reverberation time value [26].

2.3.2 Definition

The *definition* at 50 ms (D_{50}) is used to measure an early to total sound energy ratio (equation 2.2).

$$D_{50} = \frac{\int_0^{50\,ms} p^2(t)dt}{\int_{0\,ms}^{\infty} p^2(t)dt} \tag{2.2}$$

Where $p(t)$ is the instantaneous sound pressure of the impulse response measured at the measurement point and 0 ms is the instant of direct field arrival [1].

2.3.3 Centre time

The *centre time* (T_s) is the time, in milliseconds, that the listener uses to receive the exact half of the total acoustics energy (equation 2.3).

$$T_s = \frac{\int_0^{\infty} tp^2(t)dt}{\int_0^{\infty} p^2(t)dt} \qquad (ms) \tag{2.3}$$

Where p(t) is the instantaneous sound pressure of the impulse response measured at the measurement point. t = 0 means the instant when the direct signal reaches the receiver [1]. This index constitutes a measure of the clarity of the sound for the listener: the lower the value, the clearer the sound is. The value of T_s, in the frequencies between 250 and 2000 Hz, is typically between 140 and 180 ms [47].

2.3.4 Reverberation time

The *reverberation time* (T_{60}) is defined as the time required for the decay of the sound pressure level of 60 dB at a point after the deactivation of a sound source in stationary regime. The decay curve is considered between -5 and -65 dB. First 5 dB are excluded to avoid the influence of early particularly strong reflections (figure 2.2).

It is often not possible to extract the reverberation time from this definition due to the presence of background noise: therefore this information is extrapolated from the first part of the decay curve. Usually the reverberation time is obtained from the decay from -5 dB to -35 dB below the level of regime (T_{30}). The first 5 dB are excludes to

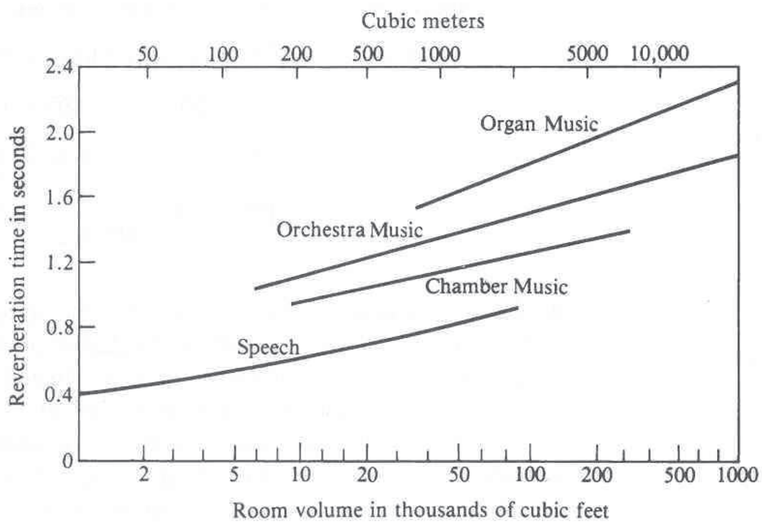


Figure 2.3: Types of events for which a room is appropriate according to the reverberation time and the volume [36].

avoid the influence of the early particularly strong reflections. Similarly, it is possible to get the T_{20} and T_{10}.

The reverberation time can be estimated through the application of Sabine equation (equation 2.4), where A is defined according to equation 2.5:

$$T_R = 0,16 * \frac{V}{A} \qquad (s) \tag{2.4}$$

$$A = \Sigma \alpha_i S_i \qquad (m^2) \tag{2.5}$$

Where α_i is the sound absorption coefficient of each surface S_i.

According to the volume and the reverberation time of a room it is possible to define for which events the room is suitable (figure 2.3).

Studies have shown that the decay part responsible for the perceptual effects of reverberation is the initial one: this has led to the definition of the *early decay time* (*EDT*), which is the time corresponding to a decay of 60 dB according the straight line obtained by interpolating the first 10 dB of the decay curve (figure 2.4). This parameter is related to feelings such as clarity of the attacks and their intensity [29]. Both the EDT and T should be calculated. EDT is subjectively more important and related to perceived reverberance, while T is related to the physical properties of the auditorium [1].

2.3.5 Inter-aural cross correlation

The process of hearing is binaural. *Inter-aural cross correlation coefficients* (IACC), measured with either a dummy head or a real head with average dimensions as exemplified by dummy heads, and with small microphones at the entrance to the ear canals, correlate well with the subjective quality "spatial impression" in a concert hall. Spatial impression may be divided into two subclasses:

- subclass 1: broadening of the source, i.e. apparent source width (ASW);
- subclass 2: a sense of being immersed or enveloped in the sound, i.e. listener envelopment (LEV) [1].

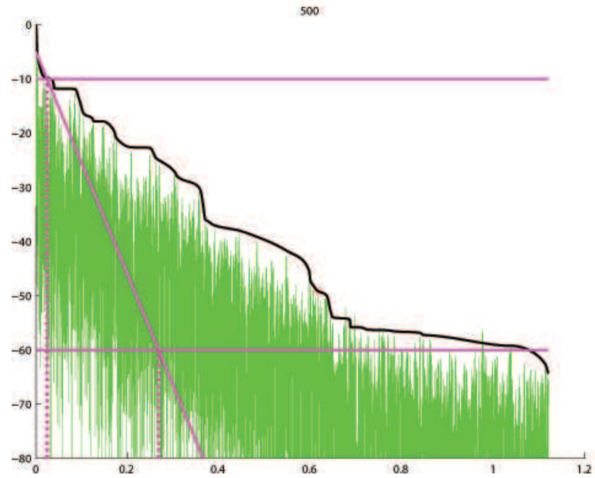


Figure 2.4: Example of extraction of EDT value at 500 Hz [28].

The normalized inter-aural cross correlation function (IACF) is first defined using equation 2.6 [1]:

$$IACF_{t_1,t_2,\tau} = \frac{\int_{t_1}^{t_2} p_l(t) * p_r(t+\tau)dt}{\sqrt{\int_{t_1}^{t_2} p_l{}^2(t)dt \int_{t_1}^{t_2} p_r{}^2(t)dt}} \tag{2.6}$$

Where $p_l(t)$ is the impulse response at the entrance to the left ear canal and $p_r(t)$ is the impulse response at the entrance to the right ear canal.

The inter-aural cross correlation coefficients, IACC, are then given by equation 2.7 [1]:

$$IACC_{t_1,t_2} = max|IACF_{t_1,t_2}| \qquad per - 1ms < \tau < +1ms \tag{2.7}$$

2.3.6 Bass ratio

The *bass ratio* (BR) is the the ratio of the average reverberation times at 125 and 250 Hz to the average of the reverberation times at 500 and 1000 Hz (equation 2.8) [49].

$$BR = \frac{RT_{125Hz} - RT_{250Hz}}{RT_{500Hz} - RT_{1000Hz}} \tag{2.8}$$

2.3.7 Signal to noise ratio

The *signal to noise ratio* (SNR) is a measure used to compare the level of a signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels (equation 2.9). A ratio higher than 1 indicates more signal than noise [48].

$$SNR = \frac{P_{signal}}{P_{noise}} \qquad (dB) \tag{2.9}$$

2.3.8 Impulse response to noise ratio

The *impulse response to noise ratio* (INR) is defined as (equation 2.10):

$$INR = L_{IR} - L_N \qquad (dB) \tag{2.10}$$

Where L_{IR} is the maximum root mean square (RMS) level in dB of p(t) and L_N is the noise level in dB [18].

2.3.9 Support

The *support* (ST) describes the ratio between the energy of the early reflections and the energy of the direct sound. This ratio is measured at 1 m from the source, which is comparable to the distance from the performer's ear to his own instrument. High ST values should correspond to a strong feeling of support. The support is the property which makes the musician feel that he/she can hear himself and that it is not necessary to force the instrument to develop the tone [17].

2.3.10 Early and Late Support

Early support (ST_{early}) (equation 2.11) is the ratio, in dB, of the reflected energy within the first 0,1 s relative to the direct sound (including the floor reflection), both measured at a distance of 1 m from the acoustic centre of an omnidirectional sound source. Other reflecting surfaces or objects should be more than 2 m from the measurement position. Early support relates to ensemble, ease of hearing other members of an orchestra. However, the influences of the direct sound, delay time and reflections from near surfaces are not included.

$$ST_{early} = 10log\frac{\int_{20\,ms}^{100\,ms} p^2(t)dt}{\int_{0}^{10\,ms} p^2(t)dt} \qquad (dB) \tag{2.11}$$

Where $p(t)$ is the impulse response and 0 ms is the instant of direct field arrival.

Late support (ST_{late}) (equation 2.12) is the ratio, in dB, of the reflected energy after the first 0,1 s relative to the direct sound (including the floor reflection), both measured at a distance of 1 m from the acoustic centre of an omnidirectional sound source. Other reflecting surfaces or objects should be more than 2 m from the measurement position. Late support relates to perceived reverberance, the response of the hall as heard by the musician.

$$ST_{late} = 10log\frac{\int_{100\,ms}^{1000ms} p^2(t)dt}{\int_{0}^{10\,ms} p^2(t)dt} \qquad (dB) \tag{2.12}$$

Where $p(t)$ is the impulse response and 0 ms is the instant of direct field arrival [1].

The UNI EN ISO 3382-1:2009 (Appendix C) [1] shows the acoustic parameters used in the classification of a orchestral platform (table 2.4):

Subjective aspects	Acoustic quantity	JND	Typical range
Ensemble conditions	ST_{early} (dB)	Not known	-24 dB; -8 dB
Perceived reverberance	ST_{late} (dB)	Not known	-24 dB; -10 dB

Table 2.4: Table from UNI EN ISO 3382-1:2009, Appendix C, Measurements on stage [1].

2.3.11 Early Ensemble Level

EEL (equation 2.13) is defined as the ratio between the received early energy (r) and the energy emitted (e), the latter being described by the direct sound measured at 1 m distance from the source.

$$EEL = 10log\frac{\int_{0}^{80\,ms} p_r^2(t)dt}{\int_{0}^{10\,ms} p_e^2(t)dt} \qquad (dB) \tag{2.13}$$

Where $p(t)$ is the impulse response and 0 ms is the instant of direct field arrival [17].

2.4 Speech intelligibility

Speech intelligibility is an important measure of the effectiveness or adequacy of a communication system or to communicate in a noisy environment. In many daily life situations it is important to understand what is being said and to be able to react to acoustic signals of different kinds. Amplified speech systems like public address systems, telephones, radio links, intercoms are vital to society, but even unamplified unaided speech is important in offices, workshops, vehicles and many other situations [9]. Speech intelligibility is the rating of the proportion of speech that is understood [45].

Detailed information on speech intelligibility measurements are contained in the IEC 60268-16 (2003-5) standard [6], which also describes the test procedures and the requirements in practice [22].

Speech transmission index (STI), *room acoustical speech transmission index* (RASTI) and *speech transmission index for public address system* (STIPA) are the most established parameters for measuring speech intelligibility. All of them basically apply the same principle, whereby RASTI and STIPA are a simplified version of STI. They are all based on measuring the MTFs (Modulation Transfer Functions) in seven octave bands. For each octave band there is one MTF quantifying the preservation degree of the intensity modulations in this band. These functions quantify how much the intensity modulations are preserved in seven octave bands covering the long-term speech spectrum. Reverberation, background noise and reflection are responsible for degrading the modulation index [22].

A typical speech intelligibility measurement can be carried out with a stimulus played through an artificial mouth-directional sound source at the talker position [9]. The STI measurement consists in emitting a synthesized test signals instead of a human speakers voice. The speech intelligibility measurement acquires and evaluates this signal as perceived by listeners ears. Speech intelligibility meter displays the result as a single number between 0 (unintelligible) and 1 (excellent intelligibility) [22].

2.4.1 Speech transmission index

The *speech transmission index* (STI) is an objective measure to predict the intelligibility of speech transmission from talker to listener by a transmission channel. The speech transmission channel is an acoustic or electro-acoustic signal path between a talker and a listener [6].

The STI is a measure of intelligibility, most suited to the evaluation of speech intelligibility in rooms, with stimuli subjected to reverberance. It measures the extent to which slow temporal intensity envelope modulations are preserved in listening environments. There are a number of variations of the STI method, that only differ in how the signals and the transmission index are calculated [27]. The STI method applies a specific test signal to the transmission channel. The speech transmission quality of the channel is derived and expressed in a value between 0 and 1, as the STI. Using the obtained STI value, the potential speech intelligibility can be determined [6]. Relation between speech intelligibility and STI are visible in table 2.5 [9].

The STI method can discriminate between male and female speech signals. Gender related factors are expressed in different test signal spectra and different weighting factors. Since female speech is generally considered to be more intelligible than male speech, male speech is generally used to assess speech transmission channels [6].

STI	$0,00 \div 0,30$	$0,30 \div 0,45$	$0,45 \div 0,60$	$0,60 \div 0,75$	$0,75 \div 1,00$
Intelligibility	Bad	Poor	Fair	Good	Excellent

Table 2.5: Relation between STI and speech intelligibility [9].

2.4.2 Room acoustical speech transmission index

The *room acoustical speech transmission index* (RASTI) is a simplified and approximate measurement method for rating speech transmission in auditoria [9]. The RASTI method has to be used for screening purposes only and focused on direct communication between people without making use of an electro-acoustic communication system [6].

2.4.3 Speech transmission index for public address system

The *speech transmission index for public address system* (STIPA) is a condensed and approximate version of the STI measurement method for PA systems. PA system refers to electro-acoustic system used to address a group of people [45]. STIPA was developed to reduce the time required to perform a measurement and the time to compute the final result [9]. The STIPA method is only validated for the male speech spectrum and its measurements time is approximately between 15 s and 20 s [6].

Chapter 3

Measurements

3.1 Previous measurements

3.1.1 Measurement system

Previous measurements for the acoustic qualification of the Civic Theatre, done before the restoration [26], have been performed recording many impulse responses, with open curtain. Implementation of such measurements follows UNI EN ISO 3382 [1] and Ferrara Chart [25]. The equipment consisted of:

- Omnidirectional dodecahedron Bruel and Kjaer 4296;
- Microphone Bruel and Kjaer 4189 half inch;
- Digigram sound card VX Pocket v.2;
- Amplifier LAB300;
- Dummy head Bruel and Kjaer 4100D;
- PC IBM with software DIRAC Bruel and Kjaer, providing exponential sine sweep.

The signal produced by the omnidirectional source is a sine sweep, a particular type of signal that reproduces one by one all the frequencies. The measurements have been performed according to ISO 3382 [1] with empty space, non occupied, with lights on. Temperature was around 18 Celsius degrees and relative humidity was about 64%. [26].

3.1.2 Measurement positions

The previous measurements have been done with 2 positions of the sound source on the stage:

- the first at 4 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S1);
- the second at 8 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S2).

The sources have been placed at 1,6 m from the floor.

The microphone has been placed in:

- 20 points in the audience, following a grid 2 m x 2 m;
- 14 points in the first order;

- 20 points in the second order;
- 6 points in the gallery;
- 6 points on the stage, in lateral position.

The receivers have been placed at 1,2 m from the floor. Due to the fact that the theatre is considered to be symmetrical, the receivers in the orders, in the gallery and on the stage have been put only in a half of the Theatre [26].

3.2 Measurements on 10/09/2015

3.2.1 Measurement system

On 10/09/2015, measurements have been performed recording many impulse responses, with open curtain. The equipment was the one of the University of Padova, it was similar to the one of previous measurements, with little differences, and it consisted of (figure 3.1):

- Omnidirectional dodecahedron Bruel and Kjaer 4296;
- 2 microphones Grass half inch;
- Digigram sound card VX Pocket v.2;
- Amplifier LAB300;
- PC IBM with software DIRAC Bruel and Kjaer, providing exponential sine sweep;
- Tascam digital recorder;
- Balloons.

The signal sent to the omnidirectional source is an exponential sine sweep. The measurements have been performed according to ISO 3382 [1] with empty space, non occupied, with lights on. The measurements have been performed with a weak background noise due to the lamps, not relevant to the extracted criteria. Temperature was around 22 Celsius degrees and relative humidity was about 45%, both at the beginning of the measurements and at the end.

3.2.2 Measurement positions

The measurements have been done with 4 positions of the sound source on the stage:

- the first at 4 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S1);
- the second at 8 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S2);
- the third at 1 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S3);
- the fourth at 1 m from the front of the stage and at 2,5 m from the symmetry longitudinal axis, in the left side of the stage (watching the stage) (S4) (figure 3.2).

(a) PC IBM with software DIRAC.

(b) Omnidirectional dodecahedron.

(c) Tascam digital recorder.

(d) Balloons.

Figure 3.1: Part of measurements equipments (10/09/2015).

The sources have been placed at 1,6 m from the floor.

The microphones has been placed in:

- 12 points in the audience, following a grid 2 m x 3,5 m;
- 14 points in the first order, 7 forward and 7 backward. The 7 forward have been placed near the railing and the 7 backward have been placed near the edge of the step;
- 10 points in the second order, 5 forward and 5 backward. The 5 forward have been placed near the railing and the 5 backward have been placed on the third step. The five boxes per side near the stage are not viable;
- no points in the gallery because it is not viable;
- 2 points on the stage, at 4 m and at 8 m from the front of the stage, on the symmetry longitudinal axis of the Theatre, measured with the source placed in S3 and S4.

The receivers have been placed at 1,2 m from the floor. Due to the fact that the Theatre is considered to be symmetrical, the receivers have been put only in a half of the Theatre (figures 3.2 and 3.3).

The Tascam digital recorder has been placed in:

- 12 points in the audience, following a grid 2 m x 2 m, the same of the microphone;
- 2 points on the stage, at 4 m and at 8 m from the front of the stage, on the symmetry longitudinal axis of the Theatre, measured with the source placed in S3 and S4.

As regard the audience, measurements in 12 positions of microphone have been performed with each of the 4 positions of the omnidirectional source. In addition,

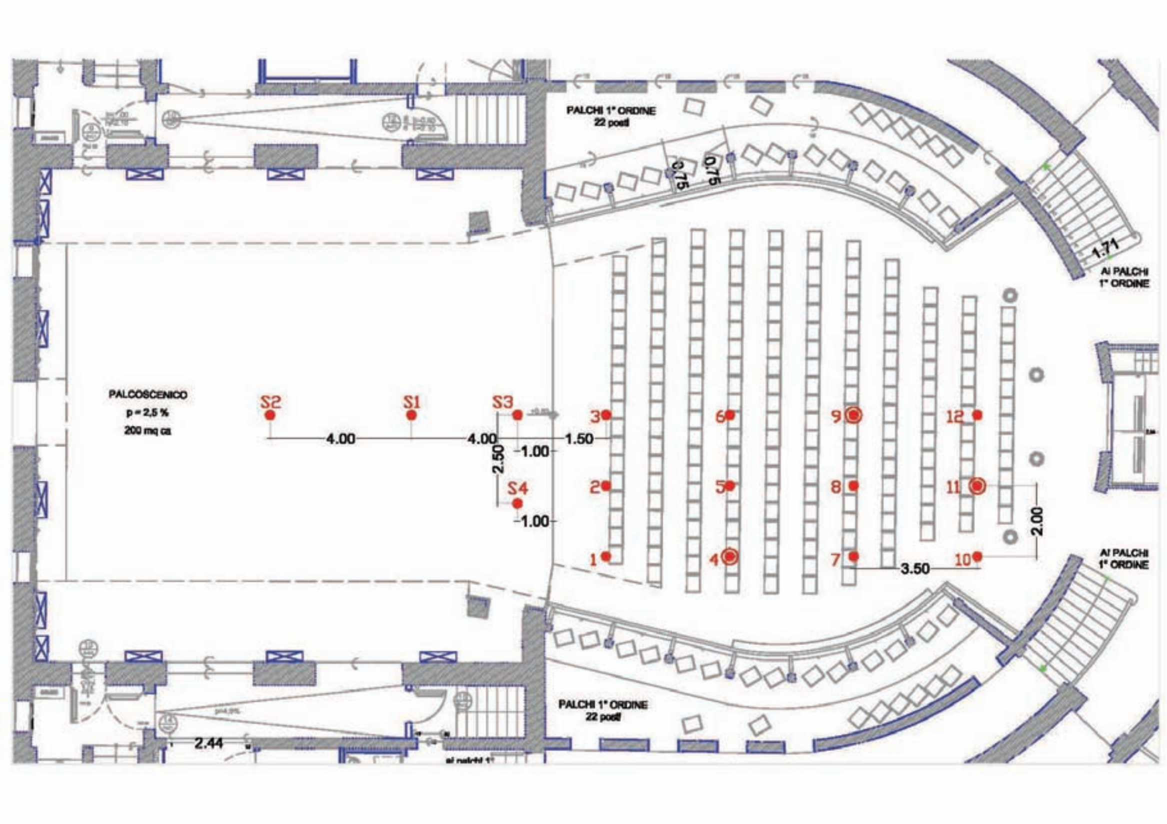


Figure 3.2: Positions of sound sources and receivers in the first set of measurements in the audience (10/09/2015).

measurements in 12 positions with Tascam digital recorder have been performed, with balloon placed in the position S1 (at 4 m from the front of the stage).

As regard the first order, measurements in 14 positions of microphone have been performed with each of the 4 positions of the omnidirectional source.

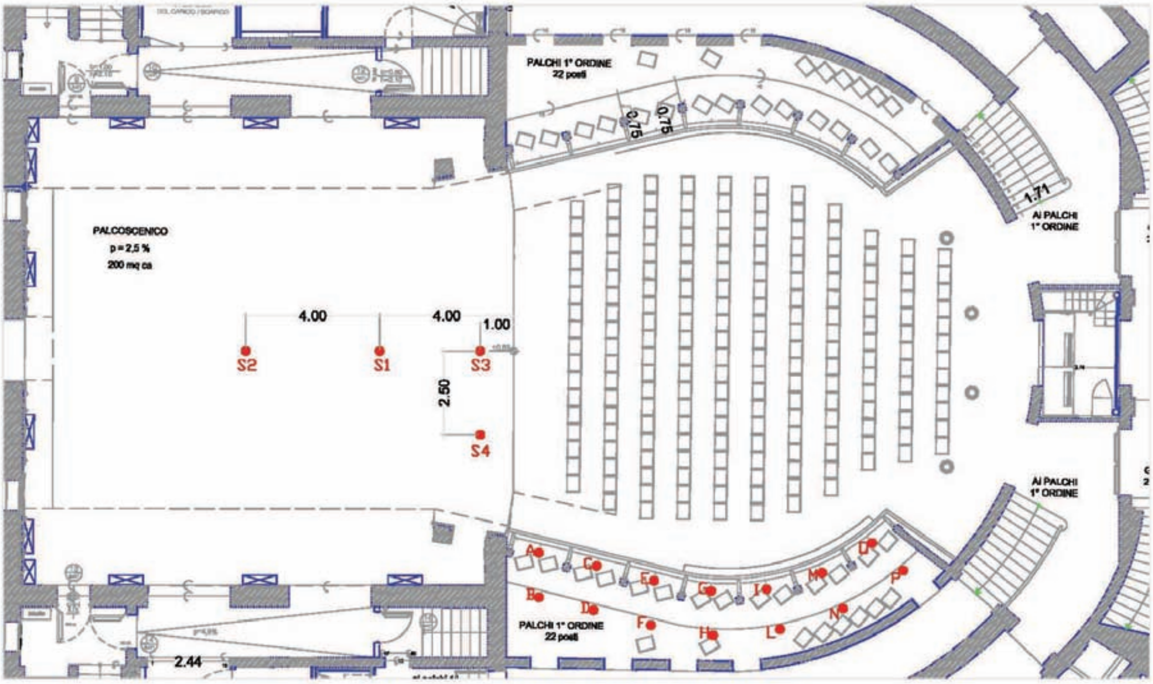
As regard the second order, measurements in 10 positions of microphone have been performed with each of the 4 positions of the omnidirectional source.

As regard the stage, measurements in 2 positions of microphone (corresponding to the positions S1 and S2) have been performed with omnidirectional source placed in position S3 and S4. Measurements in 2 positions of microphone have been performed (corresponding to the positions S1 and S2) with balloon placed in the positions S3 and S4 (2 measurements for each configuration). In addition, measurements in 2 positions with Tascam digital recorder have been performed (corresponding to the positions S1 and S2) with balloon placed in the positions S3 and S4. Measurements in 2 positions with Tascam digital recorder with external microphones have been performed (corresponding to the positions S1 and S2) with balloon placed in the positions S3 and S4.

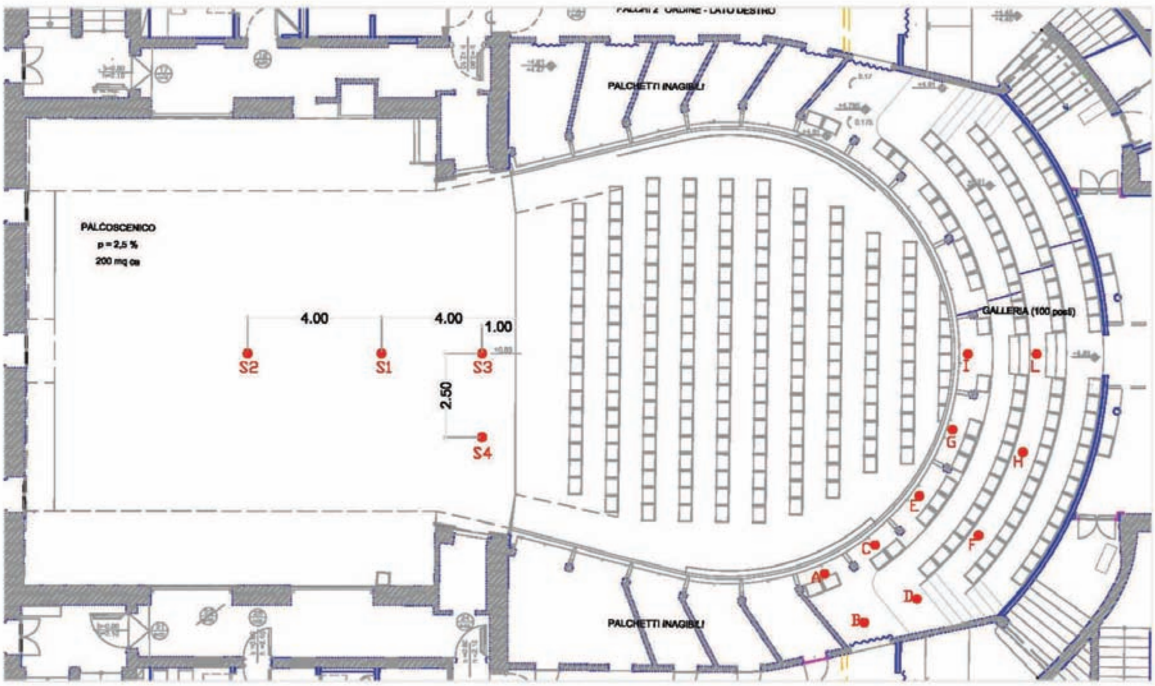
3.3 Measurements on 11/09/2015

3.3.1 Measurement system

On 11/09/2015, measurements have been performed recording many impulse responses, with open curtain. The equipment was the one of the University of Bologna and it



(a) First order.



(b) Second order.

Figure 3.3: Positions of sound sources and receivers in the first set of measurements in the first and second orders (10/09/2015).

consisted of (figure 3.4):

- Omnidirectional dodecahedron with custom 8 inches loudspeakers;
- Directive loudspeaker placed at 1,5 m, with amplitude directivity about 60 degrees on the horizontal plane and 90 degrees on the vertical plane;
- 4 monoaural microphones Bruel and Kjaer 4190 half inch;
- Preamplifier Bruel and Kjaer 2669;
- Spherical mic Schoeps KSM6;
- AD/DA converter RME fireface 800;
- MacBook with custom acquisition software, providing exponential sine sweep.

The signal sent to the omnidirectional and directive sources is an exponential sine sweep (256 K length at 48 kHz). The measurements have been performed according to ISO 3382 [1] with empty space, non occupied, with lights on. The measurements have been performed with a weak background noise due to the lamps, not relevant to the extracted criteria. Temperature was around 22 Celsius degrees and relative humidity was about 70 %.

3.3.2 Measurement positions

The measurements in the audience and in the boxes have been done with 4 positions of the sound source on the stage:

- the first at 4 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S1);
- the second at 8 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S2);
- the third at 1 m from the front of the stage, on the symmetry longitudinal axis of the Theatre (S3);
- the fourth at 1 m from the front of the stage and at 2,5 m from the symmetry longitudinal axis, in the left side of the stage (watching the stage) (S4).

In addition, for the measurements on the stage, another source position has been added:

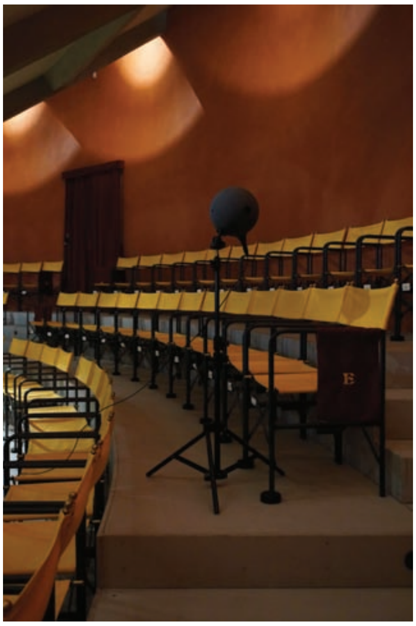
- at 6 m from the front of the stage and at 2,5 m from the symmetry longitudinal axis, in the right side of the stage (watching the stage) (S5).

The sources have been placed at 1,6 m from the floor.

The microphone has been placed in:

- 12 points in the audience, following a grid 2 m x 3,5 m;
- 6 points in the first order, placed near the railing;
- 6 points in the second order, 3 placed near the railing and 3, in correspondence, on the fourth step;
- no points in the gallery because it is not viable;

(a) Part of measurements equipment.



(b) Spherical mic.

(c) Omnidirectional dodecahedron.

(d) Directive loudspeaker.

Figure 3.4: Part of measurements equipments (11/09/2015).

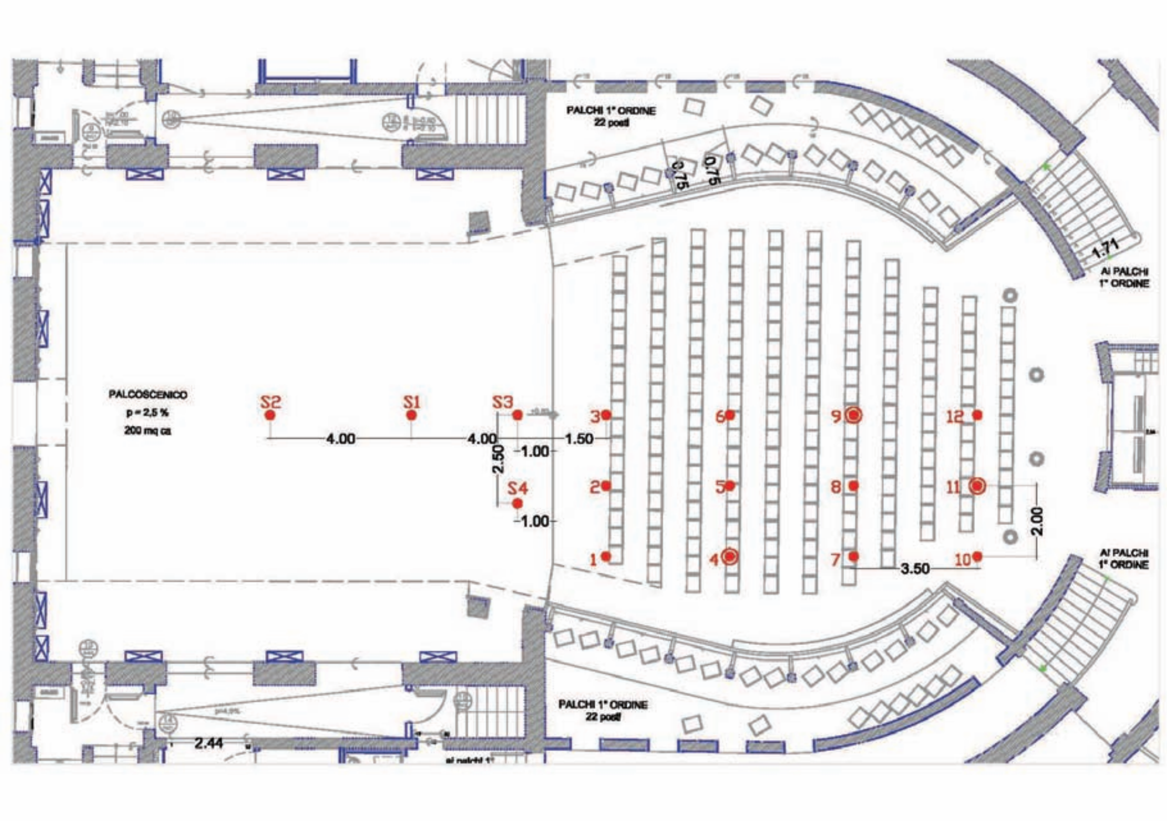


Figure 3.5: Positions of sound sources and receivers in the second set of measurements in the audience (11/09/2015).

- 20 points on the stage, measured with each of the five source positions, with omnidirectional source.

The receivers have been placed at 1,2 m from the floor. Due to the fact that the Theatre is considered to be symmetrical, the receivers have been put only in a half of the Theatre (figures 3.5 and 3.6).

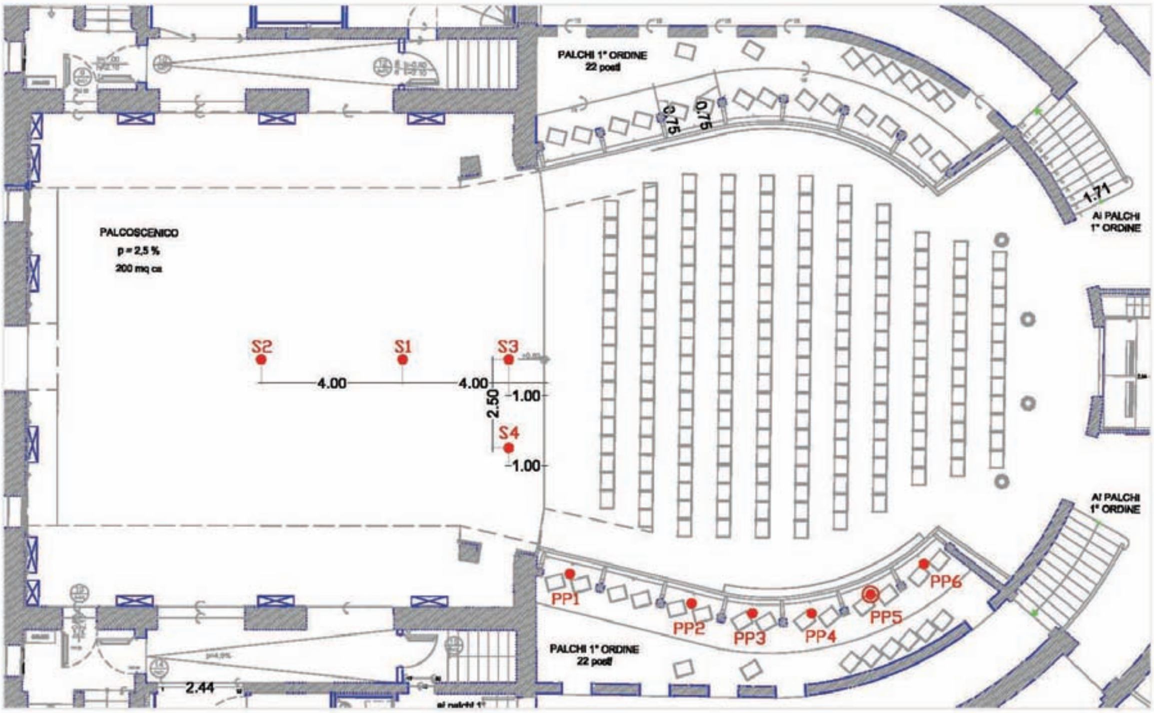
As regard the audience, measurements in 12 positions of microphone have been performed with each of the 4 positions of the source, both with omnidirectional and directive source. Measurements in 3 positions (4, 9, 11) with the spherical mic have been performed with both omnidirectional and directive source.

As regard the first order, measurements in 6 positions of microphone have been performed with each of the 4 positions of the source, both with omnidirectional and directive source. Measurements in one position (SS5) with the spherical mic has been performed with both omnidirectional and directive source.

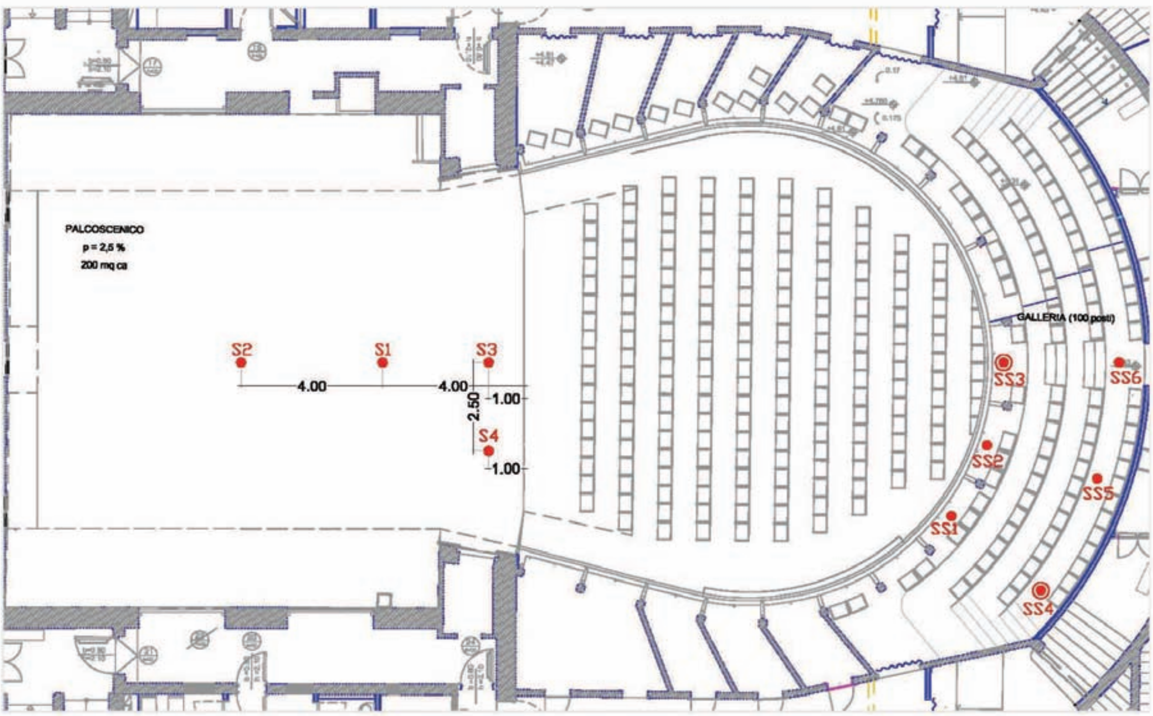
As regard the second order, measurements in 6 positions of microphone have been performed with each of the 4 positions of the source, both with omnidirectional and directive source. Measurements in 2 positions (SS3, SS4) with the spherical mic have been performed with both omnidirectional and directive source.

As regard the stage, 5 positions of omnidirectional sources and 20 positions of receivers have been used. For each couple of positions of source, for example S1 and S2, 2 measurements have been performed:

- one with the dodecahedron in S1 and the receivers at 1 m from S1 and at 1 m from S2, in the direction of the joining line between the two positions;



(a) First order.



(b) Second order.

Figure 3.6: Positions of sound sources and receivers in the second set of measurements in the first and second orders (11/09/2015).

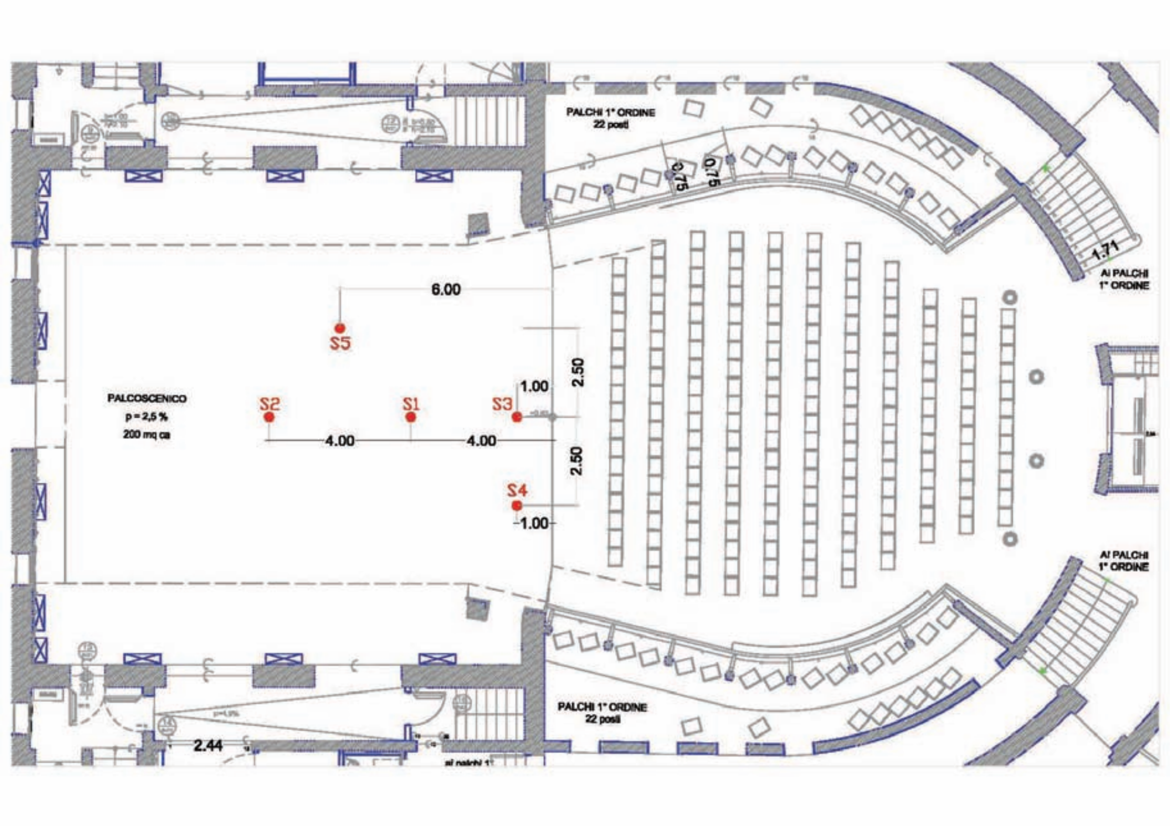


Figure 3.7: Source positions in the second set of measurements on the stage (11/09/2015).

- one with the dodecahedron in S2 and the receivers at 1 m from S1 and at 1 m from S2, in the direction of the joining line between the two positions.

This procedure has been done for each couple of positions. In addition, a set of measurements have been performed with the omnidirectional source in S1 and 12 positions of the receivers in 12 points around S1, at 1 m from it (figures 3.7 and 3.8).

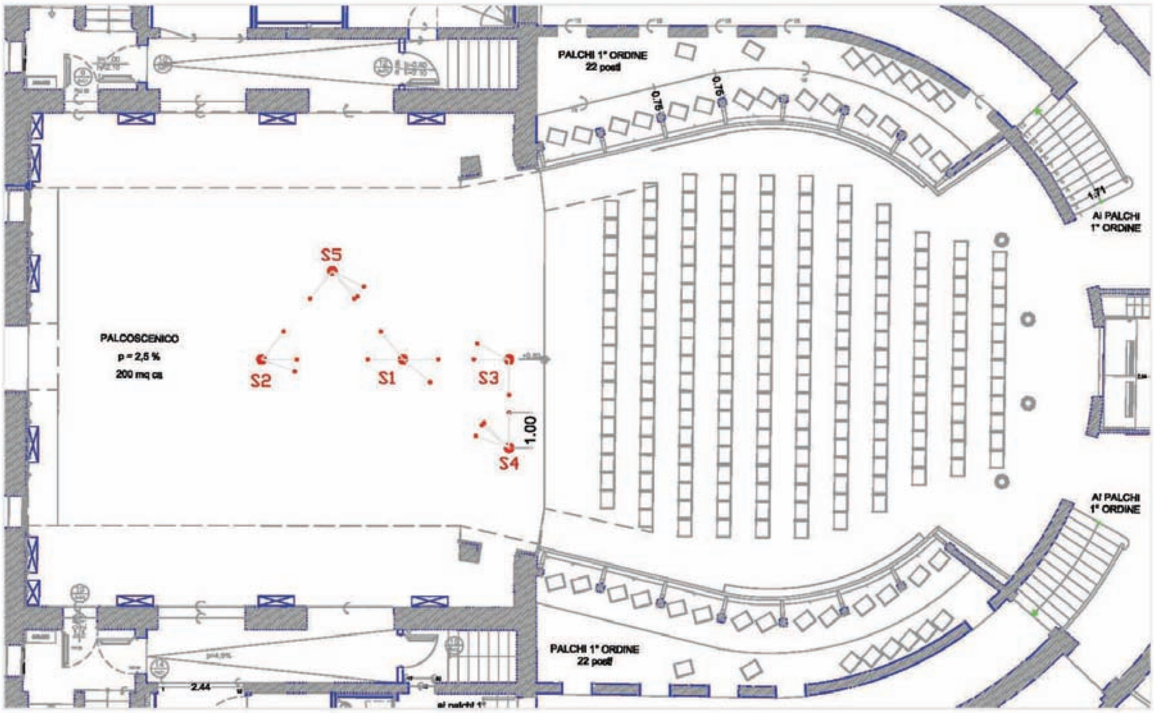
In addition to these measurements, some measurements of STIPA have been performed. The equipment consisted of (figure 3.9):

- NTI Audio Talk Box, that simulates a person talking at a precise acoustic level;
- XL2 Analyser, that measures the speech intelligibility and displays it as STI and STIPA. It includes ambient noise correction and automated averaging of measurements [23].

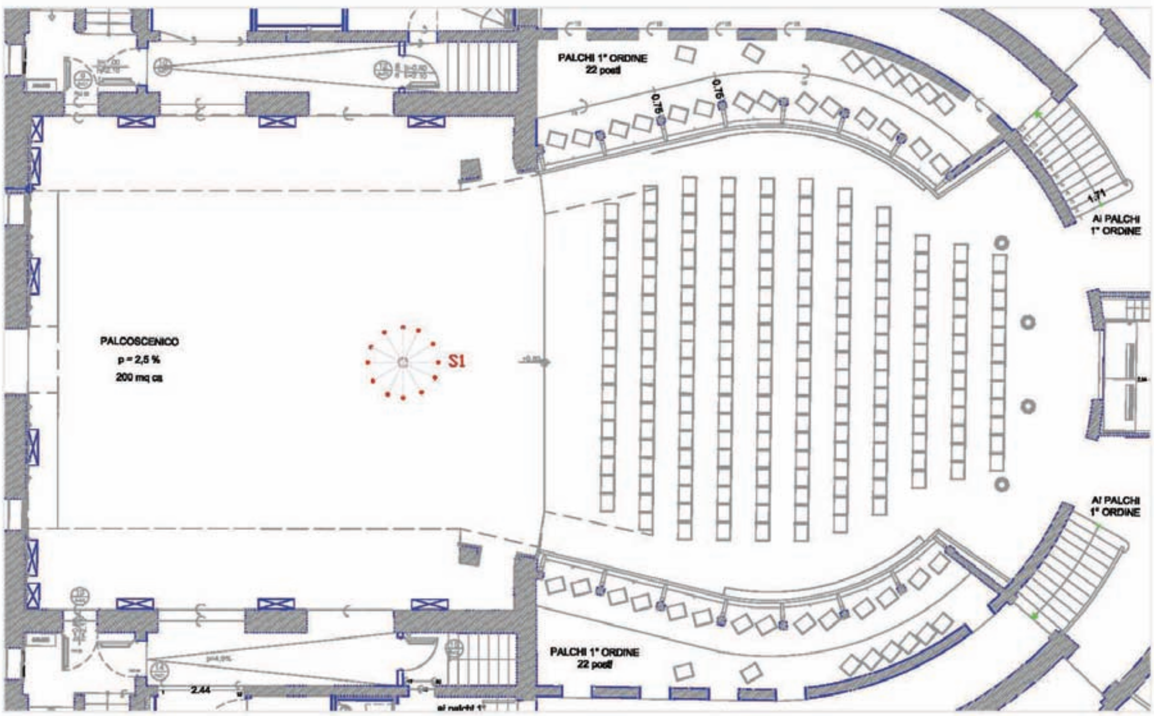
The measurements have been performed with empty space, non occupied, with lights on.

The measurements have been performed with the Talk Box (70 dB at 1 m) placed in each of the 4 positions on the stage (S1, S2, S3, S4), with microphone placed in:

- 12 points in the audience, following a grid 2 m x 3,5 m;
- 14 points in the first order, 7 forward and 7 backward. The 7 forward have been placed near the railing and the 7 backward have been placed near the edge of the step;
- 10 points in the second order, 5 forward and 5 backward. The 5 forward have been placed near the railing and the 5 backward have been placed on the third step. The five boxes per side near the stage are not viable;

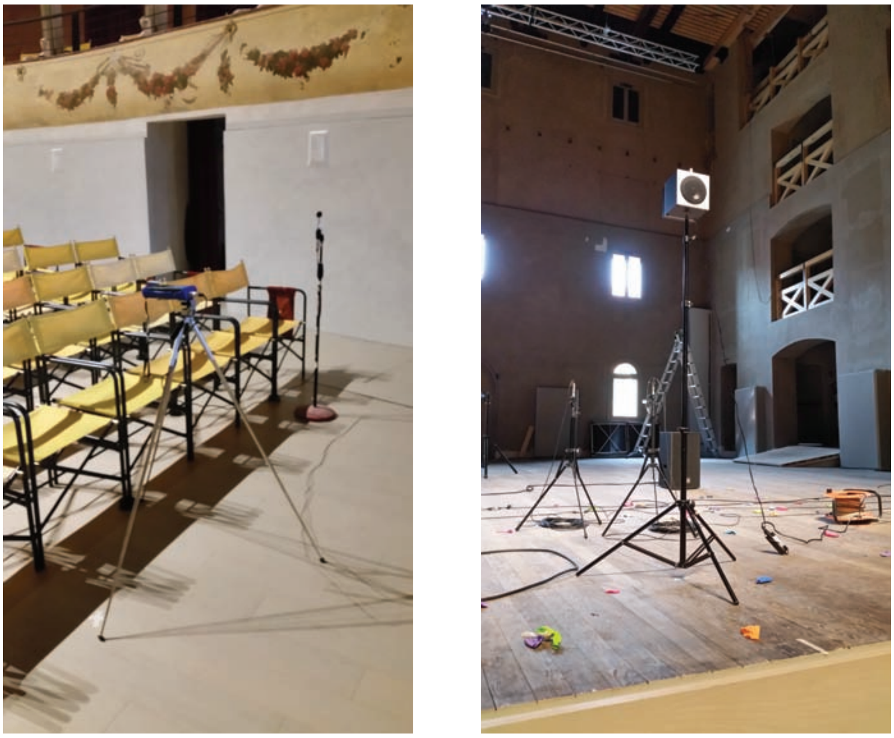


(a) Receivers positions for EEL and ST measurement.



(b) Microphones configuration for sound source calibration for strenght calibration.

Figure 3.8: Positions of sound sources and receivers in the second set of measurements on the stage (11/09/2015).



(a) XL2 Analyser. (b) NTI Audio Talk Box.

Figure 3.9: Speech intelligibility measurements equipments (11/09/2015).

- no points in the gallery because it is not viable.

In addition, measurements have been performed with the Talk Box (60 dB at 1 m) placed in S1, with microphone placed in:

- 12 points in the audience, following a grid 2 m x 3,5 m.

For the acoustic characterization of the Civic Theatre of Schio, more than 600 measurements have been performed in 2 days, with the contribution of the University of Padova and the University of Bologna.

Chapter 4

Comparisons with the situation before the restoration

4.1 Conditions of the Theatre before and after the restoration

The Civic Theatre of Schio in 2005 was in a condition of serious architectural and structural deterioration [26]. As visible in figure 4.1, in 2005 the ceiling was badly damaged and there was a safety net, the orchestra pit was open and so the audience had reduced dimensions and the gallery had steps in which it was possible to make acoustic measurements. These are the main differences with the situation of the Theatre in 2015: the ceiling has been restored, the orchestra pit has been closed and so all the space is now occupied by the seats of the audience, that are more than in 2005, and the gallery is not viable, as well as the lateral boxes in the second order (figure 4.2).

4.2 Analysis procedure

For the comparisons with the previous measurements, done before the restoration [26], it has been decided to compare the main energy parameters (C_{80} and D_{50}) and the main reverberation parameters (EDT and T_{30}).

The values of the parameters (C_{80}, D_{50}, EDT and T_{30}) measured in 2005 are the ones obtained with the omnidirectional source, emitting a sine sweep, placed in the position S1 (data from [26]). The values of the parameters (C_{80}, D_{50}, EDT and T_{30}) measured in 2015 are the ones obtained with the omnidirectional source, emitting a sine sweep, placed in the position S1, from the measurements performed on 10/09/2015. As regard the first and the second orders, only the receivers in forward positions have been taken into account, both in the measurements of 2005 and the ones of 2015.

Measurements performed in 2005 and 2015 have been done with the same equipment:

- Omnidirectional dodecahedron Bruel e Kjaer 4296;
- Microphone half inch;
- Digigram sound card VX Pocket v.2;
- Amplifier LAB300;
- PC IBM with software DIRAC Bruel e Kjaer [26].

(a) Internal view of the Theatre.

(b) Orchestra pit.

(c) Gallery.

(d) Stage.

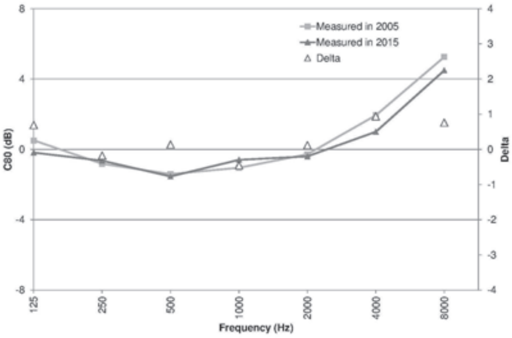
Figure 4.1: Views of the Civic Theatre in 2005 [8] [26].

(a) Internal view of the Theatre.

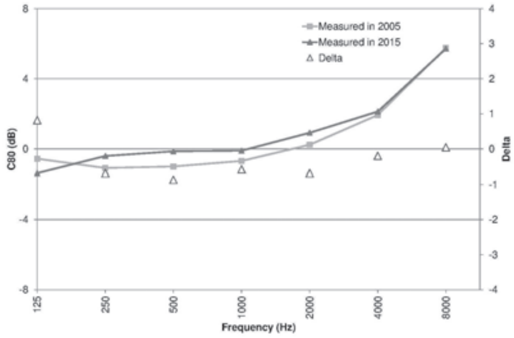
(b) Gallery.

Figure 4.2: Views of the Civic Theatre in 2015.

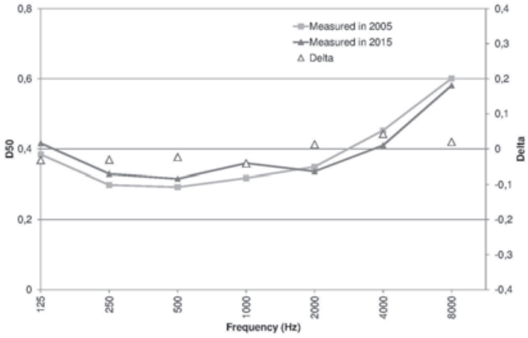
The main difference between the measurements performed in 2005 and the measurements performed in 2015 is that the positions of receivers are not exactly the same, because some areas in the Theatre have been changed during the restoration works. The orchestra pit is now closed and the seats in the audience are more than in 2005. The gallery is not viable now, so it has been impossible to done measurements, while in 2005 measurements in 6 positions in the gallery have been performed. In the second order, the lateral boxes are not viable now, so measurements have been performed in less positions in the second order respect to 2005. In the audience, in 2015 it has been preferred to perform the measurements only in one half of the Theatre, due to the fact



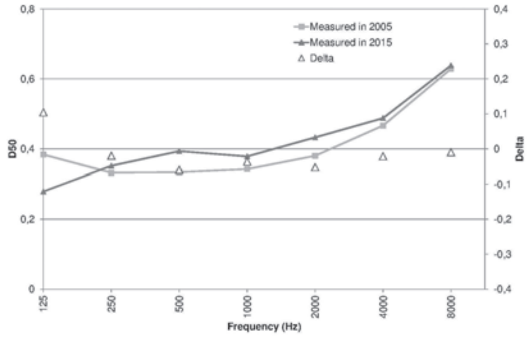
(a) C_{80} in the audience.



(b) C_{80} in the orders.



(c) D_{50} in the audience.



(d) D_{50} in the orders.

Figure 4.3: Comparisons between values of energy parameters measured in 2005 and in 2015.

that the Theatre is considered to be symmetrical.

The analysis of the results has been carried out comparing the arithmetic mean of the parameters in the different areas of the Theatre (audience and orders). The arithmetic mean has been chosen for all the parameters, even the ones in decibels (dB), as the ISO 3382 suggests [1], because the difference between arithmetic and energetic mean is very small, as explained later, and in order to adopt the same method of the Dirac software, that presents the average as arithmetic one.

4.3 Energy parameters

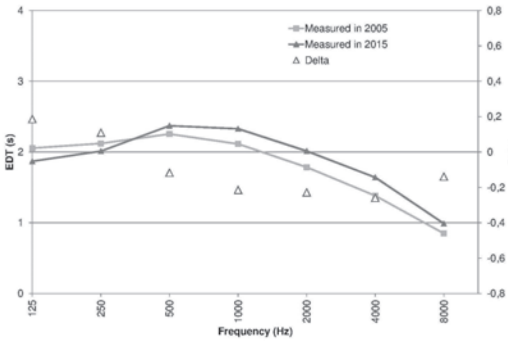
No great differences can be noticed in the comparisons regarding C_{80}. Both in the audience and in the orders the values are very similar, even if a small increase of C_{80} in the measurements performed in 2015 can be noticed in the orders for mid frequency bands.

Comparisons regarding D_{50} show almost the same behaviour of C_{80}: in the audience the values are very similar and also in the orders, but with a small increase of D_{50} in the measurements performed in 2015 in the orders for mid frequency bands.

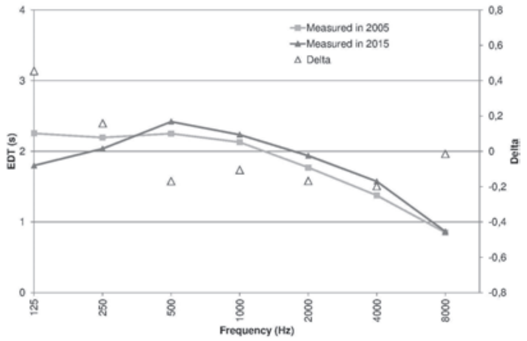
4.4 Reverberation parameters

As regard EDT, measurements done in 2015 show lower value in low frequency bands and higher values in mid and high frequency bands, but no great differences are present (figure 4.4).

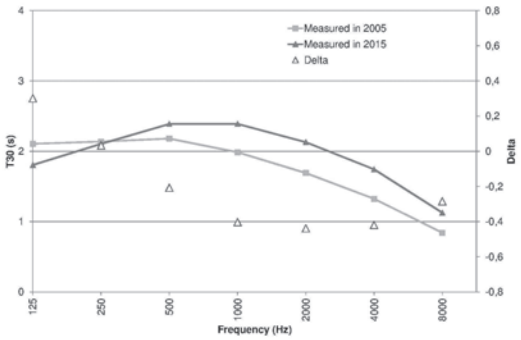
As regard T_{30}, more pronounced differences are noticeable from 500 Hz to 8000 Hz. The values obtained form measurements performed in 2015 are higher than ones



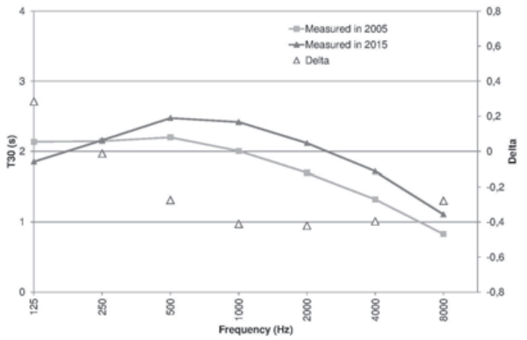
(a) EDT in the audience.



(b) EDT in the orders.



(c) T_{30} in the audience.



(d) T_{30} in the orders.

Figure 4.4: Comparisons between values of reverberation parameters measured in 2005 and in 2015.

obtained in 2005 (figure 4.4).

4.5 Absorption

As said before, the reverberation time can be estimated through the application of Sabine equation (equation 4.1), where A is defined according to equation 4.2:

$$T_R = 0,16 * \frac{V}{A} \qquad (s) \tag{4.1}$$

$$A = \Sigma \alpha_i S_i \qquad (m^2) \tag{4.2}$$

Where α_i is the sound absorption coefficient of each surface S_i.

The absorption A can be estimated as (equation 4.1):

$$A = 0,16 * \frac{V}{T_R} \qquad (m^2) \tag{4.3}$$

For the estimation of the absorption, the volume of the entire Theatre has been estimated with the volume of the model realized in 2005, that is 7200 m^3 [26]. The absorption of 2005 has been calculated in frequency using the T_{30} obtained from the measurements performed in 2005 and the absorption of 2015 has been calculated in frequency using the T_{30} obtained from the measurements performed in 2015. Then the difference has been calculated.

As visible in figure 4.5, the absorption is increased in 2015 at low (125 Hz) and high (8000 Hz) frequencies, while for the mid frequencies the absorption is not changed very much, even if is a bit lower in 2015.

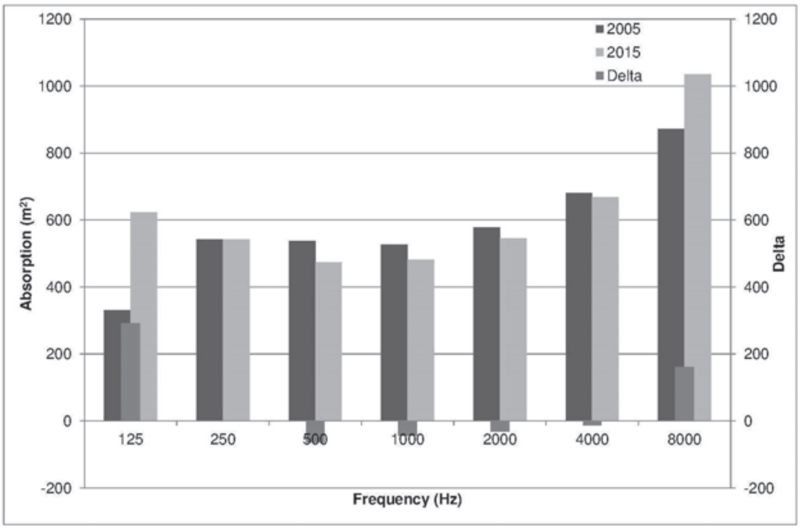


Figure 4.5: Absorption variation between 2005 and 2015.

4.6 Conclusions

From the comparisons between energy and reverberation parameters (C_{80}, D_{50}, EDT and T_{30}) measured in 2005 and the same parameters measured in 2015, it can be noticed that the Theatre has maintained its characteristics. A little increase of the C_{80} can be noticed in the orders, while a noticeable increase of T_{30} can be seen in all the Theatre, even if it has to be considered that the positions of receivers are not exactly the same, because of the differences between the Theatre conditions before and after the restoration.

All the differences that can be noticed between the measurements performed in 2005 and 2015 are around the just noticeable difference (JND) or a bit more than JND:

- differences of C_{80} assume values to the maximum of 1 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume values around 0,05 (JND equal to 0,05 [1]);
- differences of EDT assume values around 0,2 s (JND equal to the 5% [1], so around 0,1 s).

As regard the absorption, it is increased in 2015 at low (125 Hz) and high (8000 Hz) frequencies, while for the mid frequencies the absorption is not changed very much, even if it is a bit lower in 2015.

Chapter 5

Measurements reproducibility with different equipments

5.1 Analysis procedure

The analysis of the results has been carried out comparing the arithmetic mean of the different parameters (C_{80}, D_{50}, T_s, EDT, T_{10}, T_{20} and T_{30}) in the different areas of the Theatre (audience, first order, second order and stage). The arithmetic mean has been chosen for all the parameters, even the ones in decibels (dB). The arithmetic mean has been preferred, as the ISO 3382 suggests [1], over the energetic one because the difference is very small, as visible in figure 5.1 (differences less than 1 dB, that is the JND for C_{80}), and to adopt the same method of the Dirac software, that presents the average as arithmetic one.

The choice of presenting and compare the values of the criteria averaged over each area of the Civic Theatre (audience, first order, second order and stage), has been done to provide an overall description of the acoustics of the Theatre, in line with the previous literature [16].

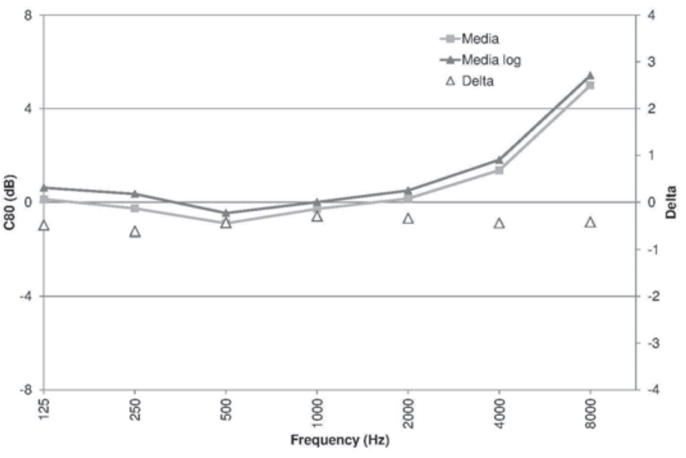


Figure 5.1: Comparison between arithmetic and energetic average regarding the C_{80} measured in the audience on 10/09/2015 with omnidirectional source.

5.2 Comparison between different equipments with omnidirectional source

The parameters obtained from the measurements done with two different equipments have been compared. Both the equipments have had an omnidirectional dodecahedron as sound source. The first equipment (indicated as PD) consisted in:

- Omnidirectional dodecahedron Bruel e Kjaer 4296;
- 2 microphones Grass half inch;
- Digigram sound card VX Pocket v.2;
- Amplifier LAB300;
- PC IBM with software DIRAC Bruel e Kjaer.

The second equipment (indicated as BO) consisted in:

- Omnidirectional dodecahedron with custom 8 inches cone;
- 4 monoaural microphones Bruel e Kjaer 4190 half inch;
- Preamplifier Bruel e Kjaer 2669;
- AD/DA converter RME fireface 800;
- MacBook with custom acquisition software.

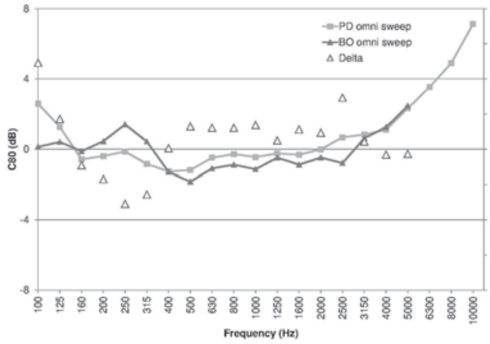
In this kind of comparison, the values of parameters obtained from the measurements done with the omnidirectional dodecahedron on 11/09/2015 have not been taken into account in the frequency bands above 5000 Hz, for 1/3 octave bands analysis, and above 4000 Hz, for octave bands analysis, because the dodecahedron used didn't emit above these frequency bands. In addition, the dodecahedron used on 11/09/2015 fully emitted at 125 Hz, while the measurements done with the dodecahedron used on 10/09/2015 are more uncertain at that frequency.

The reproducibility of the measurement has been studied comparing different and independent equipments, applied by different and independent operators, performing the same set of measurements. The measurements, however, have not been performed exactly in the same way, because, for example, the positions chosen have not been the same. In addition, the analysis has been performed only with regard to the decay curve, not for example by evaluating the *inter aural cross correlation* (IACC).

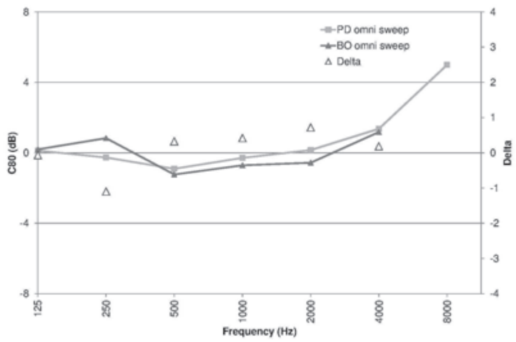
5.2.1 Audience

Comparisons regarding the audience are shown in figure 5.2 and 5.3.

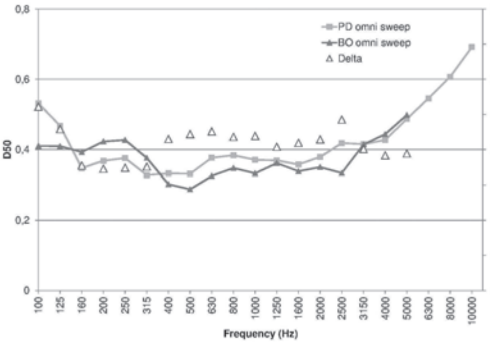
Regarding the clarity, the definition and the centre time, the averages of the measurements done with two different equipments with the same type of source, omnidirectional one, are very similar. The analysis in 1/3 octave bands and in octave bands shown the same behaviour, even if more fluctuation of the parameters are shown in 1/3 octave bands analysis. For clarity, the difference is almost always under than 1 dB, while, for definition, it is always under 0,1, so a bit more than the just noticeable difference of the quantities. The averages of the centre time are similar, but some differences can be noticed comparing the 1/3 octave bands analysis and the octave bands



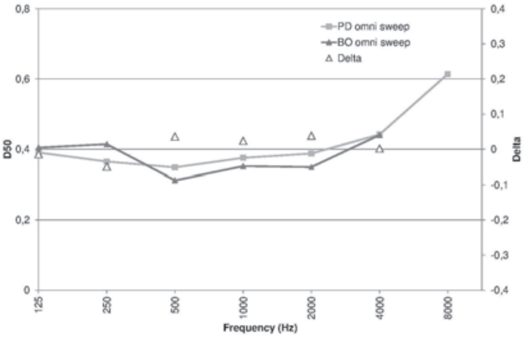
(a) C_{80} in 1/3 octave bands.



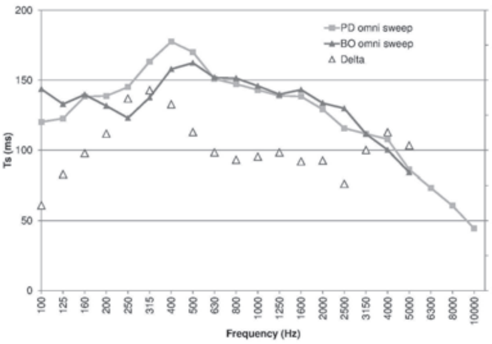
(b) C_{80} in octave bands.



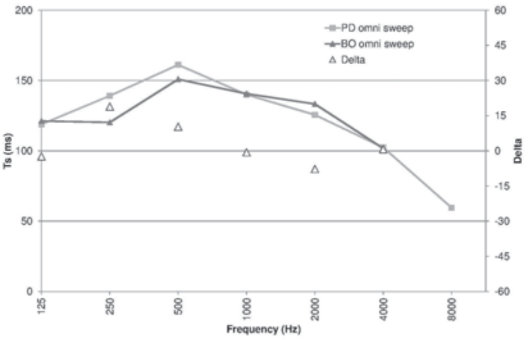
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.



(e) T_s in 1/3 octave bands.



(f) T_s in octave bands.

Figure 5.2: Comparisons regarding the audience between different equipments, with omnidirectional source (C_{80}, D_{50} and T_s).

analysis. In 1/3 octave bands, in fact, there are a noticeable difference in the averages in the lower frequencies (100 ÷ 400 Hz).

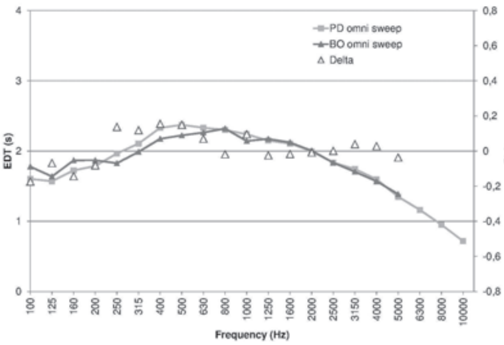
As regard the reverberation time and the early decay time, the averages of the two sets of measurement are almost equal, with a difference near to zero.

5.2.2 First order

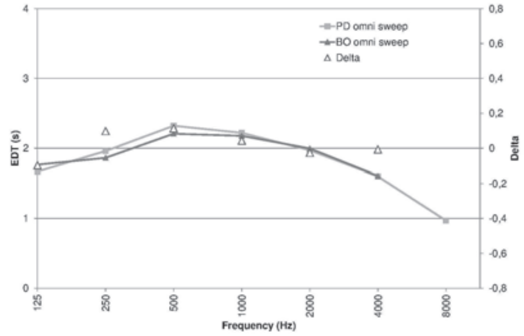
Comparisons regarding the first order are shown in figure 5.4 and 5.5.

Regarding the clarity, the definition and the centre time, a difference (greater than just noticeable difference) can be noticed both in 1/3 octave band analysis (200 ÷ 400 Hz) and in octave bands (250 Hz).

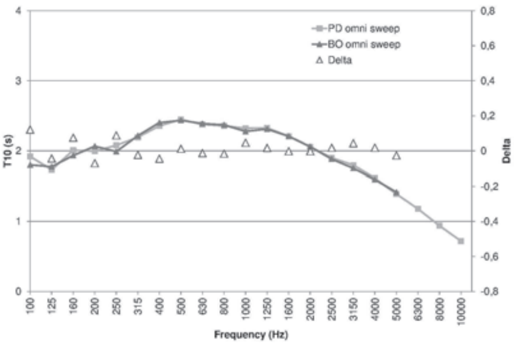
As regard the reverberation time and the early decay time, the averages of the two sets of measurement are almost equal, with a difference near to zero.



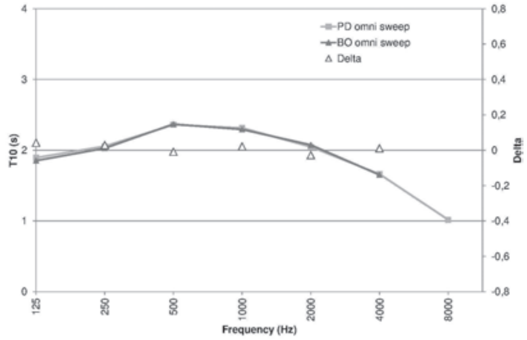
(a) EDT in 1/3 octave bands.



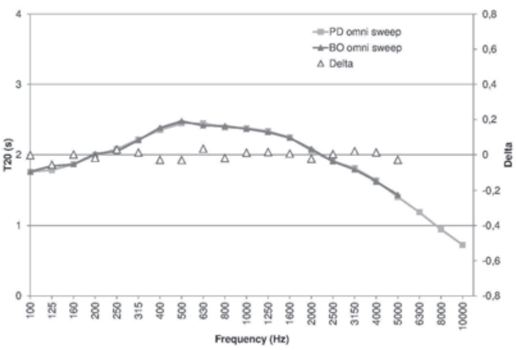
(b) EDT in octave bands.



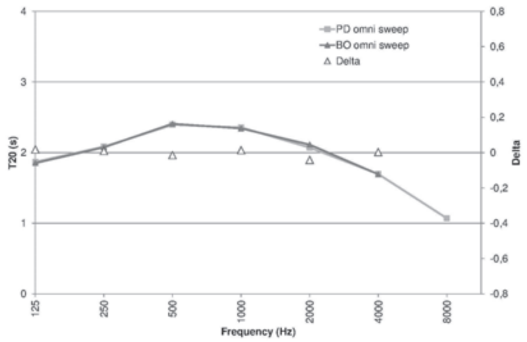
(c) T_{10} in 1/3 octave bands.



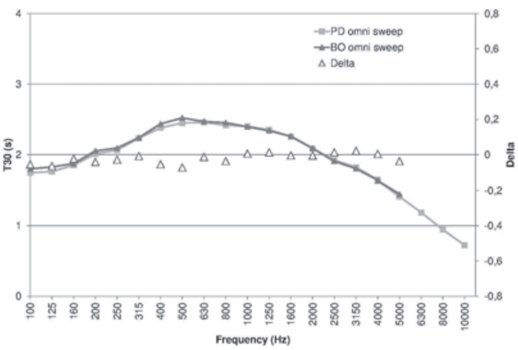
(d) T_{10} in octave bands.



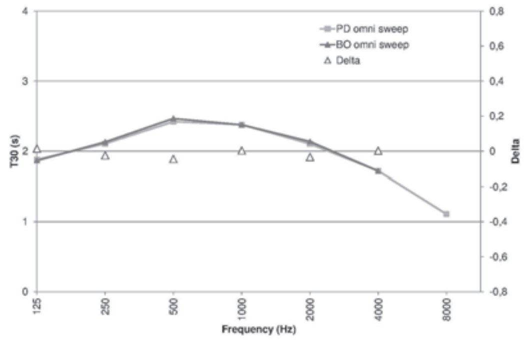
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.

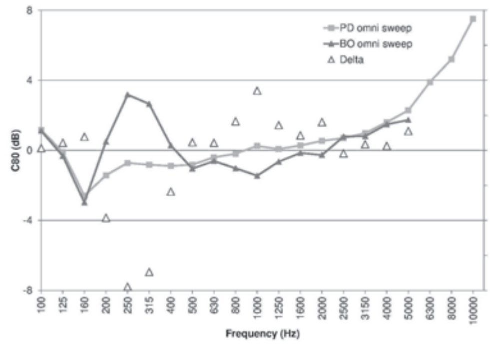


(g) T_{30} in 1/3 octave bands.

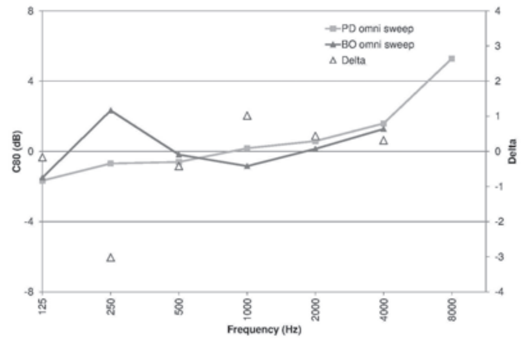


(h) T_{30} in octave bands.

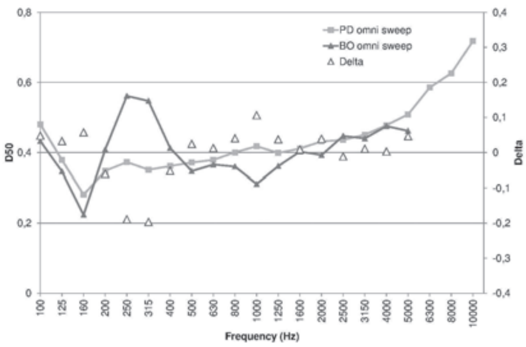
Figure 5.3: Comparisons regarding the audience between different equipments, with omnidirectional source (EDT, T_{10}, T_{20} and T_{30}).



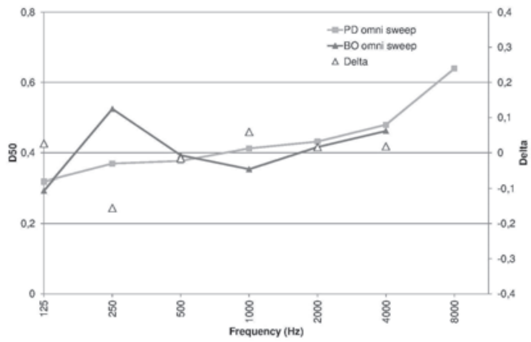
(a) C_{80} in 1/3 octave bands.



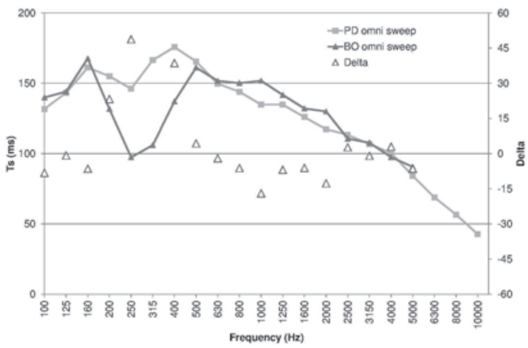
(b) C_{80} in octave bands.



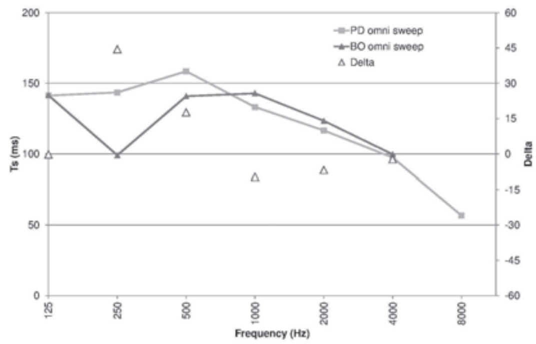
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

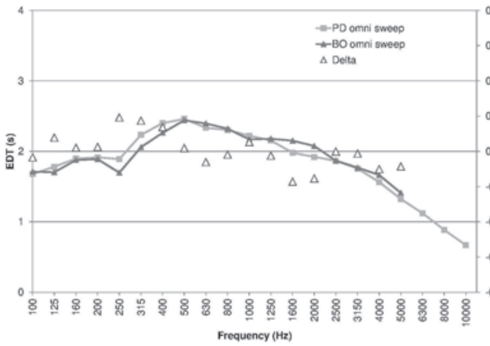


(e) T_s in 1/3 octave bands.

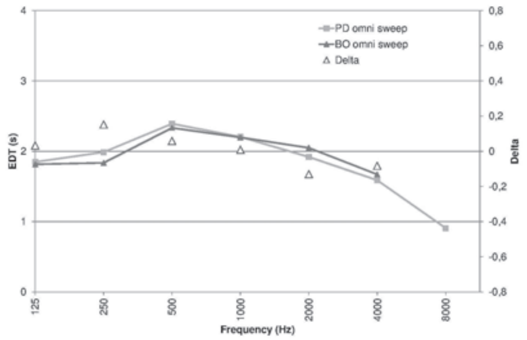


(f) T_s in octave bands.

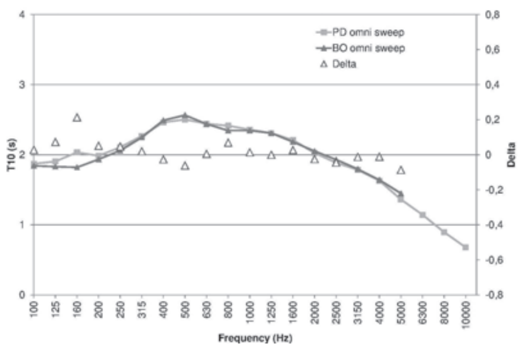
Figure 5.4: Comparisons regarding the first order between different equipments, with omnidirectional source (C_{80}, D_{50} and T_s).



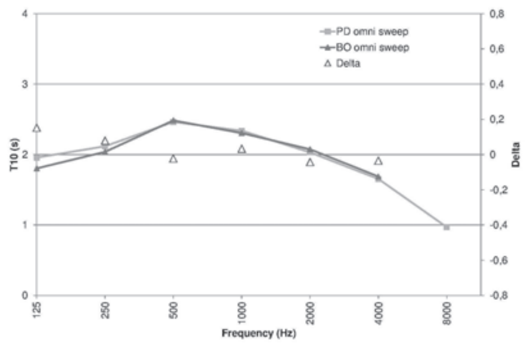
(a) EDT in 1/3 octave bands.



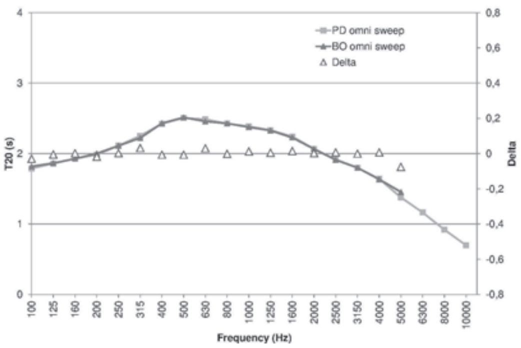
(b) EDT in octave bands.



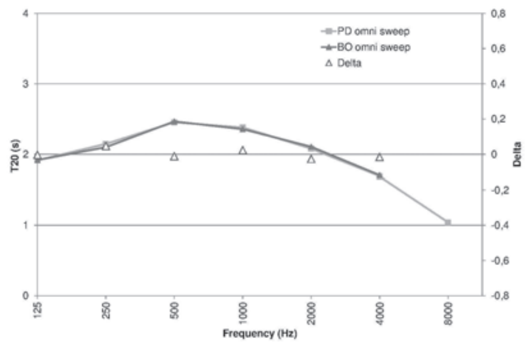
(c) T_{10} in 1/3 octave bands.



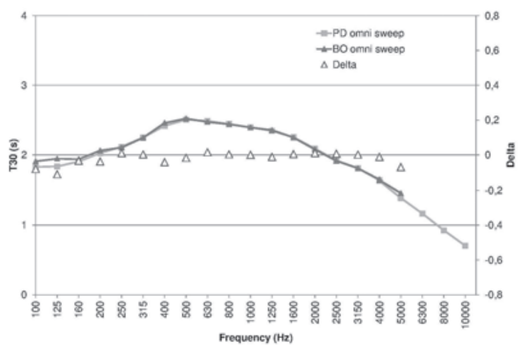
(d) T_{10} in octave bands.



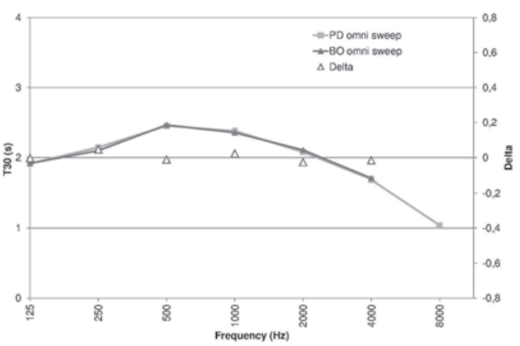
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.

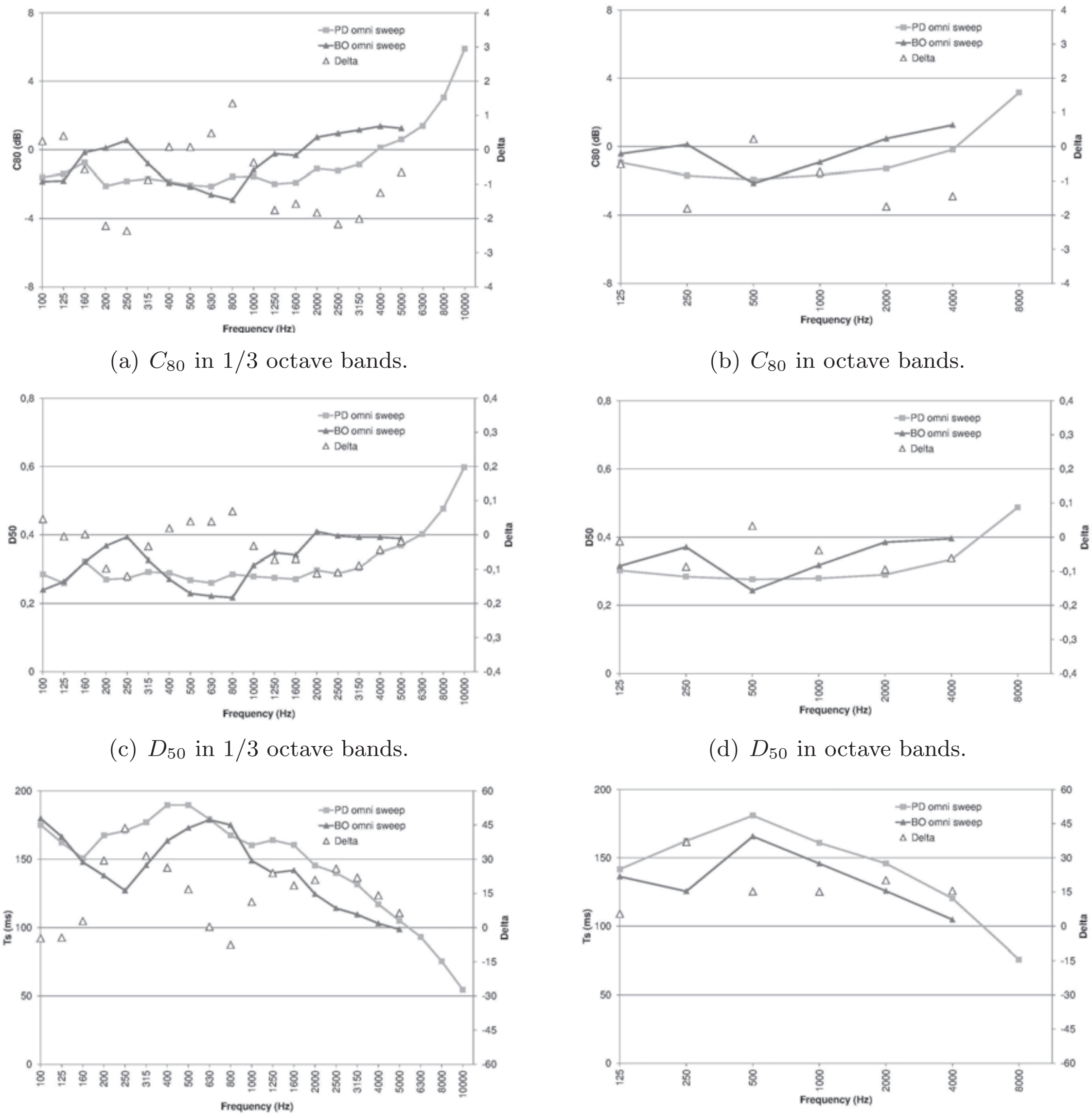


(g) T_{30} in 1/3 octave bands.



(h) T_{30} in octave bands.

Figure 5.5: Comparisons regarding the first order between different equipments, with omnidirectional source (EDT, T_{10}, T_{20} and T_{30}).



(a) C_{80} in 1/3 octave bands.

(b) C_{80} in octave bands.

(c) D_{50} in 1/3 octave bands.

(d) D_{50} in octave bands.

(e) T_s in 1/3 octave bands.

(f) T_s in octave bands.

Figure 5.6: Comparisons regarding the second order between different equipments, with omnidirectional source (C_{80}, D_{50} and T_s).

5.2.3 Second order

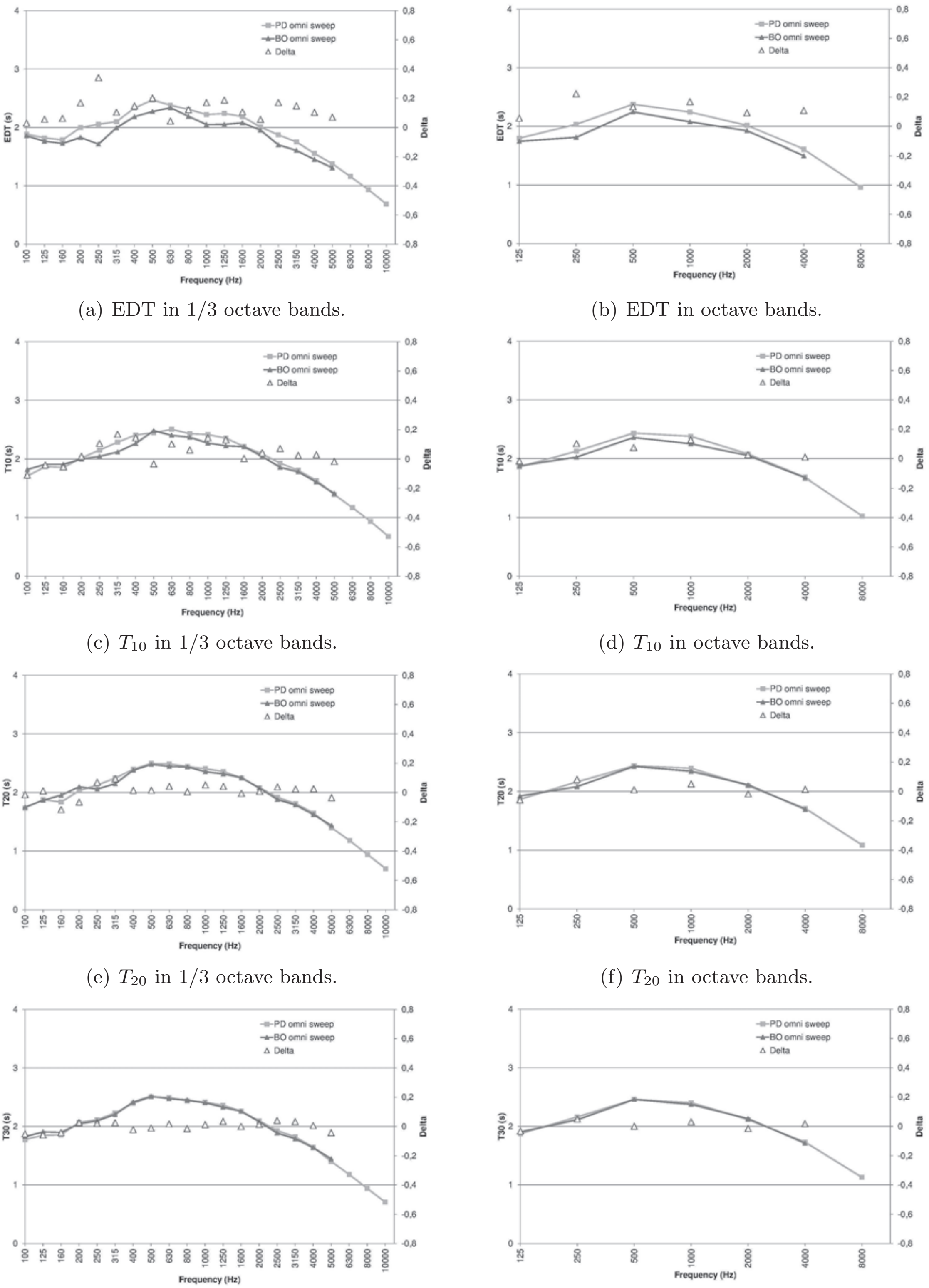
Comparisons regarding the second order are shown in figure 5.6 and 5.7.

Regarding the clarity, the definition and the centre time, the differences of the averages are more pronounced than ones in the audience and in the first order.

As regard EDT and T_{10}, the averages are slightly different; the average referred to the second equipment (BO) is a little lower than the one referred to the first equipment (PD). As regard the T_{20} and the T_{30}, the averages of the two sets of measurement are almost equal, with a difference near to zero.

5.3 Conclusions

Analysing the comparisons between different equipments with omnidirectional source, some conclusions can be done.



(a) EDT in 1/3 octave bands.

(b) EDT in octave bands.

(c) T_{10} in 1/3 octave bands.

(d) T_{10} in octave bands.

(e) T_{20} in 1/3 octave bands.

(f) T_{20} in octave bands.

(g) T_{30} in 1/3 octave bands.

(h) T_{30} in octave bands.

Figure 5.7: Comparisons regarding the second order between different equipments, with omnidirectional source (EDT, T_{10}, T_{20} and T_{30}).

In all the comparisons, the reverberation time (T_{10}, T_{20} and T_{30}) and the EDT have a more stable behaviour, almost equal for both the equipments.

C_{80}, D_{50} and T_s show greater differences in the first order in low frequency bands and in the second order in all the frequencies. Regarding this comparisons, another situation can be noticed: at 250 Hz, the energy parameters have a different behaviour, in fact C_{80} and D_{50} are higher with the equipment of the 11/09/2015, while T_s is lower with the equipment of the 11/09/2015.

All the differences that can be noticed between the measurements performed with the 2 different equipments with omnidirectional source in the audience are around the just noticeable difference (JND) or a bit more than JND:

- differences of C_{80} assume values around 1 dB, to the maximum of 2 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume values around 0,1 (JND equal to 0,05 [1]);
- differences of T_s assume values between 0 and 30 ms (JND equal to 10 ms [1]);
- differences of EDT assume values around 0, to the maximum of 0,2 s (JND equal to the 5% [1], so around 0,1 s).

The differences that can be noticed between the measurements performed with the 2 different equipments with omnidirectional source in the orders are a bit more than JND, the differences are a bit higher:

- differences of C_{80} assume values to the maximum of 4 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume values to the maximum of 0,2 (JND equal to 0,05 [1]);
- differences of T_s assume values to the maximum of 45 ms (JND equal to 10 ms [1]);
- differences of EDT assume values around 0, to the maximum of 0,35 s (JND equal to the 5% [1], so around 0,1 s).

In tables 5.1 and 5.2 the results have been shown averaged also between some representative frequency bands, to give a synthetic overview of the characteristics of the Theatre and to better visualize the possible differences between the 2 equipments. The results reported in table 5.2 have been extracted using Matlab. It can be seen that values of EDT and T_{30} are very similar, although the values of EDT referred to the measurements done on 11/09/2015 are a bit lower in the second order. Values of T_s referred to the measurements done on 11/09/2015 are lower in all the configurations. Values of C_{80} don't have a specific trend: some values are similar, while some other values, referred to the measurements done on 11/09/2015, are lower (in the audience and in the first order for S3, in the first and second orders for S1 and in the second order for S2).

source	receiver	EDT_3 (s)	$T_{30,3}$ (s)	$T_{s,M}$ (ms)	$C_{80,3}$ (dB)
proscenium (S3)	audience	2,03	2,31	132	0,7
	first order	2,09	2,31	137	0,5
	second order	2,12	2,32	163	-1,2
centre stage (S1)	audience	2,24	2,30	159	-0,8
	first order	2,21	2,34	145	0,5
	second order	2,23	2,32	174	-1,4
back stage (S2)	audience	2,35	2,30	183	-2,1
	first order	2,32	2,31	176	-1,9
	second order	2,30	2,33	177	-1,9

Table 5.1: Results of measurements done on 10/09/2015 (PD). The measured values have been averaged for the receivers area (audience, first order and second order). The pedix "M" specifies that the value is averaged in 500 and 1000 Hz octave bands. The pedix "3" specifies that the value is averaged in 500, 1000 and 2000 Hz octave bands.

source	receiver	EDT_3 (s)	$T_{30,3}$ (s)	$T_{s,M}$ (ms)	$C_{80,3}$ (dB)
proscenium (S3)	audience	2,00	2,30	125	-0,1
	first order	2,10	2,33	128	0,0
	second order	2,05	2,33	147	-1,2
centre stage (S1)	audience	2,20	2,33	146	-1,0
	first order	2,20	2,35	141	-0,8
	second order	2,00	2,33	137	-0,2
back stage (S2)	audience	2,29	2,34	168	-2,4
	first order	2,31	2,34	152	-1,4
	second order	2,09	2,32	145	-0,8

Table 5.2: Results of measurements done on 11/09/2015 (BO). The measured values have been averaged for the receivers area (audience, first order and second order). The pedix "M" specifies that the value is averaged in 500 and 1000 Hz octave bands. The pedix "3" specifies that the value is averaged in 500, 1000 and 2000 Hz octave bands.

Chapter 6

Sensitivity analysis of the acoustic parameters

6.1 Analysis procedure

As previously said, the analysis of the results has been carried out comparing the arithmetic mean of the different parameters (C_{80}, D_{50}, T_s, EDT, T_{10}, T_{20} and T_{30}) in the different areas of the Theatre (audience, first order, second order and stage). The arithmetic mean has been chosen for all the parameters, even the ones in decibels (dB), as the ISO 33382 suggests [1], because the difference between arithmetic and energetic mean is very small and in order to adopt the same method of the Dirac software, that presents the average as arithmetic one.

The choice of presenting and compare the values of the criteria averaged over each area of the Civic Theatre (audience, first order, second order and stage), has been done to provide an overall description of the acoustics of the Theatre, in line with the previous literature [16].

In addition, a comparison between different settings in the measurements of intelligibility parameters is presented, analysing the values of STIPA in the receiver positions in the audience.

6.2 Comparisons between source types: omnidirectional and directional

The parameters obtained from the measurements done with two different types of source, omnidirectional and directional, have been compared. The first equipment (indicated as OMNI) consisted in:

- Omnidirectional dodecahedron with custom 8 inches loudspeakers;
- 4 monoaural microphones Bruel e Kjaer 4190 half inch;
- Preamplifier Bruel e Kjaer 2669;
- AD/DA converter RME fireface 800;
- MacBook with custom acquisition software.

The second equipment (indicated as DIR) consisted in:

- Directive loudspeaker placed at 1,5 m with amplitude directivity about 60 degrees on the horizontal plane and 90 degrees on the vertical plane;

- 4 monoaural microphones Bruel e Kjaer 4190 half inch;
- Preamplifier Bruel e Kjaer 2669;
- AD/DA converter RME fireface 800;
- MacBook with custom acquisition software.

It has to be noticed that the graphical representations of the comparisons between measurements with omnidirectional and directional source have a different scale of representation respect to other graphs. In fact, in this kind of comparisons, the values of parameters obtained from the measurements on 11/09/2015 have not been taken into account in the frequency bands above 5000 Hz, for 1/3 octave bands analysis, and above 4000 Hz, for octave bands analysis, because the dodecahedron used didn't emit above these frequency bands.

6.2.1 Audience

Comparisons regarding the audience are shown in figure 6.1 and 6.2.

Both the clarity, the definition and the centre time show a parallel shift in averages in the frequency bands above 500 Hz, with bigger differences in 1/3 octave bands analysis. The clarity shows differences around 4 dB, the definition around 0,2 and centre time around 50 ms, that are almost four times the just noticeable differences.

As regard EDT and T_{10}, the averages are slightly different; the average referred to the second equipment (DIR) is a little lower than the one referred to the first equipment (OMNI). As regard the T_{20} and the T_{30}, the averages of the two sets of measurement are almost equal, with a difference near to zero.

6.2.2 First order

Comparisons regarding the first order are shown in figure 6.3 and 6.4.

The clarity, the definition and the centre time show the same parallel shift in averages in the frequency bands above 500 Hz, as in the audience.

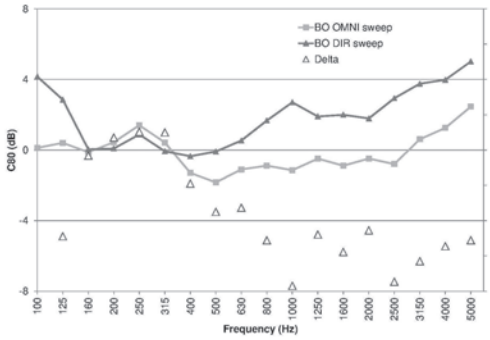
As regard EDT and T_{10}, the averages are slightly different; the average referred to the directional source is lower than the one referred to the omnidirectional one, especially as regard the EDT, where differences are around 0,5 s. As regard the T_{20} and the T_{30}, the averages of the two sets of measurement are almost equal, with a difference near to zero.

6.2.3 Second order

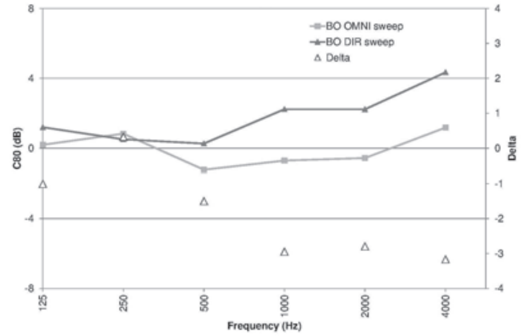
Comparisons regarding the second order are shown in figure 6.5 and 6.6.

As regard the second order, all the averages show the same behaviour as the ones referred to the first order. The clarity, the definition and the centre time show a parallel shift in averages in the frequency bands above 500 Hz.

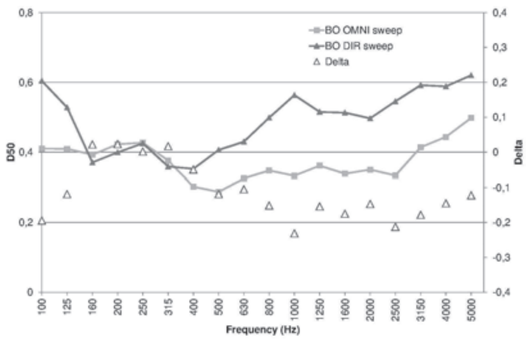
As regard EDT and T_{10}, the averages are slightly different; the average referred to the directional source is lower than the one referred to the omnidirectional one, especially as regard the EDT, where differences are around 0,5 s. As regard the T_{20} and the T_{30}, the averages of the two sets of measurement are almost equal, with a difference near to zero.



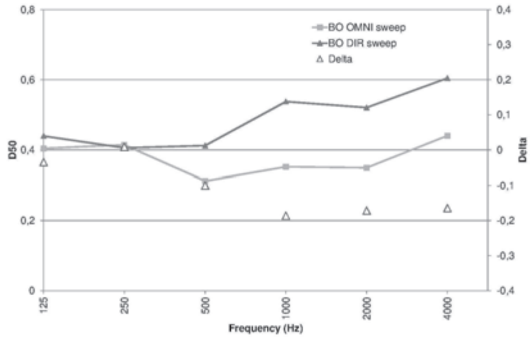
(a) C_{80} in 1/3 octave bands.



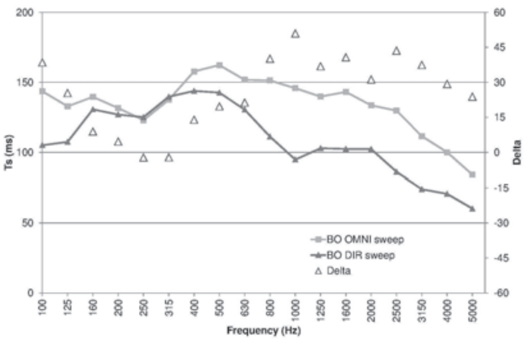
(b) C_{80} in octave bands.



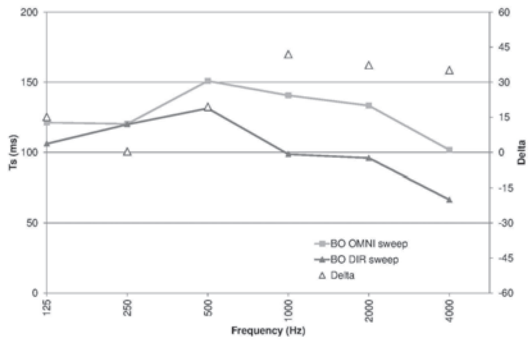
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

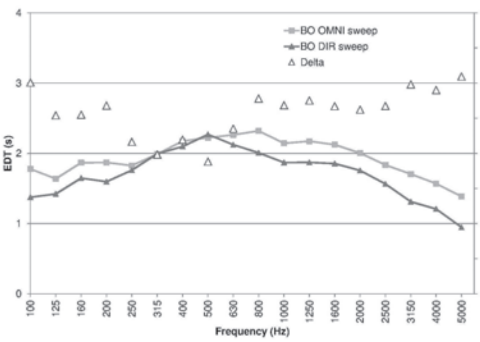


(e) T_s in 1/3 octave bands.

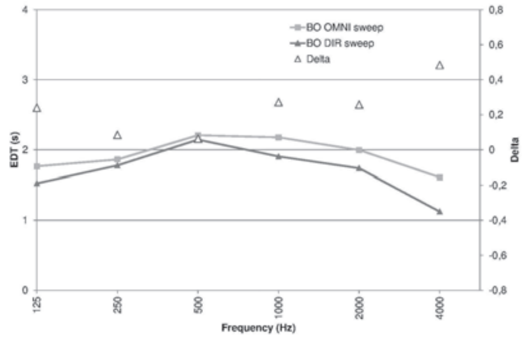


(f) T_s in octave bands.

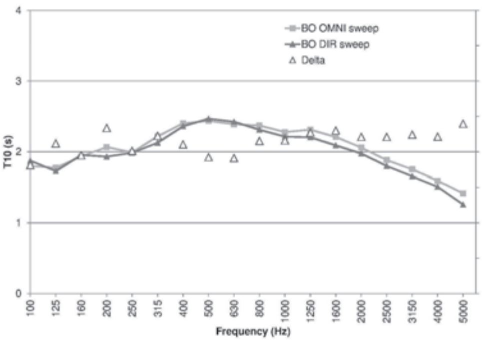
Figure 6.1: Comparisons regarding the audience between omnidirectional and directional source (C_{80}, D_{50} and T_s).



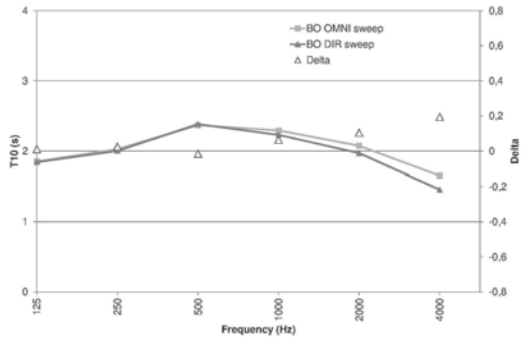
(a) EDT in 1/3 octave bands.



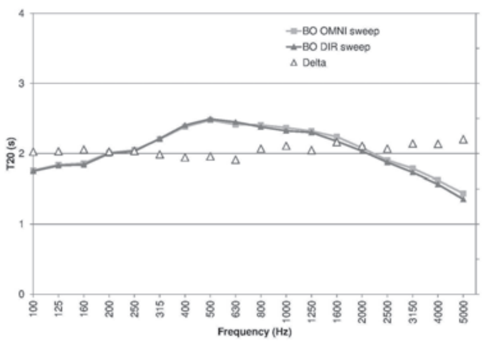
(b) EDT in octave bands.



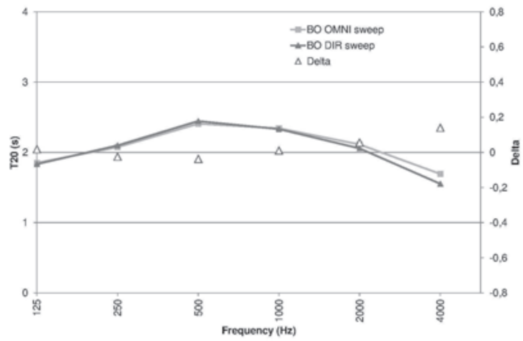
(c) T_{10} in 1/3 octave bands.



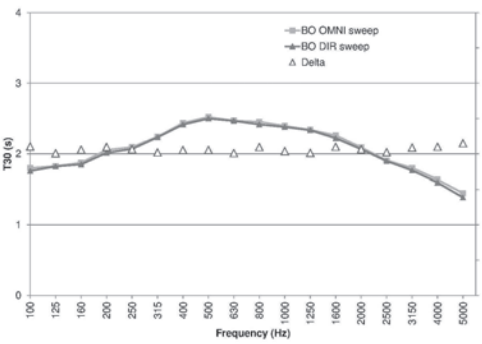
(d) T_{10} in octave bands.



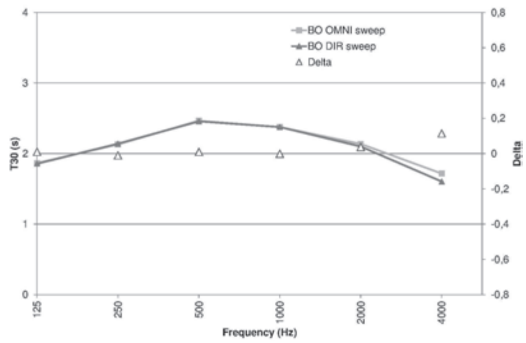
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.

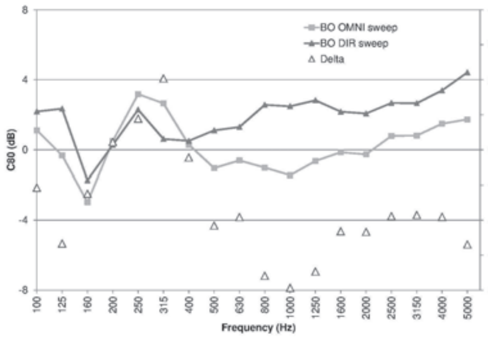


(g) T_{30} in 1/3 octave bands.

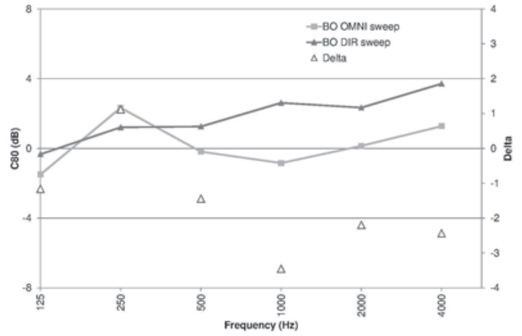


(h) T_{30} in octave bands.

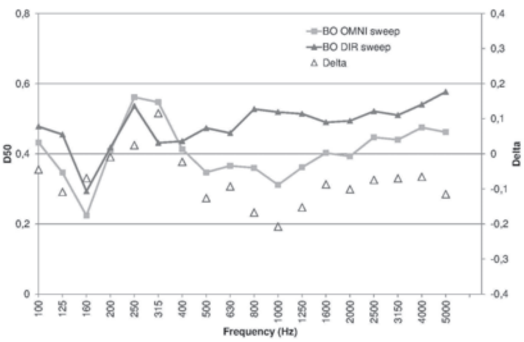
Figure 6.2: Comparisons regarding the audience between omnidirectional and directional source (EDT, T_{10}, T_{20} and T_{30}).



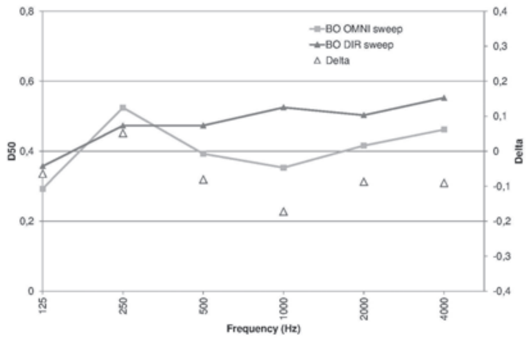
(a) C_{80} in 1/3 octave bands.



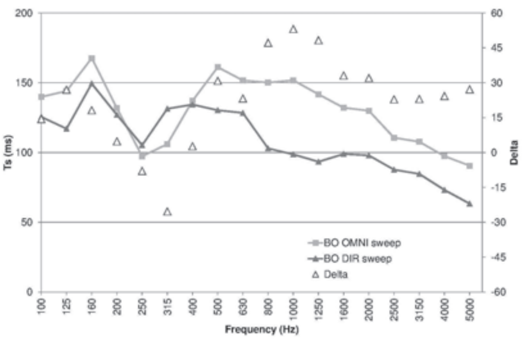
(b) C_{80} in octave bands.



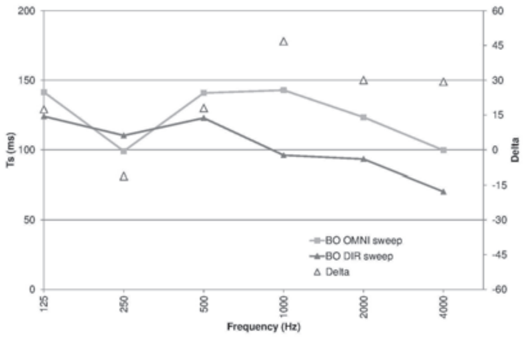
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

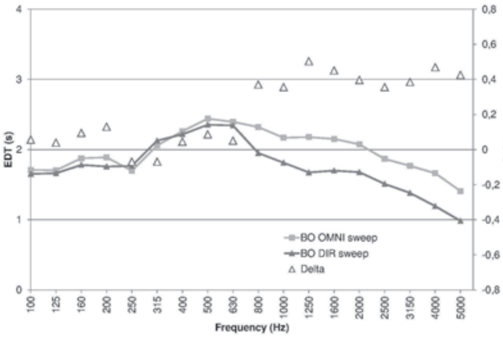


(e) T_s in 1/3 octave bands.

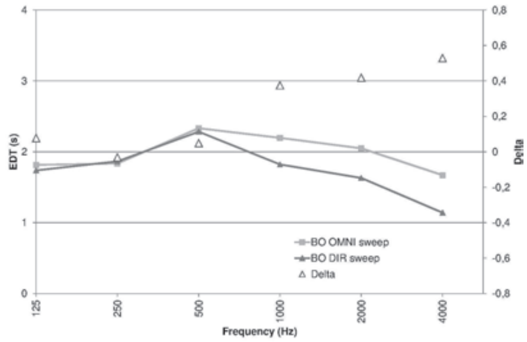


(f) T_s in octave bands.

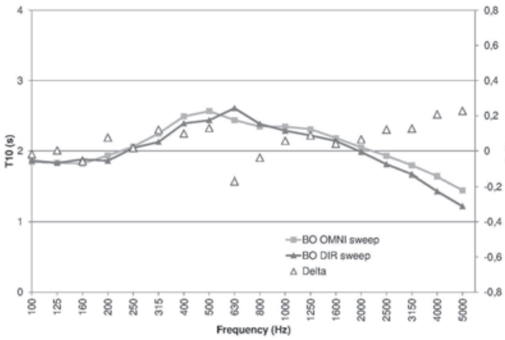
Figure 6.3: Comparisons regarding the first order between omnidirectional and directional source (C_{80}, D_{50} and T_s).



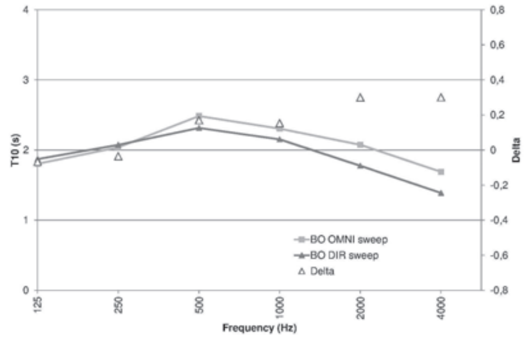
(a) EDT in 1/3 octave bands.



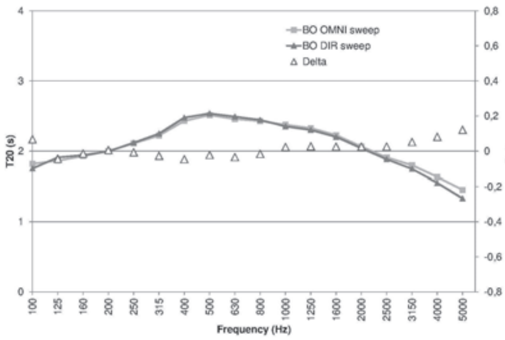
(b) EDT in octave bands.



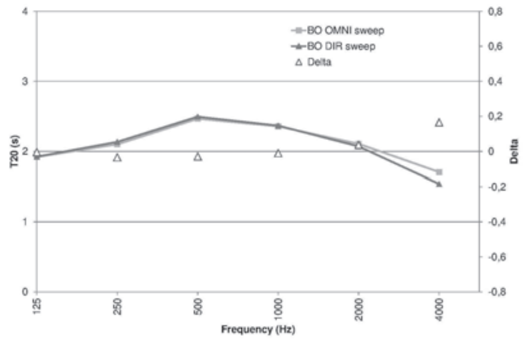
(c) T_{10} in 1/3 octave bands.



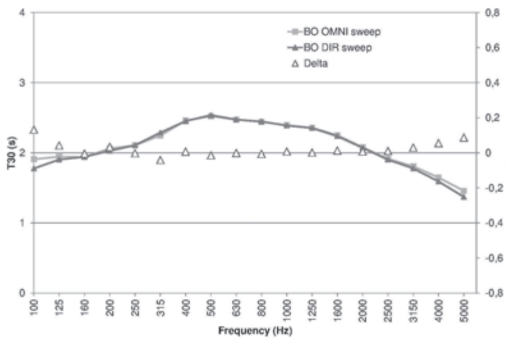
(d) T_{10} in octave bands.



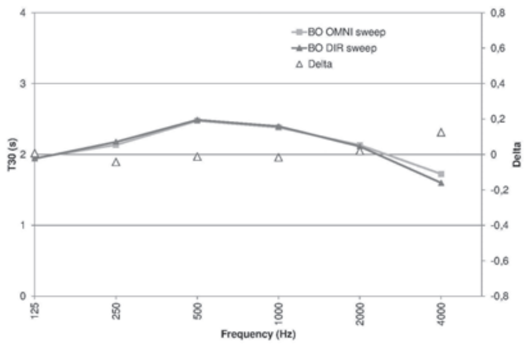
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.

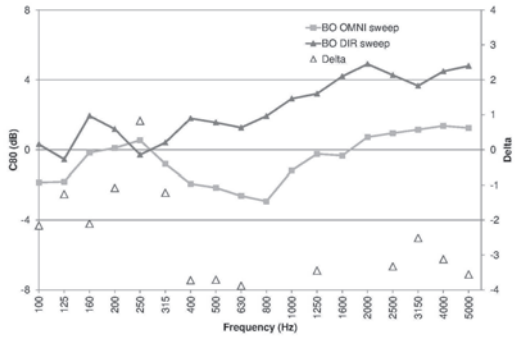


(g) T_{30} in 1/3 octave bands.

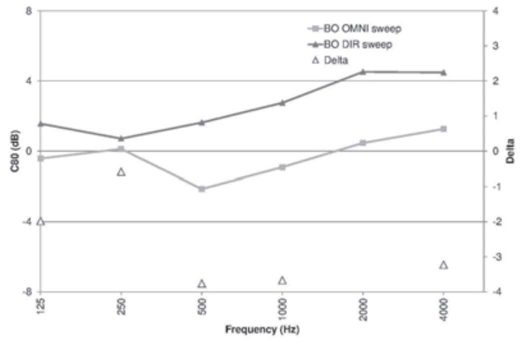


(h) T_{30} in octave bands.

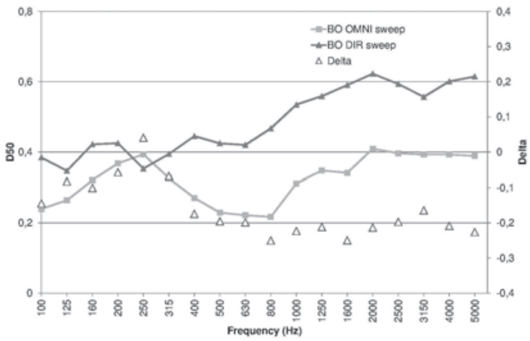
Figure 6.4: Comparisons regarding the first order between omnidirectional and directional source (EDT, T_{10}, T_{20} and T_{30}).



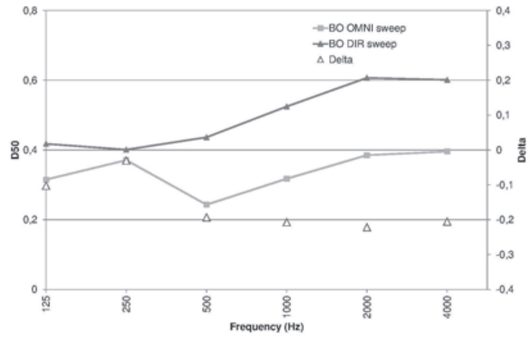
(a) C_{80} in 1/3 octave bands.



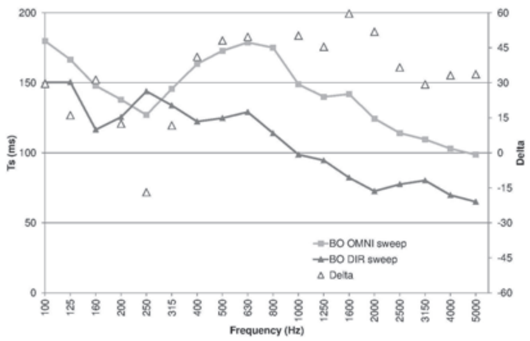
(b) C_{80} in octave bands.



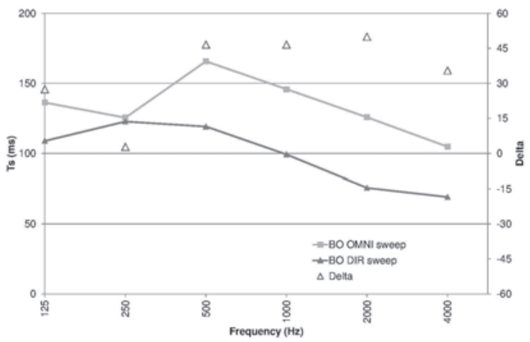
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

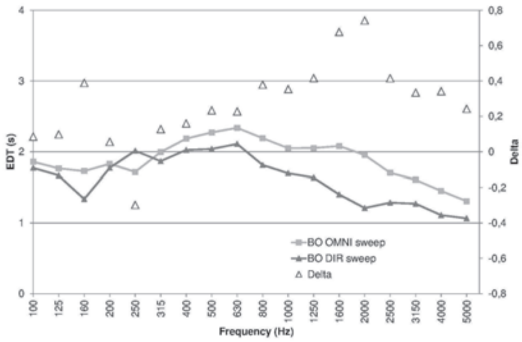


(e) T_s in 1/3 octave bands.

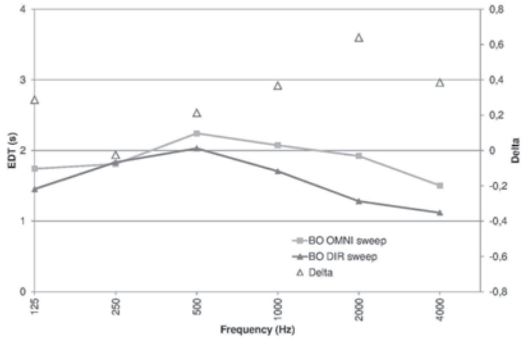


(f) T_s in octave bands.

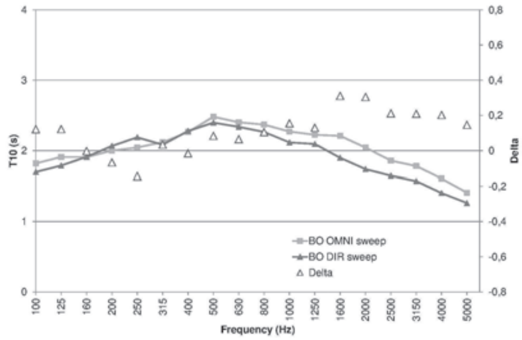
Figure 6.5: Comparisons regarding the second order between omnidirectional and directional source (C_{80}, D_{50} and T_s).



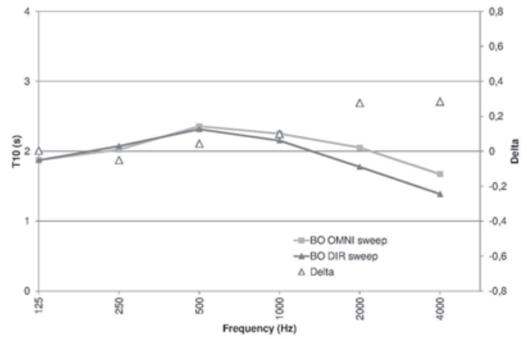
(a) EDT in 1/3 octave bands.



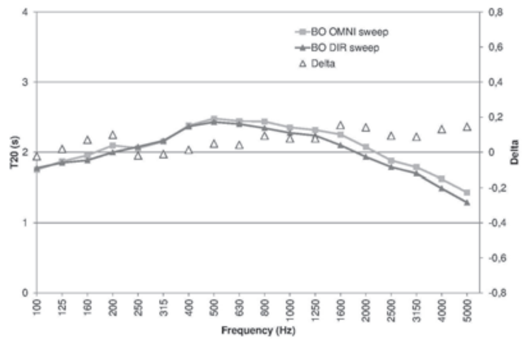
(b) EDT in octave bands.



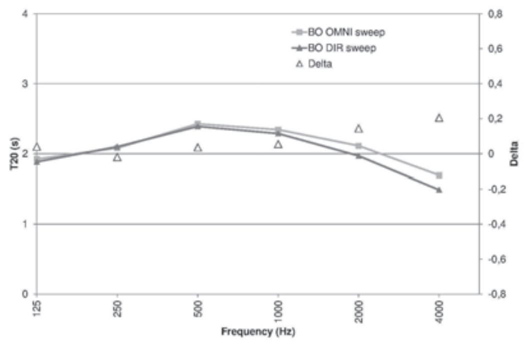
(c) T_{10} in 1/3 octave bands.



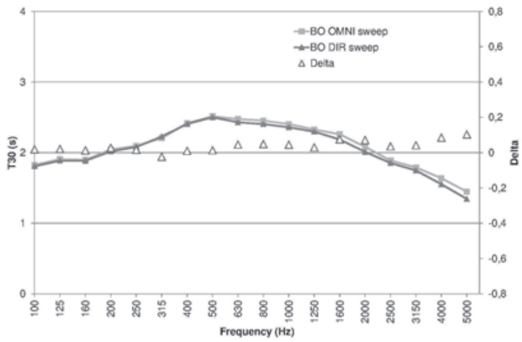
(d) T_{10} in octave bands.



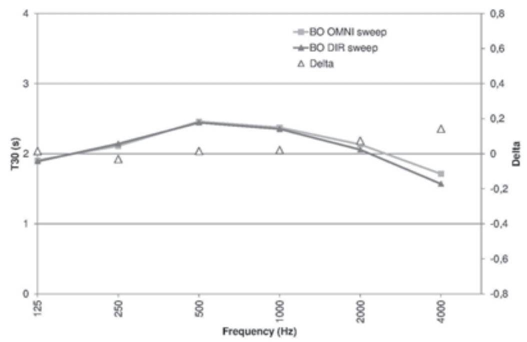
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.



(g) T_{30} in 1/3 octave bands.



(h) T_{30} in octave bands.

Figure 6.6: Comparisons regarding the second order between omnidirectional and directional source (EDT, T_{10}, T_{20} and T_{30}).

6.3 Comparisons between source types: sweep and balloon

The parameters obtained from the measurements done with two different types of source, omnidirectional dodecahedron and balloon, have been compared. The first equipment (indicated as SWEEP) consisted in:

- Omnidirectional dodecahedron Bruel e Kjaer 4296;
- 2 microphones Grass half inch;
- Digigram sound card VX Pocket v.2;
- Amplifier LAB300;
- PC IBM with software DIRAC Bruel e Kjaer, providing exponential sine sweep.

The second equipment (indicated as BALLOON) consisted in:

- Balloons;
- 2 microphones Grass half inch;
- Digigram sound card VX Pocket v.2;
- Amplifier LAB300;
- PC IBM with software DIRAC Bruel e Kjaer.

6.3.1 Audience

Comparisons regarding the audience are shown in figure 6.7 and 6.8.

The clarity, the definition and the centre time show a parallel shift in averages in all the frequency bands. As regard clarity and definition, the average obtained with the measurements with balloons is lower than the one obtained with a omnidirectional source emitting a sine sweep, while for the centre time the average obtained with the balloons is higher than the one obtained with the sine sweep.

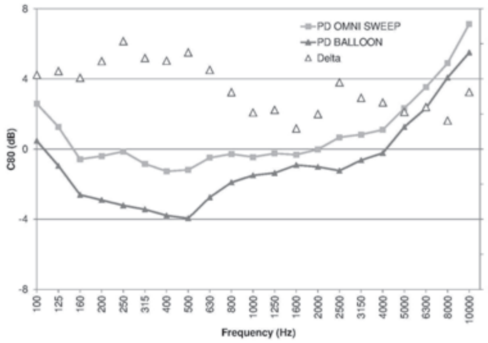
As regard the reverberation time and the early decay time, the averages of the two sets of measurement are almost equal, with a difference near to zero.

6.3.2 Stage

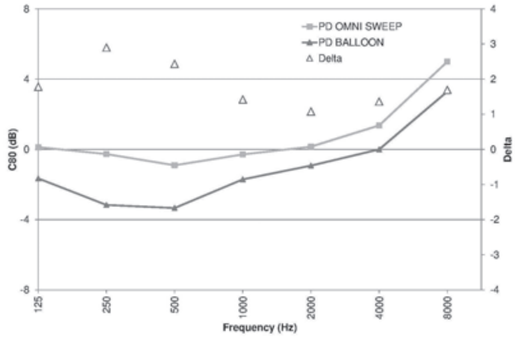
Comparisons regarding the stage are shown in figure 6.9 and 6.10. It has to be noticed that the graphical representations of C_{80} and T_s on the stage have a different scale of representation as regards the delta respect to the other graphs, because differences are bigger.

The clarity, the definition and the centre time show a parallel shift in averages in all the frequency bands. As regard clarity and definition, the average obtained with the measurements with balloons is lower than the one obtained with a omnidirectional source emitting a sine sweep, while for the centre time the average obtained with the balloons is higher than the one obtained with the sine sweep.

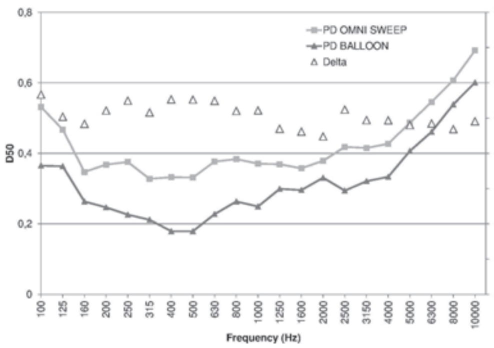
As regard the reverberation time and the early decay time, the averages of the two sets of measurement are almost equal, with a difference near to zero. It can be noticed that, for the reverberation times, the averages obtained from the measurements done with the balloons are slightly higher than the ones obtained with the sine sweep.



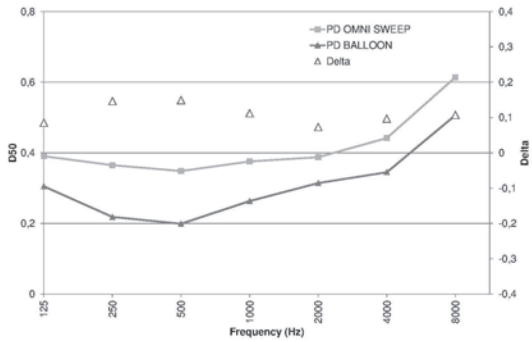
(a) C_{80} in 1/3 octave bands.



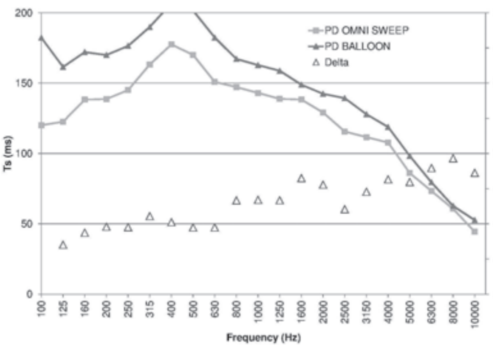
(b) C_{80} in octave bands.



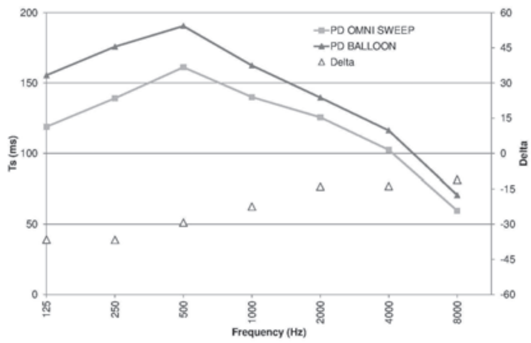
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

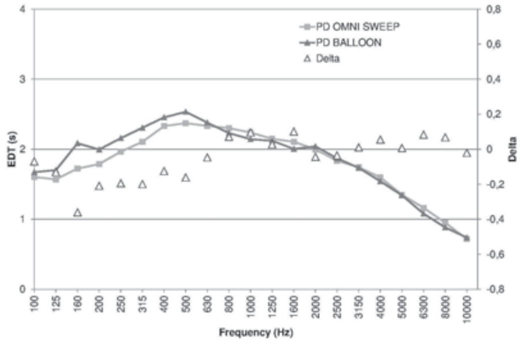


(e) T_s in 1/3 octave bands.

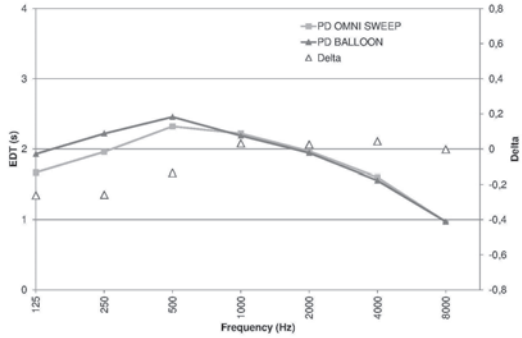


(f) T_s in octave bands.

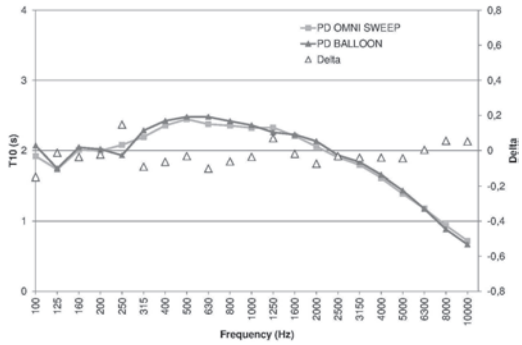
Figure 6.7: Comparisons regarding the audience between sweep and balloons (C_{80}, D_{50} and T_s).



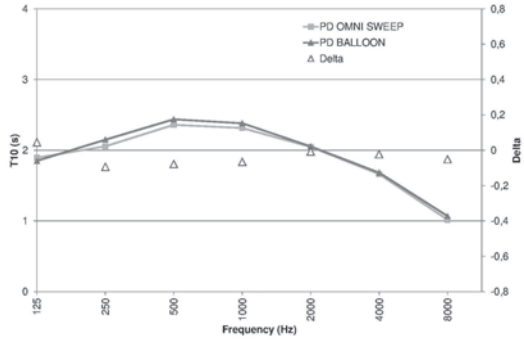
(a) EDT in 1/3 octave bands.



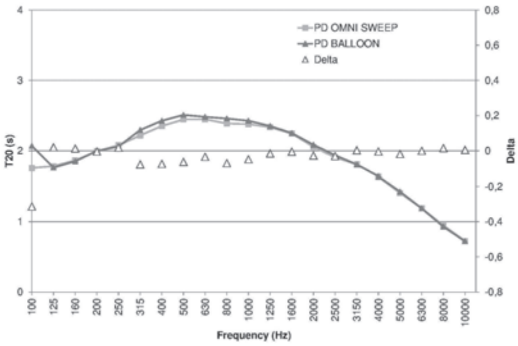
(b) EDT in octave bands.



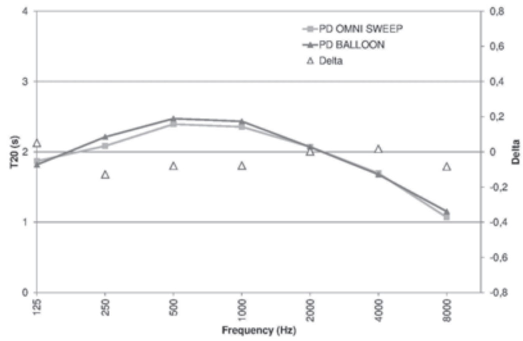
(c) T_{10} in 1/3 octave bands.



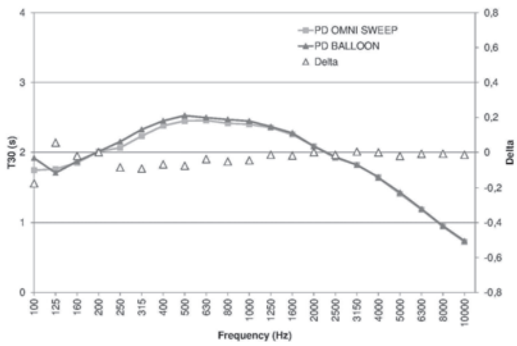
(d) T_{10} in octave bands.



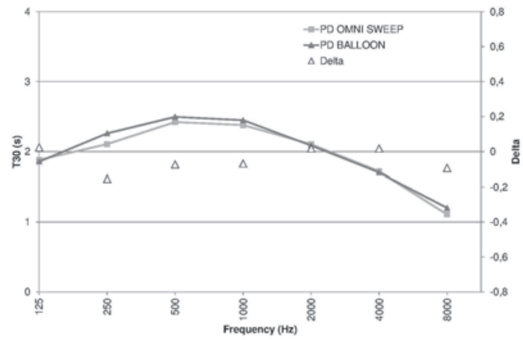
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.

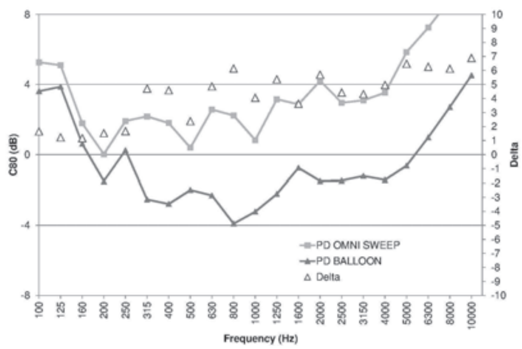


(g) T_{30} in 1/3 octave bands.

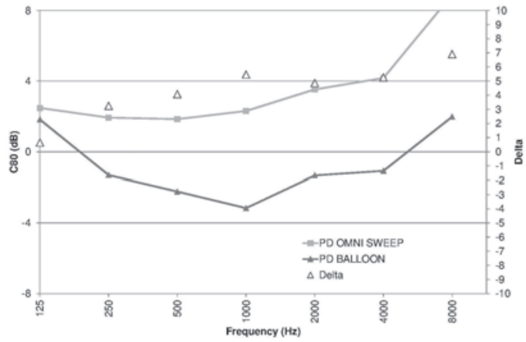


(h) T_{30} in octave bands.

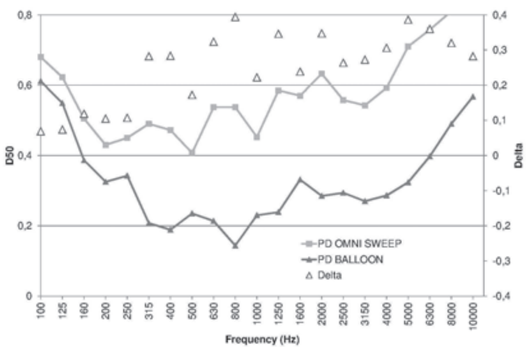
Figure 6.8: Comparisons regarding the audience between sweep and balloons (EDT, T_{10}, T_{20} and T_{30}).



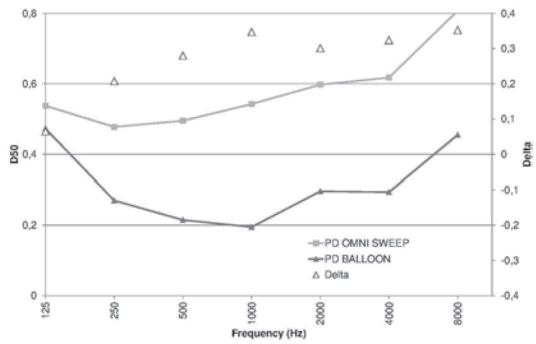
(a) C_{80} in 1/3 octave bands.



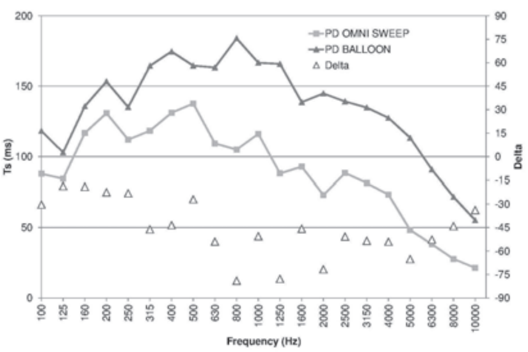
(b) C_{80} in octave bands.



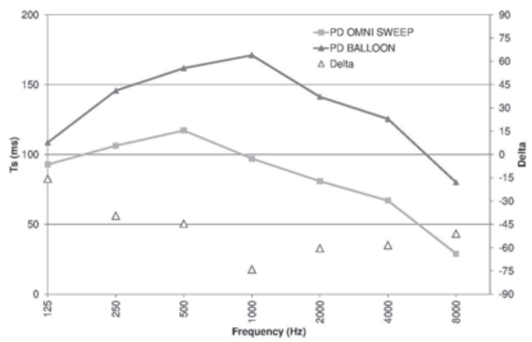
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

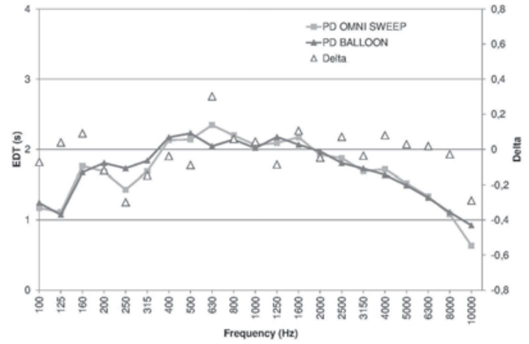


(e) T_s in 1/3 octave bands.

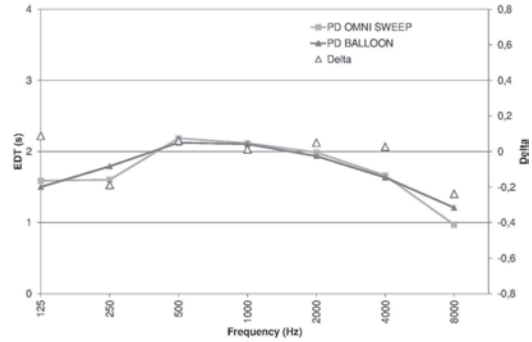


(f) T_s in octave bands.

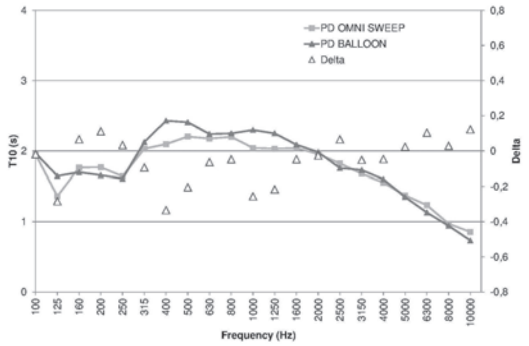
Figure 6.9: Comparisons regarding the stage between sweep and balloons (C_{80}, D_{50} and T_s).



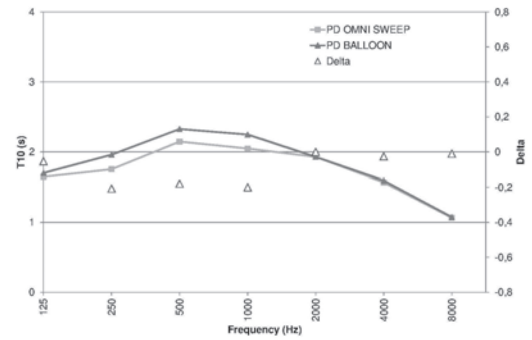
(a) EDT in 1/3 octave bands.



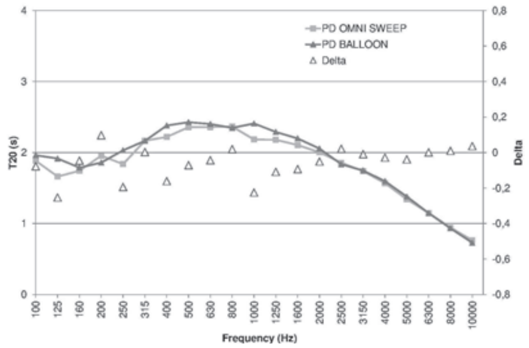
(b) EDT in octave bands.



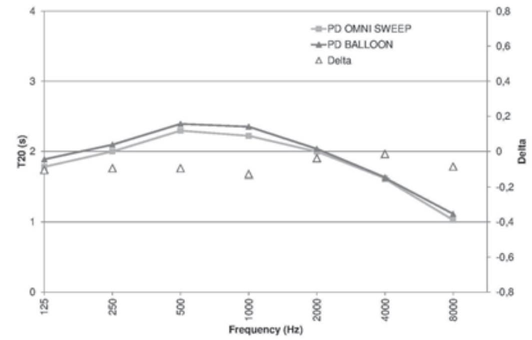
(c) T_{10} in 1/3 octave bands.



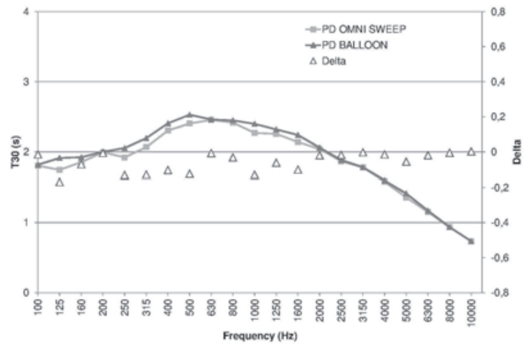
(d) T_{10} in octave bands.



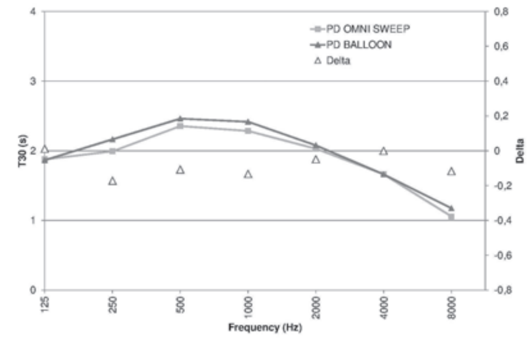
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.



(g) T_{30} in 1/3 octave bands.



(h) T_{30} in octave bands.

Figure 6.10: Comparisons regarding the stage between sweep and balloons (EDT, T_{10}, T_{20} and T_{30}).

6.4 Comparisons between acquisition equipments: Dirac and Tascam

The parameters obtained from the measurements done with two different equipments for the acquisition have been compared. The first equipment (indicated as DIRAC) consisted in:

- Balloons;
- 2 microphones Bruel e Kjaer 4189 half inch;
- Amplifier LAB300;
- PC IBM with software DIRAC Bruel e Kjaer.

The second equipment (indicated as TASCAM) consisted in:

- Balloons;
- Tascam digital recorder.

6.4.1 Audience

Comparisons regarding the audience are shown in figure 6.11 and 6.12.

The clarity, the definition and the centre time show a parallel shift in averages in all the frequency bands. As regard clarity and definition, the average obtained with the acquisition done with Tascam digital recorder is higher than the one obtained with the other equipment, while for the centre time the average obtained with the Tascam digital recorder is lower than the one obtained with the other equipment.

As regard the reverberation time and the early decay time, the averages of the two sets of measurement are almost equal, with a difference near to zero.

6.4.2 Stage

Comparisons regarding the stage are shown in figure 6.13 and 6.14. It has to be noticed that the graphical representations of C_{80} and T_s on the stage have a different scale of representation as regards the delta respect to the other graphs, because differences are bigger.

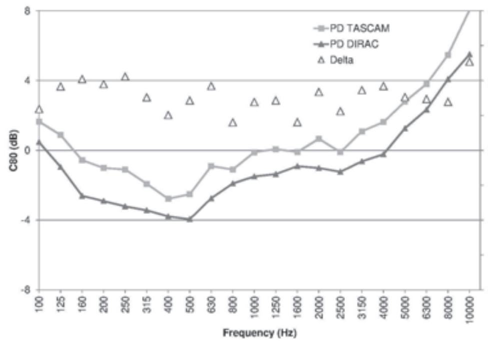
The clarity, the definition and the centre time show a parallel shift in averages in all the frequency bands. As regard clarity and definition, the average obtained with the acquisition done with Tascam digital recorder is higher than the one obtained with the other equipment, while for the centre time the average obtained with the Tascam digital recorder is lower than the one obtained with the other equipment.

As regard the reverberation time and the early decay time, the averages of the two sets of measurement are almost equal, with a difference near to zero.

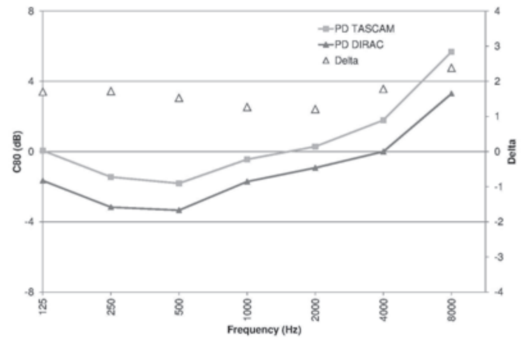
6.5 Conclusions

Analyzing the comparisons between different equipments, some conclusions can be done.

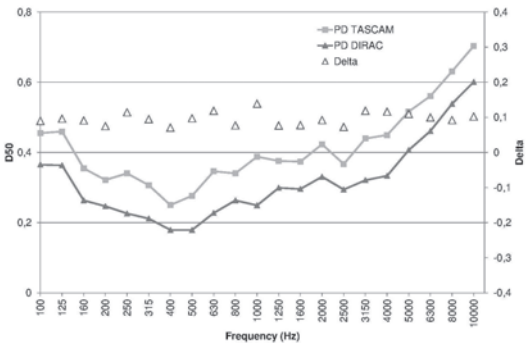
In all the comparisons, the reverberation time (T_{10}, T_{20} and T_{30}) and the EDT have a more stable behaviour, almost equal for all the equipments.



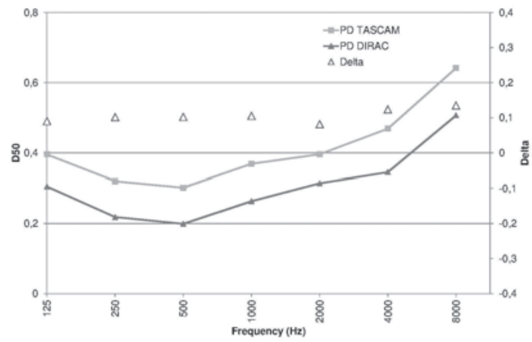
(a) C_{80} in 1/3 octave bands.



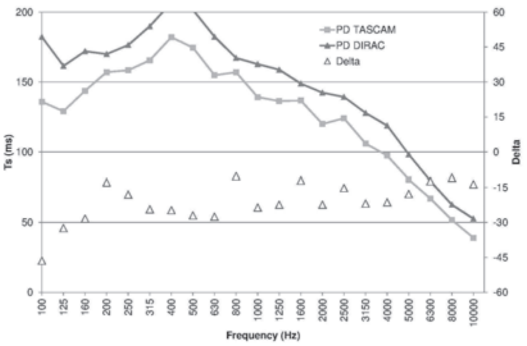
(b) C_{80} in octave bands.



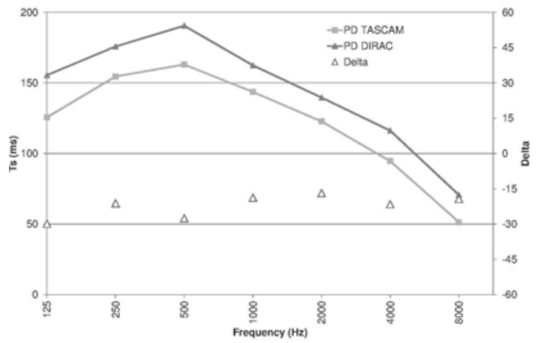
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

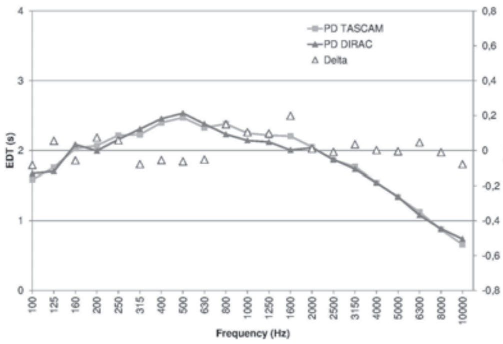


(e) T_s in 1/3 octave bands.

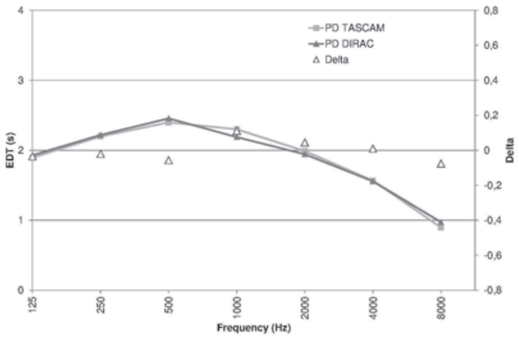


(f) T_s in octave bands.

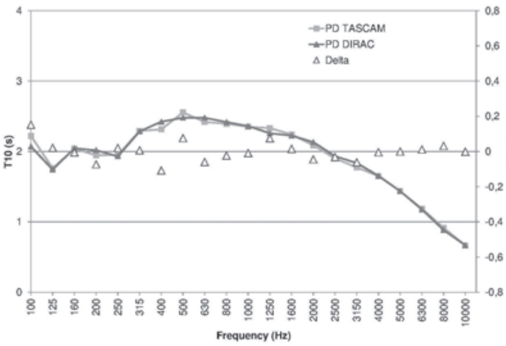
Figure 6.11: Comparisons regarding the audience between acquisition with Dirac and Tascam (C_{80}, D_{50} and T_s).



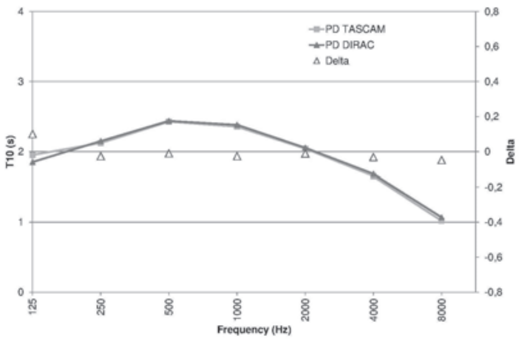
(a) EDT in 1/3 octave bands.



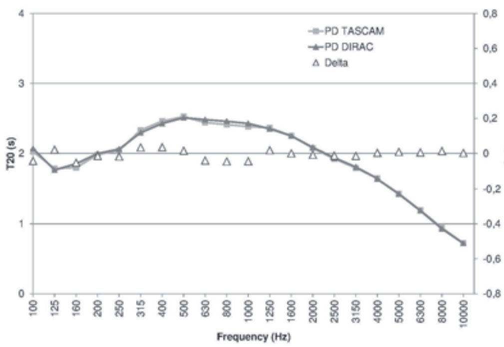
(b) EDT in octave bands.



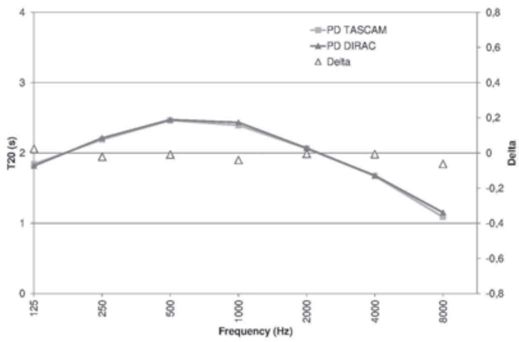
(c) T_{10} in 1/3 octave bands.



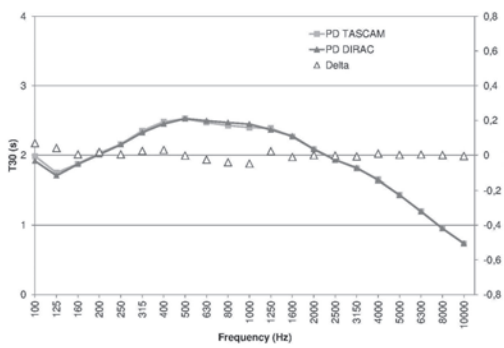
(d) T_{10} in octave bands.



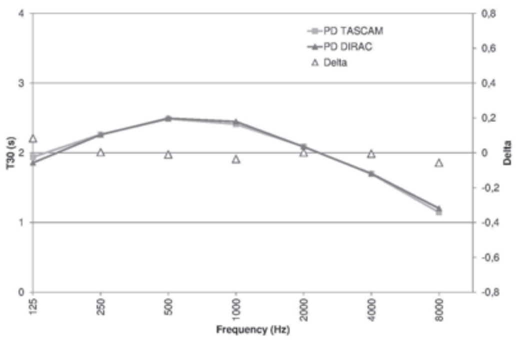
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.

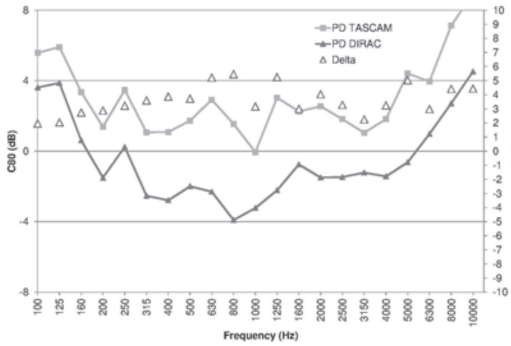


(g) T_{30} in 1/3 octave bands.

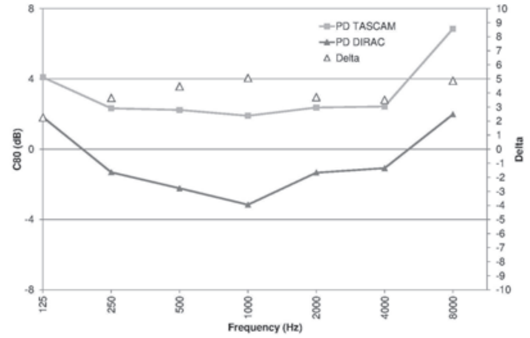


(h) T_{30} in octave bands.

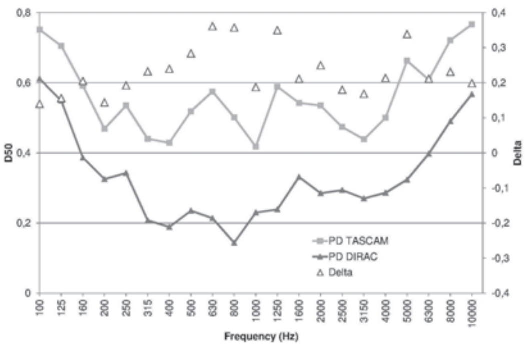
Figure 6.12: Comparisons regarding the audience between acquisition with Dirac and Tascam (EDT, T_{10}, T_{20} and T_{30}).



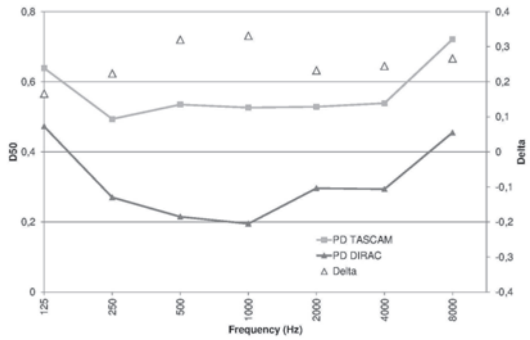
(a) C_{80} in 1/3 octave bands.



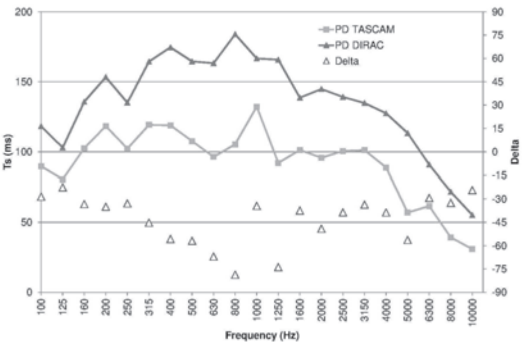
(b) C_{80} in octave bands.



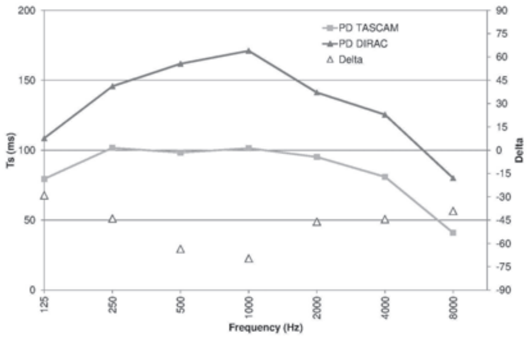
(c) D_{50} in 1/3 octave bands.



(d) D_{50} in octave bands.

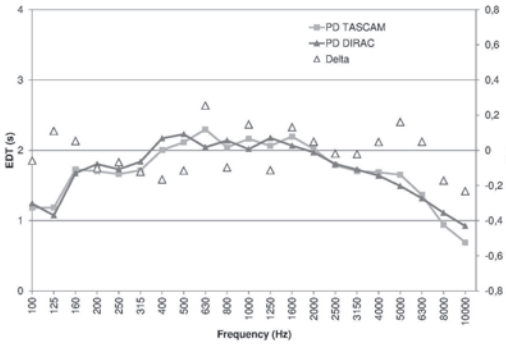


(e) T_s in 1/3 octave bands.

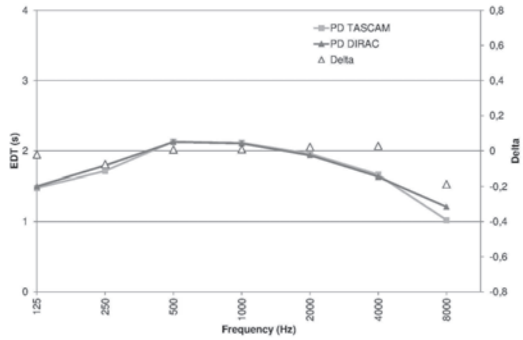


(f) T_s in octave bands.

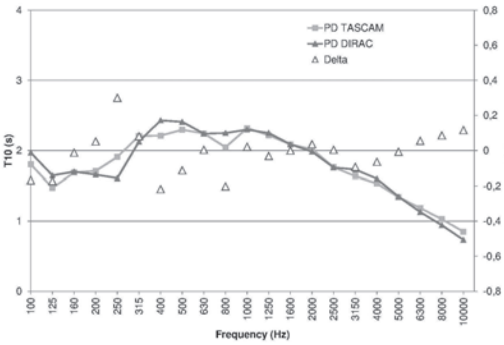
Figure 6.13: Comparisons regarding the stage between acquisition with Dirac and Tascam (C_{80}, D_{50} and T_s).



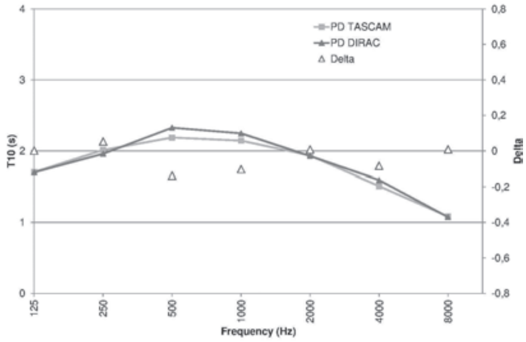
(a) EDT in 1/3 octave bands.



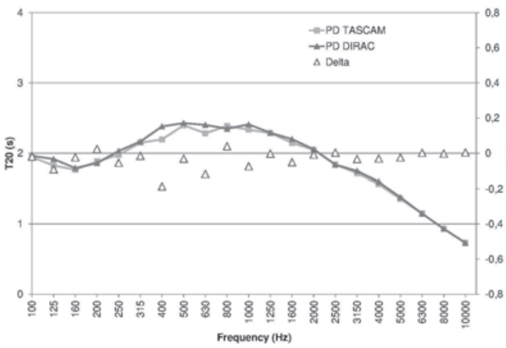
(b) EDT in octave bands.



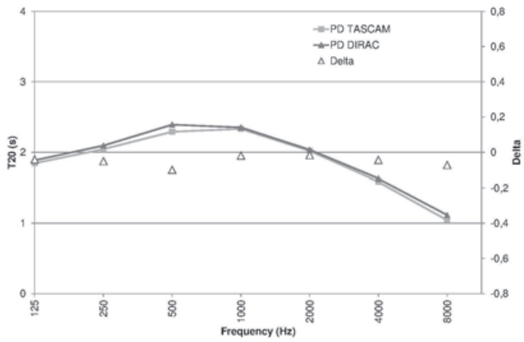
(c) T_{10} in 1/3 octave bands.



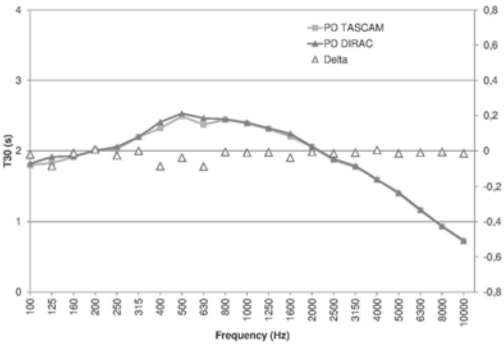
(d) T_{10} in octave bands.



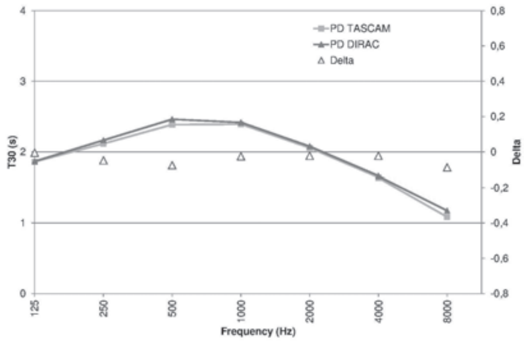
(e) T_{20} in 1/3 octave bands.



(f) T_{20} in octave bands.



(g) T_{30} in 1/3 octave bands.



(h) T_{30} in octave bands.

Figure 6.14: Comparisons regarding the stage between acquisition with Dirac and Tascam (EDT, T_{10}, T_{20} and T_{30}).

As regard the comparison between omnidirectional and directional source, C_{80}, D_{50} and T_s have a different behaviour in the frequency bands above 500 Hz in all the area: C_{80} and D_{50} are higher with directional source, while T_s is higher with omnidirectional source. Also the EDT has a different behaviour above 500 Hz: it is higher with omnidirectional source. T_{10} shows the same behaviour of EDT, but less pronounced.

The differences that can be noticed between the measurements performed with the omnidirectional and the directional source in the audience and the orders are a bit more than JND:

- differences of C_{80} assume values to the maximum of 4 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume to the maximum of 0,2 (JND equal to 0,05 [1]);
- differences of T_s assume values to the maximum of 60 ms (JND equal to 10 ms [1]);
- differences of EDT assume values to the maximum of 0,4 s and, in the second order, to the maximum of 0,8 s (JND equal to the 5% [1], so around 0,1 s).

Regarding the comparison between sweep and balloons, both for the audience and for the stage, C_{80} and D_{50} are higher if they are obtained with sine sweep, while T_s is higher if they are obtained with balloon as source.

The differences that can be noticed between the measurements performed with the sweep and balloons in the audience are a bit more than JND:

- differences of C_{80} assume values between 1 and 3 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume values around 0,1 (JND equal to 0,05 [1]);
- differences of T_s assume values between 15 and 45 ms (JND equal to 10 ms [1]);
- differences of EDT assume values between 0 and 0,1 s, to maximum values of 0,4 s (JND equal to the 5% [1], so around 0,1 s).

The differences that can be noticed between the measurements performed with the sweep and balloons on the stage are almost always more than JND:

- differences of C_{80} assume values around 5 dB, with maximum values of 7 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume values between 0,1 and 0,4 (JND equal to 0,05 [1]);
- differences of T_s assume values between 15 and 75 ms (JND equal to 10 ms [1]);
- differences of EDT assume values around 0, to maximum values of 0,3 s (JND equal to the 5% [1], so around 0,1 s).

As regard the comparison between Dirac and Tascam acquisition, C_{80} and D_{50} are higher if they are obtained with Tascam digital recorder, while T_s is higher if it is obtained with Dirac equipment.

The differences that can be noticed between the measurements acquired with Dirac and Tascam in the audience are a bit more than JND:

- differences of C_{80} assume values around 2 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume values around 0,1 (JND equal to 0,05 [1]);

- differences of T_s assume values between 15 and 30 ms (JND equal to 10 ms [1]);
- differences of EDT assume values around 0 s, to maximum values of 0,2 s (JND equal to the 5% [1], so around 0,1 s).

The differences that can be noticed between the measurements acquired with Dirac and Tascam on the stage are almost always more than JND:

- differences of C_{80} assume values between 3 and 5 dB (JND equal to 1 dB [1]);
- differences of D_{50} assume values between 0,2 and 0,4 (JND equal to 0,05 [1]);
- differences of T_s assume values between 15 and 75 ms (JND equal to 10 ms [1]);
- differences of EDT assume values around 0, to maximum values of 0,3 s (JND equal to the 5% [1], so around 0,1 s).

Regarding the comparisons of the measurements acquired with Dirac and Tascam, the clarity, the definition and the centre time show a parallel shift in averages in all the frequency bands. As regard clarity and definition, the average obtained with the acquisition done with Tascam digital recorder is higher than the one obtained with the other equipment, while for the centre time the average obtained with the Tascam is lower than the one obtained with the other equipment.

Clarity, definition and centre time are the most influenceable parameters by the variation of source type and acquisition equipment. The other parameters that can be influenceable are EDT and T_{10}. On the stage, the measurements performed show the grater differences, bigger than the JND for each parameter.

6.6 Comparison between different settings in the measurements of intelligibility parameters

STIPA values have been calculated with a direct method, using a Talk Box as source. The direct method uses test signals that have similar spectral and temporal properties to those found in natural speech. Consequently, STI test signals consists of a number of frequency bands of noise whose intensity is sinusoidally modulated [6].

In the audience, it has been possible to compare the results from two levels of emission of the source placed in S1, 70 dB at 1 m and 60 dB at 1 m (table 6.2). Differences can be noticed in all the positions, with a decrease in speech intelligibility when the source emits 60 dB at 1 m: the majority of the positions shown a value of STIPA in the range of poor speech intelligibility, according to the classification visible in table 6.1 [9]. The choice to set the level to 70 dB and to make some comparisons with a level set to 60 dB has been done because, for the measurements with a talker in the absence of a PA system, test speech level shall be set to 60 dB measured at 1 m, but, if it is required to simulate a condition with a raised vocal effort (Lombard effect), the level shall be set to 70 dB. The Lombard effect is the spontaneous increase of the vocal effort induced by the increase of the ambient noise level at the speaker's ear [6]. In a theatre, actors tend to raise their voice and so 70 dB have been chosen for the wider analysis.

Graphical representations of the results are visible in figure 6.15.

STI	0,00 ÷ 0,30	0,30 ÷ 0,45	0,45 ÷ 0,60	0,60 ÷ 0,75	0,75 ÷ 1,00
Intelligibility	Bad	Poor	Fair	Good	Excellent

Table 6.1: Relation between STI and speech intelligibility [9].

	S1 70 dB	S1 60 dB	Δ
1	0,50	0,43	0,07
2	0,57	0,50	0,07
3	0,60	0,51	0,09
4	0,49	0,42	0,07
5	0,55	0,44	0,11
6	0,56	0,43	0,13
7	0,51	0,45	0,06
8	0,52	0,40	0,12
9	0,52	0,47	0,05
10	0,55	0,43	0,12
11	0,56	0,44	0,12
12	0,55	0,45	0,10

Table 6.2: STIPA values in the audience with source in S1, with Talk Box at 70 dB at 1 m and at 60 dB at 1 m and relative differences.

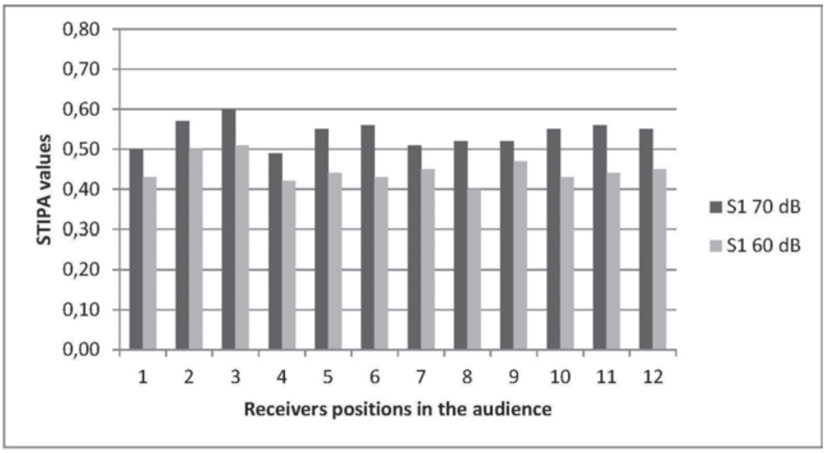


Figure 6.15: STIPA values with the sound source placed in S1 with two different levels of emission, 70 dB and 60 dB at 1 m.

6.7 Conclusions

Differences can be noticed in all the positions, with a decrease in speech intelligibility when the source emits 60 dB at 1 m: the majority of the positions shown a value of STIPA in the range of poor speech intelligibility, while, when the source emits 70 dB at 1 m, the values are in the range of fair speech intelligibility.

A good speech intelligibility can be achieved in the Theatre of Schio with a raised vocal effort (Lombard effect, 70 dB). This is the situation of actors on the stage, that use raised voice. In fact, it is not usual to speak on the stage with a tone of voice as in a conversation (60 dB).

Chapter 7

Analysis of the acoustic quality of the Theatre

7.1 Analysis procedure

The parameters have been further analysed, grouping them according to main subjective sensations, as done in literature [10]:

- energy parameters (C_{80}, T_s);
- reverberation parameters (reverberation time, EDT);
- intelligibility parameters (STI).

These parameters are associated with the main subjective qualities of the hall:

- *transparency*: with regard to the audition of music, transparency refers to the perception of separate tones in time and instruments played simultaneously;
- *reverberation*: it represents the degree of vivacity of the hall;
- *intelligibility*: it is essential for verbal audition and it quantifies verbal comprehension [10].

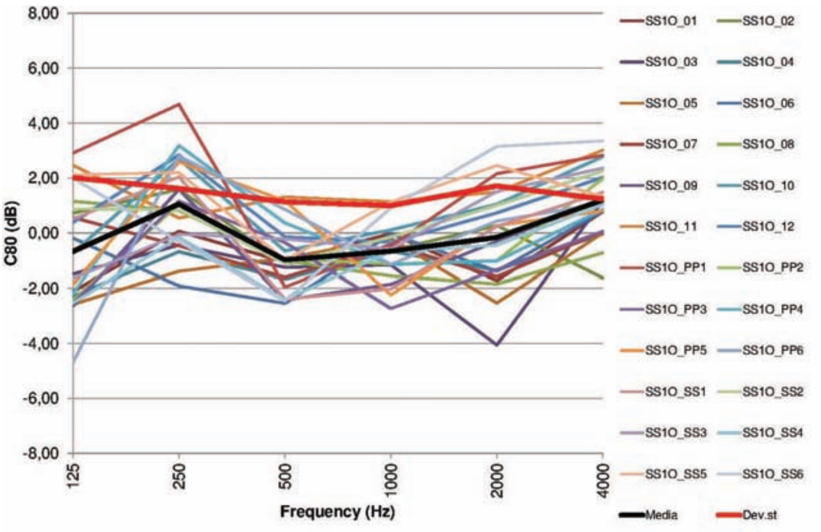
The mean values of the different quantities can provide an overall description of the acoustics of the hall, but this can ignore the fact that many quantities vary significantly with location. Averaging over all measurement positions seems to be helpful only in case of reverberation time [7]. So, an analysis of the different parameters in the various locations in the Theatre has been performed.

7.2 Energy parameters

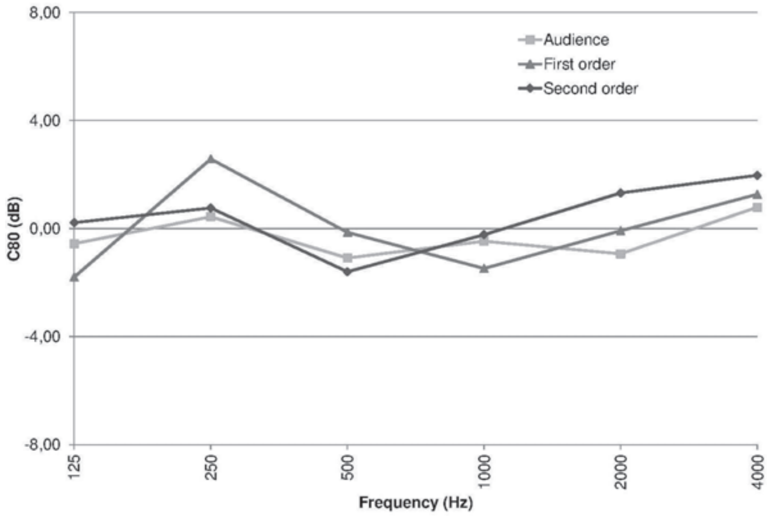
Usually, a high C_{80} corresponds with a low EDT and *viceversa*. In subjective terms, high clarity is often associated with low reverberance, as occurs for istance with a short reverberation time. C_{80} tends to be higher close to the source [7].

7.2.1 Clarity

The values of C_{80} have been analyzed with reference to the results obtained with the omnidirectional source, emitting a sine sweep, placed in the position S1, from the measurements performed on 11/09/2015.



(a) C_{80} values obtained with the omnidirectional source placed in position S1.



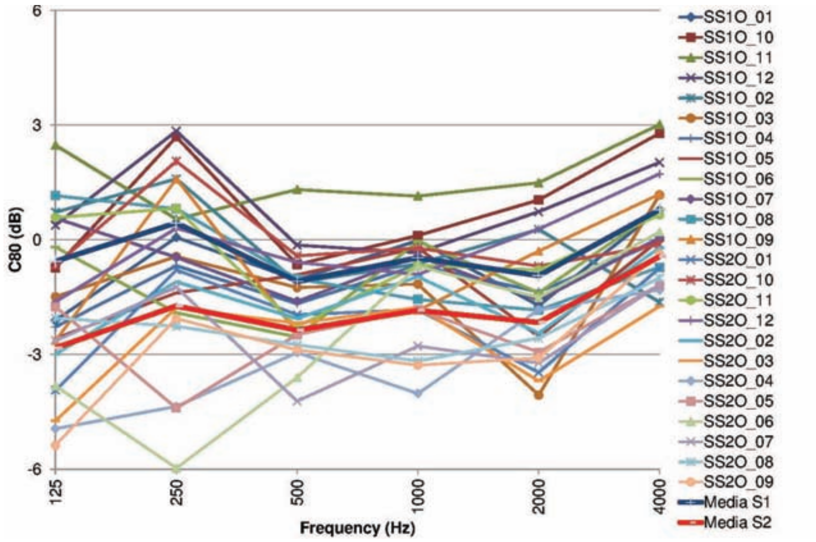
(b) C_{80} averages for audience, first order and second order.

Figure 7.1: C_{80} values and averages obtained with the omnidirectional source placed in position S1.

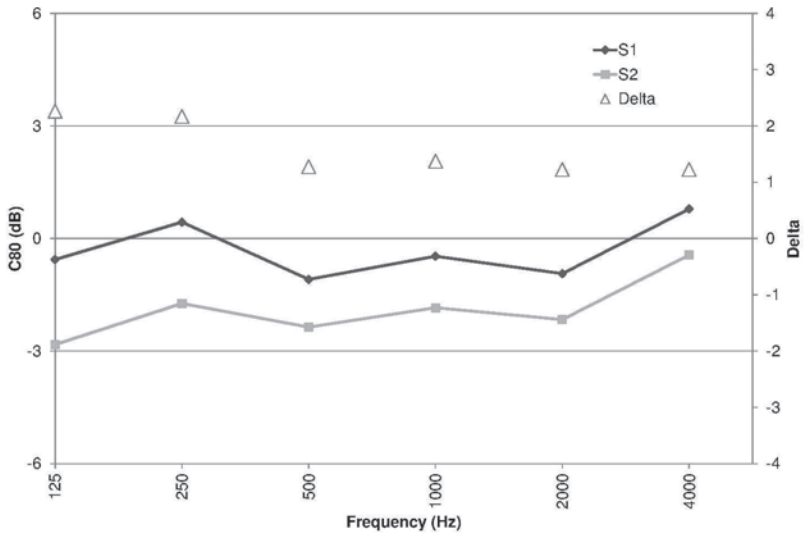
As visible in figure 7.1, the values of clarity vary between -5 and 5 dB, but the majority of the values vary between -3 and 3 dB.

No significant differences can be noticed between the three areas in which it has been decided to divide the Theatre (audience, first order and second order), as visible in figure 7.1. The behaviour is the same for the three areas, with an increase of clarity with the frequency, from 500 Hz to 4000 Hz, and a hump in the trend at 250 Hz, probably due to the reflection of the stage.

Changing the position of the source, from S1 (forward position) to S2 (backward position), the values of C_{80} in the audience vary in all frequency, with differences between 1 and 2 dB: higher values of clarity correspond to the forward position S1, as visible in figure 7.2.



(a) C_{80} distributions.



(b) Comparison between C_{80} averages.

Figure 7.2: Comparisons between C_{80} values obtained with 2 different source positions, S1 and S2, in the audience.

7.2.2 Conclusions

The analysis of the C_{80} distribution in the Theatre doesn't show great difference as regard the position of the receivers. All the three areas of the Theatre have almost the same behaviour. In the audience, the positions more distant from the stage (10, 11,12), and so from the source, show the highest values of clarity.

Regarding the position of the source, values of C_{80} vary in all frequencies with differences between 1 and 2 dB. Higher values correspond to the forward positions: more advanced the source is, higher the clarity is.

7.3 Reverberation parameters

As reported in literature [7], reverberation time varies little throughout a well-designed concert auditorium and usually the mean value can be assessed alone. The mean EDT/T_{30} ratio in concert auditorium takes values between about 0,8 and 1,1. If surfaces direct early reflections on audience seating, this reduces the early decay time, giving a low value to the ratio. In a well-designed hall with a diffuse field, there should be few observable trends in terms of variation of EDT with position. EDT values close to the source will be less because of the relatively strong direct sound; however, for source-receiver distances in excess of 10 m, this effect is very small [7].

7.3.1 Early decay time

The values of EDT have been analysed with reference to the results obtained with the omnidirectional source, emitting a sine sweep, placed in the position S1, from the measurements performed on 11/09/2015.

As visible in figure 7.3, the values of EDT vary between 1 and 2,5 s.

The main difference can be noticed between the audience and first order and second order, as visible in figure 7.3. The EDT in the second order show lower values in the frequency band of 250 and 500 Hz, around 0,5 s less.

Changing the position of the source, from S1 (forward position) to S2 (backward position), the values of EDT in the audience vary with differences between 0,1 and 0,2 s: higher values of EDT correspond to the backward position S2, as visible in figure 7.4.

7.3.2 Reverberation time

The values of T_{30} have been analysed with reference to the results obtained with the omnidirectional source, emitting a sine sweep, placed in the position S1, from the measurements performed on 11/09/2015.

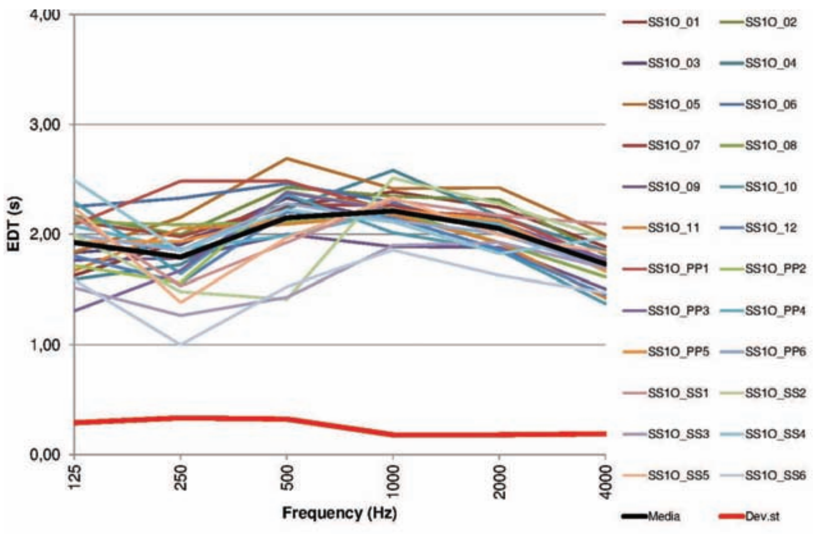
As visible in figure 7.5, the values of T_{30} are very precise and they have the same behaviour for all the measurements.

No differences can be noticed between the three main areas of the Theatre, as visible in figure 7.5.

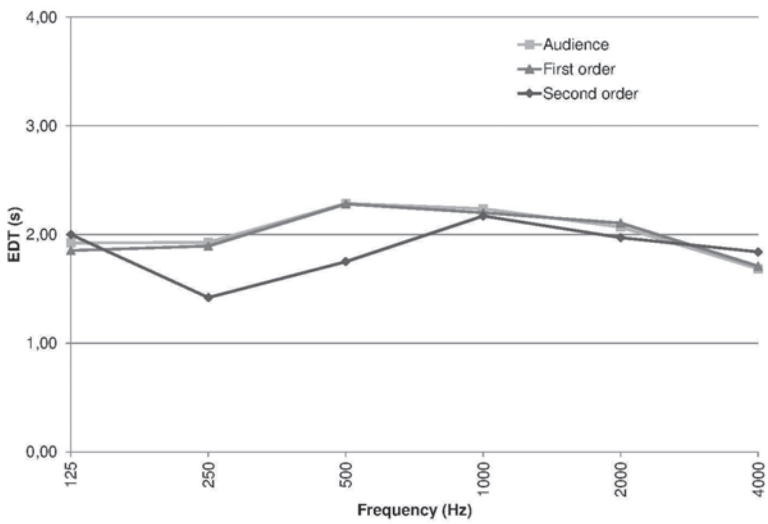
Changing the position of the source, from S1 (forward position) to S2 (backward position), the values of T_{30} in the audience don't vary, as visible in figure 7.4.

7.3.3 EDT/T30 ratio

The values of EDT and T_{30} and the EDT/T_{30} ratio have been analysed with reference to the results obtained with the omnidirectional source, emitting a sine sweep, placed

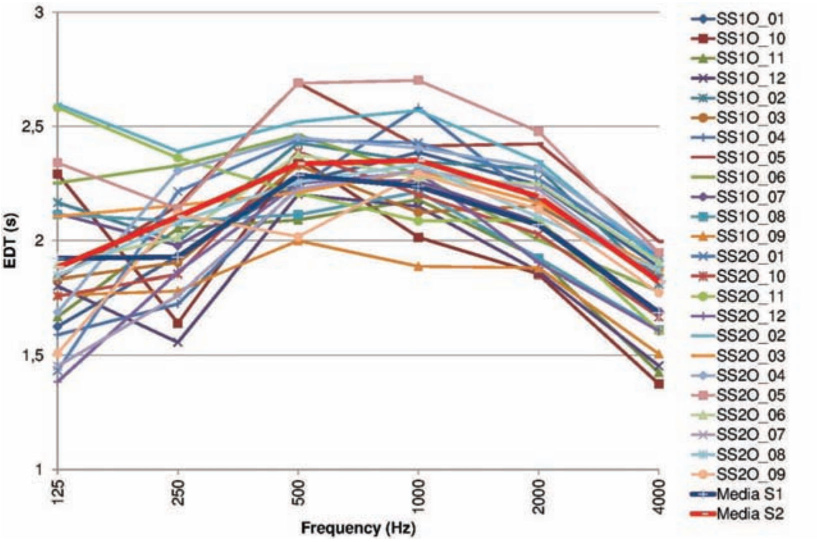


(a) EDT values obtained with the omnidirectional source placed in position S1.

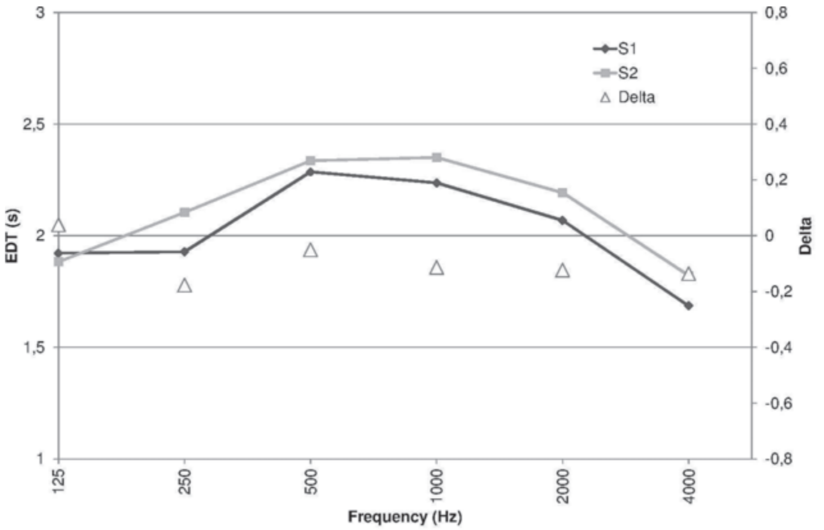


(b) EDT averages for audience, first order and second order.

Figure 7.3: EDT values and averages obtained with omnidirectional source placed in position S1.

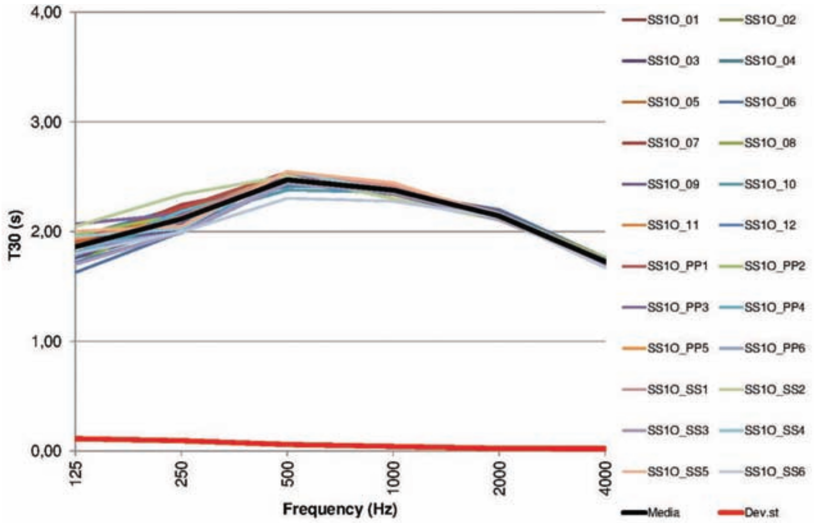


(a) EDT distributions.

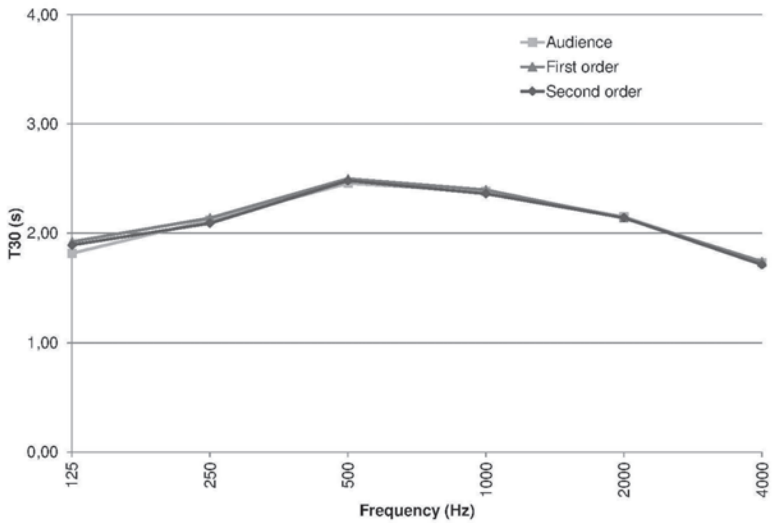


(b) Comparison between EDT averages.

Figure 7.4: Comparisons between EDT values obtained with 2 different source positions, S1 and S2, in the audience.

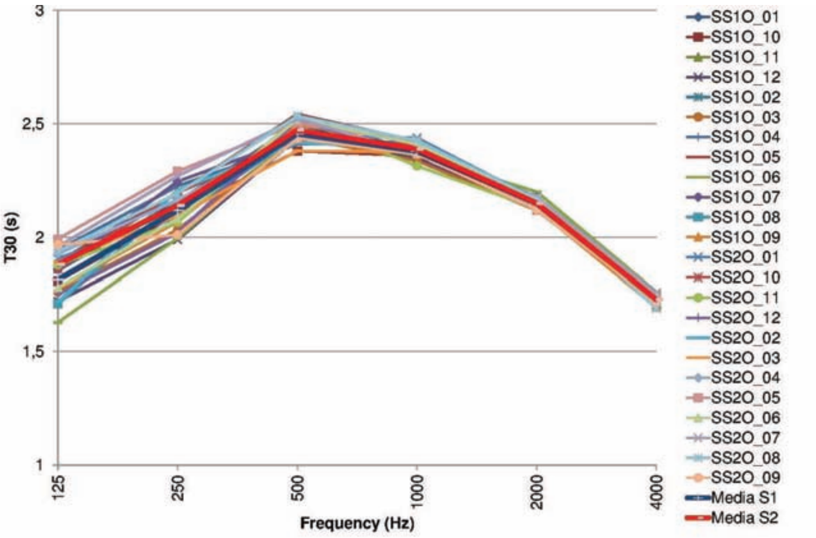


(a) T_{30} values obtained with the omnidirectional source placed in position S1.

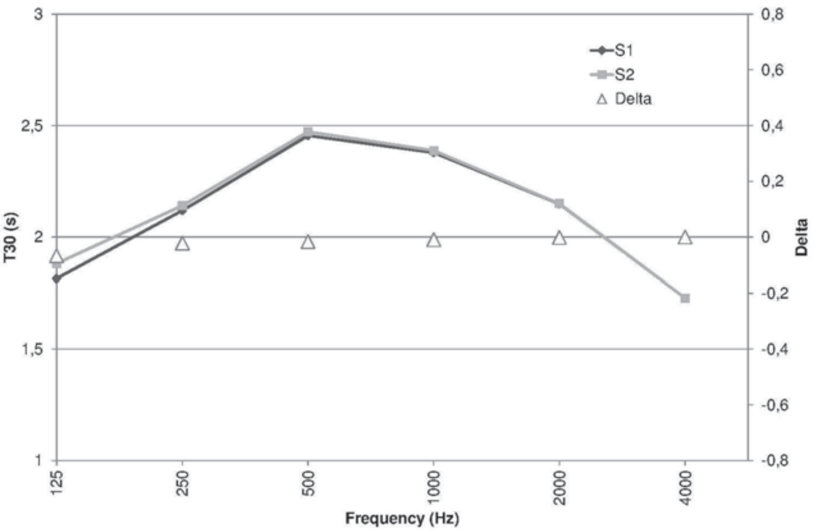


(b) T_{30} averages for audience, first order and second order.

Figure 7.5: T_{30} values and averages obtained with omnidirectional source placed in position S1.



(a) T_{30} distributions.



(b) Comparison between T_{30} averages.

Figure 7.6: Comparisons between T_{30} values obtained with 2 different source positions, S1 and S2, in the audience.

in the position S1, from the measurements performed on 11/09/2015.

According to previous literature [7], EDT/T_{30} ratio generally takes values between 0,8 and 1,1. In the Italian historical opera houses, the typical impulse responses are characterised by the presence of strong early reflections provided by the proscenium arch, the vault and, for the audience area, from the smooth side walls. In this cases, the EDT is smaller than T_{30}. The *proscenium arch* is the arch between the auditorium and the stage and it is the primary acoustic element of the Italian theatre: it splits the volume of the stage from the volume of the audience. The proscenium arch provides the typical strong early reflection on the audience [16].

In addition, while in the audience the direct sound comes with strong early reflections (proscenium, vault, side walls), and it is followed by the revereberant field, the field inside the boxes is strongly related to the field which originates inside the box. This results in a decrease in the EDT/T_{30} ratio in the boxes [16].

7.3.3.1 Audience

As regard the audience (figures 7.7 and 7.8), the EDT/T_{30} ratio is near 1, and so EDT and T_{30} are very similar, in the positions more close to the stage. In the backward positions, more distant from the stage, the EDT is lower than the T_{30}, so the ratio is slightly under 1. The behaviour, anyway, is the same, with higher values in the mid frequency range, between 500 Hz and 2000 Hz.

7.3.3.2 First order

In the first order (figure 7.9), EDT and T_{30} have a quite different behaviour in the low and mid frequency range. In general, EDT is always a bit lower than T_{30}. The ratio is around 1 or a little bit lower.

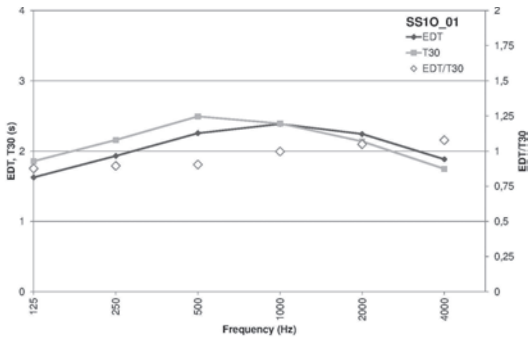
7.3.3.3 Second order

In all the positions of the second order (figure 7.10), EDT is lower than T_{30}, so the ratio is almost always lower than 1. An almost parallel shift can be noticed between T_{30} and EDT in the positions SS1, SS3 (in forward positions), SS5 and SS6 (in backward position), while for the positions SS2 (in forward positions) and SS4 (in backward positions) some differences can be noticed: in SS2 the behaviour is different at low frequencies, while in SS4 the behaviour is more different at mid frequencies.

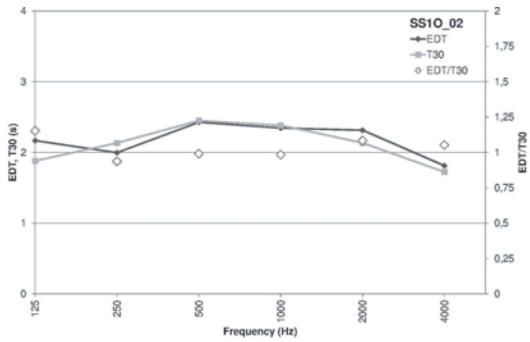
7.3.4 Conclusions

As regard EDT, the values are similar in all the areas of the Theatre, even if in the second order lower values are found in the frequency bands of 125 and 500 Hz. Changing the position of the source, higher values of EDT correspond to the backward position. The values of T_{30} are the same in all the Theatre and they don't change with the position of the source.

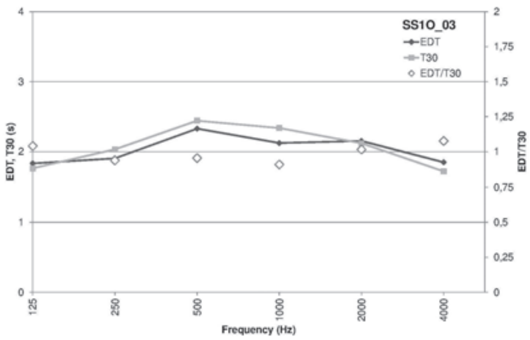
For all the positions in the Theatre, the EDT/T_{30} ratio is around 1, showing a great similarity between EDT and T_{30} values. The mean EDT/T_{30} ratio in the Civic Theatre is 0,9, in line with the values in literature: between about 0,8 and 1,1 [7]. The main difference that can be noticed is that in many positions of the Theatre, especially the ones far from the source on the stage, the EDT values are lower than T_{30} values, and this usually indicates a higher speech intelligibility, because of the contribution of strong early reflections. The EDT/T_{30} ratio doesn't decrease in the orders, except for



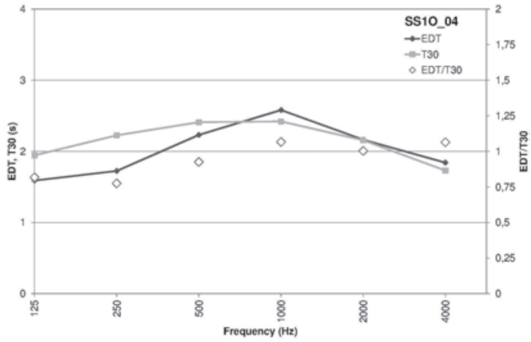
(a) SS1O-01



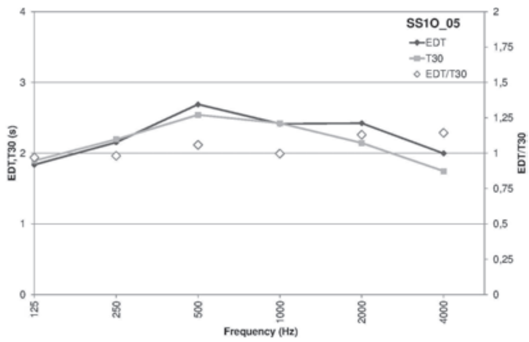
(b) SS1O-02



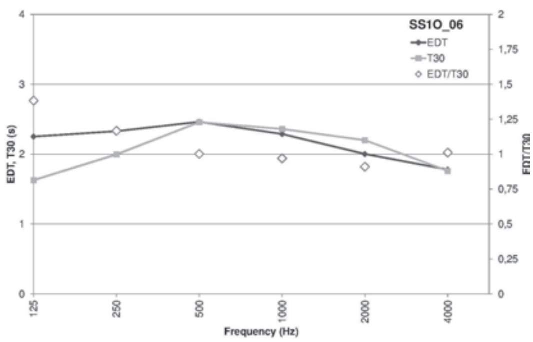
(c) SS1O-03



(d) SS1O-04

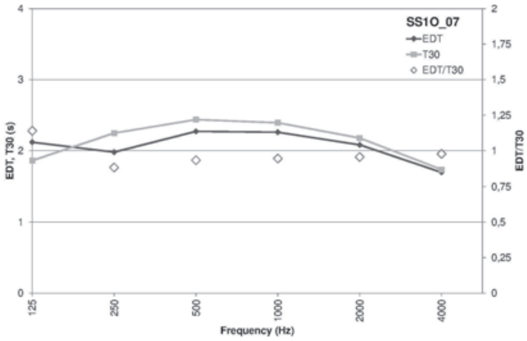


(e) SS1O-05

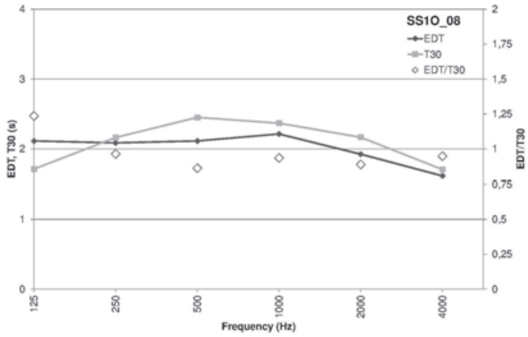


(f) SS1O-06

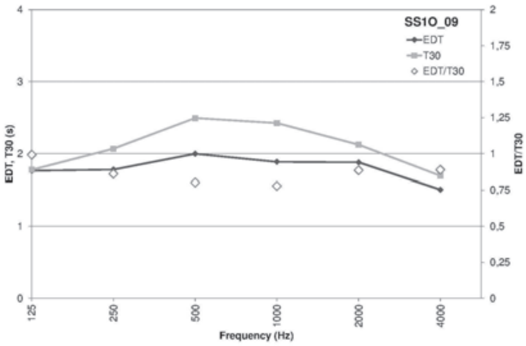
Figure 7.7: EDT/T_{30} ratio regarding the measurements with source position S1, in the audience (1, 2, 3, 4, 5, 6).



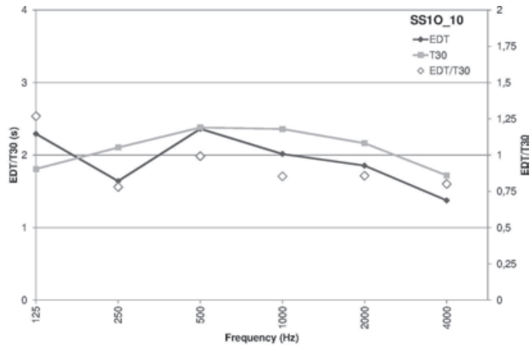
(a) SS1O-07



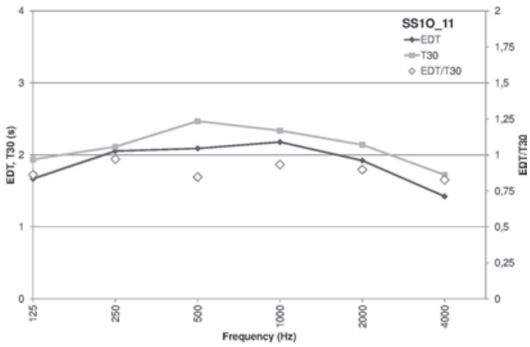
(b) SS1O-08



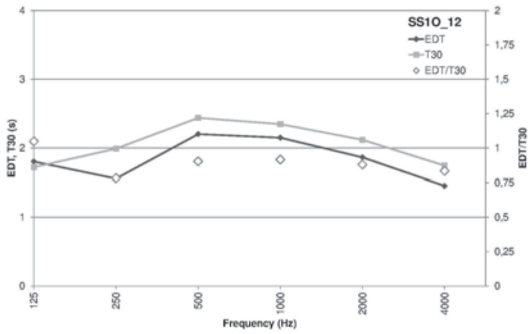
(c) SS1O-09



(d) SS1O-10

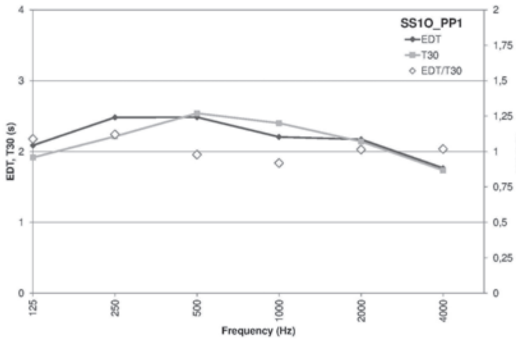


(e) SS1O-11

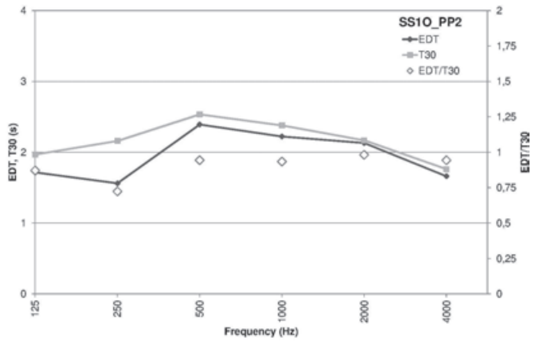


(f) SS1O-12

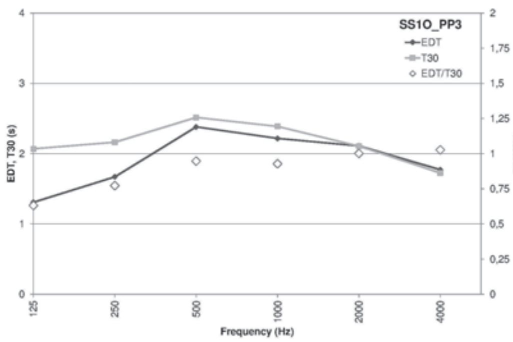
Figure 7.8: EDT/T_{30} ratio regarding the measurements with source position S1, in the audience (7, 8, 9, 10, 11, 12).



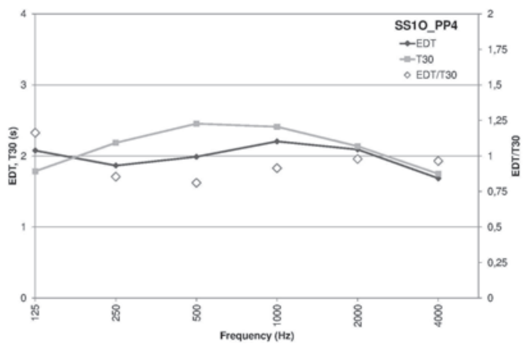
(a) SS1O-PP1



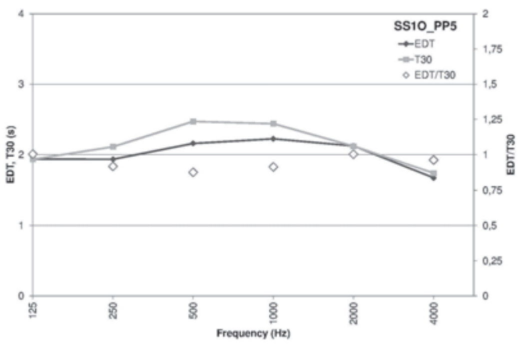
(b) SS1O-PP2



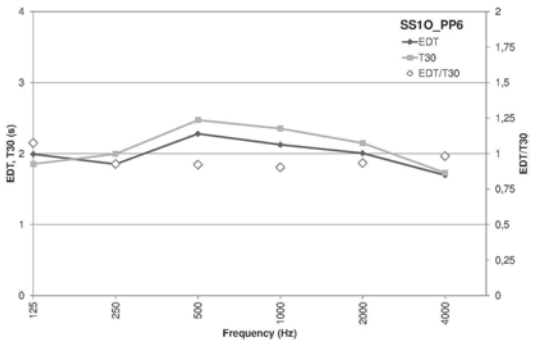
(c) SS1O-PP3



(d) SS1O-PP4

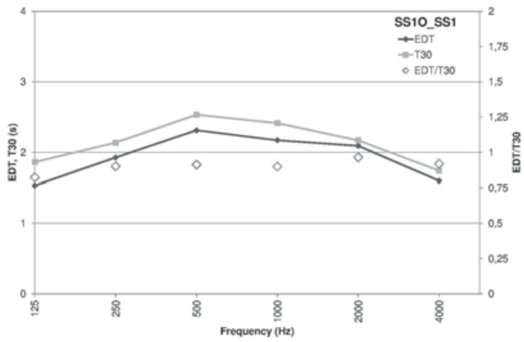


(e) SS1O-PP5

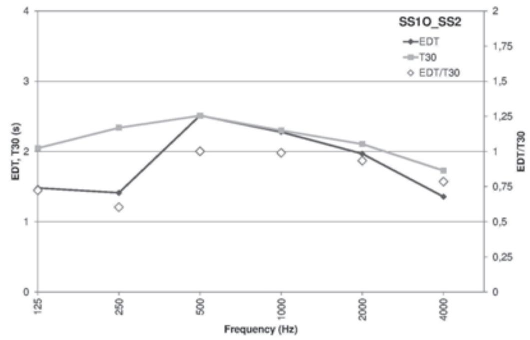


(f) SS1O-PP6

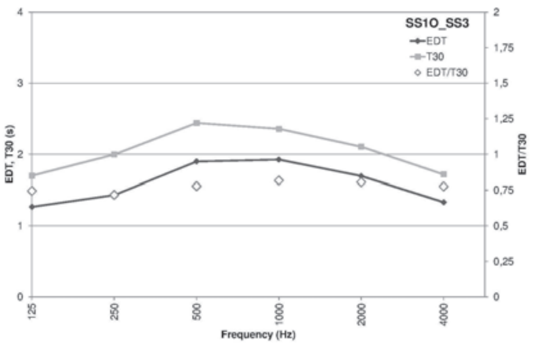
Figure 7.9: EDT/T_{30} ratio regarding the measurements with source position S1 in the first order.



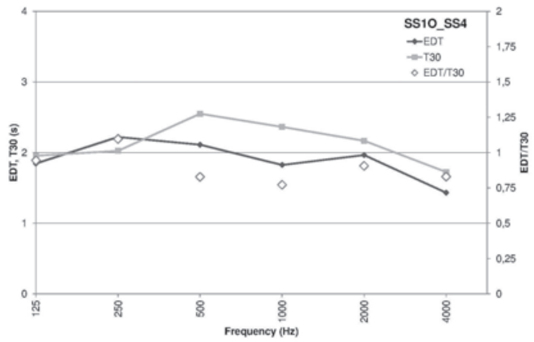
(a) SS1O-SS1



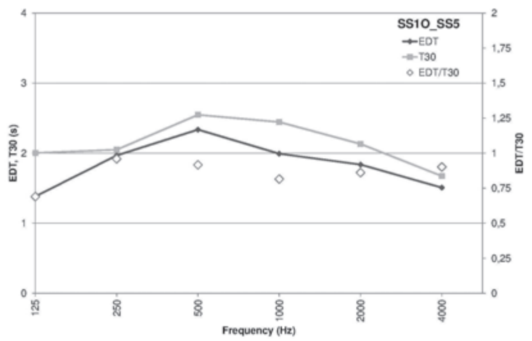
(b) SS1O-SS2



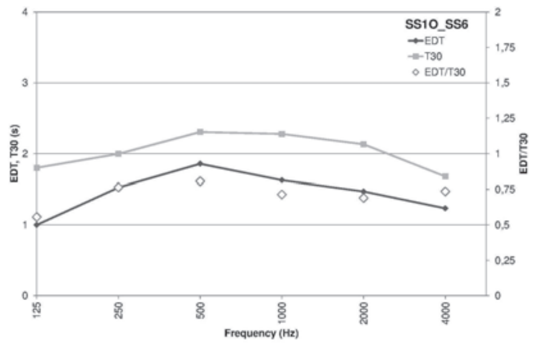
(c) SS1O-SS3



(d) SS1O-SS4



(e) SS1O-SS5



(f) SS1O-SS6

Figure 7.10: EDT/T_{30} ratio regarding the measurements with source position S1 in the second order.

some positions in the second order. A bit lower values of EDT/T_{30} ratio can be found in some backward positions in the audience.

It has to be noticed that the measurements done on 10/09/2015 and 11/09/2015 have been performed without lateral curtains. This fact can lead to an overestimation of the reverberation parameters, that can be decreased by the addition of the curtains, as curtains are usually used.

7.4 Musicians perception

7.4.1 Previous research

To understand how the musicians and conductors perceive the acoustic conditions of the theatres, a survey of their impression through the distribution of a questionnaire was carried out in a previous research [28], investigating the subjective impressions of the musicians in 5 theatres of Emilia Romagna region. The questionnaires was divided into two parts: the first section investigated the sex, age, instrument played and experience in symphony orchestras or chamber groups, the importance of acoustic parameters for the musicians and the general situation of musicians and conductors on the stage, while in the second section specific questions about the Italian theatres, especially Masini Theatre of Faenza, Rossini Theatre of Lugo, Bonci Theatre of Cesena, Alighieri Theatre of Ravenna and Comunale of Bologna were asked. The questionnaire was distributed to various conductors and musicians, covering all instruments. The Theatres Masini, Rossini and Bonci do not have a permanent orchestra, so the interviewed musicians are experienced professionals who play in these theatres as needed. 63 people were interviewed, between musicians and conductors, including 52 men and 11 women, aged between 22 and 55 years.

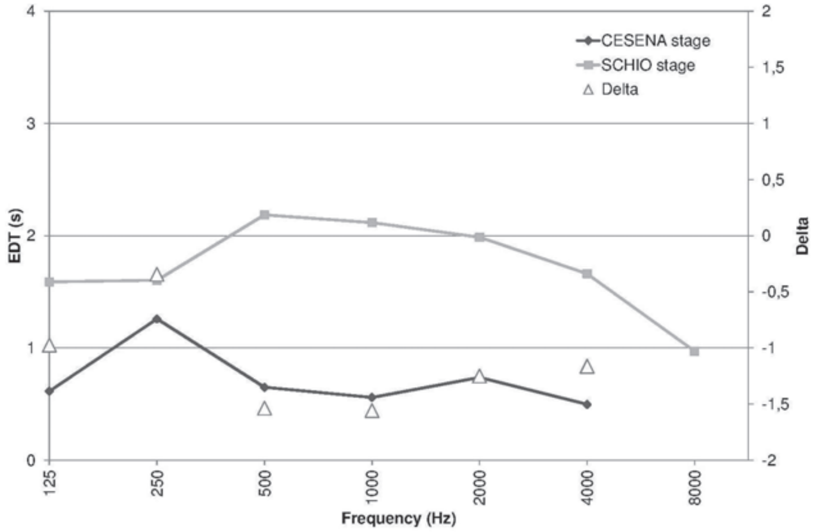
The vast majority of respondents said that the acoustics are very variable between the halls in which they played. The places that respondents remind more acoustically comfortable are generally not Italian theatres (although some are mentioned, Comunale of Bologna, Bonci of Cesena and Alighieri of Ravenna), but halls abroad. The theatre with a higher degree of comfort appears to be the Comunale in Bologna, followed by the Bonci theatre, a trend often found in the answers to various questions. These Italian theatres are perceived as non-reverberant, especially Masini and Rossini, while Bonci of Cesena and Comunale of Bologna are considered more reverberant. The overall impression of the acoustic conditions of these theatres is quite good, especially in the theatres of Bologna, Cesena and Ravenna, a little less for those of Faenza and Lugo.

From these results, the subjective preference of the musicians seems to be for more reverberant hall. The values of reverberation time, T_{30}, evaluated on the stage, seem to confirm the fact that the Bonci Theatre is more reverberant, as reported by the musicians in the questionnaires, respect the Theatres of Faenza and, especially, Lugo, which have lower values of T_{30} on stage, perceived in fact as less comfortable [28].

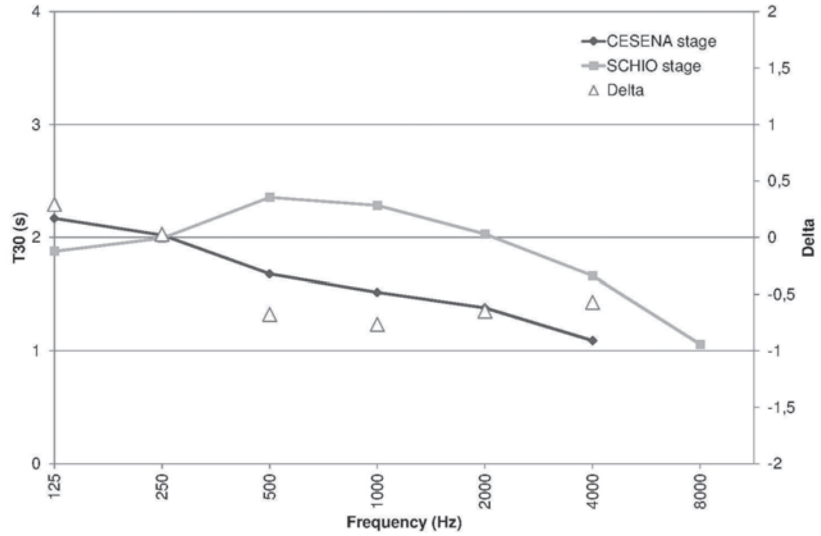
7.4.2 Comparison between Bonci Theatre of Cesena and Civic Theatre of Schio

The values of EDT and T_{30} obtained from the measurements performed in the Bonci Theatre of Cesena and in the Civic Theatre of Schio have been compared.

As regard the Bonci Theatre, two possible ensembles were simulated on the stage, a trio and an orchestra, identifying 3 positions for members of the trio and 5 positions for the sections of the orchestra, to which the position of the director was added. The



(a) EDT



(b) T_{30}

Figure 7.11: Comparison between parameters obtained from the measurements performed in the Bonci Theatre of Cesena [28] and from the ones performed in the Civic Theatre of Schio.

omnidirectional source was placed in each position and the measurements were made in all other points of the group [28].

As regard the Civic Theatre of Schio, measurements in 2 positions of microphone (corresponding to the positions S1 and S2) have been performed with omnidirectional source placed in position S3 and S4 (10/09/2015).

The mean values of EDT and T_{30} on the stage of the 2 theatres have been compared, as visible in figure 7.11. It has to be noticed that the measurements performed on the stage of the Bonci Theatre are considerably more than the ones performed on the stage of the Civic Theatre of Schio. In addition, in the Civic Theatre of Schio no curtains are present on the stage during the measurements, while in the Bonci Theatre the curtains are in the configuration used for the performances.

Values of the parameters obtained from the measurements done in Cesena have not been taken into account in the frequency bands above 4000 Hz because the dodecahedron used didn't emit above these frequency bands.

7.4.3 Conclusions

Even if it has to be taken into account that the configurations of the source and receivers and of the curtains on the stage were different during the measurements performed in the Bonci Theatre of Cesena and the Civic Theatre of Schio, it can be noticed that the values of EDT and T_{30} are considerably different in the 2 theatres.

In the Civic Theatre of Schio the values are higher, especially as regard EDT. The differences of T_{30} vary between 0 (at 250 Hz) and 0,8 s (at 1000 Hz), while the differences of EDT vary between 0,3 (at 250 Hz) and 1,6 s (at 1000 Hz). The Theatre of Cesena was among the most appreciated by musicians, according to the previous research [28], as they perceived higher reverberation time. Having reverberation time even more high, the Civic Theatre seems to be pleasing for musicians. The Civic Theatre seems also versatile because it can be modified by the addition of the curtains. With high reverberation times, this Theatre seems to be suitable for symphonic music.

7.5 Intelligibility parameters

7.5.1 STIPA

STIPA values have been calculated with a direct method, using a Talk Box as source. The direct method uses test signals that have similar spectral and temporal properties to those found in natural speech. Consequently, STI test signals consists of a number of frequency bands of noise whose intensity is sinusoidally modulated [6].

From the calculation of STIPA (results in tables 7.2, 7.3 and 7.4), some considerations can be done. It can be noted that, according to the classification visible in table 7.1 [9], the general trend of the Theatre is to have a fair speech intelligibility. In fact, the majority of the measurements shows values from 0,45 and 0,60.

As regard the audience (table 7.2), better values, in the range of good speech intelligibility, can be found in measurements performed with the sound source placed in S3 and S4, so in the most advanced positions, at 1 m from the front of the stage, more close to the audience. Advanced positions of receivers among the seats in the audience improve the speech intelligibility. Other positions shown a fair speech intelligibility value. No position shown a poor speech intelligibility value, with the source that emits 70 dB at 1 m.

As regard the first order (table 7.3), the majority of the positions shown a value in the range of fair speech intelligibility, but some positions have a poor speech intelligibility. These lower values are found in particular when the source has been placed in S2, the source most far from the public. It can be noticed that the positions with lower speech intelligibility are the ones in backward position and in lateral positions.

As regard the second order (table 7.4), the majority of the positions shown a fair speech intelligibility, even if two positions are easily distinguishable, because, for all the source positions, they show a poor speech intelligibility. These positions are placed backward, in lateral positions.

Graphical representations of the results are visible in figures 7.12 and 7.13.

As visible in figure 7.13, differences between maximum and minimum values of STIPA (between the various source locations) are greater in the audience respect to the first order and in particular respect to the second order.

STI	$0,00 \div 0,30$	$0,30 \div 0,45$	$0,45 \div 0,60$	$0,60 \div 0,75$	$0,75 \div 1,00$
Intelligibility	Bad	Poor	Fair	Good	Excellent

Table 7.1: Relation between STI and speech intelligibility [9].

	S1	S2	S3	S4
1	0,50	0,49	0,54	0,73
2	0,57	0,51	0,64	0,72
3	0,60	0,51	0,72	0,59
4	0,49	0,45	0,54	0,62
5	0,55	0,46	0,57	0,62
6	0,56	0,49	0,61	0,55
7	0,51	0,45	0,56	0,58
8	0,52	0,47	0,56	0,57
9	0,52	0,49	0,65	0,56
10	0,55	0,5	0,57	0,6
11	0,56	0,55	0,57	0,61
12	0,55	0,54	0,56	0,58

Table 7.2: STIPA values in the audience with different source positions, with Talk Box at 70 dB at 1 m.

	S1	S2	S3	S4
A	0,51	0,50	0,49	0,59
B	0,42	0,41	0,45	0,57
C	0,54	0,48	0,46	0,58
D	0,47	0,44	0,48	0,57
E	0,51	0,48	0,47	0,55
F	0,5	0,44	0,47	0,51
G	0,5	0,48	0,47	0,55
H	0,47	0,44	0,45	0,51
I	0,52	0,47	0,49	0,56
L	0,47	0,51	0,48	0,52
M	0,48	0,50	0,54	0,52
N	0,53	0,52	0,52	0,54
O	0,53	0,55	0,56	0,61
P	0,56	0,54	0,55	0,60

Table 7.3: STIPA values in the first order with different source positions, with Talk Box at 70 dB at 1 m.

	S1	S2	S3	S4
A	0,45	0,49	0,46	0,47
B	0,37	0,38	0,37	0,36
C	0,46	0,47	0,49	0,49
D	0,42	0,41	0,43	0,42
E	0,49	0,49	0,48	0,53
F	0,47	0,47	0,50	0,43
G	0,48	0,50	0,51	0,55
H	0,50	0,50	0,55	0,50
I	0,60	0,56	0,54	0,51
L	0,53	0,55	0,55	0,49

Table 7.4: STIPA values in the second order with different source positions, with Talk Box at 70 dB at 1 m.

	S1		S2		S3		S4	
	STI male	STI female	STI male	STI female	STI male	STI female	STI male	STI female
1	0,48	0,49	0,47	0,48	0,58	0,60	0,64	0,65
2	0,52	0,53	0,48	0,49	0,64	0,66	0,65	0,65
3	0,51	0,52	0,43	0,44	0,62	0,62	0,58	0,58
4	0,47	0,47	0,45	0,45	0,52	0,52	0,57	0,58
5	0,47	0,47	0,42	0,43	0,53	0,54	0,51	0,52
6	0,45	0,46	0,42	0,42	0,49	0,50	0,51	0,52
7	0,48	0,48	0,45	0,46	0,50	0,51	0,49	0,50
8	0,47	0,47	0,45	0,45	0,50	0,50	0,49	0,50
9	0,50	0,51	0,45	0,45	0,55	0,55	0,51	0,52
10	0,52	0,52	0,48	0,49	0,50	0,50	0,51	0,51
11	0,51	0,51	0,48	0,48	0,50	0,51	0,52	0,53
12	0,50	0,51	0,50	0,50	0,51	0,51	0,52	0,53

Table 7.5: STI values in the audience with different source positions.

	S1		S2		S3		S4	
	STI male	STI female	STI male	STI female	STI male	STI female	STI male	STI female
A	0,58	0,59	0,48	0,49	0,59	0,60	0,67	0,68
B	0,48	0,49	0,42	0,43	0,61	0,62	0,62	0,63
C	0,58	0,59	0,47	0,48	0,54	0,55	0,59	0,60
D	0,54	0,55	0,43	0,43	0,57	0,58	0,62	0,62
E	0,56	0,58	0,46	0,47	0,51	0,52	0,55	0,56
F	0,55	0,57	0,42	0,43	0,50	0,50	0,56	0,56
G	0,53	0,54	0,47	0,47	0,49	0,50	0,53	0,54
H	0,53	0,54	0,44	0,45	0,49	0,49	0,51	0,52
I	0,52	0,52	0,45	0,46	0,49	0,49	0,51	0,51
L	0,50	0,51	0,44	0,45	0,47	0,47	0,49	0,49
M	0,52	0,52	0,47	0,48	0,51	0,52	0,50	0,51
N	0,50	0,50	0,48	0,48	0,49	0,50	0,51	0,52
O	0,52	0,52	0,49	0,50	0,53	0,53	0,53	0,53
P	0,53	0,54	0,49	0,50	0,52	0,52	0,55	0,56

Table 7.6: STI values in the first order with different source positions.

7.5.2 STI

From the impulse responses and the following elaboration with the Dirac software, with a indirect method, the values of STI for male and for female can be obtained. The indirect method computes the modulation transfer function (MTF), as the basis of STI, from the impulse response of a transmission channel, using the process known as Schroeder method. The impulse responses are acquired with computer-based equipment and the MTF is derived, from which the STI is subsequently calculated [6].

Graphical representations of the results are visible in figures 7.14 and 7.15. Values of STI are reported in tables 7.5, 7.6 and 7.7.

7.5.3 Comparisons between STIPA and STI

The graphical representations of the comparisons between direct measurements of STIPA and indirect measurements of STI male and STI female are visible, for the four different source positions, in figures 7.16, 7.17, 7.18 and 7.19.

As regard the measurements done with the source placed in position S1, the STIPA values in the audience are higher than STI male and female values, while in the first order the STIPA values are lower than STI male and female, except for the three positions more distant from the stage (N, O, P). In the second order, the differences are less pronounced, and it is not present a general trend: in some positions the STIPA values is slightly higher, in other positions it is slightly lower.

	S1		S2		S3		S4	
	STI male	STI female	STI male	STI female	STI male	STI female	STI male	STI female
A	0,48	0,49	0,46	0,46	0,45	0,46	0,47	0,48
B	0,40	0,41	0,40	0,40	0,42	0,42	0,42	0,43
C	0,49	0,50	0,45	0,45	0,47	0,47	0,46	0,47
D	0,42	0,42	0,39	0,40	0,43	0,43	0,40	0,40
E	0,48	0,49	0,46	0,47	0,50	0,50	0,48	0,49
F	0,44	0,45	0,44	0,44	0,47	0,47	0,46	0,47
G	0,50	0,50	0,47	0,48	0,51	0,51	0,52	0,52
H	0,47	0,48	0,47	0,48	0,49	0,50	0,46	0,47
I	0,54	0,54	0,53	0,53	0,51	0,51	0,51	0,51
L	0,50	0,50	0,51	0,51	0,48	0,48	0,48	0,49

Table 7.7: STI values in the second order with different source positions.

As regard the measurements done with the source placed in position S2, STIPA values in the audience are almost always greater than STI male and female values. This is also the general trend in the first and in the second orders.

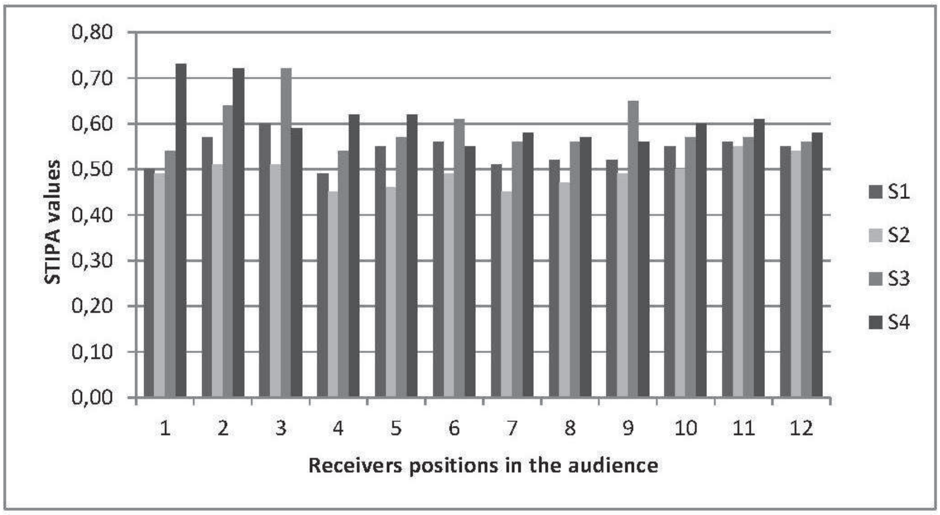
As regard the measurements done with the source placed in position S3, the behaviour is similar to the one seen with the source placed in position S1. In the audience the STIPA values are higher than STI male and female, while in the first order are lower, except for the positions more distant from the stage (L, M, N, O, P). In the second order no general trend can be noticed.

As regard the measurements done with the source placed in position S4, in the audience the STIPA values are higher than STI male and female. In the first order, the behaviour of the area is divided in two trends: positions more close to the stage (A, B, C, D, E, F) have a lower value of STIPA respect to STI male and female, while the positions more distant from the stage (G, H, I, L, M, N, O, P) have a higher value of STIPA respect to STI male and female. In the second order, no general trend can be noticed.

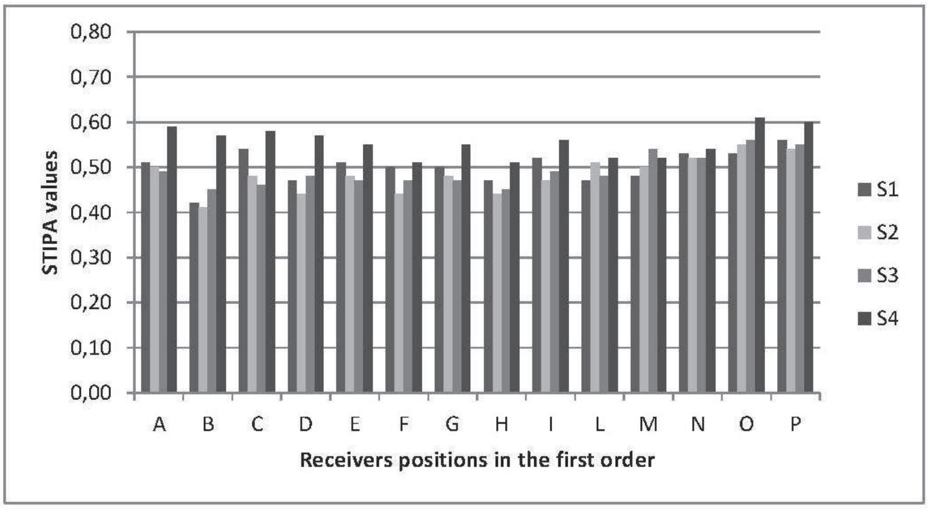
7.5.4 Conclusions

Despite some differences have been highlighted, the values of STIPA and STI return consistent results, that define a fair speech intelligibility in all the Theatre.

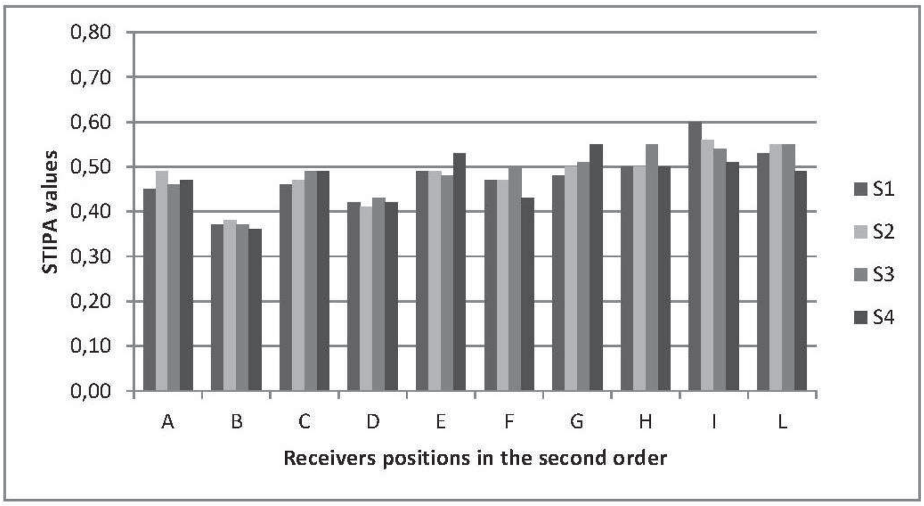
The differences between minimum and maximum STIPA values in each receiver position, regarding the different positions of the source, are not very high, so the results are similar for all the positions of the source.



(a) Audience.

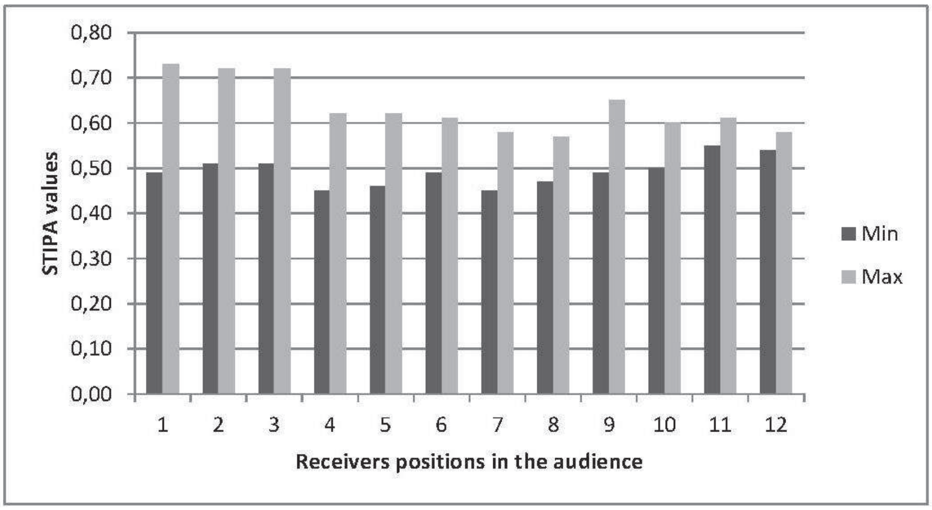


(b) First order.

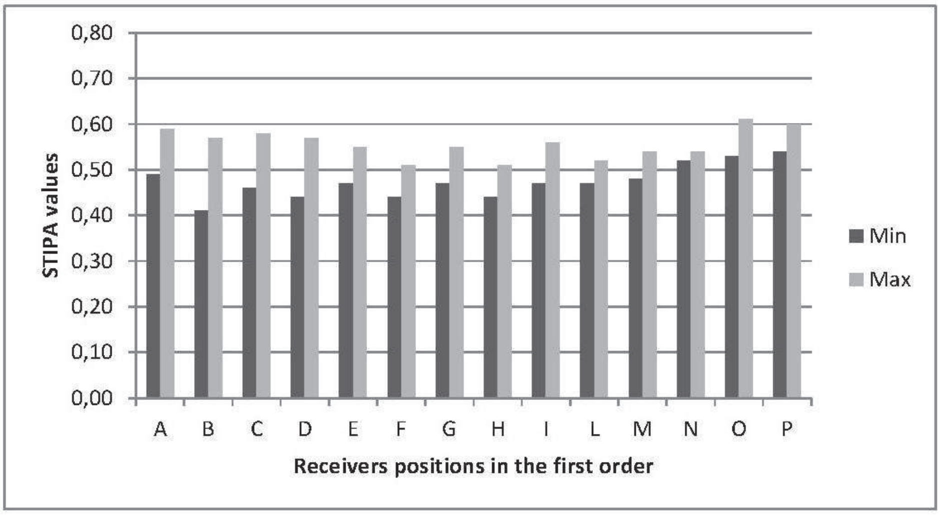


(c) Second order.

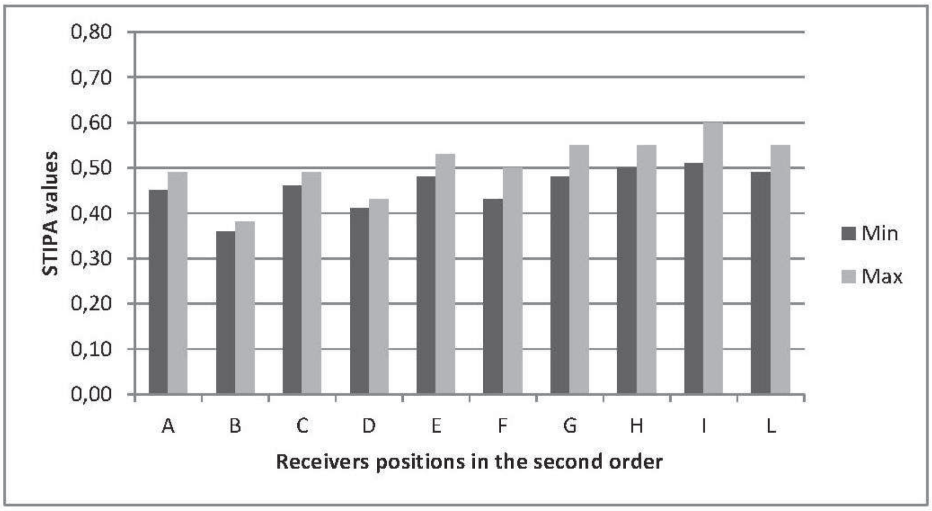
Figure 7.12: STIPA values for the different source positions.



(a) Audience.

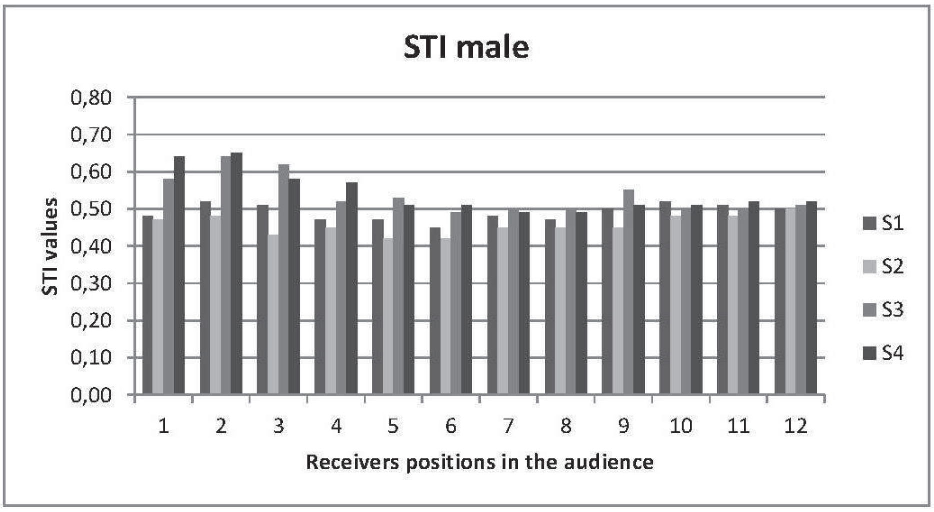


(b) First order.

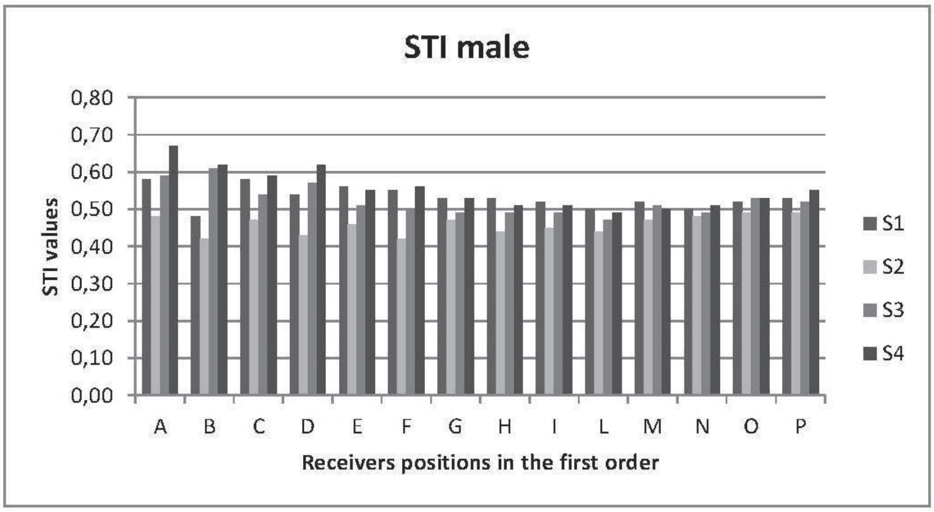


(c) Second order.

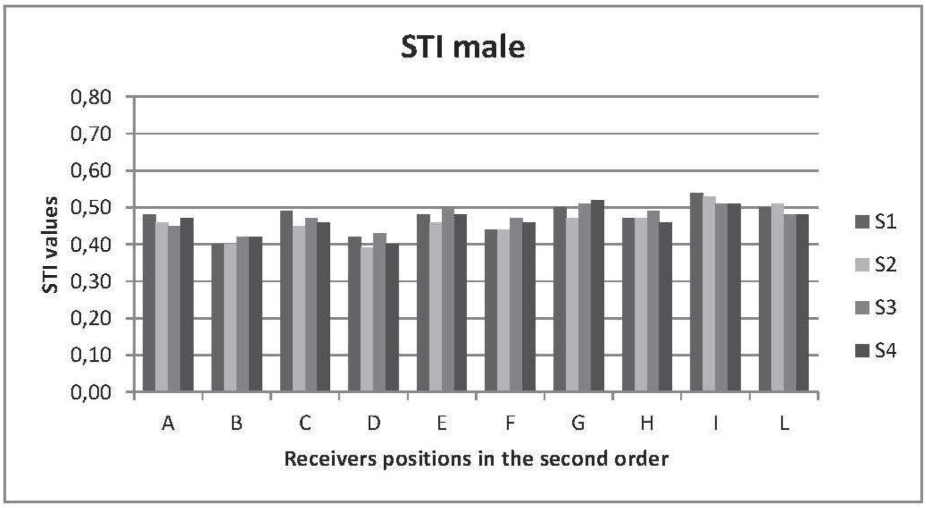
Figure 7.13: Difference between minimum and maximum measured value of STIPA for each receiver position.



(a) Audience.

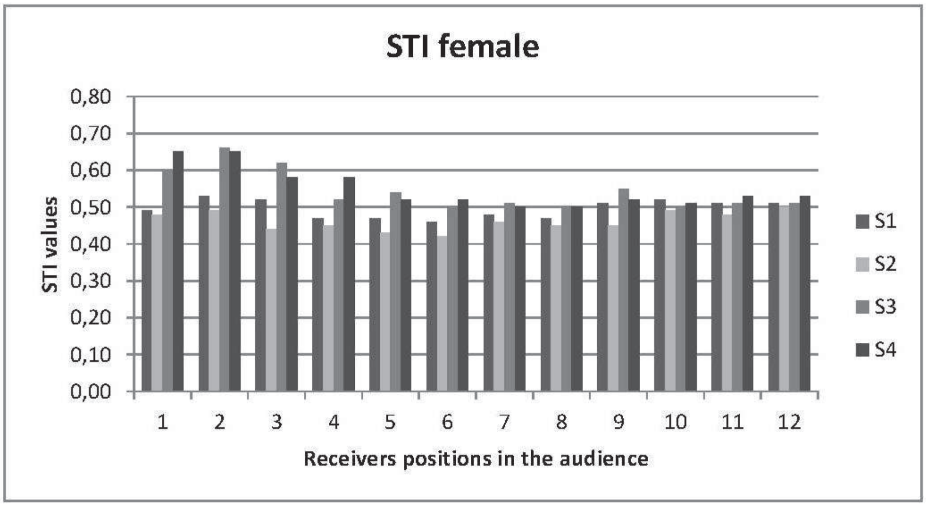


(b) First order.

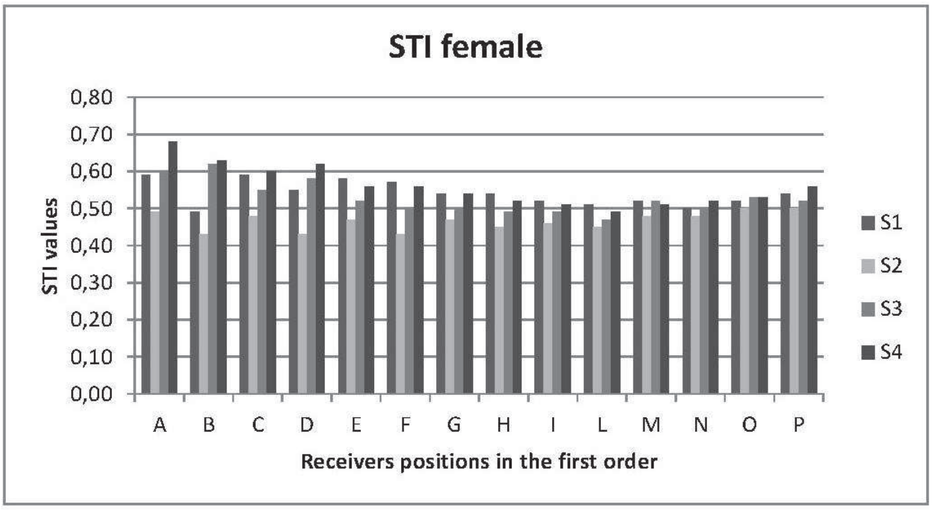


(c) Second order.

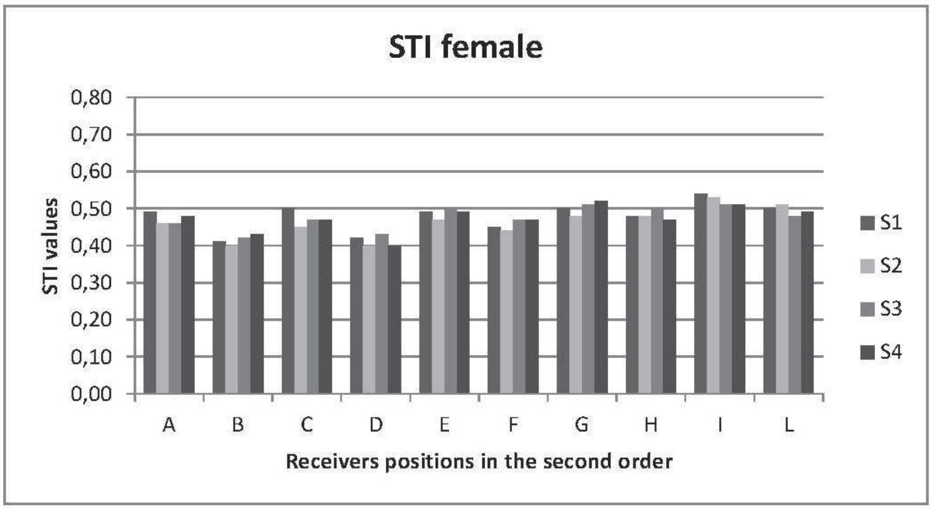
Figure 7.14: STI male values for the different source positions.



(a) Audience.

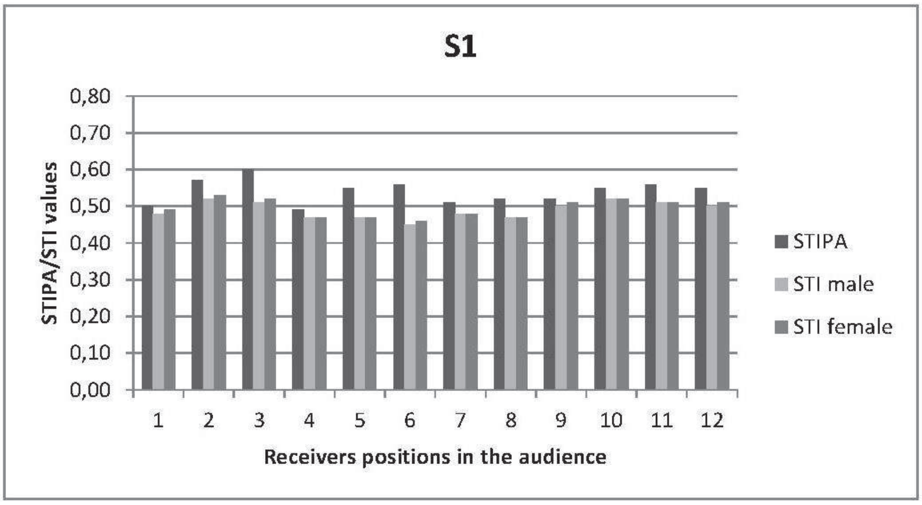


(b) First order.

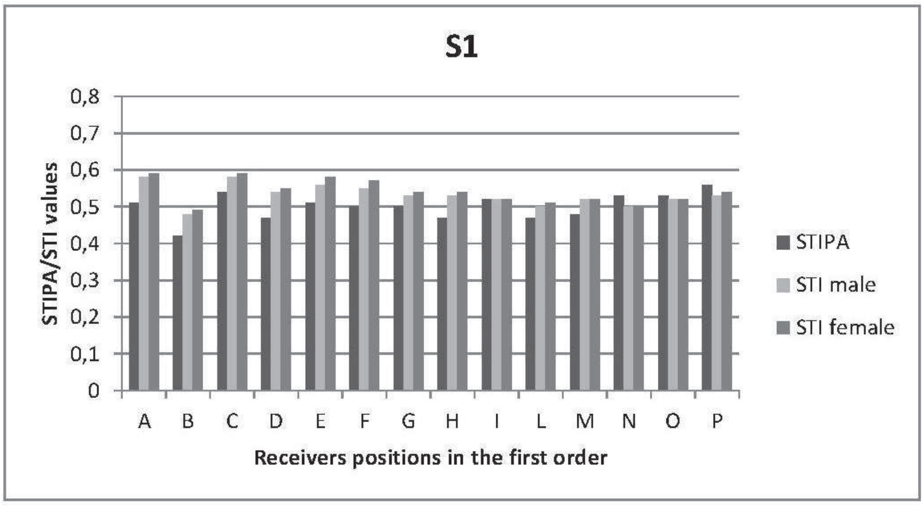


(c) Second order.

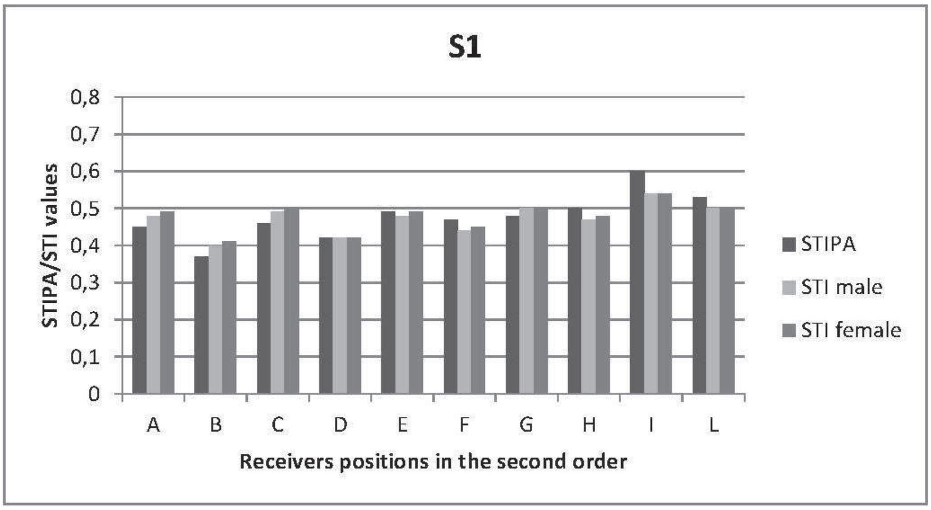
Figure 7.15: STI female values for the different source positions.



(a) Audience.

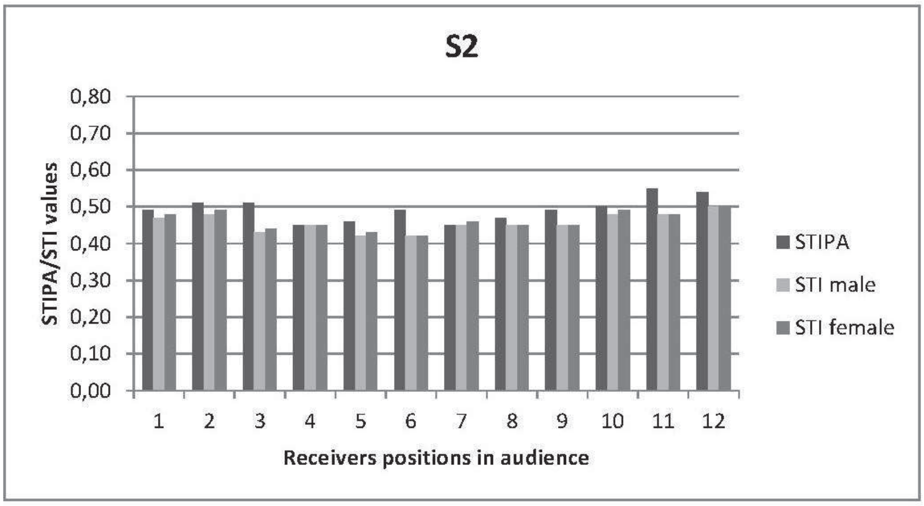


(b) First order.

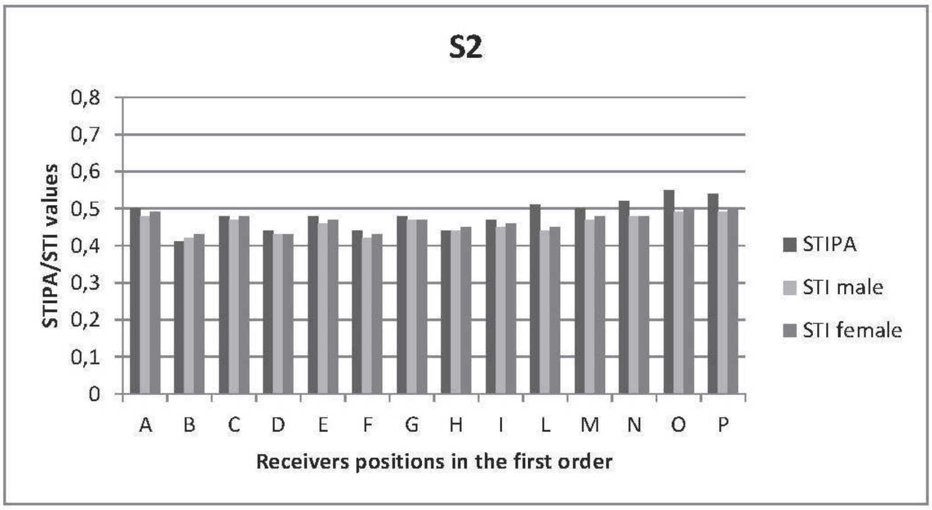


(c) Second order.

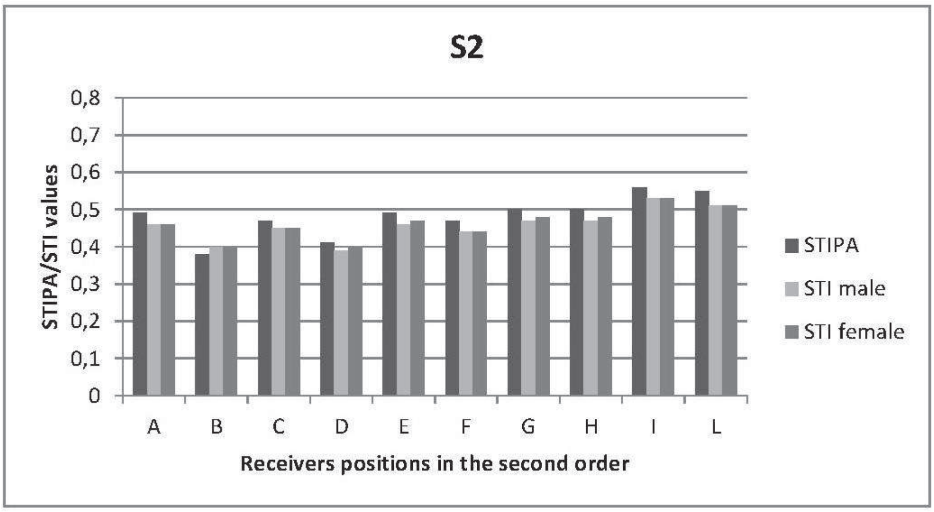
Figure 7.16: Comparison between STIPA, STI male and STI female for source position S1.



(a) Audience.

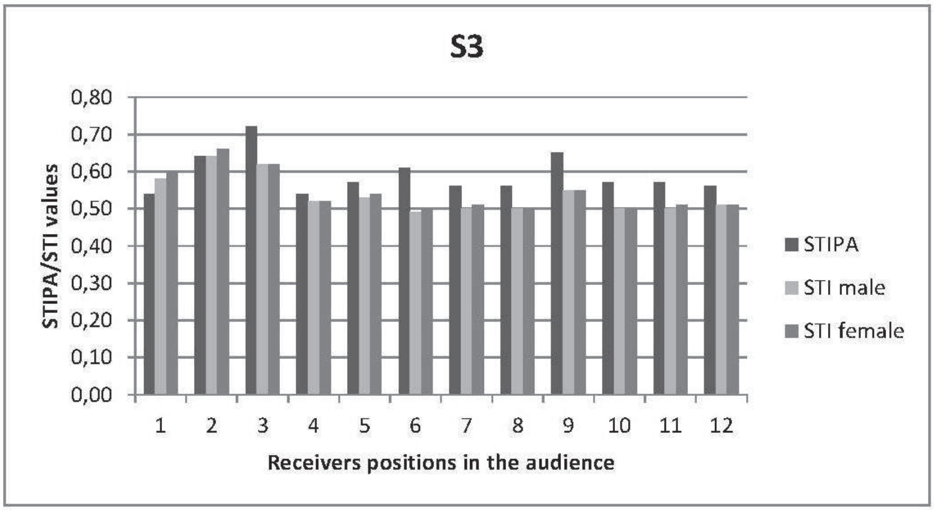


(b) First order.

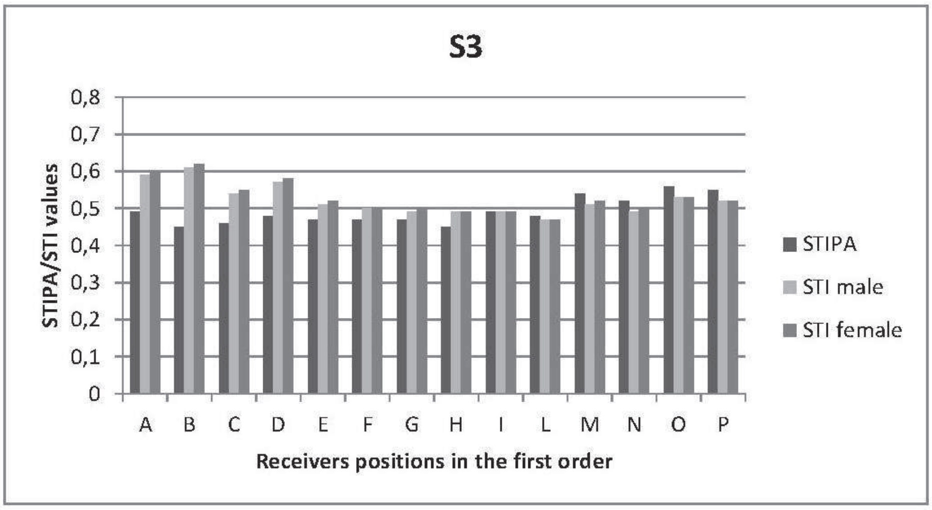


(c) Second order.

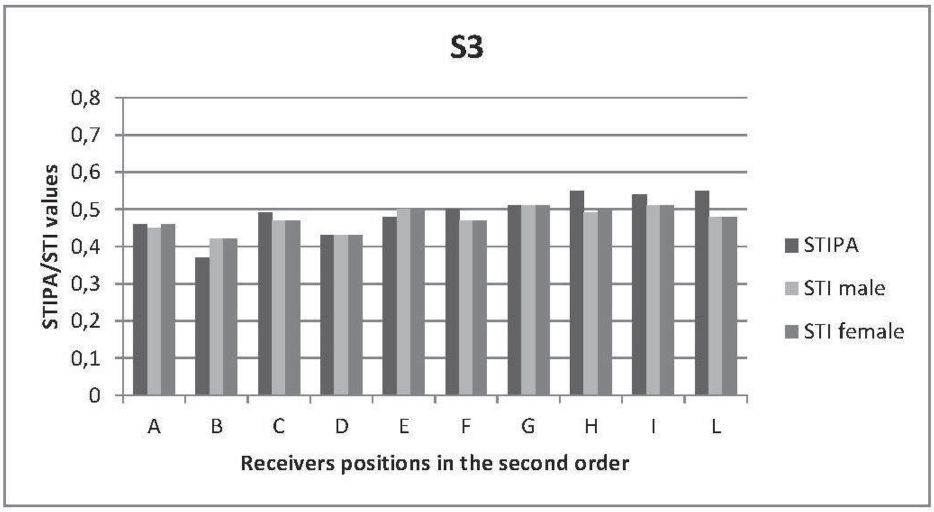
Figure 7.17: Comparison between STIPA, STI male and STI female for source position S2.



(a) Audience.

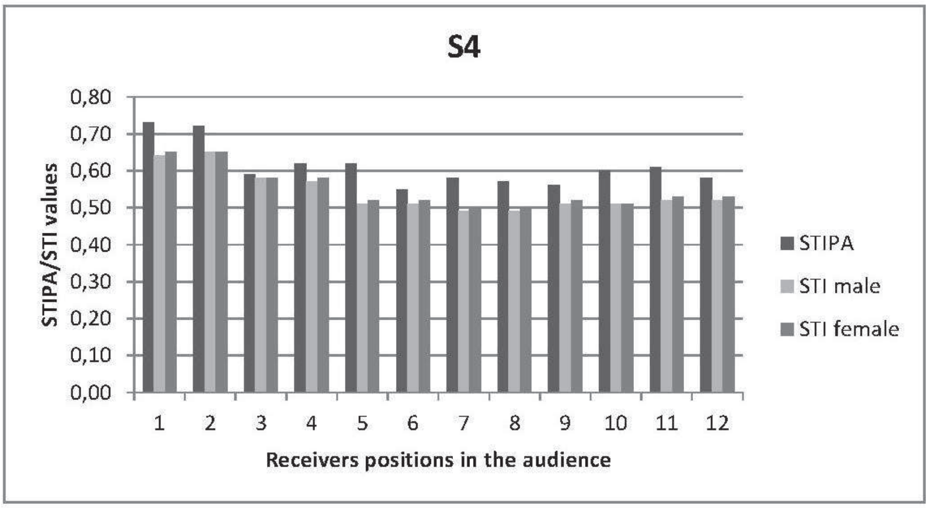


(b) First order.

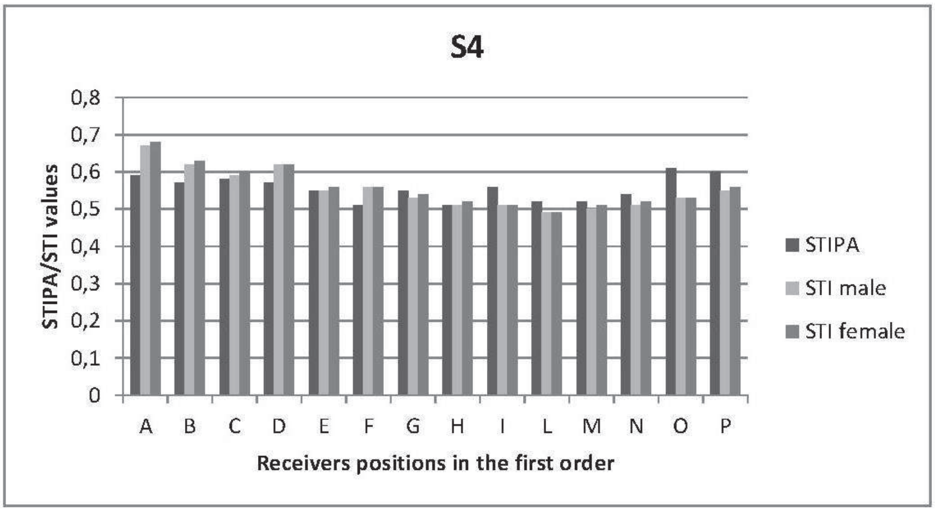


(c) Second order.

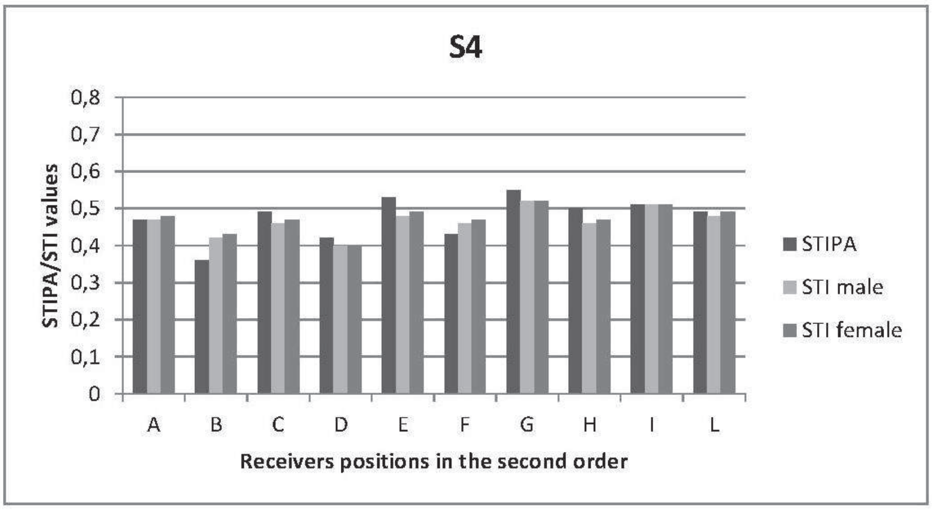
Figure 7.18: Comparison between STIPA, STI male and STI female for source position S3.



(a) Audience.



(b) First order.



(c) Second order.

Figure 7.19: Comparison between STIPA, STI male and STI female for source position S4.

Chapter 8

Discussion

8.1 Comparison with the situation before the restoration

From the comparisons between energy and reverberation parameters (C_{80}, D_{50}, EDT and T_{30}) measured in 2005 and the same parameters measured in 2015, it can be noticed that the Theatre has maintained its characteristics. A little increase of the C_{80} can be noticed in the orders, while a noticeable increase of T_{30} can be seen in all the Theatre, even if it has to be considered that the positions of receivers are not exactly the same, because of the differences between the Theatre conditions before and after the restoration.

All the differences that can be noticed between the measurements performed in 2005 and 2015 are around the just noticeable difference (JND) or a bit more.

As regard energy parameters as C_{80}, the obtained result is not clear: the differences found about the energy parameters are very small, while noticeable differences could be expected, because these parameters depend heavily on the measurements positions. In this case, the positions measured in 2005 and in 2015 are different and also the conditions of the Theatre are very different.

As regard the absorption, it is increased in 2015 at low (125 Hz) and high (8000 Hz) frequencies, while for the mid frequencies the absorption is not changed very much, even if it is a bit lower in 2015 (in accordance with T_{30} results). The differences at 8000 Hz may be disregarded because they may be due to differences in the measurement equipments, while differences in the frequency bands between 500 and 4000 Hz may be due to the different Theatre conditions (curtains, etc.).

8.2 Measurements reproducibility

Analysing the comparisons between the results obtained from the measurements performed on 10/09/2015 and on 11/09/2015 with different equipments with omnidirectional source, some conclusions can be done. In all the comparisons, the reverberation time (T_{10}, T_{20} and T_{30}) and the EDT have a more stable behaviour, almost equal for both the equipments. These parameters can be obtained with a relative certainty using both the equipments analysed (omnidirectional ones).

C_{80}, D_{50} and T_s show greater differences in the first order in low frequency bands and in the second order in all the frequencies. Regarding this comparisons, another situation can be noticed: at 250 Hz, the energy parameters have a different behaviour, in fact C_{80} and D_{50} are higher with the equipment of the 11/09/2015, while T_s is lower with the equipment of the 11/09/2015.

This situation can be explained comparing the different positions of the source: on 10/09/2015 the omnidirectional dodecahedron used has been placed on a tripod, while on 11/09/2015 the omnidirectional dodecahedron used has been placed on the floor of the stage. C_{80} and D_{50} obtained with the measurements performed on 11/09/2015 are higher at 250 Hz probably due to the reflection on the stage.

All the differences that can be noticed between the measurements performed with the 2 different equipments with omnidirectional source in the audience are around the just noticeable difference (JND) or a bit more. The differences that can be noticed between the measurements performed with the 2 different equipments with omnidirectional source in the orders are a bit more than JND: in the orders the differences are a bit higher.

The results obtained from the 2 equipments with omnidirectional source have been averaged also between some representative frequency bands, to give a synthetic overview of the characteristics of the Theatre and to better visualize the possible differences between the 2 equipments. It can be seen that values of EDT and T_{30} are very similar, although the values of EDT referred to the measurements done on 11/09/2015 are a bit lower in the second order. Values of T_s referred to the measurements done on 11/09/2015 are lower in all the configurations. Values of C_{80} don't have a specific trend: some values are similar, while some other values, referred to the measurements done on 11/09/2015, are lower (in the audience and in the first order for S3, in the first and second orders for S1 and in the second order for S2).

For reverberation time and EDT, the changes between the 2 equipments are little, because the energy has been balanced by the various reflections of the sound in the environment. In energy criteria, the changes between the 2 equipments are more marked also because of the different directivity of dodecahedral sources in high frequencies, in addition to the fact that the positions chosen by the operators were similar, but not exactly the same. Energy criteria, in fact, are very dependent on position and directivity.

It has to be noticed that the 2 equipments used differ in the type of acquisition software and a big difference between the 2 software is the data encoding: 16 bit for Dirac software and 24 bit for the custom software of the University of Bologna. The second software may then have a better definition than the other.

8.3 Sensitivity analysis

Analysing the comparisons between the results obtained from the measurements performed on 10 and 11/09/2015 with different equipments, some conclusions can be done. In all the comparisons, the reverberation time (T_{10}, T_{20} and T_{30}) and the EDT have a more stable behaviour, almost equal for all the equipments. These parameters can be obtained with a relative certainty using all the equipments analysed.

As regard the comparison between omnidirectional and directional source, C_{80}, D_{50} and T_s have a different behaviour in the frequency bands above 500 Hz in all the area: C_{80} and D_{50} are higher with directional source, while T_s is higher with omnidirectional source. Also the EDT has a different behaviour above 500 Hz: it is higher with omnidirectional source. T_{10} shows the same behaviour of EDT, but less pronounced. C_{80} and D_{50} are higher with the directional source because the directional source doesn't emit in the rear volume of the source, so, the majority of non intelligibility derives from the rear volume. The EDT is lower when it is obtained with the directional source because the directional source provides more energy in the direct field respect to omnidirectional one. No great differences can be noticed up to 250 Hz because at low frequencies the dodecahedron and the directional loudspeaker are both almost omnidirectional. The differences that can be noticed between the measurements performed with the omnidirectional and the directional source in the audience and the orders are a bit more than JND.

Regarding the comparison between sweep and balloons, both for the audience and for the stage, C_{80} and D_{50} are higher if they are obtained with sine sweep, while T_s is higher if it is obtained with balloon as source. This situation can be explained by the fact that balloons provide less energy in the environment respect to sine sweep. The differences that can be noticed between the measurements performed with the sweep and balloons in the audience are a bit more than JND. The differences that can be noticed between the measurements performed with the sweep and balloons on the stage are a bit more than JND.

As regard the comparison between Dirac and Tascam acquisition, C_{80} and D_{50} are higher if they are obtained with Tascam digital recorder, while T_s is higher if it is obtained with Dirac equipment. The differences that can be noticed between the measurements acquired with Dirac and Tascam in the audience are a bit more than JND. The differences that can be noticed between the measurements acquired with Dirac and Tascam on the stage are almost always more than JND. Regarding the comparisons of the measurements acquired with Dirac and Tascam, the clarity, the definition and the centre time show a parallel shift in averages in all the frequency bands. As regard clarity and definition, the average obtained with the acquisition done with Tascam digital recorder is higher than the one obtained with the other equipment, while for the centre time the average obtained with the Tascam is lower than the one obtained with the other equipment. This behaviour may be explained by the fact that the receivers used in the Dirac set of measurements are omnidirectional, so they receive even from behind (from the rear volume), while the Tascam's microphones are directed towards the sides, not behind, and the fact that the majority of non intelligibility derives from the rear volume. On the stage this behaviour is even more pronounced.

Clarity, definition and centre time are the most influenceable parameters by the variation of source type and acquisition equipment. The other parameters that can be influenceable are EDT and T_{10}. On the stage, the measurements performed show the grater differences, bigger than the JND for each parameter.

As regard the comparison between different settings in the measurements of intelligibility parameters, differences can be noticed in all the positions, measured in the audience, with a decrease in speech intelligibility when the source emits 60 dB at 1 m: the majority of the positions shown a value of STIPA in the range of poor speech intelligibility, while, when the source emits 70 dB at 1 m, the values are in the range of fair speech intelligibility. A good speech intelligibility can be achieved in the Theatre of Schio with a raised vocal effort (Lombard effect, 70 dB). This is the situation of actors on the stage, that use raised voice. In fact, it is not usual to speak on the stage with a tone of voice as in a conversation (60 dB).

8.4 Acoustic quality of the Theatre

For the characterization of the environment, the parameters obtained from the measurements performed on 10 and 11/09/2015 have been analysed grouping them according to main subjective sensations:

- energy parameters (C_{80}, T_s);
- reverberation parameters (reverberation time, EDT);

- intelligibility parameters (STI).

8.4.1 Energy and reverberation parameters

As regard energy parameters, the analysis of the C_{80} distribution in the Theatre doesn't show grat difference as regard the position of the receivers. All the three areas of the Theatre have almost the same behaviour. In the audience, the positions more distant from the stage (10, 11,12), and so from the source, show the highest values of clarity, probably due to the first reflections from the back structures. Regarding the position of the source, values of C_{80} vary in all frequencies with differences between 1 and 2 dB. Higher values correspond to the forward positions: more advanced the source is, higher the clarity is, due to the higher amount of first energy.

Regarding reverberation parameters, EDT values are similar for all the Theatre, even if in the second order lower values are found in the frequency bands of 125 and 500 Hz. This situation is different from other Italian theatres, where EDT values decrease in the orders, and it can be explained with the different configuration of the boxes: in the Civic Theatre of Schio, the first and the second orders are not characterised by boxes, because the parts now fit for use, and so investigated, are galleries, both in the first order and in the second order, without walls in between to separate the boxes. Regarding the position of the source, higher values of EDT correspond to backward positions. The values of T_{30} are the same in all the Theatre and they don't change with the position of the source.

For all the positions in the Theatre, the EDT/T_{30} ratio is around 1, showing a great similarity between EDT and T_{30} values. The mean EDT/T_{30} ratio in the Civic Theatre is 0,9, in line with the values in literature: between about 0,8 and 1,1 [7]. The main difference that can be noticed is that in many positions of the Theatre, expecially the ones far from the source on the stage, the EDT values are lower than T_{30} values, and this usually indicates a higher speech intelligibility, because of the contribution of strong early reflections. In the Civic Theatre of Schio the proscenium arch is thin, almost not present, and so it is possible to think that the first reflections are not so strong. The EDT/T_{30} ratio shows however values less than 1 in many situations, where the EDT values are lower than T_{30}, so speech intelligibility seems to be high.

Usually, the audience area is characterised by a very absorbing surface (seats), by a very reflecting surface at the listeners' height (the *marmorino*, a plaster made of marble and slaked lime) and by the presence of boxes [16]. This is not completely true for the Civic Theatre of Schio, because the seats are not of the same type of classical theatre's seats, padded and covered with velvet, but they are the usual director seats, not padded, so the absorption due to the seats is lower. In addition, in the Civic Theatre of Schio, the first and the second orders are not characterised by boxes, because the parts of the orders now fit for use, and so investigated, are galleries, both in the first order and in the second order, without walls in between to separate the boxes. The acoustics field in the orders is different respect to the classical one inside divided boxes. The EDT/T_{30} ratio doesn't decrease in the orders, as it can be expected, except for some positions in the second order (SS3 and SS6 in particular). A bit lower values of EDT/T_{30} ratio can be found in some backward positions in the audience (9, 10, 11, 12). The situation is not therefore completely equal to other Italian theatres analysed in literature [16].

The Theatre shows high values of reverberation times and this can lead to a negative effect on the speech intelligibility. On the contrary, these high values of reverberation times may be an advantage for symphonic music. It has to be noticed that the measurements done on 10/09/2015 and 11/09/2015 have been performed without lateral curtains. This fact can lead to an overestimation of the reverberation parameters, that can be decreased by the addition of the curtains, as curtains are usually used.

8.4.2 Comparison with Bonci Theatre

A further analysis has been carried out comparing the results on the stage obtained in the Civic Theatre of Schio with the ones obtained in the Bonci Theatre of Cesena. Even if it has to be taken into account that the configurations of the source and receivers and of the curtains on the stage were different during the measurements performed in the Bonci Theatre of Cesena and the Civic Theatre of Schio, it can be noticed that the values of EDT and T_{30} are considerably different in the 2 theatres. In the Civic Theatre of Schio the values are higher, especially as regard EDT. The differences of T_{30} vary between 0 (at 250 Hz) and 0,8 s (at 1000 Hz), while the differences of EDT vary between 0,3 (at 250 Hz) and 1,6 s (at 1000 Hz). The Theatre of Cesena was among the most appreciated by musicians, according to the previous research [28], as they perceived higher reverberation time. Having reverberation time even more high, the Civic Theatre seems to be pleasing for musicians. The Civic Theatre seems also versatile because it can be modified by the addition of the curtains. With high reverberation time, these Theatre seems to be so suitable for symphonic music.

8.4.3 Intelligibility parameters

As regard intelligibility parameters, despite some differences have been highlighted, the values of STIPA and STI return consistent results, that define a fair speech intelligibility in all the Theatre. The differences between minimum and maximum STIPA values in each receiver position, regarding the different positions of the source, are not very high, so the results are similar for all the positions of the source.

It has to be noticed that measurements through the amplifiers can be made, but in this study they are not present. Although it should be verified with additional measurements, probably amplifiers may cause problems with so high reverberation time. The setting of the amplifiers, in case of their use, must therefore be done carefully, also because the modern fruition of the Theatre doesn't tend to use it for the opera, but often for amplified performances. It always has to be taken into account that the measurements performed have been done without curtains: the addition of curtains could improve the conditions also for the use of amplifiers.

Chapter 9

Conclusions

A multiparametric analysis of the Civic Theatre of Schio has been done, but the same analysis is applicable to other environmental problems. The scientific approach and the techniques used are applicable to any other problem of environmental noise, for closed environments (diffuse field), as optimization of the warning signals, safety problems and environmental and industrial acoustic problems.

The reproducibility of the measurements has been studied: different and independent techniques, applied by different and independent operators, have been compared. As it has been possible to see, they converge on the same results, so the reproducibility appears good. Measurements carried out with omnidirectional dodecahedra, in fact, give congruent results, especially with regard to the reverberation time.

A sensitivity analysis of the parameters has been carried out, comparing the results obtained with different techniques. It can be noticed that the parameters that present more differences changing the source and the way of acquisition are energy parameters. This is probably due to the fact that they are very dependent on the position and directivity of sources and receivers.

Finally, the acoustic characterization of the Theatre has been carried out, also comparing the current acoustic situation with the one before the restoration. The main parameters used to characterized large environments for music and speech listening have been analysed: energy parameters, reverberation parameters and speech intelligibility parameters. Compared to the situation before the restoration, the characteristics of the Theatre are remained similar. In addition, the values of the parameters measured after the restoration are homogeneous throughout all the Theatre; there are no big differences varying the positions of sources and receivers. Speech intelligibility is fair in almost all the positions of the Theatre, even if measurements through the amplifiers are not present in this study. Probably amplifiers may cause problems with so high reverberation time. The setting of the amplifiers, in case of their use, must therefore be done carefully. The addition of curtains could improve the conditions for the use of amplifiers.

The mean EDT/T_{30} ratio is 0,9, in line with the values in literature. The EDT/T_{30} ratio doesn't decrease in the orders, probably because the orders of the Civic Theatre are galleries, without walls in between to separate the boxes. The acoustics field is different respect to the classical one inside divided boxes in Italian opera theatre. Reverberation times are higher than other Italian opera theatres as Bonci Theatre of Cesena, condition that can be good for symphonic music, but not for speech.

Measurements have been conducted without curtains on stage; adding curtains, reverberation time could be lower and so the Theatre seems to be versatile and suitable both for music and speech listening.

Appendix A

SNR and INR

Signal to noise ratio (SNR) and *impulse to noise ratio* (INR) are parameters related to the quality of the measurement. The SNR is a measure used to compare the level of a signal to the level of background noise. The SNR has to be maximize to obtain a good measurement. A room acoustic impulse response can be used to derive the reverberation time and other parameters. For this, a certain minimum energy decay range or effective signal to noise ratio is required, which relates to the difference between the initial signal level and the noise level. The impulse response parameter INR can be used as an estimator for the decay range. INR serves as a quality parameter for impulse response measurements. Most practical INR values range from 35 to 60 dB; minimum INR values for some parameters are shown in table A.1 [18].

Parameter	INR
Speech Transmission Index STI	> 15 dB
Reverberation Time T20 (s)	> 35 dB
Reverberation Time T30 (s)	> 45 dB

Table A.1: Minimum INR for some parameters [18].

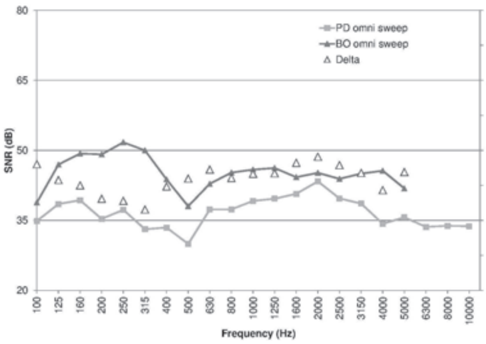
All the measurements performed have the INR greater than 50 dB, except for a few little exceptions at 125 Hz, where INR assumes values of around 45 dB. All the measurements meet the minimum INR required.

As regard the comparisons between the 2 different equipments with omnidirectional source (figures A.1, A.2 and A.3), SNR and INR averages in the audience and in the orders show different behaviours, with differences over than 10 dB.

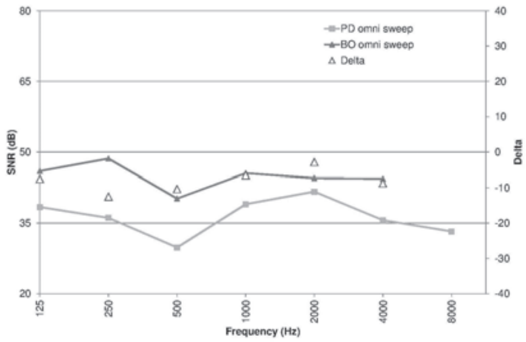
As regard the comparisons between omnidirectional and directional source (figures A.4, A.5 and A.6), SNR and INR averages in the audience and in the orders are quite similar, with differences almost always 5 dB, except for the high frequency bands (5000 Hz in 1/3 octave bands and 8000 Hz in octave bands), where bigger differences are noticeable.

Regarding the comparisons between sweep and balloon (figures A.7 and A.8), SNR and INR averages in the audience and on the stage result higher in the measurements done with balloons respect the ones done with the sine sweep, with differences around 10 and 20 dB.

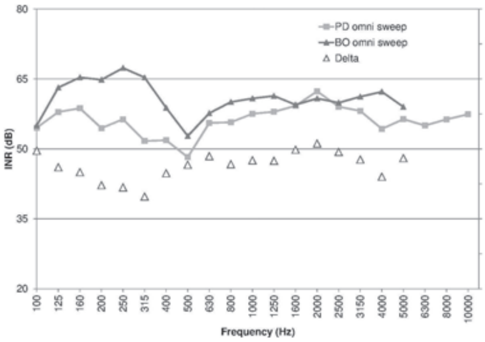
As regard the comparisons between the acquisition with Dirac and the acquisition with Tascam digital recorder (figures A.9 and A.10), SNR and INR in the audience show the same behaviour, except for the higher frequencies, where a little difference can be noticed. On the stage, INR shows the same behaviour, except for the higher frequencies, where a little difference can be noticed, while SNR shows a little shift for all the frequencies, with differences around 5 dB.



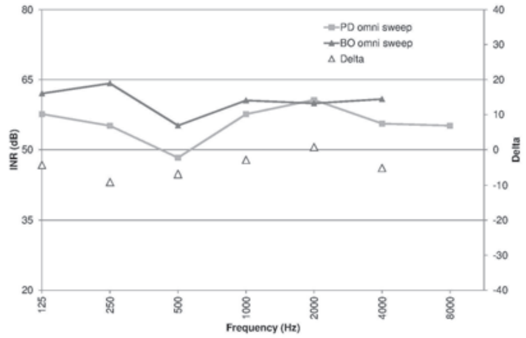
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

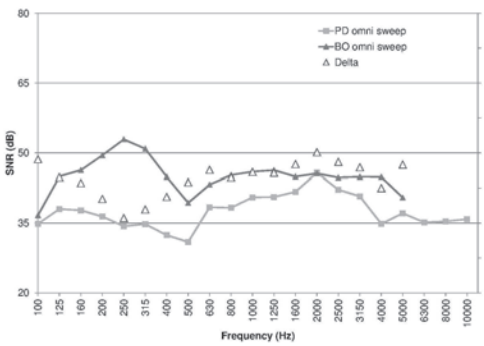


(c) INR in 1/3 octave bands.

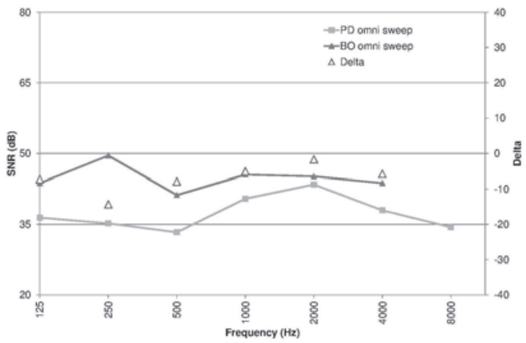


(d) INR in octave bands.

Figure A.1: Comparisons between different equipments with omnidirectional source in the audience.

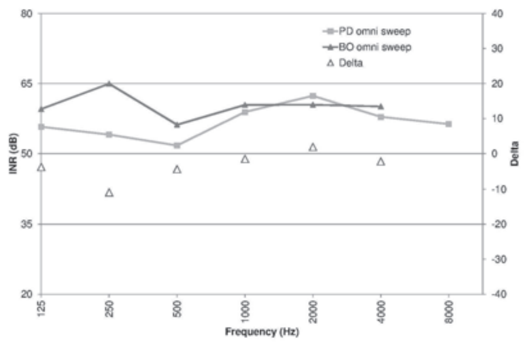


(a) SNR in 1/3 octave bands.



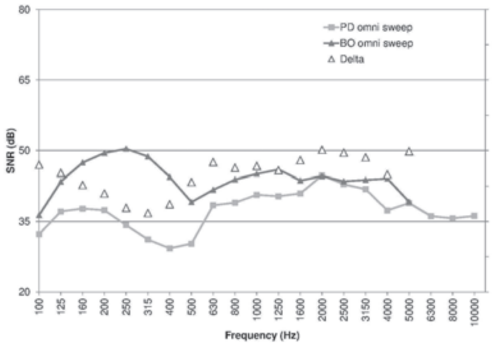
(b) SNR in octave bands.

(c) INR in 1/3 octave bands.

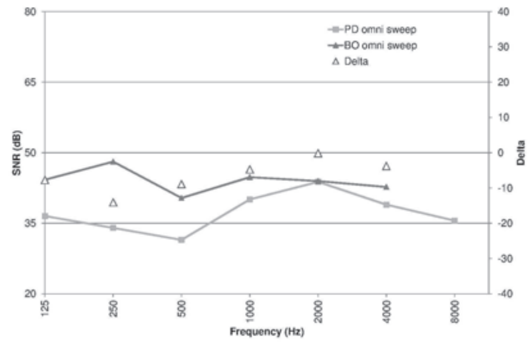


(d) INR in octave bands.

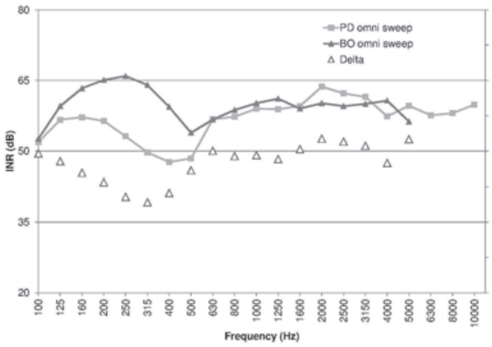
Figure A.2: Comparisons between different equipments with omnidirectional source in the first order.



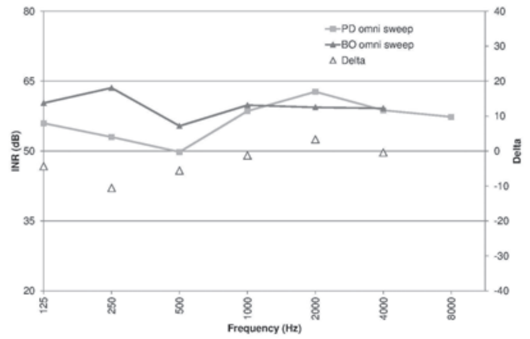
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

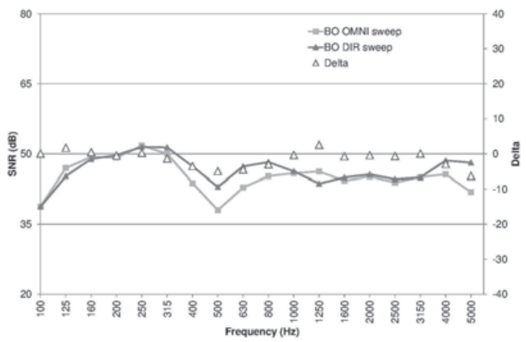


(c) INR in 1/3 octave bands.

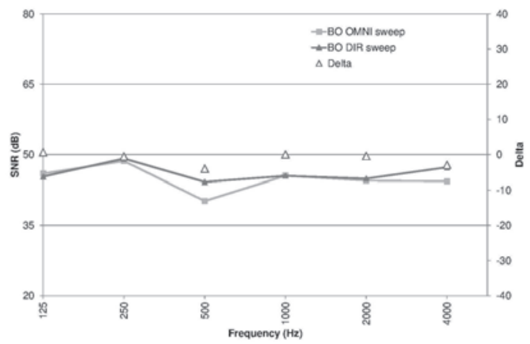


(d) INR in octave bands.

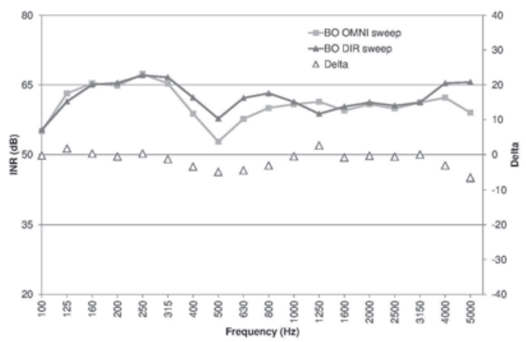
Figure A.3: Comparisons between different equipments with omnidirectional source in the second order.



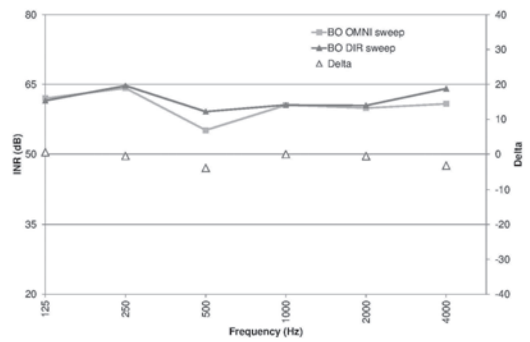
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

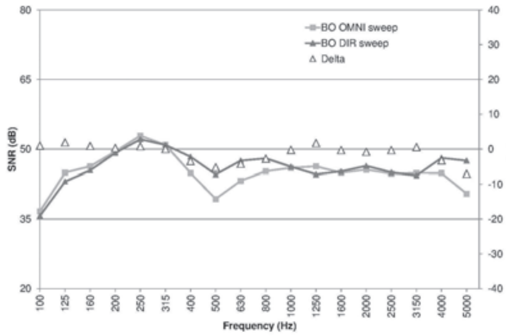


(c) INR in 1/3 octave bands.

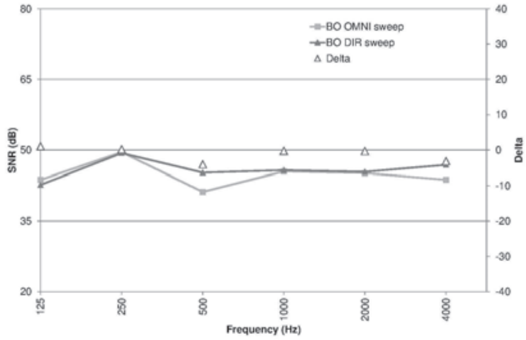


(d) INR in octave bands.

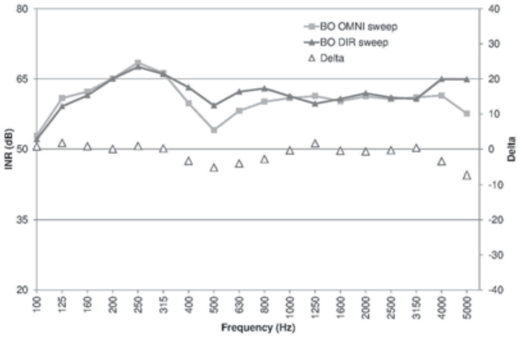
Figure A.4: Comparisons between omnidirectional and directional source in the audience.



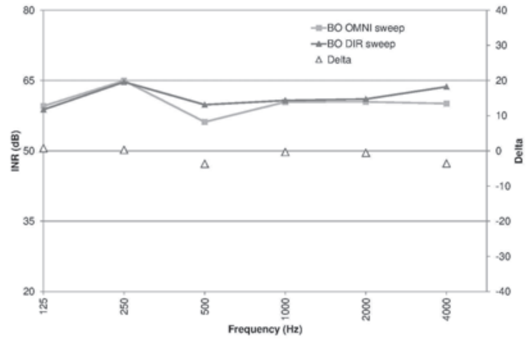
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

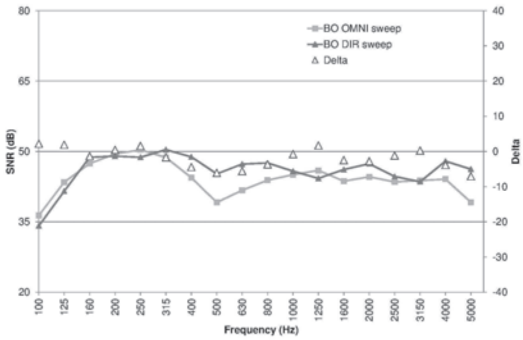


(c) INR in 1/3 octave bands.

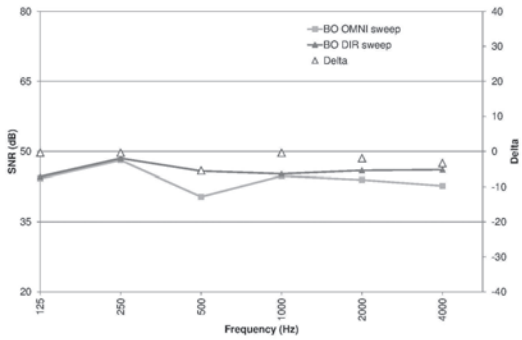


(d) INR in octave bands.

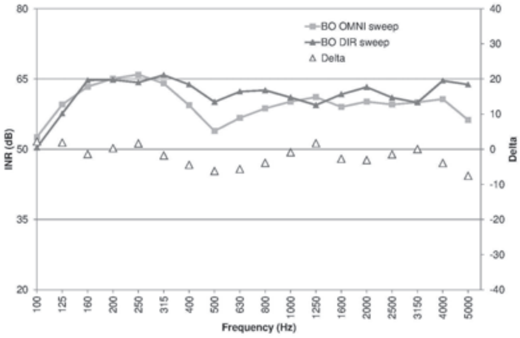
Figure A.5: Comparisons between omnidirectional and directional source in the first order.



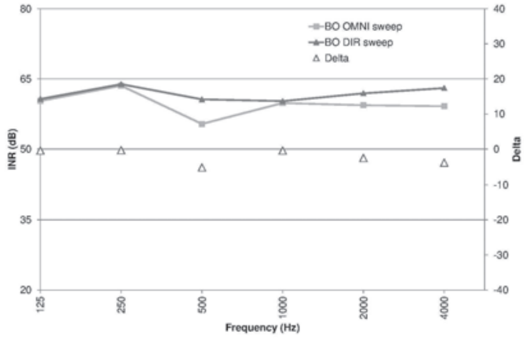
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

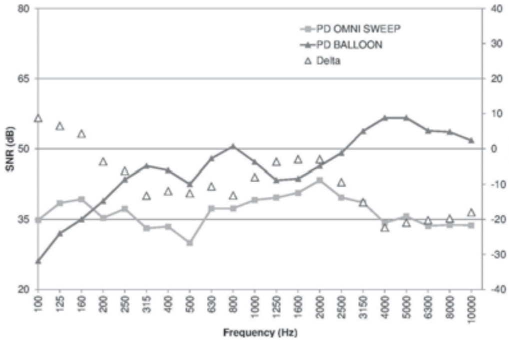


(c) INR in 1/3 octave bands.

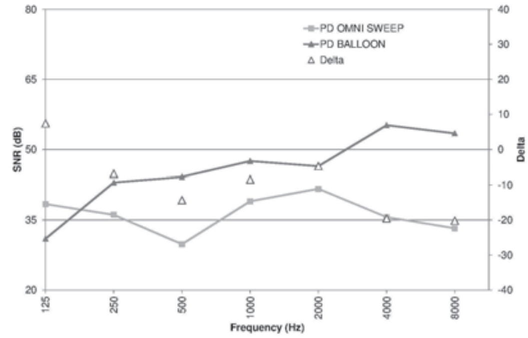


(d) INR in octave bands.

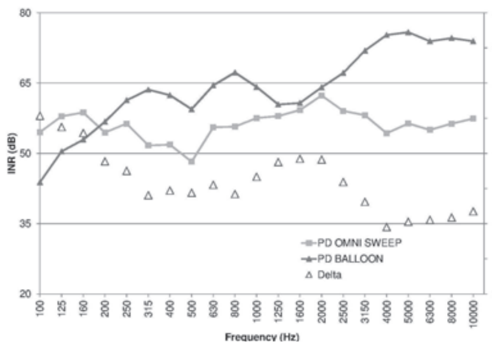
Figure A.6: Comparisons between omnidirectional and directional source in the second order.



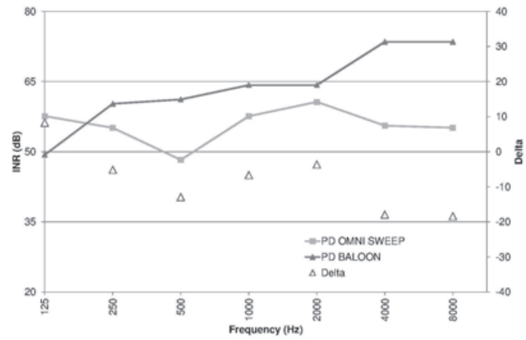
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

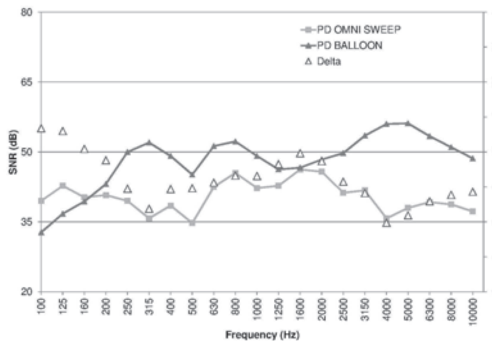


(c) INR in 1/3 octave bands.

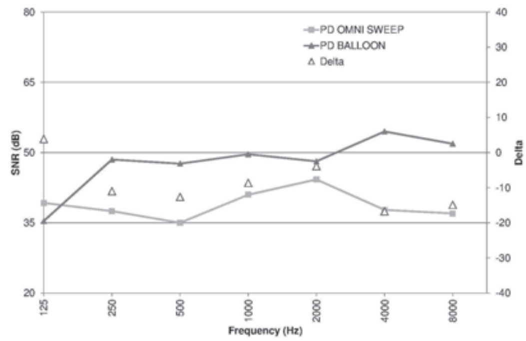


(d) INR in octave bands.

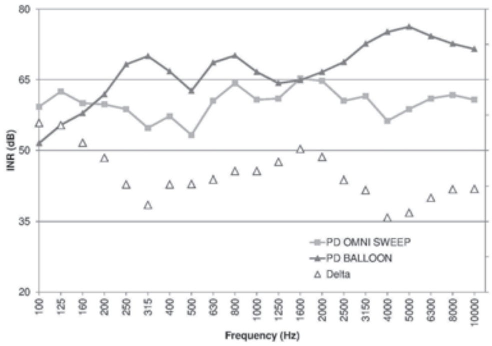
Figure A.7: Comparisons between sweep and balloons in the audience.



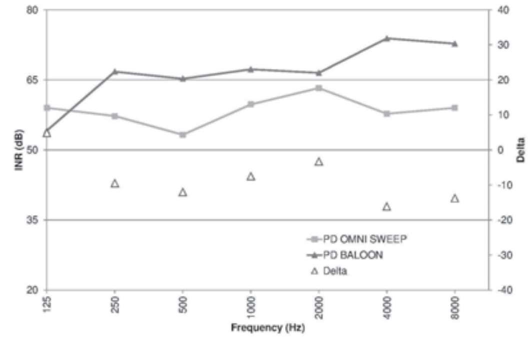
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

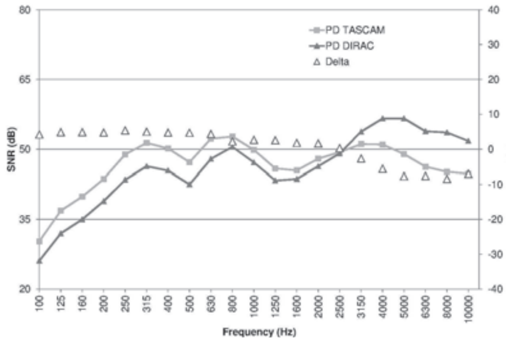


(c) INR in 1/3 octave bands.

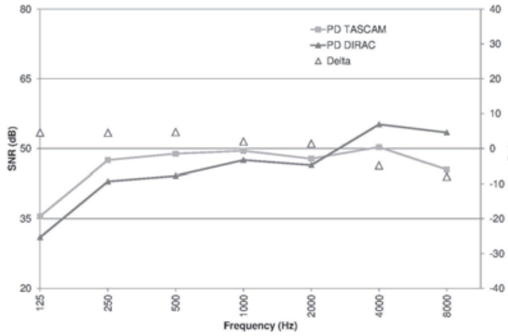


(d) INR in octave bands.

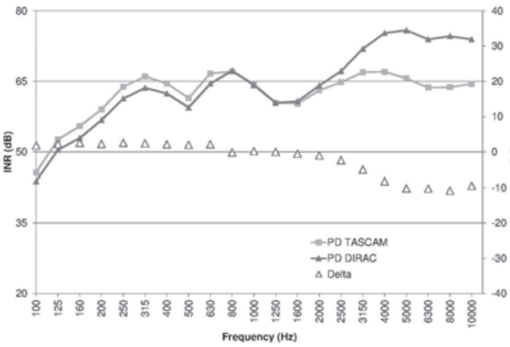
Figure A.8: Comparisons between sweep and balloons on the stage.



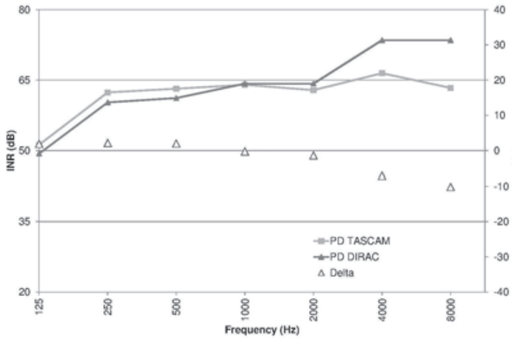
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.

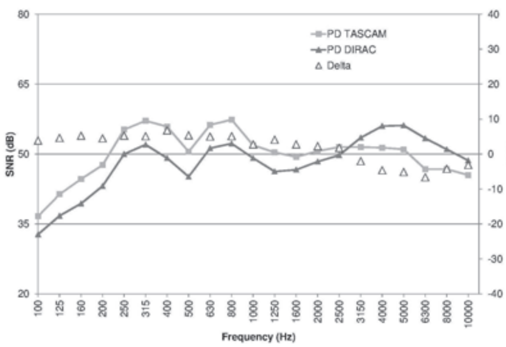


(c) INR in 1/3 octave bands.

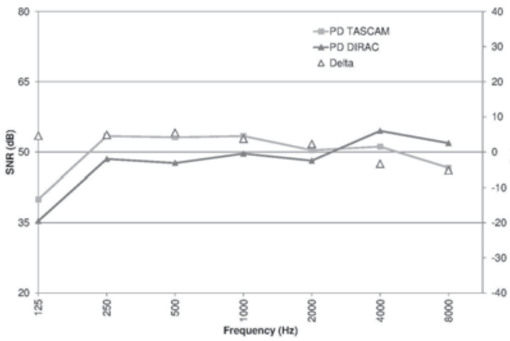


(d) INR in octave bands.

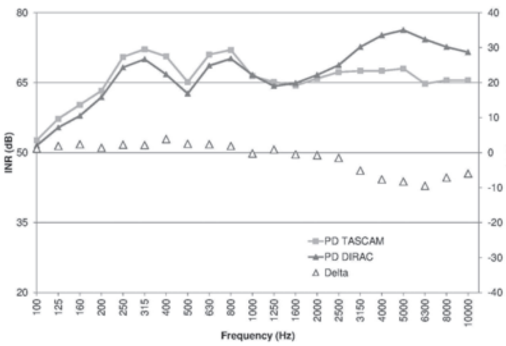
Figure A.9: Comparisons between acquisition with Dirac and Tascam in the audience.



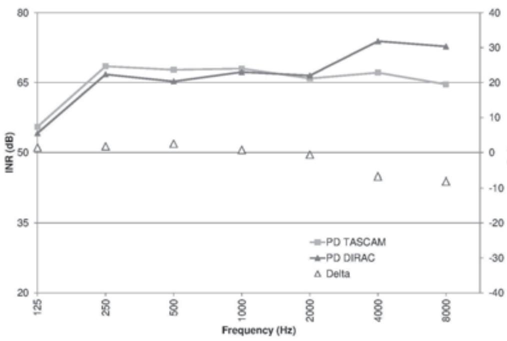
(a) SNR in 1/3 octave bands.



(b) SNR in octave bands.



(c) INR in 1/3 octave bands.



(d) INR in octave bands.

Figure A.10: Comparisons between acquisition with Dirac and Tascam on the stage.

Appendix B

Measurements results

Values of some parameters obtained from the measurements done on 10 and 11/09/2015 are reported in the following figures of this appendix. All the parameters shown are reported only in octave bands, for readability. The values have been obtained through the use of Dirac software, that allows to extract all the parameters analyzed from the impulse response obtained in the Theatre. For each group of values, already divided according to the area in which the receivers have been placed, average, standard deviation, minimum and maximum have been calculated using Excel.

Values regarding the measurements done on 11/09/2015 have been shown from 125 to 4000 Hz, due to the uncertainties in low frequencies below 125 Hz and the fact that the omnidirectional source used on 11/09/2015 doesn't emit above 4000 Hz. Values regarding the measurements done on 10/09/2015 have been shown from 125 to 8000 Hz, because the omnidirectional source used emits until the frequency band of 8000 Hz.

Values of C_{80}, D_{50}, EDT and T_{30} have been reported in octave bands, according to the areas of the Theatre in which receivers have been placed (audience, first order, second order and stage) and for each equipment.

	125	250	500	1000	2000	4000	8000
S1M01	-0,77	0,29	-1,6	-1,33	-1,78	0,41	5,22
S1M02	0,96	2,8	-1,26	-1,07	0,11	1,67	4,65
S1M03	-1,15	-0,32	-1,54	-1,07	0,77	2,07	4,78
S1M07	-2,61	-2,54	-0,68	-0,46	-0,59	-0,29	4,71
S1M08	-0,93	-1,83	-2,26	-0,83	-0,29	1,04	3,92
S1M09	0,56	1,82	-2,07	-0,1	0,59	1,48	3,56
S2M01	-4,84	0,51	-2,4	-2,17	-0,64	0,93	4,34
S2M02	-0,23	-0,41	-1,57	-1,42	-0,39	1,58	4,29
S2M03	-2,17	-2,01	-2,45	-2,15	-2,79	-1,86	2,57
S2M07	-1,88	-3,83	-5,01	-2,1	-1,53	-0,65	3,35
S2M08	-1,23	-2,35	-3,98	-2,22	-1,86	-0,35	3,41
S2M09	-1,2	-1,34	-3,6	-2,88	-2,37	-1,39	3,72
S3M01	-1,41	3,27	0,11	0,9	2,07	5,15	7,5
S3M02	2,62	4,02	1,04	3,07	4,46	6,08	10,12
S3M03	3,56	2,36	2,32	2,52	3,43	3,87	8,68
S3M07	0,41	-1,64	0,43	0,57	-0,3	0,9	3,97
S3M08	0,04	-2,62	0,66	-0,85	-0,01	0,71	3,8
S3M09	2,16	2,47	0,75	1,47	1,71	2,1	5,71
S4M01	4,4	3,99	2,09	3,2	3,78	6,04	10,61
S4M02	4,19	4,72	4,21	3,19	3,98	5,53	8,87
S4M03	1,4	3,18	0,97	2,1	2,19	3,65	5,46
S4M07	-0,16	0,23	0,45	-0,87	0,2	0,84	4,2
S4M08	-0,48	-1,14	0,16	-1,08	-0,09	0,47	4,31
S4M09	0,66	-1,7	-0,07	1,03	0,48	1,11	3,92
S1M04	-0,85	-2,05	-2,52	-0,22	-2,16	-0,43	4,68
S1M05	-1,34	-2,07	-1,88	-1,33	-1,09	0,38	3,64
S1M06	0,55	-3,59	-2,36	-2,16	-1,22	0,63	2,9
S1M10	4	1,98	-0,94	0,9	0,98	0,93	4,77
S1M11	-1,94	-1,74	0,13	0,96	0	2,3	5,64
S1M12	1,31	-0,49	-1,5	-0,42	-0,11	1,79	5,45
S2M04	-2,99	-5,56	-3,08	-3,04	-1,11	0,7	3,64
S2M05	-1,38	-4,26	-2,32	-2,28	-2,33	-0,45	3,54
S2M06	-3,5	-4,14	-3,14	-2,05	-2,72	-1,9	4,09
S2M10	-0,17	-0,34	-4,3	-0,87	0,84	0,95	4,59
S2M11	0,12	-0,83	-3,24	-1,11	-0,2	0,52	5,04
S2M12	2,21	1,1	-3,73	-1,1	-0,2	1,02	5,08
S3M04	1,47	0,02	2,07	1,61	0,14	1,39	4,02
S3M05	0,28	1,53	0,52	-0,92	1,15	3,05	5,82
S3M06	-0,64	-0,28	-0,7	-0,79	-0,79	0,5	6,39
S3M10	3,8	-1	-0,87	-0,73	0,11	0,39	4,25
S3M11	2,97	-0,03	0,29	0,21	-0,23	0,69	4,5
S3M12	2,15	0,81	-0,91	-0,09	1,3	1,15	5,08
S4M04	1,06	0,79	2,21	0,97	2,32	4,85	6,98
S4M05	-1,29	1,96	-0,7	-0,54	-0,1	1,75	5,55
S4M06	-0,97	0,91	0,04	0,04	0,03	1,72	6,15
S4M10	0,68	-0,91	-0,66	1,1	-0,36	-0,28	3,35
S4M11	-0,74	-0,74	-1,53	1,11	0,97	0,25	3,39
S4M12	-0,62	-1,85	0,99	-0,64	1,05	2,41	5,46
Media	0,126458	-0,26771	-0,90479	-0,29042	0,154167	1,3625	4,993125
Dev.st	2,055824	2,332625	1,947244	1,574202	1,674478	1,862569	1,742445

Figure B.1: C_{80} values in the audience with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1M01	0,42	0,47	0,35	0,37	0,29	0,43	0,69
S1M02	0,53	0,61	0,4	0,38	0,43	0,53	0,66
S1M03	0,36	0,42	0,36	0,36	0,44	0,55	0,66
S1M07	0,31	0,25	0,35	0,37	0,34	0,35	0,58
S1M08	0,34	0,32	0,25	0,28	0,3	0,4	0,53
S1M09	0,45	0,36	0,23	0,36	0,33	0,36	0,45
S2M01	0,15	0,39	0,29	0,31	0,39	0,46	0,64
S2M02	0,33	0,36	0,3	0,32	0,39	0,5	0,63
S2M03	0,22	0,3	0,26	0,29	0,21	0,27	0,54
S2M07	0,29	0,14	0,19	0,24	0,31	0,35	0,56
S2M08	0,29	0,18	0,2	0,24	0,3	0,36	0,55
S2M09	0,3	0,21	0,18	0,25	0,25	0,29	0,57
S3M01	0,37	0,65	0,45	0,49	0,55	0,72	0,8
S3M02	0,57	0,69	0,53	0,62	0,7	0,76	0,88
S3M03	0,6	0,6	0,6	0,6	0,62	0,64	0,84
S3M07	0,41	0,28	0,44	0,39	0,36	0,4	0,54
S3M08	0,42	0,3	0,37	0,33	0,39	0,39	0,54
S3M09	0,56	0,52	0,4	0,44	0,42	0,42	0,53
S4M01	0,69	0,66	0,58	0,62	0,63	0,75	0,89
S4M02	0,69	0,72	0,67	0,64	0,68	0,74	0,84
S4M03	0,5	0,65	0,52	0,54	0,57	0,63	0,7
S4M07	0,37	0,26	0,36	0,32	0,39	0,39	0,57
S4M08	0,42	0,37	0,39	0,34	0,37	0,38	0,59
S4M09	0,47	0,25	0,29	0,39	0,4	0,41	0,53
S1M04	0,39	0,18	0,27	0,42	0,27	0,31	0,6
S1M05	0,34	0,23	0,34	0,34	0,35	0,42	0,53
S1M06	0,32	0,11	0,26	0,29	0,31	0,41	0,5
S1M10	0,68	0,5	0,36	0,38	0,28	0,28	0,5
S1M11	0,35	0,2	0,31	0,4	0,31	0,42	0,64
S1M12	0,5	0,3	0,31	0,36	0,38	0,46	0,63
S2M04	0,15	0,13	0,26	0,22	0,3	0,41	0,56
S2M05	0,23	0,17	0,26	0,27	0,28	0,34	0,56
S2M06	0,13	0,18	0,24	0,26	0,2	0,21	0,56
S2M10	0,28	0,34	0,18	0,34	0,43	0,41	0,59
S2M11	0,41	0,39	0,23	0,31	0,37	0,36	0,61
S2M12	0,51	0,41	0,18	0,31	0,38	0,42	0,59
S3M04	0,4	0,44	0,49	0,47	0,35	0,42	0,54
S3M05	0,28	0,44	0,45	0,33	0,47	0,56	0,68
S3M06	0,37	0,42	0,35	0,38	0,34	0,38	0,71
S3M10	0,52	0,24	0,28	0,32	0,36	0,38	0,56
S3M11	0,5	0,32	0,33	0,37	0,34	0,37	0,55
S3M12	0,43	0,25	0,3	0,34	0,34	0,4	0,57
S4M04	0,19	0,45	0,56	0,44	0,48	0,66	0,75
S4M05	0,32	0,47	0,38	0,36	0,4	0,48	0,68
S4M06	0,32	0,4	0,4	0,39	0,41	0,46	0,69
S4M10	0,37	0,33	0,36	0,43	0,39	0,32	0,51
S4M11	0,33	0,34	0,3	0,48	0,4	0,38	0,52
S4M12	0,36	0,32	0,36	0,33	0,4	0,47	0,54
Media	0,390417	0,365	0,348333	0,375625	0,3875	0,441875	0,614167
Dev.st	0,133671	0,15748	0,115728	0,100401	0,110135	0,128372	0,103653

Figure B.2: D_{50} values in the audience with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1M01	1,922	2,094	2,569	2,548	2,187	1,823	1,244
S1M02	2,266	2,459	2,217	2,515	2,143	1,843	1,233
S1M03	1,959	2,147	2,292	2,176	2,235	1,813	1,25
S1M07	1,297	1,924	2,325	2,322	1,768	1,496	0,796
S1M08	1,628	1,853	2,35	2,18	1,91	1,539	0,859
S1M09	1,875	1,453	2,162	2,087	1,725	1,487	0,845
S2M01	1,743	2,137	2,654	2,507	2,275	1,84	1,236
S2M02	2,101	2,204	2,519	2,66	2,242	1,789	1,182
S2M03	2,472	2,22	2,153	2,198	2,183	1,854	1,203
S2M07	1,979	1,937	2,745	2,412	2,28	1,753	1,092
S2M08	1,372	1,858	2,601	2,497	1,971	1,611	0,945
S2M09	1,72	1,866	2,189	2,205	1,955	1,679	1,037
S3M01	1,878	2,436	2,455	2,188	1,966	1,803	1,104
S3M02	1,374	2,344	2,071	2,248	1,964	1,703	0,807
S3M03	1,634	1,893	2,085	2,151	2,025	1,738	1,182
S3M07	1,764	2,112	2,246	2,12	1,831	1,381	0,815
S3M08	1,475	2,074	2,179	2,058	1,77	1,329	0,816
S3M09	0,942	1,45	1,876	1,615	1,627	1,272	0,665
S4M01	2,123	1,907	2,265	2,217	1,959	1,716	0,888
S4M02	1,206	2,005	2,556	2,319	1,992	1,713	1,022
S4M03	1,605	2,134	2,499	2,143	2,002	1,742	1,079
S4M07	2,004	1,842	1,743	1,992	1,989	1,431	0,91
S4M08	1,306	2,097	2,24	2,057	1,928	1,518	0,906
S4M09	1,232	1,724	1,998	1,913	1,732	1,486	0,834
S1M04	1,542	2,031	2,374	2,485	2,173	1,693	1,015
S1M05	1,946	2,051	2,96	2,676	2,32	1,952	1,118
S1M06	2,515	2,184	2,397	2,421	2,293	1,912	1,17
S1M10	1,924	2,206	2,234	2,087	1,634	1,25	0,768
S1M11	1,833	1,803	2,09	2,094	1,785	1,403	0,759
S1M12	1,719	1,935	2,486	2,344	1,984	1,479	0,79
S2M04	1,953	2,344	2,662	2,51	2,182	1,791	1,15
S2M05	1,977	2,277	2,965	2,785	2,319	1,926	1,174
S2M06	1,836	2,142	2,64	2,555	2,35	1,803	1,169
S2M10	1,483	1,918	2,333	2,206	2,069	1,614	0,97
S2M11	1,728	2,275	2,528	2,033	1,912	1,66	0,948
S2M12	1,422	1,696	2,197	2,167	2,016	1,699	0,953
S3M04	1,617	2,057	2,137	2,228	1,852	1,549	0,983
S3M05	1,572	2,064	2,569	1,92	2,085	1,497	1,017
S3M06	1,91	2,045	2,158	2,149	1,955	1,558	0,975
S3M10	1,337	1,602	2,144	1,934	1,772	1,442	0,804
S3M11	1,432	1,285	2,106	2,059	1,849	1,486	0,787
S3M12	1,157	1,548	2,116	2,014	1,585	1,357	0,771
S4M04	1,505	2,088	2,562	2,218	1,756	1,539	0,996
S4M05	1,784	1,651	2,271	2,25	1,919	1,608	1,041
S4M06	1,459	1,947	2,357	2,253	1,984	1,453	0,932
S4M10	0,906	1,758	2,112	1,887	1,785	1,289	0,831
S4M11	1,422	1,57	1,92	1,936	1,627	1,203	0,77
S4M12	1,171	1,413	2,058	1,98	1,655	1,3	0,725
Media	1,667229	1,959583	2,320104	2,219146	1,969167	1,600458	0,970125
Dev.st	0,356011	0,274224	0,261803	0,236611	0,20995	0,198327	0,164652

Figure B.3: EDT values in the audience with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1M01	1,901	2,163	2,395	2,384	2,098	1,748	1,109
S1M02	1,832	2,115	2,436	2,39	2,138	1,721	1,115
S1M03	1,747	1,87	2,256	2,394	2,094	1,747	1,107
S1M07	1,668	1,962	2,236	2,255	2,388	1,822	1,156
S1M08	1,582	2,256	2,48	2,394	2,112	1,755	1,125
S1M09	1,782	2,05	2,302	2,381	2,138	1,686	1,104
S2M01	1,592	2,238	2,294	2,352	2,091	1,742	1,141
S2M02	1,966	2,106	2,543	2,368	2,129	1,76	1,141
S2M03	2,333	2,161	2,248	2,062	2,105	1,741	1,139
S2M07	1,92	2,208	2,481	2,43	2,115	1,772	1,156
S2M08	2,016	2,303	2,457	2,41	2,084	1,737	1,132
S2M09	1,84	2,124	2,471	2,385	2,068	1,696	1,141
S3M01	1,758	2,189	2,434	2,375	2,068	1,692	1,067
S3M02	1,95	1,982	2,403	2,416	2,092	1,678	1,046
S3M03	1,821	1,496	2,399	2,198	2,132	1,652	1,041
S3M07	1,904	2,199	2,474	2,381	2,057	1,703	1,089
S3M08	1,899	2,122	2,416	2,391	2,07	1,699	1,103
S3M09	1,935	2,037	2,376	2,426	2,058	1,707	1,076
S4M01	1,824	1,575	2,306	2,38	2,079	1,655	1,059
S4M02	1,911	2,12	2,439	2,329	2,081	1,632	1,064
S4M03	1,833	2,041	2,426	2,447	2,099	1,709	1,052
S4M07	1,942	2,048	2,535	2,386	2,106	1,69	1,1
S4M08	1,932	2,168	2,476	2,406	2,062	1,723	1,056
S4M09	2,102	2,181	2,446	2,367	2,103	1,718	1,09
S1M04	2,101	2,314	2,512	2,419	2,099	1,749	1,131
S1M05	1,844	2,132	2,494	2,427	2,048	1,729	1,16
S1M06	1,774	1,936	2,263	2,412	2,176	1,739	1,146
S1M10	1,926	2,249	2,408	2,356	2,106	1,743	1,136
S1M11	1,868	2,192	2,424	2,448	2,049	1,752	1,101
S1M12	1,627	2,014	2,447	2,408	2,101	1,727	1,124
S2M04	1,955	2,123	2,472	2,339	2,113	1,766	1,154
S2M05	1,805	2,256	2,453	2,396	2,098	1,778	1,186
S2M06	1,77	2,177	2,422	2,415	2,114	1,751	1,183
S2M10	1,977	2,154	2,405	2,372	2,136	1,73	1,133
S2M11	1,902	2,123	2,502	2,394	2,151	1,725	1,124
S2M12	1,929	2,084	2,382	2,401	2,104	1,698	1,129
S3M04	1,779	2,112	2,547	2,429	2,09	1,677	1,098
S3M05	1,972	2,152	2,463	2,433	2,073	1,71	1,104
S3M06	1,833	2,1	2,366	2,412	2,11	1,71	1,09
S3M10	1,883	2,188	2,44	2,377	2,158	1,698	1,096
S3M11	2,04	2,257	2,543	2,359	2,043	1,691	1,089
S3M12	1,844	2,074	2,446	2,393	2,135	1,745	1,095
S4M04	1,875	2,008	2,415	2,398	2,087	1,712	1,076
S4M05	1,905	2,15	2,411	2,31	2,148	1,724	1,098
S4M06	1,988	2,196	2,446	2,398	2,092	1,702	1,091
S4M10	1,989	2,076	2,465	2,414	2,064	1,7	1,088
S4M11	1,795	2,112	2,452	2,373	2,063	1,691	1,072
S4M12	1,885	2,182	2,328	2,363	2,053	1,729	1,093
Media	1,880333	2,105729	2,421563	2,378188	2,103708	1,720021	1,108458
Dev.st	0,131513	0,151712	0,077817	0,064347	0,052248	0,034864	0,034858

Figure B.4: T_{30} values in the audience with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G1Ma	-2,27	2,6	0,81	1,32	2,48	4,24	6,67
S1G1Mc	-0,53	-3,34	2,1	2,14	2,7	3,93	7,97
S1G1Me	-0,75	-2,02	0,24	0,98	2,89	3,57	7,89
S1G1Mg	-2,79	-1,05	-0,48	0,18	1,24	3,14	7,36
S1G1Mi	-4,15	0,23	0,08	-0,56	1,67	2,26	6,59
S1G1Mm	-6,41	-2,33	-0,11	0,12	0,63	1,21	6,14
S1G1Mo	-1,81	1,91	0,13	0,43	0,44	1,75	6,27
S2G1Ma	-0,27	-4,78	-2,8	-1,43	-0,34	1,43	2,48
S2G1Mc	-3,42	-4,85	-1,34	-1,75	-0,9	0,08	2,22
S2G1Me	-3,47	-2,46	-2,26	-1,44	-1,84	-0,01	3,87
S2G1Mg	-2,48	-4,09	-3,17	-0,26	-0,32	-0,86	2,68
S2G1Mi	-5,14	-2,16	-2,87	-1,32	-1,57	0,13	3,41
S2G1Mm	-1,2	-0,06	-1,49	-0,25	-0,96	0,25	3,91
S2G1Mo	-2,81	0,05	-2,07	-0,57	0,08	0,68	4,45
S3G1Ma	-2,29	2,49	0,67	1,36	3,53	4,96	7,79
S3G1Mc	-1,49	4,13	-0,45	1,11	0,8	2,33	6
S3G1Me	-0,55	1,69	0,05	0,97	-0,5	1,11	4,64
S3G1Mg	0,98	0,97	-0,79	0,05	-0,29	0,61	4,79
S3G1Mi	-0,22	-0,42	-0,18	-0,57	-0,58	0,19	4,3
S3G1Mm	-0,82	2,72	0,58	0,66	-0,2	0,9	4,07
S3G1Mo	1,57	2,41	-0,18	1,84	0,32	1,24	4,5
S4G1Ma	4,71	6,37	3,55	4,33	3,81	6,57	11,57
S4G1Mc	1,69	4,29	2,24	2,5	1,8	2,68	7,6
S4G1Me	-1,02	3,01	1,77	1,18	1,31	2	5,61
S4G1Mg	0,09	1,62	1,07	0,49	0,34	1,59	6,45
S4G1M	-3,82	0,62	0,73	-0,11	-0,01	0,87	5,08
S4G1Mm	-1,98	2,63	0,62	0,36	0,15	1,2	5
S4G1Mo	1,7	3,67	0,68	0,32	0,41	2,09	5,33
S1G1Mb	-1,84	-4,21	-2,78	-1,6	-0,84	0,13	3,84
S1G1Md	-0,94	-3,71	0,35	1,34	2,69	1,72	4,84
S1G1Mf	-4,32	-3,1	-1,98	-0,08	3,47	4,63	8,07
S1G1Mh	-5,05	-2,81	-1,21	-1,13	1,3	3,92	7,93
S1G1Ml	-5,81	-2,85	-0,8	-0,57	0,86	1,39	5,61
S1G1Mn	-3,81	-2,85	-0,71	0,31	0,46	1,28	6,69
S1G1Mp	-1,1	0,52	0,21	0,38	2,04	2,69	7,43
S2G1Mb	-6,32	-9,88	-5,17	-4,78	-3,59	-2,25	-0,61
S2G1Md	-0,64	-7	-5,21	-3,54	-1,26	-1,95	0,64
S2G1Mf	-4,1	-5,54	-4,81	-1,96	-2,35	-1,53	0,11
S2G1Mh	-5,8	-3,84	-3,11	-3,48	-1,72	0,23	2,19
S2G1Ml	-5,04	-3,44	-2,07	-2,99	-1,35	-0,39	2,81
S2G1Mn	-1,94	-3,52	-2,54	-0,67	-0,34	0,39	4,62
S2G1Mp	-1,38	-0,54	-1,97	-0,2	0,16	0,75	6,22
S3G1Mb	-0,3	-0,65	-0,69	3,08	5,21	5,14	8,07
S3G1Md	0,4	-0,2	1,45	2,28	1,57	3,5	7,22
S3G1Mf	-0,7	1,31	-0,27	0,45	-0,05	-0,19	4,5
S3G1Mh	-2,55	-1,74	-0,19	0,57	-0,02	-0,05	3,73
S3G1Ml	-4,58	-3,85	-1,27	-0,08	-1,26	-0,89	3,38
S3G1Mn	-0,85	-1,78	-0,59	-0,33	0,17	0,71	3,8
S3G1Mp	-0,96	-0,67	-0,37	1,22	0,79	0,72	4,75
S4G1Mb	2,6	1,86	1,11	3,62	2,58	4,69	10,93
S4G1Mc	3,69	3,16	1,92	3,08	3,94	4,88	7,7
S4G1Mf	2,77	1,38	0,09	0,49	2,12	2,93	6,85
S4G1Mh	-2,52	-0,92	-0,72	0,13	-0,32	2,35	6,04
S4G1Ml	-2,13	-0,65	-1,41	-0,68	0,05	0,02	3,8
S4G1Mn	-0,36	1,35	0,5	0,94	-0,01	0,6	4,56
S4G1Mp	-0,74	1,61	1,27	2,19	1,29	3,48	5,63
Media	-1,66554	-0,69125	-0,60429	0,179821	0,583571	1,59	5,285536
Dev.st	2,465794	3,12736	1,80522	1,722646	1,711665	1,909314	2,338633

Figure B.5: C_{80} values in the first order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G1Ma	0,35	0,62	0,5	0,53	0,59	0,67	0,75
S1G1Mc	0,38	0,27	0,57	0,55	0,58	0,64	0,8
S1G1Me	0,35	0,29	0,46	0,45	0,59	0,62	0,77
S1G1Mg	0,17	0,34	0,42	0,42	0,48	0,55	0,73
S1G1Mi	0,12	0,34	0,43	0,34	0,47	0,5	0,67
S1G1Mm	0,15	0,28	0,4	0,42	0,42	0,44	0,69
S1G1Mo	0,17	0,42	0,35	0,34	0,39	0,48	0,67
S2G1Ma	0,29	0,16	0,28	0,35	0,41	0,49	0,5
S2G1Mc	0,28	0,17	0,34	0,32	0,36	0,43	0,5
S2G1Me	0,21	0,26	0,29	0,35	0,28	0,42	0,57
S2G1Mg	0,15	0,22	0,23	0,37	0,36	0,36	0,5
S2G1Mi	0,23	0,32	0,28	0,33	0,31	0,39	0,52
S2G1Mm	0,34	0,42	0,28	0,37	0,33	0,4	0,58
S2G1Mo	0,28	0,28	0,3	0,37	0,38	0,42	0,6
S3G1Ma	0,34	0,59	0,47	0,52	0,65	0,71	0,81
S3G1Mc	0,27	0,68	0,38	0,46	0,46	0,55	0,72
S3G1Me	0,38	0,57	0,45	0,45	0,35	0,44	0,61
S3G1Mg	0,34	0,42	0,37	0,39	0,36	0,41	0,64
S3G1Mi	0,32	0,4	0,42	0,31	0,32	0,38	0,59
S3G1Mm	0,34	0,59	0,41	0,44	0,36	0,42	0,59
S3G1Mo	0,47	0,51	0,38	0,5	0,41	0,43	0,59
S4G1Ma	0,73	0,8	0,64	0,71	0,67	0,79	0,91
S4G1Mc	0,52	0,64	0,56	0,57	0,55	0,57	0,8
S4G1Me	0,37	0,58	0,53	0,48	0,48	0,53	0,68
S4G1Mg	0,37	0,45	0,48	0,42	0,42	0,51	0,74
S4G1M	0,23	0,4	0,42	0,37	0,37	0,43	0,64
S4G1Mm	0,36	0,55	0,36	0,37	0,36	0,45	0,62
S4G1Mo	0,56	0,63	0,42	0,4	0,43	0,5	0,64
S1G1Mb	0,35	0,22	0,28	0,35	0,38	0,43	0,6
S1G1Md	0,39	0,21	0,44	0,52	0,59	0,51	0,64
S1G1Mf	0,23	0,25	0,28	0,41	0,61	0,68	0,78
S1G1Mh	0,11	0,17	0,37	0,32	0,49	0,62	0,79
S1G1Ml	0,12	0,17	0,38	0,37	0,44	0,47	0,66
S1G1Mn	0,26	0,29	0,31	0,4	0,39	0,43	0,68
S1G1Mp	0,31	0,44	0,37	0,41	0,46	0,48	0,72
S2G1Mb	0,14	0,07	0,2	0,17	0,22	0,26	0,32
S2G1Md	0,19	0,08	0,17	0,23	0,3	0,26	0,36
S2G1Mf	0,16	0,12	0,14	0,26	0,25	0,29	0,33
S2G1Mh	0,15	0,14	0,22	0,23	0,31	0,39	0,43
S2G1Ml	0,13	0,19	0,27	0,26	0,28	0,35	0,49
S2G1Mn	0,36	0,24	0,26	0,38	0,38	0,38	0,6
S2G1Mp	0,38	0,28	0,27	0,39	0,42	0,43	0,71
S3G1Mb	0,42	0,38	0,41	0,62	0,73	0,71	0,81
S3G1Md	0,49	0,43	0,49	0,58	0,5	0,61	0,77
S3G1Mf	0,38	0,49	0,38	0,39	0,38	0,35	0,59
S3G1Mh	0,28	0,28	0,36	0,36	0,38	0,35	0,55
S3G1Ml	0,16	0,22	0,34	0,37	0,3	0,28	0,49
S3G1Mn	0,41	0,35	0,38	0,36	0,35	0,36	0,53
S3G1Mp	0,33	0,35	0,32	0,47	0,41	0,38	0,61
S4G1Mb	0,58	0,52	0,52	0,65	0,61	0,71	0,9
S4G1Mc	0,63	0,54	0,55	0,6	0,66	0,7	0,8
S4G1Mf	0,63	0,49	0,4	0,45	0,54	0,59	0,75
S4G1Mh	0,25	0,32	0,38	0,34	0,37	0,56	0,7
S4G1Ml	0,22	0,26	0,31	0,36	0,4	0,36	0,54
S4G1Mn	0,4	0,47	0,43	0,45	0,38	0,4	0,56
S4G1Mp	0,32	0,49	0,43	0,48	0,5	0,58	0,67
Media	0,31875	0,368929	0,376429	0,412143	0,431607	0,479464	0,639464
Dev.st	0,1407	0,167502	0,103246	0,106031	0,115409	0,126007	0,129663

Figure B.6: D_{50} values in the first order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G1Ma	2,002	1,972	2,589	2,385	2,201	1,761	1,148
S1G1Mc	2,358	2,153	2,281	2,082	1,965	1,716	0,95
S1G1Me	1,9	2,401	2,457	2,169	1,997	1,606	0,966
S1G1Mg	1,765	1,963	2,515	2,289	2,05	1,583	0,8
S1G1Mi	1,204	1,764	2,85	2,289	1,826	1,501	0,779
S1G1Mm	1,637	1,985	2,162	2,184	1,886	1,611	0,792
S1G1Mo	1,72	2,023	1,976	2,115	1,857	1,495	0,754
S2G1Ma	1,714	2,162	2,491	2,329	2,105	1,815	1,168
S2G1Mc	2,081	1,899	2,38	2,228	2,083	1,753	1,118
S2G1Me	1,697	2,151	2,669	2,454	2,059	1,756	1,003
S2G1Mg	1,364	1,935	2,481	2,425	2,096	1,718	1,041
S2G1Mi	2,138	2,228	2,622	2,37	2,064	1,759	1,079
S2G1Mm	2,055	2,054	2,577	2,393	2,079	1,715	0,973
S2G1Mo	1,779	1,924	2,638	2,333	1,977	1,715	0,944
S3G1Ma	1,608	1,517	2,458	2,128	1,982	1,584	0,979
S3G1Mc	1,346	2,133	2,428	1,992	1,759	1,429	0,878
S3G1Me	1,664	2,035	2,345	2,303	1,801	1,562	0,978
S3G1Mg	2,499	2,293	2,468	2,298	1,91	1,601	0,923
S3G1Mi	1,334	1,747	2,43	2,079	1,756	1,536	0,877
S3G1Mm	1,271	1,957	2,388	2,199	1,843	1,403	0,847
S3G1Mo	2,359	1,566	1,884	1,999	1,693	1,366	0,753
S4G1Ma	2,625	1,942	2,241	2,155	1,829	1,694	0,384
S4G1Mc	2,098	1,725	2,185	2,188	1,86	1,555	0,837
S4G1Me	1,511	1,507	2,02	2,084	1,898	1,503	0,99
S4G1Mg	1,831	1,986	2,087	2,12	1,922	1,53	0,991
S4G1M	1,336	1,844	2,282	2,078	1,927	1,584	0,952
S4G1Mm	1,58	1,673	2,13	2,24	1,817	1,567	0,893
S4G1Mo	1,668	1,912	2,161	2,314	1,932	1,55	0,841
S1G1Mb	2,292	2,115	2,45	2,421	1,9	1,542	1,048
S1G1Md	1,681	1,907	2,497	2,149	2,089	1,542	0,936
S1G1Mf	1,801	2,073	2,527	2,422	2,035	1,601	0,865
S1G1Mh	1,657	1,825	2,647	2,265	1,84	1,607	0,85
S1G1Ml	2,174	2,155	2,617	2,176	1,885	1,602	0,874
S1G1Mn	1,501	2,04	2,177	2,233	2,088	1,557	0,775
S1G1Mp	1,902	1,998	2,363	2,22	1,811	1,43	0,712
S2G1Mb	1,912	1,913	2,448	2,279	2,009	1,749	1,118
S2G1Md	2,144	2,382	2,332	2,318	1,986	1,766	1,085
S2G1Mf	2,454	2,245	2,404	2,426	2,044	1,81	1,105
S2G1Mh	1,676	1,879	2,648	2,497	2,232	1,788	1,009
S2G1Ml	2,16	2,131	2,528	2,526	2,051	1,695	1,036
S2G1Mn	2,698	2,27	2,688	2,177	2,033	1,705	0,974
S2G1Mp	2,174	1,718	2,501	2,234	2,08	1,667	0,842
S3G1Mb	2,107	1,839	2,16	1,994	1,684	1,618	0,816
S3G1Md	2,057	2,086	2,667	1,925	1,826	1,502	0,921
S3G1Mf	1,567	2,028	2,299	1,95	1,85	1,571	0,959
S3G1Mh	1,874	1,925	2,564	2,097	1,893	1,576	0,939
S3G1Ml	1,853	2,025	2,45	2,058	1,905	1,529	0,943
S3G1Mn	1,979	2,172	2,602	2,236	1,638	1,342	0,87
S3G1Mp	1,591	2,021	2,109	2,207	1,572	1,309	0,818
S4G1Mb	1,698	1,873	2,336	2,077	1,822	1,437	0,398
S4G1Mc	2,082	2,238	2,433	2,105	1,693	1,451	0,715
S4G1Mf	1,446	1,679	2,281	2,142	1,908	1,578	0,912
S4G1Mh	1,825	2,275	2,444	2,074	1,959	1,521	0,918
S4G1Ml	2,235	1,962	2,088	2,097	1,873	1,575	0,984
S4G1Mn	1,6	2,12	2,094	1,94	1,797	1,421	0,882
S4G1Mp	1,157	1,903	2,369	1,974	1,77	1,434	0,864
Media	1,847161	1,986571	2,391393	2,204304	1,918696	1,587375	0,90725
Dev.st	0,359589	0,201749	0,206059	0,149106	0,139719	0,123846	0,147846

Figure B.7: EDT values in the first order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G1Ma	1,471	2,192	2,507	2,352	2,142	1,73	1,074
S1G1Mc	1,814	2,195	2,595	2,415	2,104	1,672	1,073
S1G1Me	1,934	2,07	2,553	2,437	2,089	1,695	1,089
S1G1Mg	1,921	2,237	2,413	2,439	2,107	1,728	1,089
S1G1Mi	1,992	2,262	2,469	2,528	2,146	1,771	1,117
S1G1Mm	1,947	2,208	2,449	2,376	2,113	1,722	1,114
S1G1Mo	1,942	2,253	2,491	2,421	2,095	1,721	1,105
S2G1Ma	2,039	2,218	2,415	2,389	2,111	1,744	1,121
S2G1Mc	1,899	2,163	2,493	2,385	2,172	1,705	1,131
S2G1Me	1,901	2,249	2,482	2,391	2,105	1,738	1,122
S2G1Mg	2,129	2,245	2,539	2,345	2,082	1,724	1,134
S2G1Mi	1,919	2	2,492	2,426	2,106	1,75	1,118
S2G1Mm	2,048	2,143	2,464	2,399	2,103	1,756	1,134
S2G1Mo	1,846	2,151	2,452	2,375	2,092	1,747	1,136
S3G1Ma	1,889	2,232	2,458	2,442	2,077	1,683	1,044
S3G1Mc	1,963	2,218	2,467	2,388	2,095	1,679	1,036
S3G1Me	1,987	2,056	2,537	2,397	2,169	1,725	1,077
S3G1Mg	1,976	2,219	2,504	2,36	2,061	1,731	1,088
S3G1Mi	1,994	2,178	2,446	2,428	2,103	1,7	1,098
S3G1Mm	1,912	2,11	2,512	2,363	2,083	1,679	1,074
S3G1Mo	2,01	2,184	2,392	2,378	2,08	1,724	1,068
S4G1Ma	1,93	2,116	2,349	2,341	2,075	1,647	1,007
S4G1Mc	1,769	2,026	2,444	2,365	2,085	1,68	1,032
S4G1Me	1,84	2,21	2,557	2,436	2,085	1,725	1,058
S4G1Mg	2,076	2,187	2,545	2,402	2,116	1,724	1,051
S4G1M	1,972	2,008	2,392	2,393	2,119	1,725	1,089
S4G1Mm	2,037	2,174	2,475	2,35	2,074	1,712	1,092
S4G1Mo	2,026	2,238	2,532	2,368	2,103	1,694	1,065
S1G1Mb	2,009	2,163	2,576	2,387	2,108	1,747	1,1
S1G1Md	1,884	2,18	2,496	2,362	2,088	1,714	1,11
S1G1Mf	1,856	2,09	2,427	2,364	2,099	1,753	1,096
S1G1Mh	1,959	2,272	2,491	2,44	2,159	1,716	1,094
S1G1Ml	1,853	1,994	2,51	2,406	2,114	1,762	1,12
S1G1Mn	1,974	2,094	2,458	2,397	2,125	1,752	1,118
S1G1Mp	1,981	2,115	2,283	2,443	2,1	1,668	1,101
S2G1Mb	2,078	2,224	2,458	2,399	2,123	1,733	1,139
S2G1Md	2,114	2,246	2,513	2,406	2,133	1,745	1,148
S2G1Mf	2,065	2,178	2,468	2,386	2,089	1,728	1,164
S2G1Mh	1,898	2,247	2,486	2,385	2,108	1,734	1,155
S2G1Ml	1,976	2,226	2,47	2,395	2,117	1,742	1,144
S2G1Mn	1,57	2,007	2,501	2,498	2,175	1,741	1,132
S2G1Mp	1,848	2,133	2,404	2,421	2,107	1,709	1,107
S3G1Mb	1,833	2,179	2,486	2,378	2,067	1,626	1,052
S3G1Md	1,943	2,145	2,456	2,339	2,054	1,66	1,051
S3G1Mf	1,945	2,175	2,393	2,361	2,113	1,705	1,093
S3G1Mh	2,108	2,261	2,511	2,407	2,085	1,723	1,095
S3G1Ml	1,932	2,123	2,235	2,399	2,11	1,727	1,1
S3G1Mn	1,952	2,071	2,317	2,381	2,13	1,731	1,081
S3G1Mp	1,814	2,189	2,464	2,351	2,124	1,687	1,068
S4G1Mb	1,962	2,219	2,391	2,365	2,056	1,635	0,996
S4G1Mc	1,752	2,008	2,312	2,362	2,073	1,64	1,022
S4G1Mf	1,819	1,987	2,58	2,301	2,079	1,707	1,038
S4G1Mh	1,832	2,274	2,477	2,371	2,125	1,697	1,065
S4G1Ml	1,912	2,184	2,479	2,378	2,083	1,745	1,104
S4G1Mn	1,908	2,131	2,419	2,41	2,121	1,748	1,111
S4G1Mp	1,812	2,043	2,449	2,364	2,092	1,669	1,09
Media	1,9245	2,158929	2,463107	2,391875	2,104446	1,713839	1,091607
Dev.st	0,117652	0,081602	0,071228	0,038203	0,027238	0,033681	0,037097

Figure B.8: T_{30} values in the first order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G2Ma	-2,28	-0,56	-1,56	-2,18	-0,36	0,25	3,73
S1G2Mc	-1,72	-2,08	-0,36	-1,16	-0,04	1,11	4,56
S1G2Me	1,17	-0,52	-1,95	-1,93	-0,72	0,78	4,83
S1G2Mg	2,65	1,56	-1,17	0,85	1,35	2,02	4,57
S1G2Mi	3,8	2,85	1,94	0,44	1,84	3,07	5,88
S2G2Ma	-2,84	-2,48	-1,47	-1,96	-2,19	0,32	1,82
S2G2Mc	-0,58	-2,7	-2,84	-2,81	-2,14	-1,17	2,62
S2G2Me	3,05	-0,7	-1,71	-1,67	-1,42	-0,4	3,29
S2G2Mg	2,27	-1,06	-1,8	-1,84	-0,75	1,37	3,95
S2G2Mi	-0,03	-0,41	1,44	1,05	1,42	2,46	5,75
S3G2Ma	-2,12	-1,03	-1,49	-1,29	-2,89	-2,49	1,92
S3G2Mc	2,42	0,87	-2,06	-0,16	-1,66	-1,07	3,07
S3G2Me	2,9	-0,58	0,35	-0,48	0,2	1,03	4,75
S3G2Mg	3,32	1,1	1,44	0,01	1,99	2,5	5,64
S3G2Mi	0,59	0,38	0,87	1,19	0,53	1,15	7,01
S4G2Ma	-3,37	-1,96	-2,02	-1,16	-0,15	0,11	4,44
S4G2Mc	-1	-0,75	-1,69	-1,58	-1,31	-1,28	3,36
S4G2Me	-1,84	-0,73	-1,14	0,88	-1,95	-0,27	3,58
S4G2Mg	3,4	0,53	-0,2	0,1	0,41	1,81	4,7
S4G2Mi	5,27	-0,12	0,73	-0,45	0,33	1,59	4,37
S1G2Mb	-5,48	-6,61	-5,44	-4,91	-4,43	-3,96	-0,06
S1G2Md	-6,6	-3,55	-3,55	-4,2	-3,07	-1,79	1,04
S1G2Mf	-0,37	-0,41	-3,78	-3,49	-1,12	0	3,78
S1G2Mh	1,15	-0,36	-2,7	-1,12	-0,85	1,19	3,26
S1G2Ml	0,18	-1,96	0,14	0,02	0,1	2,29	3,79
S2G2Mb	-7,01	-8,54	-7,26	-6,87	-4,73	-5,07	-1,9
S2G2Md	-5,44	-5,48	-5,63	-4,78	-4,65	-2,61	0,23
S2G2Mf	-1,25	-0,9	-1,16	-1,79	-1,83	-1,56	2,12
S2G2Mh	-1,35	-1,45	-2,2	-1,14	0,19	0,36	3,41
S2G2Ml	-1,11	0,05	0,32	0,35	1,67	2,39	4,11
S3G2Mb	-5,71	-4,99	-4,81	-4,47	-5,74	-4,32	-1,35
S3G2Md	-2,78	-4,47	-4,25	-3,34	-3,08	-2,97	-0,48
S3G2Mf	-0,61	-2,15	-2,99	-1,43	-0,67	-0,42	3,73
S3G2Mh	0,36	0,27	-1,48	-0,71	0,71	0,89	5,38
S3G2Ml	0	-2,42	-0,59	0,21	-0,96	0,02	3,8
S4G2Mb	-5,67	-7,79	-5,7	-4,85	-5,16	-3,52	-0,39
S4G2Md	-6,76	-4,03	-4,36	-4,67	-4,98	-2,73	1,32
S4G2Mf	-4,67	-1,43	-3,08	-1,19	-2,56	0,95	3,46
S4G2Mh	-1,01	-1,74	-2,01	-2,17	-1,39	-0,34	3,42
S4G2Ml	1,71	-0,95	-1,38	-1,29	-1,22	0,81	3,96
Media	-0,934	-1,6825	-1,915	-1,64975	-1,282	-0,1875	3,16175
Dev.st	3,230566	2,432899	2,121885	1,933222	2,039414	2,046734	2,041626

Figure B.9: C_{80} values in the second order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G2Ma	0,32	0,34	0,36	0,27	0,37	0,42	0,6
S1G2Mc	0,36	0,29	0,32	0,29	0,38	0,44	0,61
S1G2Me	0,49	0,34	0,3	0,29	0,32	0,38	0,58
S1G2Mg	0,22	0,39	0,29	0,35	0,28	0,33	0,41
S1G2Mi	0,27	0,3	0,32	0,29	0,32	0,38	0,38
S2G2Ma	0,29	0,28	0,32	0,31	0,28	0,44	0,5
S2G2Mc	0,33	0,19	0,26	0,27	0,31	0,32	0,55
S2G2Me	0,27	0,31	0,29	0,3	0,29	0,35	0,56
S2G2Mg	0,32	0,31	0,31	0,28	0,34	0,39	0,54
S2G2Mi	0,36	0,34	0,41	0,32	0,39	0,44	0,57
S3G2Ma	0,32	0,27	0,32	0,31	0,26	0,24	0,45
S3G2Mc	0,41	0,35	0,29	0,37	0,3	0,3	0,54
S3G2Me	0,48	0,38	0,35	0,31	0,36	0,41	0,56
S3G2Mg	0,5	0,4	0,43	0,33	0,37	0,35	0,54
S3G2Mi	0,44	0,36	0,32	0,33	0,29	0,37	0,55
S4G2Ma	0,26	0,33	0,3	0,34	0,4	0,41	0,63
S4G2Mc	0,31	0,35	0,29	0,32	0,32	0,3	0,55
S4G2Me	0,33	0,35	0,32	0,45	0,27	0,36	0,57
S4G2Mg	0,57	0,46	0,4	0,42	0,41	0,5	0,62
S4G2Mi	0,6	0,37	0,39	0,32	0,35	0,43	0,54
S1G2Mb	0,16	0,1	0,14	0,13	0,13	0,14	0,31
S1G2Md	0,11	0,19	0,21	0,15	0,17	0,19	0,34
S1G2Mf	0,23	0,35	0,18	0,21	0,29	0,32	0,5
S1G2Mh	0,32	0,35	0,27	0,32	0,3	0,42	0,52
S1G2Ml	0,2	0,26	0,26	0,34	0,3	0,49	0,51
S2G2Mb	0,12	0,05	0,09	0,1	0,09	0,11	0,19
S2G2Md	0,08	0,11	0,13	0,13	0,17	0,2	0,34
S2G2Mf	0,25	0,27	0,33	0,3	0,27	0,29	0,45
S2G2Mh	0,31	0,34	0,29	0,32	0,41	0,37	0,51
S2G2Ml	0,29	0,33	0,28	0,29	0,46	0,48	0,55
S3G2Mb	0,17	0,17	0,11	0,14	0,11	0,12	0,22
S3G2Md	0,13	0,17	0,19	0,19	0,18	0,15	0,27
S3G2Mf	0,3	0,3	0,24	0,32	0,35	0,33	0,55
S3G2Mh	0,43	0,32	0,33	0,35	0,38	0,39	0,61
S3G2Ml	0,23	0,22	0,33	0,37	0,29	0,32	0,49
S4G2Mb	0,14	0,08	0,1	0,11	0,11	0,15	0,27
S4G2Md	0,1	0,11	0,14	0,12	0,13	0,17	0,39
S4G2Mf	0,18	0,29	0,23	0,25	0,22	0,4	0,53
S4G2Mh	0,36	0,31	0,26	0,24	0,31	0,35	0,55
S4G2Ml	0,53	0,33	0,34	0,31	0,31	0,42	0,54
Media	0,30225	0,284	0,276	0,279	0,28975	0,33425	0,48725
Dev.st	0,13221	0,096365	0,085778	0,085509	0,092167	0,107343	0,114824

Figure B.10: D_{50} values in the second order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G2Ma	2,367	2,684	2,868	2,273	1,904	1,657	0,976
S1G2Mc	2,09	2,112	2,524	2,241	1,967	1,614	0,882
S1G2Me	1,932	1,946	2,394	2,291	2,092	1,549	0,853
S1G2Mg	1,341	2,002	2,583	2,267	1,844	1,418	0,828
S1G2Mi	1,267	1,437	1,826	2,228	1,665	1,369	0,654
S2G2Ma	1,598	2,031	2,588	2,396	2,199	1,782	1,184
S2G2Mc	2,001	1,924	2,543	2,561	2,211	1,796	1,149
S2G2Me	1,5	2,113	2,657	2,32	2,155	1,723	1,096
S2G2Mg	1,416	1,977	2,429	2,454	2,145	1,63	1,002
S2G2Mi	1,804	1,667	2,076	2,052	1,745	1,374	0,747
S3G2Ma	1,832	1,819	2,546	2,131	2,006	1,61	1,034
S3G2Mc	2,27	2,116	2,324	2,123	2,022	1,595	0,951
S3G2Me	1,355	1,826	2,583	1,958	1,849	1,557	0,84
S3G2Mg	1,755	2,009	2,46	2,254	1,61	1,358	0,755
S3G2Mi	1,49	1,653	1,872	1,776	1,755	1,521	0,625
S4G2Ma	1,921	2,102	2,259	2,137	2,11	1,727	0,904
S4G2Mc	2,054	2,035	2,372	2,305	2,075	1,598	0,98
S4G2Me	1,535	1,833	2,163	2,233	2,061	1,647	0,939
S4G2Mg	1,257	2,087	2,412	2,409	2,136	1,685	0,955
S4G2Mi	1,446	1,808	2,153	2,241	1,904	1,501	0,849
S1G2Mb	2,04	2,088	2,63	2,301	2,232	1,736	1,094
S1G2Md	2,039	2,389	2,783	2,423	2,167	1,629	1,046
S1G2Mf	1,707	1,77	2,312	2,379	2,056	1,573	0,935
S1G2Mh	2,242	1,705	2,457	2,207	2,069	1,579	0,957
S1G2Ml	1,56	2,075	2,043	2,18	1,824	1,544	0,915
S2G2Mb	2,286	2,53	2,471	2,433	2,233	1,83	1,214
S2G2Md	1,715	2,396	2,506	2,313	2,366	1,793	1,186
S2G2Mf	1,916	2,337	2,557	2,329	2,19	1,83	1,202
S2G2Mh	1,843	2,077	2,376	2,187	2,169	1,724	1,082
S2G2Ml	1,454	1,846	2,212	2,045	1,949	1,529	0,934
S3G2Mb	1,932	2,32	2,478	2,439	2,023	1,676	1,067
S3G2Md	1,816	1,816	2,38	2,347	1,962	1,629	1,07
S3G2Mf	1,922	2,456	2,428	2,255	1,873	1,532	0,932
S3G2Mh	1,705	1,926	2,36	2,105	1,9	1,535	0,77
S3G2Ml	1,444	1,731	1,792	1,843	2,038	1,591	0,933
S4G2Mb	2,067	2,231	2,614	2,388	2,074	1,624	1,056
S4G2Md	2,225	2,295	2,495	2,38	2,125	1,65	1,062
S4G2Mf	1,746	1,963	2,316	2,164	1,985	1,54	1,008
S4G2Mh	2,209	2,367	2,12	2,139	1,957	1,571	0,993
S4G2Ml	1,715	1,742	2,047	2,115	1,882	1,587	0,96
Media	1,79535	2,031025	2,375225	2,24055	2,013225	1,610325	0,965475
Dev.st	0,306998	0,269102	0,244936	0,163006	0,165628	0,117604	0,140659

Figure B.11: EDT values in the second order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
S1G2Ma	1,981	2,1	2,51	2,416	2,141	1,723	1,133
S1G2Mc	1,57	2,138	2,492	2,466	2,147	1,711	1,13
S1G2Me	1,974	2,108	2,438	2,386	2,129	1,734	1,138
S1G2Mg	1,713	2,141	2,504	2,416	2,114	1,727	1,119
S1G2Mi	1,955	1,989	2,268	2,352	2,08	1,682	1,108
S2G2Ma	2,017	2,33	2,554	2,399	2,122	1,748	1,166
S2G2Mc	1,992	2,247	2,419	2,451	2,14	1,733	1,169
S2G2Me	2,074	2,232	2,467	2,437	2,119	1,74	1,135
S2G2Mg	2,015	2,252	2,34	2,379	2,13	1,736	1,13
S2G2Mi	1,797	1,892	2,454	2,338	2,095	1,721	1,117
S3G2Ma	1,897	2,187	2,476	2,42	2,099	1,754	1,105
S3G2Mc	1,966	2,259	2,502	2,439	2,135	1,746	1,117
S3G2Me	1,92	2,187	2,471	2,418	2,151	1,715	1,082
S3G2Mg	1,973	2,213	2,525	2,365	2,095	1,678	1,074
S3G2Mi	1,794	1,935	2,351	2,356	2,084	1,718	1,097
S4G2Ma	1,897	2,158	2,523	2,452	2,098	1,701	1,098
S4G2Mc	1,695	2,218	2,585	2,393	2,086	1,738	1,109
S4G2Me	1,902	2,1	2,463	2,367	2,11	1,722	1,105
S4G2Mg	1,909	2,126	2,414	2,425	2,165	1,763	1,115
S4G2Mi	2,033	2,178	2,491	2,405	2,106	1,714	1,1
S1G2Mb	1,634	2,14	2,45	2,455	2,124	1,763	1,173
S1G2Md	2,007	2,014	2,514	2,398	2,077	1,74	1,166
S1G2Mf	2,013	2,372	2,434	2,364	2,093	1,742	1,144
S1G2Mh	1,714	2,292	2,441	2,441	2,129	1,73	1,13
S1G2Ml	1,646	2,054	2,453	2,338	2,115	1,705	1,138
S2G2Mb	1,976	2,211	2,507	2,429	2,161	1,762	1,209
S2G2Md	1,965	2,18	2,48	2,441	2,116	1,776	1,175
S2G2Mf	1,958	2,163	2,484	2,434	2,16	1,756	1,161
S2G2Mh	1,561	2,239	2,52	2,383	2,12	1,733	1,158
S2G2Ml	1,789	2,096	2,462	2,355	2,033	1,698	1,128
S3G2Mb	1,898	2,319	2,37	2,402	2,142	1,729	1,149
S3G2Md	1,966	2,29	2,551	2,42	2,158	1,755	1,142
S3G2Mf	2,03	2,166	2,509	2,412	2,066	1,699	1,104
S3G2Mh	1,873	2,116	2,447	2,453	2,096	1,715	1,119
S3G2Ml	1,604	2,061	2,258	2,38	2,105	1,734	1,103
S4G2Mb	1,503	2,169	2,483	2,415	2,147	1,749	1,161
S4G2Md	2,083	2,097	2,446	2,377	2,107	1,745	1,168
S4G2Mf	2,022	2,121	2,418	2,396	2,103	1,743	1,129
S4G2Mh	1,664	2,085	2,43	2,367	2,125	1,723	1,127
S4G2Ml	1,963	2,298	2,482	2,399	2,13	1,708	1,112
Media	1,873575	2,161825	2,45965	2,403475	2,116325	1,730225	1,131075
Dev.st	0,159996	0,104292	0,068547	0,034529	0,028424	0,02232	0,02881

Figure B.12: T_{30} values in the second order with omnidirectional source (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1M01	-1,83	-0,68	-4,25	-4,81	-2,4	-2,15	1,46
P1M02	-2,09	-0,29	-3,1	-5,08	-2,39	-3,26	0
P1M03	-5,97	-4,78	-4,69	-4,72	-3,01	-1,1	3,64
P1M07	-2,06	-4,25	-3,62	-0,88	0,29	0,95	2,63
P1M08	1,46	-4	-4,54	-0,37	-0,27	0,32	4,45
P1M09	-2,37	-2,94	-1,91	0,64	-0,82	1,85	4,52
P1M04	-1,66	-4,54	-4,71	-3,02	-2,63	0,25	3,42
P1M05	-1,93	-3,27	-4,07	-3,43	-0,66	-1,59	2,17
P1M06	-1,34	-6,8	-3,25	-1,73	-2,23	-0,32	4,11
P1M10	-0,03	-1,44	-2,43	1,11	1,42	0,7	2,82
P1M11	-0,07	-1,52	0,24	2,05	0,91	1,51	4,35
P1M12	-1,97	-3,5	-3,75	-0,3	0,69	2,82	6
Media	-1,655	-3,1675	-3,34	-1,71167	-0,925	-0,00167	3,2975
Dev.st	1,774683	1,90413	1,430257	2,46405	1,55914	1,765914	1,601738

Figure B.13: C_{80} values in the audience with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1M01	0,36	0,36	0,16	0,15	0,25	0,29	0,5
P1M02	0,24	0,4	0,23	0,14	0,29	0,21	0,36
P1M03	0,18	0,2	0,17	0,17	0,23	0,33	0,61
P1M07	0,29	0,2	0,25	0,32	0,38	0,37	0,44
P1M08	0,41	0,18	0,15	0,28	0,34	0,32	0,56
P1M09	0,3	0,18	0,18	0,32	0,28	0,4	0,49
P1M04	0,3	0,13	0,16	0,17	0,24	0,37	0,47
P1M05	0,29	0,21	0,17	0,19	0,36	0,26	0,43
P1M06	0,24	0,06	0,15	0,23	0,23	0,35	0,55
P1M10	0,34	0,28	0,26	0,38	0,43	0,35	0,43
P1M11	0,41	0,18	0,3	0,44	0,31	0,37	0,56
P1M12	0,3	0,24	0,21	0,37	0,43	0,52	0,68
Media	0,305	0,218333	0,199167	0,263333	0,314167	0,345	0,506667
Dev.st	0,068024	0,093111	0,049992	0,102188	0,073541	0,076811	0,089273

Figure B.14: D_{50} values in the audience with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1M01	2,082	2,275	2,531	2,244	2,033	1,711	1,202
P1M02	2,097	2,172	2,598	2,484	2,134	1,765	1,205
P1M03	2,06	2,235	2,392	2,294	2,122	1,729	1,214
P1M07	1,713	2,199	2,419	2,264	1,841	1,496	0,867
P1M08	1,612	2,215	2,561	2,229	1,869	1,437	0,828
P1M09	1,709	2,187	1,946	1,522	1,814	1,21	0,69
P1M04	1,898	2,401	2,814	2,349	2,152	1,62	0,978
P1M05	2,038	2,341	2,786	2,313	2,201	1,833	1,172
P1M06	2,217	2,053	2,616	2,411	2,085	1,778	1,132
P1M10	2,192	2,254	2,335	1,924	1,705	1,356	0,778
P1M11	1,846	2,352	2,17	1,953	1,682	1,399	0,848
P1M12	1,684	1,932	2,286	2,264	1,683	1,345	0,755
Media	1,929	2,218	2,4545	2,187583	1,943417	1,556583	0,972417
Dev.st	0,212391	0,12929	0,250518	0,265428	0,198154	0,207668	0,200629

Figure B.15: EDT values in the audience with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1M01	1,96	2,307	2,503	2,487	2,141	1,706	1,185
P1M02	1,858	2,344	2,565	2,432	2,12	1,689	1,207
P1M03	1,868	2,195	2,415	2,431	2,036	1,716	1,182
P1M07	1,989	2,279	2,439	2,46	2,03	1,713	1,218
P1M08	1,873	2,243	2,481	2,469	2,093	1,676	1,213
P1M09	1,812	2,121	2,505	2,444	2,06	1,683	1,173
P1M04	1,978	2,214	2,425	2,502	2,107	1,737	1,206
P1M05	1,857	2,39	2,607	2,469	2,117	1,721	1,237
P1M06	1,825	2,175	2,49	2,432	2,081	1,77	1,217
P1M10	1,769	2,402	2,587	2,417	2,026	1,693	1,216
P1M11	1,784	2,244	2,476	2,366	2,117	1,65	1,201
P1M12	1,703	2,201	2,45	2,454	2,105	1,676	1,166
Media	1,856333	2,259583	2,49525	2,446917	2,086083	1,7025	1,20175
Dev.st	0,086804	0,087178	0,062606	0,035659	0,039186	0,031919	0,021085

Figure B.16: T_{30} values in the audience with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3M04_bis	1,29	-0,23	-1,8	-4,38	-2,78	-1,39	2,06
P3M04	1,82	-0,86	-2,93	-3,61	-2	-1,93	1,89
P4M04_bis	2,68	-0,29	-2,49	-2,19	1,32	-0,37	3,35
P4M04	2,39	-0,81	-2,66	-3,8	-1,34	0,1	3,16
P3M08_bis	2,32	-2,12	-2,83	-3,47	-2,14	-1,74	0,5
P3M08	1,86	-2,29	-2,85	-3,95	-1,28	-2,2	-0,41
P4M08_bis	1,45	-2,19	-1,38	-1,55	-0,61	-0,4	3,13
P4M08	0,81	-1,77	-0,89	-2,34	-1,86	-0,74	2,17
Media	1,8275	-1,32	-2,22875	-3,16125	-1,33625	-1,08375	1,98125
Dev.st	0,627188	0,866932	0,773664	1,001862	1,255365	0,843715	1,338703

Figure B.17: C_{80} values on the stage with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3M04_bis	0,44	0,32	0,18	0,15	0,22	0,29	0,48
P3M04	0,48	0,29	0,14	0,18	0,28	0,26	0,48
P4M04_bis	0,53	0,29	0,18	0,27	0,47	0,33	0,55
P4M04	0,51	0,27	0,19	0,18	0,3	0,39	0,55
P3M08_bis	0,41	0,22	0,22	0,2	0,24	0,23	0,33
P3M08	0,36	0,2	0,22	0,19	0,26	0,23	0,27
P4M08_bis	0,54	0,28	0,27	0,21	0,32	0,33	0,51
P4M08	0,51	0,29	0,32	0,18	0,28	0,29	0,47
Media	0,4725	0,27	0,215	0,195	0,29625	0,29375	0,455
Dev.st	0,06364	0,04	0,057071	0,035051	0,077078	0,055016	0,1017

Figure B.18: D_{50} values on the stage with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3M04_bis	1,722	1,753	2,023	2,09	1,939	1,627	1,293
P3M04	1,675	1,827	2,121	2,094	1,936	1,716	1,324
P4M04_bis	1,3	1,846	2,34	2,205	2,002	1,686	1,197
P4M04	1,314	1,803	2,345	2,196	2,117	1,614	1,267
P3M08_bis	1,09	1,649	1,798	2,029	1,786	1,624	1,186
P3M08	1,097	1,659	1,916	1,948	1,792	1,604	1,215
P4M08_bis	1,881	1,891	2,231	2,116	1,926	1,601	1,092
P4M08	1,929	1,903	2,222	2,155	1,989	1,6	1,104
Media	1,501	1,791375	2,1245	2,104125	1,935875	1,634	1,20975
Dev.st	0,34105	0,09713	0,198673	0,085913	0,109068	0,043296	0,08372

Figure B.19: EDT values on the stage with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3M04_bis	1,837	2,186	2,452	2,374	2,052	1,659	1,154
P3M04	1,821	2,138	2,412	2,374	2,128	1,664	1,209
P4M04_bis	1,692	2,266	2,521	2,482	2,028	1,654	1,136
P4M04	1,788	2,267	2,549	2,507	2,124	1,656	1,161
P3M08_bis	2,026	2,093	2,411	2,424	2,022	1,676	1,182
P3M08	1,956	2,052	2,42	2,459	2,101	1,69	1,222
P4M08_bis	1,923	2,153	2,464	2,355	2,054	1,67	1,168
P4M08	1,877	2,159	2,462	2,354	2,113	1,625	1,16
Media	1,865	2,16425	2,461375	2,416125	2,07775	1,66175	1,174
Dev.st	0,104395	0,075502	0,050732	0,060525	0,043519	0,018994	0,028879

Figure B.20: T_{30} values on the stage with balloons (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1_12_sn	-0,13	-1,42	-2,16	0,31	2,03	2,49	6,24
P1_11_sn	1,79	-0,71	-1,34	-0,21	0,48	1,45	6,47
P1_10_sn	0,45	-1,93	-2,04	0,46	0,88	1,12	3,37
P1_09_sn	-1,09	-2,14	-2,47	-0,06	-0,04	3,16	5,7
P1_08_sn	1,61	-1,66	-1,84	-0,24	0,07	2,15	4,27
P1_07_sn	-1,17	-3,55	-1,55	0,06	1,15	2,7	6,15
P1_06_sn	0,5	-7,01	-3,56	-1,22	-1,78	1	7,1
P1_05_sn	-0,76	-3,69	-3,39	-1,07	-0,64	-0,72	5,84
P1_04_sn	-0,02	-2,18	-2,06	-1,69	-0,08	-0,37	4,6
P1_03_sn	-2,3	-0,28	-1,31	1,13	1,36	3,31	7,54
P1_02_sn	1,03	4,63	1,1	-0,48	0,23	2,77	4,74
P1_01_sn	0,6	2,72	-0,32	-2,97	-0,24	-0,59	2,64
P1_12_dx	-0,22	-1,51	-2,27	0,74	0,81	2,92	6,82
P1_11_dx	1,54	-0,68	-1,7	0,06	0,2	2,63	6,52
P1_10_dx	0,56	-2,17	-1,94	0,7	0,84	1,25	3,17
P1_09_dx	-0,95	-2,16	-2,13	-0,04	-0,26	3,06	6,39
P1_08_dx	1,85	-1,41	-2,47	-0,95	-0,17	2,32	4,02
P1_07_dx	-1,53	-4,04	-1,63	0,01	0,37	2,64	5,32
P1_06_dx	0,57	-7,03	-3,29	-1,13	-1,96	1,4	7,95
P1_05_dx	-0,72	-3,69	-3,62	-1,12	0,05	-0,45	6,7
P1_04_dx	-0,21	-2,42	-2,36	-1,33	0,78	0,41	6,08
P1_03_dx	-2,21	-0,41	-1,72	1,23	1,95	4,24	9,1
P1_02_dx	1,19	4,67	1,13	-0,27	0,35	3,52	6,16
P1_01_dx	0,83	3,37	-0,53	-2,58	0,45	0,4	3,46
Media	0,050417	-1,44583	-1,81125	-0,44417	0,284583	1,78375	5,68125
Dev.st	1,203735	2,98612	1,221725	1,062957	0,938792	1,434136	1,617559

Figure B.21: C_{80} values in the audience with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1_12_sn	0,39	0,3	0,26	0,43	0,5	0,49	0,66
P1_11_sn	0,52	0,33	0,28	0,36	0,35	0,42	0,67
P1_10_sn	0,31	0,2	0,26	0,42	0,37	0,37	0,44
P1_09_sn	0,38	0,29	0,11	0,31	0,33	0,51	0,61
P1_08_sn	0,41	0,26	0,29	0,28	0,27	0,42	0,52
P1_07_sn	0,33	0,2	0,35	0,39	0,46	0,54	0,64
P1_06_sn	0,36	0,1	0,21	0,33	0,26	0,44	0,75
P1_05_sn	0,35	0,21	0,26	0,37	0,38	0,32	0,69
P1_04_sn	0,33	0,24	0,33	0,31	0,39	0,3	0,48
P1_03_sn	0,32	0,45	0,38	0,52	0,52	0,63	0,81
P1_02_sn	0,52	0,69	0,52	0,39	0,45	0,59	0,68
P1_01_sn	0,52	0,59	0,4	0,27	0,42	0,38	0,57
P1_12_dx	0,38	0,29	0,27	0,47	0,4	0,57	0,73
P1_11_dx	0,51	0,31	0,28	0,35	0,31	0,47	0,65
P1_10_dx	0,31	0,18	0,27	0,41	0,4	0,4	0,49
P1_09_dx	0,39	0,28	0,12	0,34	0,34	0,51	0,64
P1_08_dx	0,42	0,27	0,27	0,27	0,34	0,47	0,56
P1_07_dx	0,3	0,19	0,34	0,38	0,39	0,51	0,61
P1_06_dx	0,37	0,11	0,21	0,34	0,28	0,45	0,78
P1_05_dx	0,35	0,21	0,25	0,36	0,41	0,36	0,73
P1_04_dx	0,34	0,23	0,32	0,33	0,44	0,34	0,48
P1_03_dx	0,32	0,44	0,36	0,52	0,56	0,68	0,86
P1_02_dx	0,53	0,69	0,51	0,41	0,47	0,64	0,75
P1_01_dx	0,53	0,62	0,39	0,29	0,46	0,44	0,6
Media	0,395417	0,32	0,301667	0,36875	0,395833	0,46875	0,641667
Dev.st	0,080756	0,171261	0,098142	0,069926	0,078403	0,102927	0,11142

Figure B.22: D_{50} values in the audience with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1_12_sn	1,787	1,946	2,279	2,295	1,797	1,49	0,721
P1_11_sn	1,875	2,234	2,276	2,292	1,857	1,398	0,681
P1_10_sn	1,925	2,006	2,367	2,081	1,866	1,341	0,714
P1_09_sn	1,59	1,965	1,798	1,641	1,718	1,127	0,679
P1_08_sn	1,603	2,095	2,162	2,146	1,873	1,389	0,84
P1_07_sn	1,72	2,222	2,744	2,514	1,858	1,488	0,697
P1_06_sn	2,32	2,454	2,601	2,499	2,173	1,748	1,115
P1_05_sn	1,685	2,178	2,839	2,768	2,201	1,831	1,083
P1_04_sn	1,977	2,624	2,774	2,341	2,089	1,553	0,879
P1_03_sn	2,223	2,271	2,232	2,296	2,081	1,861	1,11
P1_02_sn	2,017	2,249	2,44	2,319	2,181	1,743	1,257
P1_01_sn	2,046	2,069	2,242	2,471	2,113	1,726	1,179
P1_12_dx	1,789	1,919	2,365	2,382	1,752	1,402	0,713
P1_11_dx	1,829	2,25	2,392	2,132	1,902	1,323	0,647
P1_10_dx	1,923	2,019	2,405	2,172	1,741	1,304	0,708
P1_09_dx	1,631	1,995	1,987	1,717	1,857	1,226	0,666
P1_08_dx	1,582	2,151	2,148	2,171	1,896	1,492	0,917
P1_07_dx	1,706	2,25	2,694	2,418	1,886	1,378	0,775
P1_06_dx	2,299	2,524	2,643	2,53	2,191	1,699	1,004
P1_05_dx	1,657	2,179	2,641	2,588	2,222	1,965	1,039
P1_04_dx	1,932	2,529	2,548	2,299	2,048	1,592	0,759
P1_03_dx	2,239	2,246	2,25	2,292	2,174	1,943	0,863
P1_02_dx	2,053	2,258	2,474	2,318	2,113	1,823	1,292
P1_01_dx	2,074	2,122	2,252	2,49	2,133	1,742	1,18
Media	1,895083	2,198125	2,398042	2,298833	1,988417	1,566	0,896583
Dev.st	0,229832	0,189474	0,255965	0,249857	0,168601	0,236823	0,21136

Figure B.23: EDT values in the audience with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000	8000
P1_12_sn	1,767	2,144	2,382	2,405	2,097	1,712	1,113
P1_11_sn	1,679	2,311	2,531	2,383	2,151	1,713	1,104
P1_10_sn	1,846	2,347	2,515	2,48	2,006	1,69	1,136
P1_09_sn	1,88	2,171	2,534	2,423	2,14	1,636	1,14
P1_08_sn	1,897	2,275	2,522	2,414	2,093	1,637	1,17
P1_07_sn	1,903	2,289	2,466	2,342	2,064	1,679	1,14
P1_06_sn	1,814	2,207	2,376	2,36	2,096	1,677	1,148
P1_05_sn	1,904	2,28	2,485	2,412	2,049	1,745	1,149
P1_04_sn	1,918	2,332	2,544	2,447	2,08	1,735	1,147
P1_03_sn	2,834	2,121	2,35	2,362	2,044	1,711	1,102
P1_02_sn	1,874	2,283	2,55	2,441	2,056	1,715	1,134
P1_01_sn	1,993	2,359	2,522	2,405	2,15	1,685	1,127
P1_12_dx	1,777	2,17	2,403	2,414	2,048	1,706	1,13
P1_11_dx	1,684	2,309	2,537	2,373	2,098	1,698	1,15
P1_10_dx	1,797	2,341	2,516	2,465	2,063	1,712	1,171
P1_09_dx	1,88	2,232	2,535	2,408	2,131	1,646	1,184
P1_08_dx	1,897	2,282	2,516	2,405	2,143	1,654	1,173
P1_07_dx	1,887	2,292	2,438	2,37	2,058	1,694	1,154
P1_06_dx	1,807	2,182	2,409	2,373	2,098	1,676	1,193
P1_05_dx	1,902	2,273	2,527	2,463	2,08	1,753	1,18
P1_04_dx	1,887	2,336	2,562	2,434	2,116	1,728	1,166
P1_03_dx	2,853	2,114	2,376	2,416	2,032	1,711	1,127
P1_02_dx	1,867	2,3	2,55	2,441	2,074	1,694	1,109
P1_01_dx	1,999	2,36	2,513	2,437	2,149	1,715	1,151
Media	1,939417	2,262917	2,485792	2,411375	2,088167	1,69675	1,14575
Dev.st	0,289143	0,076543	0,06703	0,036176	0,040983	0,031498	0,025288

Figure B.24: T_{30} values in the audience with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3_M4 _sn	5,46	8,11	5,12	2,24	3,69	3,5	6,82
P3_M8 _sn	4,37	-0,69	1,1	-1	-0,45	1,43	3,25
P4_M8 _sn	3,98	-0,36	1,13	1,03	0,34	1,32	5,51
P4_M4 _sn	2,72	1,88	1,45	5,22	5,22	2,45	10,69
P3_M4 _dx	5,34	8,1	4,88	1,78	3,47	3,2	5,74
P3_M8 _dx	4,46	-0,49	1,25	-0,9	-0,43	0,81	2,36
P4_M8 _dx	3,85	0	1,21	1,19	0,32	1,21	8,14
P4_M4 _dx	2,53	2,04	1,71	5,65	6,76	5,52	12,3
Media	4,08875	2,32375	2,23125	1,90125	2,365	2,43	6,85125
Dev.st	1,071373	3,717245	1,72134	2,470566	2,789332	1,587055	3,428054

Figure B.25: C_{80} values on the stage with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3_M4 _sn	0,7	0,83	0,73	0,57	0,63	0,63	0,76
P3_M8 _sn	0,63	0,28	0,45	0,34	0,3	0,45	0,54
P4_M8 _sn	0,68	0,38	0,49	0,48	0,41	0,46	0,66
P4_M4 _sn	0,55	0,47	0,48	0,73	0,72	0,54	0,88
P3_M4 _dx	0,69	0,82	0,71	0,55	0,63	0,61	0,72
P3_M8 _dx	0,64	0,29	0,45	0,32	0,31	0,42	0,47
P4_M8 _dx	0,67	0,39	0,49	0,47	0,44	0,47	0,81
P4_M4 _dx	0,55	0,49	0,48	0,75	0,79	0,73	0,93
Media	0,63875	0,49375	0,535	0,52625	0,52875	0,53875	0,72125
Dev.st	0,059627	0,217449	0,115388	0,158829	0,18803	0,108817	0,159413

Figure B.26: D_{50} values on the stage with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3_M4 _sn	1,669	1,694	2,572	2,095	1,979	1,836	1,097
P3_M8 _sn	1,16	1,689	1,937	1,887	1,923	1,575	1,162
P4_M8 _sn	1,745	1,688	2,161	2,298	1,986	1,472	0,979
P4_M4 _sn	1,371	1,774	1,951	2,208	1,936	1,582	1,179
P3_M4 _dx	1,722	1,626	2,45	2,076	2,092	1,905	1,412
P3_M8 _dx	1,143	1,686	1,902	1,942	1,864	1,594	1,209
P4_M8 _dx	1,649	1,755	2,102	2,17	1,913	1,548	1,116
P4_M4 _dx	1,375	1,808	1,979	2,23	1,971	1,781	0,029
Media	1,47925	1,715	2,13175	2,11325	1,958	1,661625	1,022875
Dev.st	0,248407	0,058965	0,251725	0,142527	0,067528	0,156376	0,419808

Figure B.27: EDT values on the stage with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000	8000
P3_M4 _sn	1,792	2,03	2,329	2,426	2,003	1,624	1,097
P3_M8 _sn	1,923	2,008	2,313	2,376	2,03	1,642	1,089
P4_M8 _sn	1,962	2,235	2,398	2,488	2,158	1,625	1,065
P4_M4 _sn	1,747	2,175	2,498	2,304	2,008	1,655	1,026
P3_M4 _dx	1,786	2,022	2,31	2,408	2,021	1,651	1,122
P3_M8 _dx	1,935	2,04	2,385	2,349	2,036	1,653	1,156
P4_M8 _dx	1,975	2,243	2,381	2,433	2,157	1,618	1,072
P4_M4 _dx	1,762	2,174	2,471	2,344	2,033	1,648	1,063
Media	1,86025	2,115875	2,385625	2,391	2,05575	1,6395	1,08625
Dev.st	0,096877	0,100575	0,069992	0,059105	0,063861	0,014861	0,039806

Figure B.28: T_{30} values on the stage with Tascam digital recorder (10/09/2015).

	125	250	500	1000	2000	4000
SS1O_01	-2,11	0,06	-1,05	-0,02	-1,72	0,78
SS1O_10	-0,73	2,69	-0,65	0,11	1,04	2,78
SS1O_11	2,47	0,54	1,31	1,14	1,49	3,01
SS1O_12	0,38	2,84	-0,14	-0,34	0,73	2,02
SS1O_02	0,72	1,59	-1,12	-0,63	0,27	-1,63
SS1O_03	-1,49	-0,44	-1,25	-1,16	-4,06	1,17
SS1O_04	-2,28	-0,68	-1,67	-0,67	-1,36	-0,04
SS1O_05	-2,58	-1,39	-0,92	-0,21	-2,53	0
SS1O_06	-0,19	-1,91	-2,54	-0,04	-1,39	0,8
SS1O_07	0,56	-0,46	-1,61	-0,43	-1,58	0,05
SS1O_08	1,15	0,81	-1,02	-1,56	-1,84	-0,72
SS1O_09	-2,64	1,59	-2,42	-1,85	-0,3	1,19
SS2O_01	-3,93	-0,79	-1,96	-1,83	-3,47	-0,74
SS2O_10	-0,66	2,05	-0,42	-0,22	-0,69	-0,13
SS2O_11	0,58	0,82	-2,28	-0,67	-0,79	0,65
SS2O_12	-1,62	0,3	-0,59	-0,91	0,28	1,72
SS2O_02	-2,99	-1,1	-2,06	-0,97	-2,44	-0,21
SS2O_03	-4,73	-1,78	-2,18	-1,77	-3,69	-1,74
SS2O_04	-4,94	-4,36	-2,95	-4,02	-1,83	-1,31
SS2O_05	-1,75	-4,4	-2,48	-1,83	-2,94	-1,18
SS2O_06	-3,82	-5,97	-3,6	-0,69	-1,51	0,2
SS2O_07	-2,64	-1,24	-4,22	-2,78	-3,22	-1,18
SS2O_08	-2,05	-2,26	-2,75	-3,17	-2,57	-1
SS2O_09	-5,37	-2,06	-2,88	-3,28	-3,09	-0,37
SS3O_01	1,32	1,22	-0,17	0,29	0,14	1,51
SS3O_10	4,66	4,41	-0,98	-1,76	-1,26	2,37
SS3O_11	1,45	3,12	-0,77	0,8	0,8	3,3
SS3O_12	-0,39	0,8	-1,2	1,67	1,14	3,76
SS3O_02	4,15	4,67	-0,47	2,23	1,62	2,95
SS3O_03	3,45	3,97	-0,93	-0,24	-0,33	-0,87
SS3O_04	1,53	1,52	-0,22	-0,13	-1,14	1,45
SS3O_05	1,25	0,72	-0,91	1,02	0,52	3
SS3O_06	0,73	-1,19	-0,99	-3,74	0,68	1,66
SS3O_07	0,63	3,51	-1,3	-0,84	0,06	1,68
SS3O_08	2,1	2,49	-2,12	-1,49	-0,26	1,78
SS3O_09	0,08	2,82	0,13	-2,26	-0,21	1,21
SS4O_01	5,24	5,66	0,96	3,36	3,35	5,19
SS4O_10	-0,59	2,19	-1,39	-0,52	-0,27	2,42
SS4O_11	3,22	0,74	-2,26	2,04	0,43	1,94
SS4O_12	3,27	3,34	-1,19	-0,49	0,45	2,86
SS4O_02	5	5,39	-0,29	-0,79	1,49	2,61
SS4O_03	1,91	3,01	-0,43	-1,08	0,31	0,75
SS4O_04	1,37	1,75	0,89	-1,34	1,13	3,11
SS4O_05	2,16	0,15	0,27	1,37	-0,01	3,14
SS4O_06	2,22	-0,95	-0,1	-0,88	1	1,68
SS4O_07	1,39	1,69	-1,5	-1,37	-0,43	1,69
SS4O_08	3,2	2,22	-1,74	-2,36	-0,94	0,78
SS4O_09	0,55	2,11	-0,98	0,22	1,79	2,39
Media	0,1925	0,829375	-1,23208	-0,71021	-0,56563	1,176667
Dev.st	2,6516	2,492865	1,146243	1,510089	1,641918	1,608862

Figure B.29: C_{80} values in the audience with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_01	0,27	0,45	0,37	0,43	0,33	0,46
SS1O_10	0,45	0,54	0,37	0,36	0,34	0,47
SS1O_11	0,45	0,41	0,41	0,39	0,44	0,52
SS1O_12	0,46	0,59	0,33	0,35	0,38	0,48
SS1O_02	0,49	0,53	0,36	0,39	0,47	0,35
SS1O_03	0,38	0,45	0,35	0,39	0,21	0,51
SS1O_04	0,25	0,24	0,24	0,4	0,33	0,36
SS1O_05	0,25	0,25	0,36	0,37	0,27	0,4
SS1O_06	0,29	0,25	0,27	0,4	0,32	0,42
SS1O_07	0,42	0,36	0,26	0,32	0,26	0,35
SS1O_08	0,32	0,34	0,29	0,34	0,29	0,28
SS1O_09	0,25	0,38	0,19	0,18	0,21	0,35
SS2O_01	0,16	0,38	0,32	0,32	0,23	0,35
SS2O_10	0,33	0,5	0,31	0,32	0,32	0,34
SS2O_11	0,48	0,38	0,3	0,3	0,33	0,4
SS2O_12	0,35	0,4	0,37	0,36	0,41	0,45
SS2O_02	0,32	0,38	0,31	0,37	0,3	0,4
SS2O_03	0,21	0,34	0,29	0,32	0,17	0,3
SS2O_04	0,15	0,14	0,17	0,19	0,26	0,26
SS2O_05	0,29	0,19	0,28	0,33	0,23	0,32
SS2O_06	0,13	0,09	0,19	0,36	0,28	0,37
SS2O_07	0,15	0,28	0,17	0,24	0,24	0,32
SS2O_08	0,3	0,25	0,2	0,24	0,27	0,33
SS2O_09	0,12	0,22	0,24	0,2	0,17	0,33
SS3O_01	0,38	0,51	0,42	0,45	0,45	0,5
SS3O_10	0,64	0,57	0,35	0,3	0,3	0,53
SS3O_11	0,49	0,58	0,33	0,43	0,37	0,53
SS3O_12	0,44	0,51	0,31	0,2	0,36	0,54
SS3O_02	0,69	0,71	0,42	0,57	0,52	0,59
SS3O_03	0,65	0,68	0,38	0,39	0,39	0,34
SS3O_04	0,42	0,34	0,32	0,42	0,29	0,44
SS3O_05	0,48	0,27	0,34	0,5	0,42	0,54
SS3O_06	0,35	0,2	0,3	0,22	0,43	0,49
SS3O_07	0,39	0,46	0,23	0,34	0,39	0,47
SS3O_08	0,47	0,4	0,24	0,26	0,33	0,46
SS3O_09	0,43	0,4	0,27	0,22	0,33	0,4
SS4O_01	0,69	0,75	0,47	0,64	0,63	0,73
SS4O_10	0,44	0,53	0,36	0,41	0,41	0,52
SS4O_11	0,64	0,5	0,26	0,47	0,4	0,53
SS4O_12	0,52	0,55	0,28	0,34	0,37	0,48
SS4O_02	0,74	0,75	0,44	0,41	0,5	0,59
SS4O_03	0,56	0,63	0,43	0,36	0,42	0,44
SS4O_04	0,43	0,35	0,39	0,31	0,46	0,55
SS4O_05	0,45	0,2	0,33	0,49	0,38	0,57
SS4O_06	0,46	0,27	0,35	0,37	0,44	0,49
SS4O_07	0,43	0,43	0,26	0,28	0,32	0,44
SS4O_08	0,57	0,45	0,24	0,24	0,3	0,34
SS4O_09	0,38	0,5	0,32	0,4	0,49	0,5
Media	0,404375	0,414167	0,312292	0,351875	0,349167	0,440208
Dev.st	0,152802	0,158475	0,07253	0,095953	0,095891	0,097773

Figure B.30: D_{50} values in the audience with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_01	1,626	1,932	2,255	2,386	2,243	1,884
SS1O_10	2,292	1,641	2,361	2,014	1,854	1,375
SS1O_11	1,669	2,053	2,09	2,179	1,922	1,424
SS1O_12	1,803	1,557	2,202	2,149	1,864	1,454
SS1O_02	2,166	1,996	2,427	2,345	2,313	1,812
SS1O_03	1,832	1,904	2,329	2,123	2,152	1,848
SS1O_04	1,59	1,725	2,232	2,581	2,163	1,842
SS1O_05	1,836	2,153	2,689	2,414	2,423	1,996
SS1O_06	2,252	2,328	2,462	2,288	2,002	1,779
SS1O_07	2,118	1,978	2,271	2,259	2,08	1,693
SS1O_08	2,113	2,085	2,113	2,213	1,923	1,613
SS1O_09	1,764	1,781	1,999	1,887	1,88	1,506
SS2O_01	1,433	2,215	2,439	2,428	2,269	1,931
SS2O_10	1,759	1,853	2,388	2,201	2,027	1,668
SS2O_11	2,582	2,362	2,208	2,086	2,09	1,607
SS2O_12	1,385	1,864	2,249	2,3	1,903	1,608
SS2O_02	2,597	2,39	2,52	2,569	2,345	1,911
SS2O_03	2,106	2,154	2,21	2,306	2,164	1,869
SS2O_04	1,689	2,305	2,45	2,405	2,318	1,941
SS2O_05	2,34	2,139	2,689	2,701	2,477	1,946
SS2O_06	1,896	2,013	2,377	2,276	2,248	1,905
SS2O_07	1,453	1,762	2,226	2,308	2,225	1,826
SS2O_08	1,847	2,081	2,256	2,333	2,102	1,871
SS2O_09	1,509	2,114	2,017	2,291	2,137	1,774
SS3O_01	2,208	2,039	2,011	2,263	2,082	1,699
SS3O_10	1,326	1,245	1,961	2,01	1,683	1,247
SS3O_11	0,941	1,558	2,04	1,799	1,608	1,22
SS3O_12	1,059	1,626	1,903	1,749	1,72	1,212
SS3O_02	2,254	1,726	2,431	2,322	2,113	1,79
SS3O_03	1,855	1,599	2,14	2,145	2,019	1,628
SS3O_04	1,046	1,564	2,004	2,152	1,934	1,571
SS3O_05	1,723	1,998	2,278	2,25	2,121	1,552
SS3O_06	1,921	2,084	2,195	2,282	2,013	1,541
SS3O_07	1,294	1,609	2,208	1,802	1,804	1,206
SS3O_08	1,57	1,668	1,837	2,041	1,76	1,387
SS3O_09	1,577	1,554	1,659	1,952	1,783	1,364
SS4O_01	2,032	2,207	2,348	2,095	2,016	1,699
SS4O_10	1,925	1,522	1,89	1,844	1,734	1,18
SS4O_11	1,647	1,402	1,726	1,787	1,504	1,155
SS4O_12	0,75	1,159	1,884	1,902	1,597	1,291
SS4O_02	1,865	1,736	2,418	2,289	2,004	1,786
SS4O_03	2,145	1,75	2,371	2,318	2,098	1,762
SS4O_04	1,92	1,981	2,317	2,075	1,978	1,591
SS4O_05	1,706	1,713	2,481	2,391	1,924	1,55
SS4O_06	1,697	1,973	2,45	2,343	1,899	1,647
SS4O_07	1,553	1,811	1,84	1,992	1,69	1,338
SS4O_08	1,392	1,691	2,192	1,971	1,837	1,362
SS4O_09	1,651	1,765	1,874	1,639	1,729	1,301
Media	1,764875	1,861771	2,206604	2,176146	1,995292	1,607542
Dev.st	0,397382	0,284679	0,238776	0,231179	0,225028	0,24446

Figure B.31: EDT values in the audience with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_01	1,856	2,158	2,494	2,392	2,138	1,747
SS1O_10	1,808	2,104	2,38	2,359	2,163	1,718
SS1O_11	1,936	2,114	2,469	2,337	2,141	1,723
SS1O_12	1,721	1,99	2,437	2,347	2,119	1,744
SS1O_02	1,88	2,133	2,449	2,383	2,134	1,722
SS1O_03	1,762	2,033	2,442	2,337	2,119	1,718
SS1O_04	1,944	2,226	2,41	2,421	2,156	1,731
SS1O_05	1,893	2,194	2,541	2,423	2,144	1,745
SS1O_06	1,628	1,996	2,457	2,36	2,2	1,76
SS1O_07	1,86	2,246	2,437	2,392	2,177	1,733
SS1O_08	1,71	2,163	2,451	2,368	2,165	1,704
SS1O_09	1,777	2,069	2,494	2,425	2,124	1,695
SS2O_01	1,908	2,088	2,446	2,437	2,165	1,758
SS2O_10	1,861	2,197	2,421	2,409	2,132	1,722
SS2O_11	1,879	2,067	2,526	2,314	2,127	1,712
SS2O_12	1,752	2,02	2,514	2,365	2,136	1,71
SS2O_02	1,718	2,207	2,417	2,39	2,171	1,746
SS2O_03	1,892	2,095	2,38	2,377	2,149	1,705
SS2O_04	1,928	2,165	2,447	2,373	2,132	1,74
SS2O_05	1,993	2,291	2,502	2,423	2,153	1,736
SS2O_06	1,78	2,082	2,519	2,41	2,171	1,749
SS2O_07	1,96	2,27	2,522	2,367	2,177	1,755
SS2O_08	1,939	2,194	2,534	2,426	2,167	1,69
SS2O_09	1,968	2,011	2,435	2,366	2,121	1,717
SS3O_01	1,839	2,186	2,476	2,385	2,141	1,717
SS3O_10	1,8	2,241	2,525	2,334	2,126	1,706
SS3O_11	1,882	2,154	2,373	2,397	2,098	1,675
SS3O_12	1,733	2,049	2,414	2,317	2,118	1,719
SS3O_02	2,143	2,191	2,476	2,335	2,103	1,694
SS3O_03	1,806	1,925	2,388	2,348	2,124	1,714
SS3O_04	1,936	2,16	2,534	2,351	2,135	1,701
SS3O_05	2,007	2,197	2,512	2,364	2,123	1,726
SS3O_06	1,74	2,071	2,408	2,322	2,119	1,718
SS3O_07	2,011	2,222	2,491	2,389	2,11	1,732
SS3O_08	1,891	2,219	2,453	2,317	2,089	1,684
SS3O_09	1,708	1,978	2,398	2,358	2,124	1,708
SS4O_01	1,941	2,153	2,477	2,322	2,094	1,675
SS4O_10	1,945	2,207	2,49	2,338	2,134	1,712
SS4O_11	1,804	2,176	2,518	2,388	2,108	1,678
SS4O_12	1,919	2,116	2,43	2,406	2,129	1,671
SS4O_02	1,825	2,11	2,473	2,421	2,144	1,698
SS4O_03	1,826	2,088	2,447	2,38	2,125	1,711
SS4O_04	1,81	2,025	2,482	2,407	2,098	1,715
SS4O_05	1,948	2,17	2,482	2,347	2,141	1,732
SS4O_06	1,938	2,095	2,503	2,429	2,169	1,719
SS4O_07	1,961	2,142	2,506	2,375	2,148	1,705
SS4O_08	1,942	2,151	2,46	2,355	2,13	1,734
SS4O_09	1,837	2,102	2,509	2,405	2,146	1,723
Media	1,865521	2,130021	2,465604	2,374813	2,136604	1,717646
Dev.st	0,099865	0,082501	0,045897	0,03448	0,024196	0,022096

Figure B.32: T_{30} values in the audience with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_PP1	2,91	4,68	-1,95	-0,47	2,16	2,83
SS1O_PP2	-2,42	1,05	-0,94	-1,13	-1,01	1,98
SS1O_PP3	-2,53	1,16	-0,35	-2,73	-1,33	0,06
SS1O_PP4	-2,19	3,18	0,36	-1,15	-1,02	0,85
SS1O_PP5	-1,87	2,58	1,17	-2,24	0,27	0,8
SS1O_PP6	-4,69	2,8	0,86	-1,14	0,43	1,08
SS2O_PP1	-0,99	1,91	-2,71	-3,42	2,46	0,46
SS2O_PP2	-2,17	-1,15	-1,46	-3,17	-2,74	0,11
SS2O_PP3	-4,34	-1,99	-0,01	-1,42	-2,63	-0,1
SS2O_PP4	-4,22	-0,41	0,3	-0,8	-2,36	-0,3
SS2O_PP5	-1,8	0,45	2,36	-2,42	-1,52	-0,06
SS2O_PP6	-1,69	3,48	0,32	-0,84	-0,3	-0,15
SS3O_PP1	6,09	5,35	-0,66	2,28	2,12	2,42
SS3O_PP2	-3,65	3,54	-0,59	0,37	1,42	1,48
SS3O_PP3	-2,11	2,37	-0,91	-0,28	-0,07	2,06
SS3O_PP4	-0,7	2,93	0,35	-1,82	0,55	0,8
SS3O_PP5	-3,28	1,18	-0,54	-1,25	-0,26	0,29
SS3O_PP6	-5,22	1,81	0,75	0,2	1,16	3,06
SS4O_PP1	7,4	4,09	3,39	2,8	1,2	3,35
SS4O_PP2	-2,13	4,78	-1,99	1,04	2,43	2,75
SS4O_PP3	-1,04	4,43	-1,69	-0,41	0,26	2,77
SS4O_PP4	-0,16	3,79	-0,02	-0,78	0,39	1,34
SS4O_PP5	0,3	2,96	-1,23	-0,59	0,6	1,35
SS4O_PP6	-5,46	0,89	0,72	-0,75	1,17	1,36
Media	-1,49833	2,3275	-0,18625	-0,83833	0,140833	1,274583
Dev.st	3,156971	1,905375	1,389094	1,498175	1,535773	1,144472

Figure B.33: C_{80} values in the first order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_PP1	0,63	0,73	0,29	0,42	0,58	0,6
SS1O_PP2	0,29	0,48	0,39	0,32	0,37	0,51
SS1O_PP3	0,14	0,48	0,42	0,27	0,33	0,38
SS1O_PP4	0,19	0,54	0,41	0,34	0,34	0,42
SS1O_PP5	0,23	0,53	0,39	0,27	0,41	0,44
SS1O_PP6	0,2	0,56	0,4	0,29	0,39	0,44
SS2O_PP1	0,42	0,54	0,28	0,21	0,58	0,46
SS2O_PP2	0,26	0,26	0,31	0,25	0,26	0,41
SS2O_PP3	0,18	0,3	0,41	0,29	0,23	0,37
SS2O_PP4	0,17	0,28	0,45	0,36	0,22	0,31
SS2O_PP5	0,27	0,35	0,54	0,26	0,32	0,38
SS2O_PP6	0,3	0,55	0,41	0,34	0,4	0,38
SS3O_PP1	0,65	0,73	0,41	0,59	0,57	0,58
SS3O_PP2	0,22	0,63	0,38	0,42	0,5	0,47
SS3O_PP3	0,2	0,57	0,36	0,37	0,42	0,47
SS3O_PP4	0,23	0,55	0,39	0,28	0,44	0,41
SS3O_PP5	0,18	0,43	0,4	0,28	0,37	0,36
SS3O_PP6	0,21	0,5	0,4	0,42	0,45	0,53
SS4O_PP1	0,77	0,68	0,61	0,61	0,51	0,62
SS4O_PP2	0,29	0,64	0,33	0,48	0,57	0,59
SS4O_PP3	0,21	0,62	0,31	0,42	0,42	0,56
SS4O_PP4	0,33	0,6	0,4	0,32	0,4	0,46
SS4O_PP5	0,31	0,59	0,29	0,33	0,44	0,46
SS4O_PP6	0,15	0,45	0,44	0,33	0,46	0,47
Media	0,292917	0,524583	0,3925	0,352917	0,415833	0,461667
Dev.st	0,165174	0,129715	0,074964	0,100498	0,103542	0,083753

Figure B.34: D_{50} values in the first order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_PP1	2,087	2,482	2,484	2,206	2,171	1,765
SS1O_PP2	1,715	1,561	2,391	2,222	2,13	1,661
SS1O_PP3	1,308	1,67	2,381	2,217	2,11	1,771
SS1O_PP4	2,076	1,865	1,989	2,205	2,09	1,685
SS1O_PP5	1,937	1,933	2,158	2,224	2,123	1,669
SS1O_PP6	1,993	1,851	2,279	2,125	2,005	1,697
SS2O_PP1	1,855	1,974	2,712	2,141	2,173	1,781
SS2O_PP2	1,976	1,655	2,466	2,375	2,162	1,814
SS2O_PP3	1,967	1,984	2,444	2,381	2,207	1,68
SS2O_PP4	1,822	1,931	2,384	2,369	2,253	1,825
SS2O_PP5	1,968	2,179	2,197	2,374	2,192	1,831
SS2O_PP6	2,199	1,671	2,475	2,253	2,013	1,797
SS3O_PP1	1,508	1,704	2,199	2,172	2,122	1,665
SS3O_PP2	1,647	1,544	2,529	2,083	1,87	1,626
SS3O_PP3	1,584	1,916	2,438	2,169	2,013	1,667
SS3O_PP4	1,823	1,798	2,112	2,022	1,917	1,566
SS3O_PP5	1,658	1,759	2,205	2,112	1,901	1,478
SS3O_PP6	1,786	1,782	2,163	2,002	1,708	1,206
SS4O_PP1	1,509	1,707	2,223	2,025	2,04	1,716
SS4O_PP2	1,571	1,893	2,44	2,342	2,107	1,75
SS4O_PP3	1,95	1,56	2,416	2,14	2,049	1,636
SS4O_PP4	1,839	1,989	2,52	2,234	1,96	1,597
SS4O_PP5	1,669	1,916	2,418	2,203	1,999	1,609
SS4O_PP6	2,102	1,704	1,959	2,106	1,852	1,593
Media	1,814542	1,8345	2,332583	2,195917	2,048625	1,670208
Dev.st	0,224025	0,210713	0,182886	0,112984	0,131492	0,133366

Figure B.35: EDT values in the first order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_PP1	1,916	2,214	2,54	2,401	2,141	1,734
SS1O_PP2	1,968	2,159	2,534	2,379	2,168	1,761
SS1O_PP3	2,069	2,163	2,515	2,388	2,107	1,725
SS1O_PP4	1,784	2,185	2,454	2,411	2,136	1,748
SS1O_PP5	1,932	2,11	2,47	2,438	2,119	1,735
SS1O_PP6	1,853	1,995	2,472	2,353	2,148	1,729
SS2O_PP1	1,965	2,138	2,43	2,432	2,13	1,733
SS2O_PP2	1,893	2,097	2,522	2,373	2,146	1,75
SS2O_PP3	1,809	2,203	2,488	2,44	2,149	1,735
SS2O_PP4	1,893	2,14	2,498	2,38	2,154	1,772
SS2O_PP5	2,05	2,129	2,513	2,413	2,157	1,707
SS2O_PP6	1,932	2,046	2,397	2,32	2,145	1,7
SS3O_PP1	1,804	2,045	2,512	2,371	2,1	1,676
SS3O_PP2	1,961	2,213	2,541	2,366	2,152	1,711
SS3O_PP3	2,043	2,14	2,428	2,338	2,144	1,721
SS3O_PP4	1,998	2,166	2,541	2,421	2,118	1,718
SS3O_PP5	1,987	2,147	2,381	2,396	2,15	1,731
SS3O_PP6	1,993	2,174	2,447	2,329	2,12	1,701
SS4O_PP1	1,845	2,064	2,46	2,408	2,1	1,68
SS4O_PP2	2,219	2,058	2,502	2,365	2,104	1,714
SS4O_PP3	1,858	2,153	2,432	2,369	2,118	1,716
SS4O_PP4	2,032	2,143	2,471	2,365	2,123	1,742
SS4O_PP5	2,048	2,244	2,415	2,326	2,117	1,731
SS4O_PP6	1,899	2,109	2,441	2,353	2,119	1,717
Media	1,947958	2,134792	2,475167	2,380625	2,131875	1,724458
Dev.st	0,101327	0,06084	0,047423	0,034998	0,019694	0,0227

Figure B.36: T_{30} values in the first order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_SS1	0,51	2,04	-2,39	-2,02	0,24	1,48
SS1O_SS2	0,88	0,84	-1,11	-0,15	1	2,26
SS1O_SS3	-1,65	-0,05	-0,22	-0,58	1,51	2,36
SS1O_SS4	-2,53	-0,16	-2,4	-0,68	-0,44	1,03
SS1O_SS5	2,12	2,2	-1	1,12	2,45	1,32
SS1O_SS6	2	-0,32	-2,45	0,92	3,15	3,35
SS2O_SS1	1,35	0,32	-0,75	-1,26	-1,09	0,06
SS2O_SS2	0,71	2,41	-1,9	-2,21	-0,5	1,9
SS2O_SS3	-4,64	-0,62	-1,01	0,48	2,21	3,21
SS2O_SS4	1,52	-0,2	-3,07	-2,38	0	0,96
SS2O_SS5	3,18	4,25	-2,61	-1,89	0,38	2,4
SS2O_SS6	5,64	4,06	-1,82	1,65	2,21	2,92
SS3O_SS1	-1,15	-0,3	-1,63	-0,81	0,22	1,04
SS3O_SS2	0,86	1,27	-0,13	-0,56	0,56	1,27
SS3O_SS3	-5,02	0,79	-3,05	-1,04	-0,58	0,86
SS3O_SS4	-2,76	-2,11	-4,53	-2,13	-0,66	-0,37
SS3O_SS5	-0,36	0,47	-3,77	-0,63	0,33	1,81
SS3O_SS6	-1,55	-2,09	-2,07	-0,56	2,02	0,72
SS4O_SS1	-2,23	0,86	-1,84	-1,27	-0,1	0,39
SS4O_SS2	-3,16	-2,31	-2,01	-1,42	0,83	0,65
SS4O_SS3	-0,69	-1,11	-1,38	-0,15	-0,07	0,79
SS4O_SS4	-3,53	-3,92	-2,69	-3	-2,14	-1,94
SS4O_SS5	-1,05	-3,35	-3,51	-1,76	-0,57	1,99
SS4O_SS6	1,43	-0,1	-3,88	-1,69	0,11	-0,33
Media	-0,42167	0,119583	-2,13417	-0,9175	0,46125	1,255417
Dev.st	2,561663	2,039291	1,144377	1,167764	1,262239	1,226345

Figure B.37: C_{80} values in the second order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_SS1	0,27	0,45	0,27	0,26	0,35	0,4
SS1O_SS2	0,26	0,43	0,26	0,28	0,34	0,33
SS1O_SS3	0,25	0,25	0,19	0,3	0,33	0,29
SS1O_SS4	0,32	0,33	0,22	0,28	0,32	0,33
SS1O_SS5	0,53	0,48	0,27	0,46	0,54	0,41
SS1O_SS6	0,56	0,44	0,19	0,46	0,52	0,44
SS2O_SS1	0,4	0,47	0,38	0,36	0,34	0,39
SS2O_SS2	0,42	0,5	0,28	0,25	0,33	0,48
SS2O_SS3	0,2	0,35	0,24	0,37	0,48	0,47
SS2O_SS4	0,42	0,33	0,23	0,29	0,35	0,42
SS2O_SS5	0,47	0,48	0,24	0,27	0,4	0,5
SS2O_SS6	0,46	0,44	0,33	0,47	0,53	0,53
SS3O_SS1	0,19	0,31	0,2	0,31	0,36	0,38
SS3O_SS2	0,27	0,38	0,3	0,27	0,39	0,36
SS3O_SS3	0,12	0,38	0,23	0,24	0,27	0,32
SS3O_SS4	0,16	0,26	0,15	0,2	0,32	0,34
SS3O_SS5	0,36	0,41	0,2	0,34	0,38	0,5
SS3O_SS6	0,27	0,31	0,22	0,37	0,5	0,4
SS4O_SS1	0,26	0,36	0,25	0,31	0,38	0,37
SS4O_SS2	0,26	0,31	0,26	0,33	0,47	0,44
SS4O_SS3	0,23	0,35	0,31	0,36	0,33	0,34
SS4O_SS4	0,19	0,2	0,23	0,22	0,23	0,23
SS4O_SS5	0,25	0,27	0,21	0,3	0,38	0,48
SS4O_SS6	0,44	0,41	0,17	0,32	0,4	0,34
Media	0,315	0,370833	0,242917	0,3175	0,385	0,395417
Dev.st	0,120794	0,081982	0,052542	0,072126	0,082145	0,074832

Figure B.38: D_{50} values in the second order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_SS1	1,533	1,926	2,311	2,17	2,092	1,599
SS1O_SS2	1,481	1,412	2,511	2,277	1,967	1,357
SS1O_SS3	1,266	1,431	1,898	1,925	1,695	1,332
SS1O_SS4	1,846	2,221	2,112	1,825	1,965	1,432
SS1O_SS5	1,383	1,968	2,336	1,993	1,837	1,508
SS1O_SS6	1	1,526	1,856	1,626	1,471	1,234
SS2O_SS1	2,04	1,844	2,61	2,176	2,077	1,751
SS2O_SS2	1,706	2,122	2,251	2,362	1,984	1,55
SS2O_SS3	1,3	1,806	2,069	2,048	1,777	1,381
SS2O_SS4	1,584	2,135	2,426	2,351	2,149	1,631
SS2O_SS5	1,372	1,737	2,305	2,143	1,897	1,549
SS2O_SS6	1,165	1,107	1,982	1,617	1,541	1,311
SS3O_SS1	2,283	1,867	2,1	2,24	1,872	1,526
SS3O_SS2	2,006	1,741	2,216	2,117	2,022	1,558
SS3O_SS3	1,601	1,634	2,033	1,958	1,907	1,441
SS3O_SS4	2,01	1,951	2,194	1,904	1,937	1,546
SS3O_SS5	1,707	1,688	2,407	1,974	1,885	1,476
SS3O_SS6	1,816	1,803	2,03	2,07	1,945	1,416
SS4O_SS1	2,263	1,794	2,412	2,448	2,059	1,641
SS4O_SS2	2,237	1,779	2,273	2,283	2,027	1,709
SS4O_SS3	1,845	2,173	2,448	2,189	2,133	1,495
SS4O_SS4	2,324	2,21	2,496	2,132	1,975	1,567
SS4O_SS5	1,981	1,981	2,239	1,871	2,007	1,477
SS4O_SS6	2,032	1,558	2,308	2,058	1,901	1,588
Media	1,740875	1,808917	2,242625	2,073208	1,92175	1,503125
Dev.st	0,377444	0,276093	0,200132	0,213626	0,166912	0,125498

Figure B.39: EDT values in the second order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1O_SS1	1,862	2,138	2,533	2,413	2,169	1,74
SS1O_SS2	2,047	2,338	2,509	2,299	2,105	1,728
SS1O_SS3	1,701	1,996	2,439	2,357	2,105	1,717
SS1O_SS4	1,955	2,025	2,55	2,364	2,168	1,725
SS1O_SS5	2,004	2,05	2,547	2,445	2,132	1,673
SS1O_SS6	1,8	1,996	2,304	2,277	2,132	1,677
SS2O_SS1	2,014	2,233	2,502	2,373	2,147	1,709
SS2O_SS2	2,039	2,178	2,456	2,319	2,116	1,732
SS2O_SS3	1,763	2,048	2,344	2,363	2,137	1,721
SS2O_SS4	2,014	2,107	2,489	2,443	2,165	1,695
SS2O_SS5	1,951	2,144	2,469	2,399	2,132	1,686
SS2O_SS6	1,62	1,989	2,387	2,317	2,067	1,699
SS3O_SS1	1,83	2,092	2,543	2,341	2,16	1,735
SS3O_SS2	1,936	2,112	2,465	2,46	2,161	1,707
SS3O_SS3	1,91	2,143	2,375	2,384	2,166	1,709
SS3O_SS4	1,973	2,113	2,418	2,356	2,114	1,728
SS3O_SS5	2,007	2,085	2,476	2,428	2,133	1,699
SS3O_SS6	1,779	1,954	2,402	2,384	2,109	1,709
SS4O_SS1	1,742	2,174	2,438	2,333	2,132	1,734
SS4O_SS2	1,943	2,178	2,496	2,386	2,117	1,682
SS4O_SS3	2,093	2,156	2,488	2,349	2,162	1,737
SS4O_SS4	1,857	2,051	2,527	2,38	2,104	1,748
SS4O_SS5	2,031	2,113	2,443	2,404	2,143	1,706
SS4O_SS6	1,86	2,274	2,41	2,378	2,065	1,685
Media	1,905458	2,111958	2,45875	2,373	2,130875	1,711708
Dev.st	0,12393	0,092432	0,065604	0,04619	0,029537	0,021538

Figure B.40: T_{30} values in the second order with omnidirectional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_01	0,54	0,64	-1,82	-2,55	-1,96	0,76
SS1D_10	3,32	2,47	0,15	4,74	2,88	6,96
SS1D_11	0,23	0,55	2,42	4,57	3,87	6,45
SS1D_12	3,15	-0,22	-0,01	3,54	4,35	6,68
SS1D_02	2,56	2,12	-0,9	-0,91	0,4	1,64
SS1D_03	0	0,07	-2,62	-2,26	1,53	2,4
SS1D_04	-0,61	-1,36	0,67	1,63	0,91	5,19
SS1D_05	0,64	-1,57	0	2,36	1,64	3,96
SS1D_06	1,37	-2,95	-1,35	1,37	2	4,45
SS1D_07	-0,65	-0,96	0,59	2,75	1,08	4,31
SS1D_08	-0,68	0,3	0,68	1,64	2,04	4,04
SS1D_09	0,98	5,2	1,38	2,96	3,86	5,16
SS2D_01	-4,58	-0,59	-1,62	0,33	-3,15	-0,01
SS2D_10	0,53	0,94	-0,69	2,27	2,23	6,34
SS2D_11	3,59	0,55	-0,18	3,55	2,11	7
SS2D_12	2,68	3,38	-2,32	3,84	3,28	6,83
SS2D_02	0,1	-0,92	-0,45	0,11	-2,24	-0,01
SS2D_03	-0,66	-0,6	-1,75	-0,06	-2,41	0,4
SS2D_04	-0,13	-2,59	-0,67	0,29	-0,97	2,94
SS2D_05	-0,85	-2,62	-0,93	1,32	-0,78	2,05
SS2D_06	-1,64	-3,29	-2,48	0,89	-0,14	2,19
SS2D_07	-0,41	-3,08	-2,5	0,13	-0,24	3,2
SS2D_08	0,32	-0,88	-2,22	0,95	0,93	4,78
SS2D_09	0,78	-0,88	-1,32	1,29	0,96	4,6
SS3D_01	-2,15	2,19	-1,31	-1,48	-1	0,25
SS3D_10	3,27	-0,02	0,81	4,49	2,58	7,03
SS3D_11	3,54	2,58	1,03	5,3	3,65	6,19
SS3D_12	3,18	2,36	0,49	4,4	4,45	6,36
SS3D_02	3,78	3,85	-0,18	0,23	1,49	-0,12
SS3D_03	3,39	1,26	-1,09	1,39	2,52	0,66
SS3D_04	1,62	-0,07	3,25	2,34	3,21	5,06
SS3D_05	1,26	0,54	1,06	2,82	4,01	4,02
SS3D_06	-0,57	-1,66	0,23	2,49	4,92	4,52
SS3D_07	2,03	0,17	2,3	3,89	3,49	5,66
SS3D_08	1,03	-1,77	0,53	3,22	3,26	6,7
SS3D_09	3,09	4,92	4,19	3,78	5,99	7,97
SS4D_01	4,85	2,69	1,72	1,62	3,4	1,67
SS4D_10	2,33	0,77	2,71	4,15	3,21	7,58
SS4D_11	2,31	1,27	2,62	5,04	5,13	7,95
SS4D_12	0,55	1,42	1,81	6,27	4,67	8,12
SS4D_02	4,38	4,39	-0,31	1,55	3,8	1,46
SS4D_03	1,82	2,44	-0,52	0,16	0,69	1,86
SS4D_04	1,67	1,69	3,4	3,86	5,45	5,75
SS4D_05	0,89	1,41	1,2	4,02	4,93	5,85
SS4D_06	-2,01	-0,31	1,02	2,23	3,77	4,26
SS4D_07	2,52	0,16	2,16	3,34	3,8	5,66
SS4D_08	1,98	0,35	0,92	2,94	2,84	5,13
SS4D_09	2,09	-0,09	2,64	4,41	4,38	6,46
Media	1,196458	0,505208	0,265417	2,233542	2,225417	4,340833
Dev.st	1,913386	2,039025	1,711831	2,006804	2,2425	2,453424

Figure B.41: C_{80} values in the audience with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_01	0,45	0,46	0,35	0,31	0,33	0,46
SS1D_10	0,63	0,44	0,35	0,68	0,52	0,72
SS1D_11	0,42	0,37	0,34	0,61	0,59	0,71
SS1D_12	0,63	0,37	0,38	0,61	0,6	0,71
SS1D_02	0,64	0,58	0,41	0,39	0,48	0,51
SS1D_03	0,41	0,45	0,31	0,32	0,55	0,53
SS1D_04	0,34	0,24	0,38	0,47	0,34	0,45
SS1D_05	0,36	0,26	0,42	0,55	0,48	0,6
SS1D_06	0,31	0,16	0,29	0,49	0,49	0,6
SS1D_07	0,36	0,31	0,47	0,53	0,46	0,61
SS1D_08	0,37	0,34	0,35	0,49	0,52	0,61
SS1D_09	0,43	0,39	0,33	0,52	0,58	0,65
SS2D_01	0,18	0,4	0,36	0,46	0,27	0,4
SS2D_10	0,37	0,43	0,35	0,55	0,49	0,69
SS2D_11	0,59	0,44	0,39	0,6	0,52	0,74
SS2D_12	0,57	0,56	0,3	0,61	0,59	0,74
SS2D_02	0,46	0,41	0,43	0,44	0,32	0,41
SS2D_03	0,28	0,36	0,34	0,43	0,27	0,42
SS2D_04	0,2	0,19	0,3	0,42	0,25	0,4
SS2D_05	0,27	0,22	0,39	0,5	0,35	0,48
SS2D_06	0,23	0,26	0,3	0,47	0,37	0,43
SS2D_07	0,34	0,26	0,31	0,44	0,4	0,58
SS2D_08	0,42	0,29	0,29	0,44	0,45	0,67
SS2D_09	0,41	0,33	0,38	0,5	0,48	0,66
SS3D_01	0,31	0,59	0,37	0,35	0,35	0,39
SS3D_10	0,64	0,39	0,42	0,65	0,55	0,78
SS3D_11	0,53	0,48	0,44	0,67	0,59	0,71
SS3D_12	0,47	0,39	0,37	0,6	0,61	0,71
SS3D_02	0,64	0,68	0,45	0,47	0,53	0,39
SS3D_03	0,59	0,51	0,38	0,55	0,61	0,49
SS3D_04	0,36	0,32	0,5	0,47	0,51	0,49
SS3D_05	0,37	0,42	0,46	0,56	0,62	0,57
SS3D_06	0,35	0,33	0,38	0,56	0,66	0,6
SS3D_07	0,46	0,32	0,54	0,65	0,6	0,71
SS3D_08	0,36	0,29	0,43	0,59	0,54	0,76
SS3D_09	0,54	0,56	0,59	0,63	0,7	0,79
SS4D_01	0,73	0,61	0,57	0,56	0,66	0,53
SS4D_10	0,47	0,42	0,54	0,67	0,6	0,78
SS4D_11	0,51	0,44	0,52	0,69	0,69	0,78
SS4D_12	0,45	0,48	0,38	0,73	0,65	0,81
SS4D_02	0,7	0,7	0,44	0,56	0,67	0,54
SS4D_03	0,46	0,6	0,43	0,48	0,48	0,52
SS4D_04	0,13	0,53	0,57	0,58	0,67	0,58
SS4D_05	0,43	0,46	0,48	0,62	0,67	0,62
SS4D_06	0,28	0,31	0,49	0,52	0,59	0,59
SS4D_07	0,58	0,37	0,51	0,6	0,59	0,69
SS4D_08	0,54	0,37	0,49	0,56	0,53	0,69
SS4D_09	0,52	0,38	0,51	0,66	0,62	0,72
Media	0,439375	0,405625	0,412083	0,537708	0,520625	0,604583
Dev.st	0,139793	0,123752	0,081683	0,09805	0,121049	0,12568

Figure B.42: D_{50} values in the audience with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_01	1,876	1,793	2,013	1,943	1,809	1,218
SS1D_10	1,308	1,42	2,191	1,702	1,569	0,864
SS1D_11	1,28	1,807	2,077	1,721	1,687	0,911
SS1D_12	1,51	1,33	2,301	1,791	1,621	0,949
SS1D_02	2,692	2,387	2,341	2,077	1,851	1,291
SS1D_03	1,748	1,893	1,989	1,814	1,763	1,306
SS1D_04	1,465	2,17	2,792	2,224	1,747	1,079
SS1D_05	1,658	2,069	2,437	2,24	2,138	1,509
SS1D_06	1,748	2,082	2,337	2,348	2,025	1,364
SS1D_07	1,406	1,675	2,392	1,951	2,016	1,21
SS1D_08	1,382	1,473	2,078	1,85	1,612	1,151
SS1D_09	1,44	1,007	1,508	1,602	1,472	0,84
SS2D_01	1,433	2,079	2,247	2,379	2,066	1,474
SS2D_10	1,326	1,977	2,389	2,009	2,005	0,947
SS2D_11	1,498	2,136	2,62	1,989	1,902	0,929
SS2D_12	1,519	1,732	2,187	1,936	1,985	0,97
SS2D_02	2,098	2,085	2,399	2,277	2,115	1,467
SS2D_03	1,652	1,727	2,308	2,122	1,834	1,429
SS2D_04	1,838	2,138	2,18	2,33	2,14	1,336
SS2D_05	1,722	2,513	2,851	2,653	2,183	1,638
SS2D_06	1,666	2,424	2,456	2,429	2,122	1,514
SS2D_07	1,695	1,851	2,43	2,375	2,062	1,538
SS2D_08	1,381	1,966	2,306	2,097	1,991	1,089
SS2D_09	1,718	1,672	2,229	2,13	1,764	1,224
SS3D_01	1,735	1,908	1,817	1,841	1,83	1,224
SS3D_10	1,115	1,611	1,823	1,821	1,73	0,973
SS3D_11	1,019	1,189	2,035	1,408	1,679	1,076
SS3D_12	1,213	1,536	1,791	1,532	1,566	1,055
SS3D_02	1,688	1,945	2,329	2,004	1,623	1,14
SS3D_03	1,164	1,524	1,91	1,801	1,59	1,094
SS3D_04	1,366	1,668	1,937	1,734	1,701	0,974
SS3D_05	1,374	1,837	2,181	1,92	1,481	1,213
SS3D_06	1,639	1,949	2,117	1,804	1,384	1,194
SS3D_07	1,34	1,775	1,98	1,94	1,661	0,994
SS3D_08	1,024	1,582	1,969	1,448	1,418	0,672
SS3D_09	1,499	0,952	1,117	0,959	0,81	0,571
SS4D_01	1,908	1,89	2,204	1,813	1,624	1,217
SS4D_10	0,969	1,233	1,83	1,645	1,476	0,814
SS4D_11	1,13	1,236	1,766	1,439	1,473	0,787
SS4D_12	1,465	1,781	1,902	1,417	1,488	0,693
SS4D_02	1,481	1,915	2,237	1,977	1,659	1,206
SS4D_03	1,579	1,747	2,264	1,888	1,721	1,293
SS4D_04	1,499	1,738	1,828	1,613	1,591	0,96
SS4D_05	2,124	1,707	2,269	1,984	1,81	1,063
SS4D_06	1,535	1,781	2,428	2,111	1,584	1,203
SS4D_07	1,213	1,647	1,864	2,086	1,694	1,274
SS4D_08	1,566	1,923	2,369	1,94	1,888	1,245
SS4D_09	1,495	1,812	1,86	1,287	1,43	0,746
Media	1,524979	1,776917	2,143438	1,904188	1,737292	1,1235
Dev.st	0,310836	0,33315	0,311297	0,327331	0,260693	0,245806

Figure B.43: EDT values in the audience with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_01	1,828	2,237	2,489	2,433	2,155	1,63
SS1D_10	1,724	2,167	2,49	2,422	2,127	1,591
SS1D_11	1,922	2,207	2,399	2,351	2,127	1,583
SS1D_12	1,782	2,078	2,39	2,329	2,103	1,573
SS1D_02	1,865	2,064	2,385	2,399	2,132	1,608
SS1D_03	1,66	2,076	2,438	2,391	2,098	1,618
SS1D_04	1,941	2,177	2,464	2,409	2,128	1,615
SS1D_05	2,036	2,21	2,519	2,445	2,133	1,636
SS1D_06	1,837	2,073	2,393	2,358	2,099	1,614
SS1D_07	1,866	2,249	2,466	2,436	2,1	1,633
SS1D_08	1,978	2,287	2,442	2,398	2,112	1,603
SS1D_09	1,917	2,026	2,494	2,318	2,098	1,613
SS2D_01	1,894	2,085	2,543	2,415	2,169	1,64
SS2D_10	1,968	2,121	2,454	2,396	2,094	1,613
SS2D_11	1,974	2,133	2,486	2,367	2,093	1,616
SS2D_12	1,766	2,048	2,419	2,366	2,101	1,602
SS2D_02	1,923	2,091	2,474	2,413	2,11	1,668
SS2D_03	1,818	2,108	2,327	2,35	2,113	1,635
SS2D_04	1,95	2,187	2,47	2,405	2,127	1,647
SS2D_05	1,825	2,186	2,537	2,482	2,153	1,646
SS2D_06	1,842	2,046	2,422	2,426	2,101	1,624
SS2D_07	1,992	2,22	2,481	2,413	2,142	1,626
SS2D_08	2,008	2,245	2,437	2,355	2,107	1,631
SS2D_09	1,764	2,026	2,331	2,369	2,15	1,609
SS3D_01	1,814	2,184	2,469	2,386	2,096	1,594
SS3D_10	1,85	2,202	2,471	2,347	2,075	1,573
SS3D_11	1,826	2,101	2,416	2,382	2,092	1,593
SS3D_12	1,642	2,115	2,433	2,338	2,07	1,59
SS3D_02	1,828	2,116	2,388	2,344	2,103	1,605
SS3D_03	1,78	2,052	2,443	2,289	2,027	1,554
SS3D_04	1,765	2,142	2,529	2,376	2,082	1,632
SS3D_05	1,909	2,205	2,495	2,387	2,075	1,608
SS3D_06	1,84	2,058	2,425	2,386	2,068	1,588
SS3D_07	1,909	2,188	2,458	2,367	2,102	1,611
SS3D_08	1,842	2,179	2,443	2,358	2,106	1,596
SS3D_09	1,697	2,116	2,398	2,366	2,047	1,552
SS4D_01	1,886	2,141	2,464	2,408	2,087	1,58
SS4D_10	2,029	2,127	2,435	2,316	2,116	1,569
SS4D_11	1,863	2,206	2,517	2,331	2,031	1,525
SS4D_12	1,809	2,126	2,507	2,398	2,083	1,562
SS4D_02	1,755	2,176	2,473	2,326	2,064	1,567
SS4D_03	1,777	2,15	2,478	2,36	2,1	1,604
SS4D_04	1,746	2,085	2,555	2,356	2,069	1,609
SS4D_05	1,823	2,215	2,549	2,349	2,039	1,595
SS4D_06	1,769	2,112	2,444	2,304	2,064	1,601
SS4D_07	2,009	2,16	2,465	2,369	2,116	1,625
SS4D_08	1,873	2,108	2,457	2,404	2,095	1,593
SS4D_09	1,932	2,108	2,437	2,346	2,084	1,568
Media	1,855271	2,139979	2,456229	2,375813	2,099229	1,6035
Dev.st	0,094717	0,064262	0,050862	0,039365	0,031125	0,028189

Figure B.44: T_{30} values in the audience with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_PP1	1,13	0,21	0,73	-0,1	-0,33	-0,58
SS1D_PP2	-1,07	-1,72	0,88	0,79	0,83	2
SS1D_PP3	-0,67	-0,86	1,37	1,48	1,79	4,33
SS1D_PP4	-1,57	-0,8	0,97	1,93	2,56	3,53
SS1D_PP5	-3,17	0,88	0,4	2,55	2,52	4,59
SS1D_PP6	-0,7	3,17	1,54	4,83	3,99	6,06
SS2D_PP1	1,28	-2,49	-0,56	0,34	0,67	1,84
SS2D_PP2	-0,58	-2,38	-1,87	2,78	0,68	2,64
SS2D_PP3	-0,86	-1,3	-0,46	4,24	1,83	3,37
SS2D_PP4	-0,57	0,5	-1,05	2,92	1,83	5,92
SS2D_PP5	1,73	0,69	-0,02	2,76	3,11	6,1
SS2D_PP6	0,64	1,96	2,07	6,23	4,72	6,61
SS3D_PP1	1,12	-1,17	0,06	-1,41	-2,19	-1,87
SS3D_PP2	-3,37	1,22	0,89	1,64	0,15	0,91
SS3D_PP3	0,17	2,23	2,04	2,03	2,66	3,11
SS3D_PP4	-1,28	1,8	1,66	2,13	3,17	3,72
SS3D_PP5	0,27	2,36	0,99	2,26	2,92	4,22
SS3D_PP6	0,38	4,89	3,34	5,36	4,72	5,06
SS4D_PP1	3,74	6,76	1,76	1,43	-0,58	-0,75
SS4D_PP2	-1,77	1,33	3,1	2,2	2,63	3,24
SS4D_PP3	2,02	2,99	2,23	3,5	3,03	4,65
SS4D_PP4	-3,77	2,18	3,24	2,33	3,98	5,51
SS4D_PP5	-0,14	3,06	3,65	5,38	4,73	6,54
SS4D_PP6	-1,07	3,47	3,16	5,09	6,65	8,27
Media	-0,33792	1,2075	1,255	2,612083	2,33625	3,709167
Dev.st	1,752638	2,297916	1,468522	1,864972	2,010948	2,521759

Figure B.45: C_{80} values in the first order with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_PP1	0,5	0,46	0,49	0,43	0,43	0,38
SS1D_PP2	0,37	0,34	0,48	0,41	0,37	0,42
SS1D_PP3	0,15	0,33	0,5	0,44	0,42	0,45
SS1D_PP4	0,19	0,35	0,47	0,43	0,49	0,53
SS1D_PP5	0,26	0,45	0,4	0,55	0,53	0,62
SS1D_PP6	0,36	0,56	0,43	0,65	0,62	0,72
SS2D_PP1	0,41	0,22	0,4	0,45	0,49	0,53
SS2D_PP2	0,34	0,27	0,35	0,57	0,42	0,53
SS2D_PP3	0,23	0,39	0,36	0,6	0,38	0,53
SS2D_PP4	0,29	0,43	0,31	0,5	0,48	0,65
SS2D_PP5	0,55	0,5	0,38	0,58	0,56	0,68
SS2D_PP6	0,48	0,4	0,51	0,74	0,7	0,76
SS3D_PP1	0,5	0,39	0,44	0,31	0,25	0,24
SS3D_PP2	0,21	0,42	0,38	0,25	0,25	0,26
SS3D_PP3	0,34	0,49	0,5	0,47	0,45	0,45
SS3D_PP4	0,26	0,51	0,5	0,48	0,53	0,55
SS3D_PP5	0,3	0,55	0,46	0,51	0,52	0,59
SS3D_PP6	0,43	0,66	0,57	0,7	0,67	0,68
SS4D_PP1	0,68	0,8	0,55	0,53	0,39	0,35
SS4D_PP2	0,37	0,55	0,58	0,53	0,53	0,52
SS4D_PP3	0,34	0,6	0,55	0,58	0,54	0,62
SS4D_PP4	0,25	0,48	0,59	0,48	0,61	0,64
SS4D_PP5	0,36	0,58	0,58	0,73	0,67	0,75
SS4D_PP6	0,4	0,62	0,58	0,68	0,77	0,81
Media	0,357083	0,472917	0,473333	0,525	0,502917	0,5525
Dev.st	0,124289	0,131198	0,083075	0,122794	0,130966	0,152123

Figure B.46: D_{50} values in the first order with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_PP1	2,245	2,05	2,556	1,866	1,594	1,188
SS1D_PP2	1,798	1,968	2,303	1,761	1,637	1,156
SS1D_PP3	1,592	1,75	2,464	1,844	1,581	1,091
SS1D_PP4	1,355	1,562	2,71	1,94	1,635	1,171
SS1D_PP5	1,468	1,852	2,258	2,066	1,69	1,127
SS1D_PP6	1,012	1,803	2,106	1,701	1,579	1,051
SS2D_PP1	1,426	1,94	2,445	1,935	1,56	1,333
SS2D_PP2	2,186	2,384	2,207	1,946	1,449	1,183
SS2D_PP3	1,197	1,955	3,013	1,84	1,532	1,066
SS2D_PP4	2,246	2,232	2,31	2,275	1,84	1,084
SS2D_PP5	1,841	2,226	2,597	2,097	1,861	1,131
SS2D_PP6	1,87	1,894	2,423	1,357	1,627	1,045
SS3D_PP1	1,82	1,82	2,211	1,7	1,701	1,18
SS3D_PP2	1,403	1,683	2,332	1,594	1,651	1,173
SS3D_PP3	2,391	2,081	2,007	1,836	1,746	1,271
SS3D_PP4	1,448	1,908	2,339	1,949	1,459	1,251
SS3D_PP5	1,447	1,569	1,991	1,994	1,76	1,238
SS3D_PP6	2,126	1,688	1,918	1,417	1,484	1,245
SS4D_PP1	2,866	1,75	2,071	1,867	1,763	1,163
SS4D_PP2	1,667	1,693	2,25	1,875	1,717	1,235
SS4D_PP3	1,665	1,937	2,177	1,806	1,778	1,196
SS4D_PP4	1,501	1,86	2,365	1,804	1,618	1,078
SS4D_PP5	1,529	1,349	1,724	1,585	1,482	1,013
SS4D_PP6	1,589	1,823	2,031	1,641	1,381	0,724
Media	1,737	1,865708	2,283667	1,820667	1,630208	1,141375
Dev.st	0,42605	0,230448	0,275931	0,207561	0,12723	0,119656

Figure B.47: EDT values in the first order with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_PP1	1,739	2,092	2,476	2,385	2,088	1,623
SS1D_PP2	1,862	2,153	2,433	2,367	2,081	1,613
SS1D_PP3	1,805	2,166	2,532	2,418	2,135	1,6
SS1D_PP4	2,078	2,256	2,458	2,444	2,139	1,631
SS1D_PP5	1,987	2,184	2,52	2,404	2,118	1,609
SS1D_PP6	1,97	2,24	2,534	2,388	2,105	1,596
SS2D_PP1	2,029	2,228	2,515	2,383	2,128	1,584
SS2D_PP2	2,034	2,134	2,531	2,414	2,146	1,635
SS2D_PP3	2,033	2,222	2,38	2,413	2,126	1,621
SS2D_PP4	1,969	2,283	2,529	2,409	2,148	1,615
SS2D_PP5	1,992	2,21	2,467	2,468	2,124	1,633
SS2D_PP6	1,91	2,225	2,515	2,367	2,118	1,579
SS3D_PP1	1,933	2,118	2,458	2,423	2,114	1,63
SS3D_PP2	1,938	2,162	2,511	2,412	2,105	1,609
SS3D_PP3	2,065	2,263	2,46	2,419	2,109	1,597
SS3D_PP4	1,81	2,155	2,434	2,39	2,143	1,591
SS3D_PP5	1,882	2,219	2,468	2,363	2,104	1,614
SS3D_PP6	2,053	2,148	2,62	2,353	2,091	1,573
SS4D_PP1	1,848	2,03	2,406	2,353	2,143	1,608
SS4D_PP2	1,804	2,15	2,475	2,394	2,067	1,584
SS4D_PP3	2,023	2,18	2,497	2,391	2,097	1,565
SS4D_PP4	1,902	2,091	2,408	2,383	2,105	1,569
SS4D_PP5	2,015	2,224	2,555	2,409	2,066	1,544
SS4D_PP6	1,899	2,113	2,507	2,375	2,083	1,549
Media	1,940833	2,176917	2,487042	2,396875	2,111792	1,598833
Dev.st	0,095099	0,062389	0,054131	0,02796	0,024413	0,026076

Figure B.48: T_{30} values in the first order with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_SS1	1,55	1,35	-0,47	0,65	2,08	2,05
SS1D_SS2	2,97	3,36	2,38	2,26	3,94	4,99
SS1D_SS3	1,22	2,07	4,31	5,46	6,56	6,03
SS1D_SS4	-1,92	0,58	2,02	1,44	2,66	3,13
SS1D_SS5	4,34	1,17	1,37	3,13	5,5	4,99
SS1D_SS6	-1,21	-0,62	3,22	5,82	6,69	6,59
SS2D_SS1	0,53	0,4	0,99	1,98	3,23	3,29
SS2D_SS2	1,94	0,05	1,8	2,85	4,4	5,25
SS2D_SS3	0,25	-0,48	3,51	4,33	7,35	6,83
SS2D_SS4	1,82	-2,26	1,63	1,35	2,49	3,69
SS2D_SS5	1,82	0,52	2,25	2	5,17	4,68
SS2D_SS6	5,01	0,89	2,83	5,27	8,41	7,17
SS3D_SS1	2,57	1,72	0,41	0,48	1,95	1,73
SS3D_SS2	3,63	2,74	1,69	3,27	3,78	4,52
SS3D_SS3	-4,97	0,82	1,51	3,09	5,81	5,32
SS3D_SS4	2,4	0,16	-0,53	1,69	2,56	3,04
SS3D_SS5	3,82	0,88	-0,29	2,84	4,89	5,95
SS3D_SS6	2,4	1,81	3,27	4,43	7,95	6,62
SS4D_SS1	-2,17	-0,33	0,19	1,18	2,43	1,84
SS4D_SS2	3,33	3,14	2,74	2,74	3,9	3,6
SS4D_SS3	0,19	0,34	0,25	3,54	4,24	5,08
SS4D_SS4	0,66	-0,79	1,52	0,15	1,56	2,19
SS4D_SS5	2,39	-0,67	-0,42	3	4,51	4,24
SS4D_SS6	4,8	0,13	2,83	3	6,28	4,69
Media	1,557083	0,7075	1,625417	2,747917	4,514167	4,479583
Dev.st	2,377049	1,325746	1,38489	1,542426	1,980259	1,62945

Figure B.49: C_{80} values in the second order with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_SS1	0,47	0,47	0,4	0,45	0,5	0,48
SS1D_SS2	0,19	0,38	0,49	0,52	0,55	0,62
SS1D_SS3	0,22	0,27	0,25	0,46	0,64	0,58
SS1D_SS4	0,23	0,35	0,5	0,45	0,53	0,52
SS1D_SS5	0,52	0,42	0,45	0,57	0,66	0,65
SS1D_SS6	0,23	0,34	0,52	0,7	0,69	0,72
SS2D_SS1	0,21	0,41	0,5	0,53	0,57	0,56
SS2D_SS2	0,4	0,4	0,53	0,58	0,6	0,61
SS2D_SS3	0,36	0,36	0,26	0,59	0,72	0,68
SS2D_SS4	0,47	0,28	0,49	0,45	0,5	0,58
SS2D_SS5	0,53	0,39	0,45	0,54	0,67	0,66
SS2D_SS6	0,62	0,45	0,54	0,69	0,79	0,75
SS3D_SS1	0,38	0,43	0,36	0,36	0,5	0,43
SS3D_SS2	0,55	0,51	0,41	0,56	0,58	0,57
SS3D_SS3	0,22	0,41	0,39	0,5	0,62	0,63
SS3D_SS4	0,56	0,4	0,37	0,4	0,48	0,51
SS3D_SS5	0,63	0,44	0,41	0,53	0,65	0,72
SS3D_SS6	0,5	0,43	0,45	0,58	0,78	0,71
SS4D_SS1	0,3	0,37	0,41	0,45	0,55	0,5
SS4D_SS2	0,54	0,6	0,54	0,59	0,58	0,58
SS4D_SS3	0,27	0,42	0,39	0,58	0,54	0,62
SS4D_SS4	0,37	0,29	0,46	0,37	0,46	0,49
SS4D_SS5	0,56	0,42	0,37	0,59	0,66	0,63
SS4D_SS6	0,69	0,38	0,53	0,55	0,74	0,62
Media	0,4175	0,400833	0,43625	0,524583	0,606667	0,600833
Dev.st	0,155347	0,071379	0,080532	0,087971	0,094486	0,084076

Figure B.50: D_{50} values in the second order with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_SS1	1,364	1,893	2,275	2,087	1,812	1,399
SS1D_SS2	1,497	1,627	1,938	2,015	1,353	1,123
SS1D_SS3	0,899	1,475	1,381	1,037	0,824	0,876
SS1D_SS4	1,679	1,944	2,228	1,702	1,397	1,19
SS1D_SS5	1,215	1,816	1,819	1,652	1,169	1,06
SS1D_SS6	0,973	1,877	1,603	1,074	0,758	0,74
SS2D_SS1	1,623	2,327	2,743	2,073	1,693	1,37
SS2D_SS2	1,402	2,275	2,219	2,188	1,542	1,141
SS2D_SS3	1,176	1,604	1,359	1,474	0,76	0,761
SS2D_SS4	1,576	2,219	1,993	1,746	1,495	1,232
SS2D_SS5	2,06	2,427	2,269	2,118	1,364	1,095
SS2D_SS6	1,742	2,012	1,691	1,214	0,529	0,662
SS3D_SS1	1,203	1,807	2,212	1,822	1,783	1,344
SS3D_SS2	1,743	1,465	2,184	1,839	1,408	1,122
SS3D_SS3	1,292	1,644	1,798	1,301	0,962	0,962
SS3D_SS4	1,581	1,983	2,205	1,727	1,399	1,196
SS3D_SS5	1,22	1,546	1,889	1,639	1,139	0,886
SS3D_SS6	1,156	1,188	1,319	1,07	0,56	0,779
SS4D_SS1	1,605	1,804	2,29	2,274	1,584	1,528
SS4D_SS2	1,546	1,737	2,365	1,979	1,591	1,41
SS4D_SS3	2,095	1,767	2,447	1,569	1,296	1,133
SS4D_SS4	1,848	1,906	2,274	1,97	1,711	1,391
SS4D_SS5	1,276	2,118	1,966	1,821	1,408	1,265
SS4D_SS6	1,103	1,545	2,24	1,534	1,232	1,164
Media	1,453083	1,833583	2,029458	1,705208	1,282042	1,117875
Dev.st	0,317284	0,301524	0,364251	0,364621	0,375232	0,238111

Figure B.51: EDT values in the second order with directional source (11/09/2015).

	125	250	500	1000	2000	4000
SS1D_SS1	1,948	2,157	2,506	2,379	2,091	1,589
SS1D_SS2	1,905	2,272	2,519	2,393	2,097	1,606
SS1D_SS3	1,855	1,955	2,309	2,3	2,044	1,592
SS1D_SS4	1,887	2,241	2,545	2,35	2,092	1,562
SS1D_SS5	1,797	2,246	2,532	2,333	2,042	1,529
SS1D_SS6	1,716	2,027	2,4	2,293	2	1,511
SS2D_SS1	1,941	2,207	2,4	2,407	2,099	1,629
SS2D_SS2	2,067	2,111	2,425	2,419	2,082	1,576
SS2D_SS3	1,698	2,034	2,341	2,325	2,033	1,572
SS2D_SS4	2,04	2,317	2,387	2,392	2,095	1,596
SS2D_SS5	1,836	2,071	2,493	2,368	2,067	1,531
SS2D_SS6	1,773	2,103	2,395	2,257	1,993	1,517
SS3D_SS1	1,931	2,39	2,46	2,483	2,108	1,625
SS3D_SS2	1,902	2,177	2,449	2,396	2,06	1,596
SS3D_SS3	1,856	2,07	2,36	2,289	2,056	1,562
SS3D_SS4	1,985	2,056	2,474	2,356	2,015	1,573
SS3D_SS5	1,814	2,15	2,448	2,336	1,996	1,522
SS3D_SS6	1,915	2,093	2,404	2,241	1,948	1,516
SS4D_SS1	1,806	2,129	2,428	2,385	2,128	1,616
SS4D_SS2	2,097	2,173	2,415	2,318	2,095	1,581
SS4D_SS3	1,967	2,083	2,436	2,406	2,091	1,587
SS4D_SS4	1,92	2,216	2,537	2,359	2,073	1,582
SS4D_SS5	1,884	2,054	2,591	2,323	2,068	1,517
SS4D_SS6	1,834	2,083	2,38	2,34	1,985	1,568
Media	1,890583	2,142292	2,443083	2,352	2,056583	1,568958
Dev.st	0,100423	0,10195	0,070365	0,055143	0,046346	0,036323

Figure B.52: T_{30} values in the second order with directional source (11/09/2015).

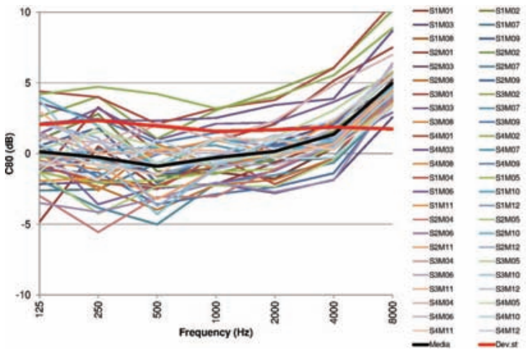
Appendix C

Graphical representation of measurements results

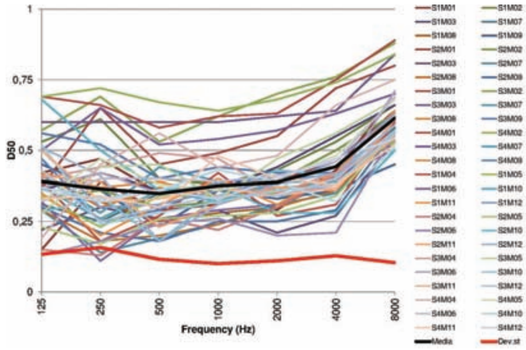
Values of some parameters obtained from the measurements done on 10 and 11/09/2015 have been plotted. Values of parameters obtained from the measurements have been reported in the following figures of this appendix to see how the measurements have been treated and to see the dispersion of the data around the average. All the graphs are reported only in octave bands, for readability. For each group of values, already divided according to the area in which the receivers have been placed, average and standard deviation have been calculated and visualized.

Values regarding the measurements done on 11/09/2015 have been shown from 125 to 4000 Hz, due to the uncertainties in low frequencies below 125 Hz and the fact that the omnidirectional source used on 11/09/2015 doesn't emit above 4000 Hz. Values regarding the measurements done on 10/09/2015 have been shown from 125 to 8000 Hz, because the omnidirectional source used emits until the frequency band of 8000 Hz.

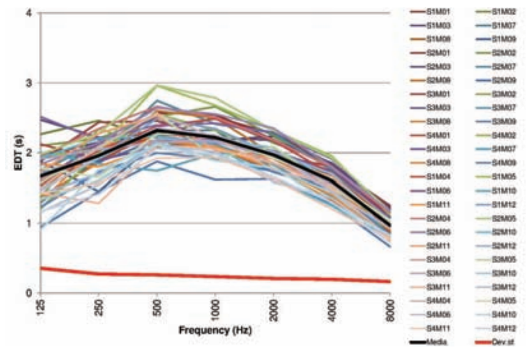
Values of C_{80}, D_{50}, EDT and T_{30} have been reported in octave bands, according to the areas of the Theatre in which receivers have been placed (audience, first order, second order and stage) and for each equipment.



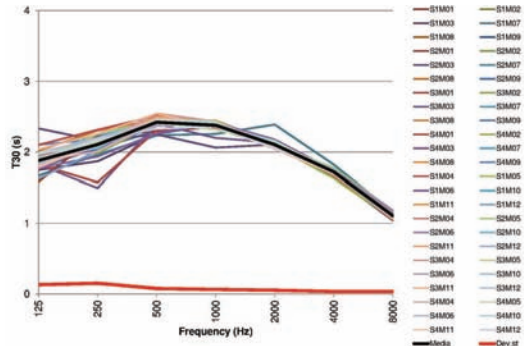
(a) C_{80}



(b) D_{50}

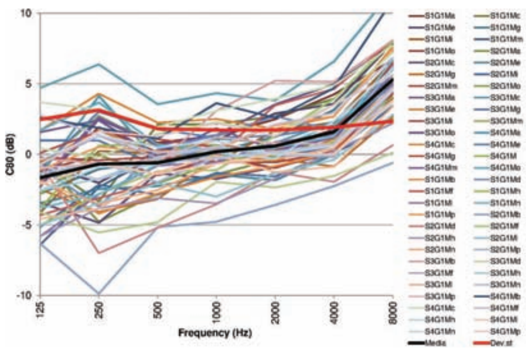


(c) EDT

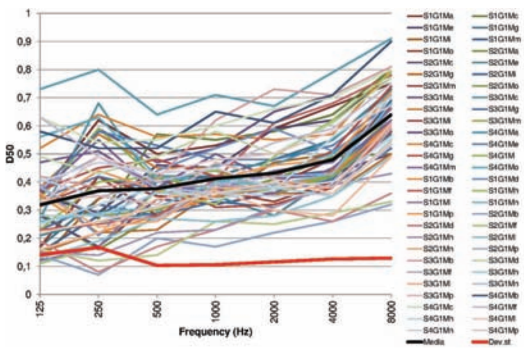


(d) T_{30}

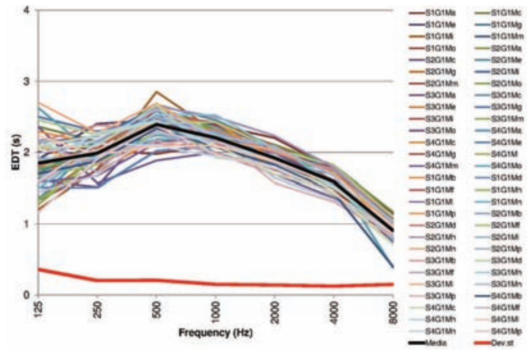
Figure C.1: Reverberation and energy parameters in the audience obtained from measurements performed with omnidirectional source (10/09/2015).



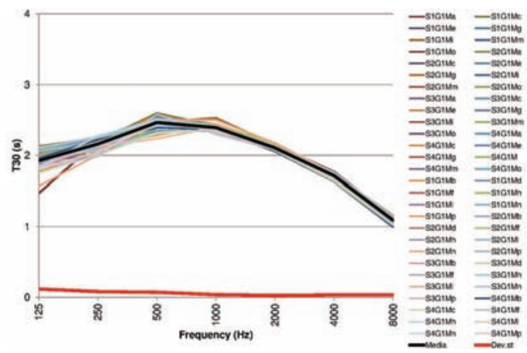
(a) C_{80}



(b) D_{50}

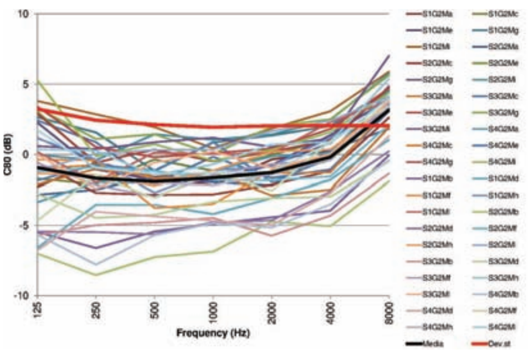


(c) EDT

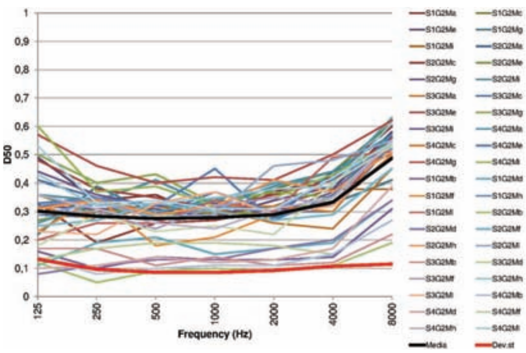


(d) T_{30}

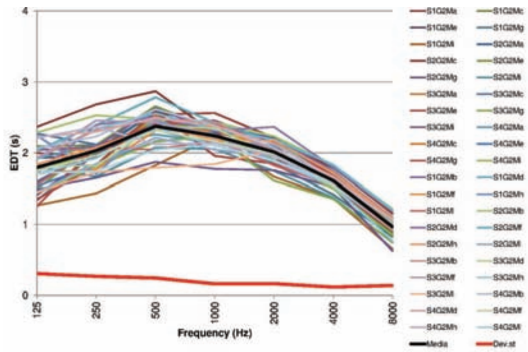
Figure C.2: Reverberation and energy parameters in the first order obtained from measurements performed with omnidirectional source (10/09/2015).



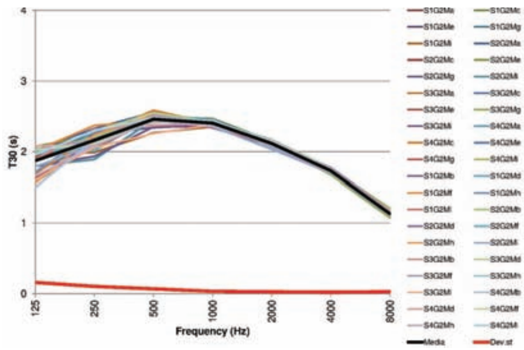
(a) C_{80}



(b) D_{50}

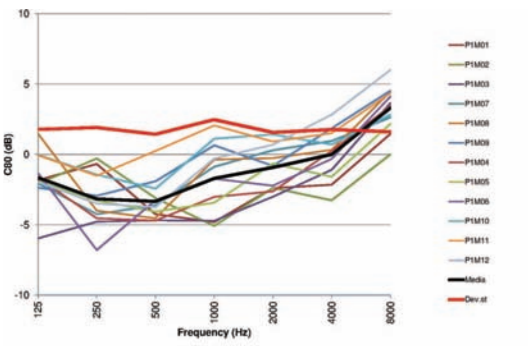


(c) EDT

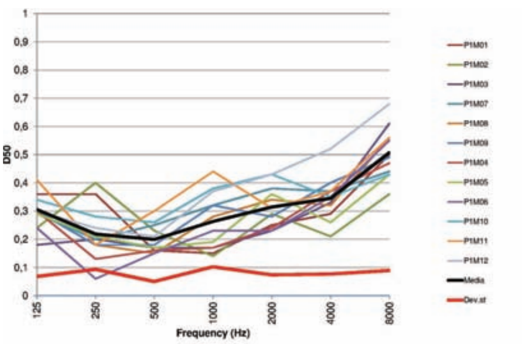


(d) T_{30}

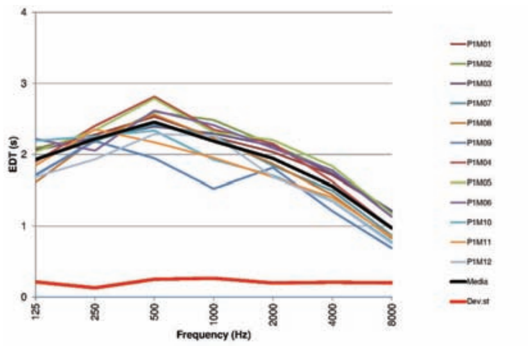
Figure C.3: Reverberation and energy parameters in the second order obtained from measurements performed with omnidirectional source (10/09/2015).



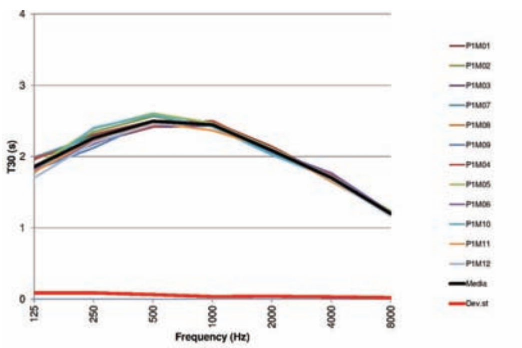
(a) C_{80}



(b) D_{50}

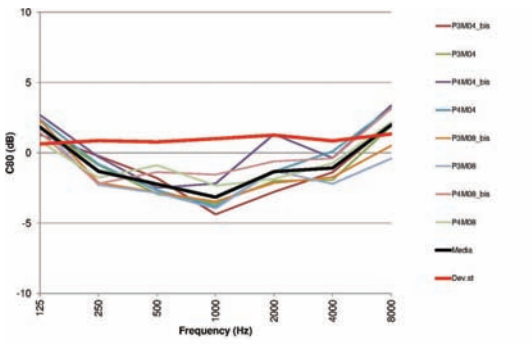


(c) EDT

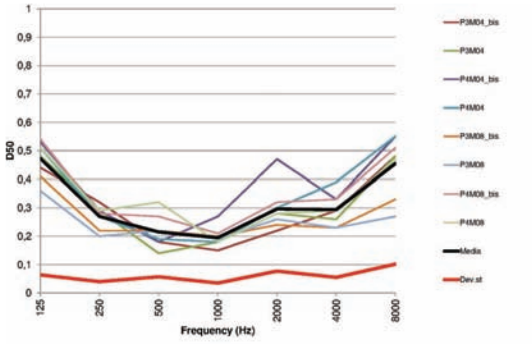


(d) T_{30}

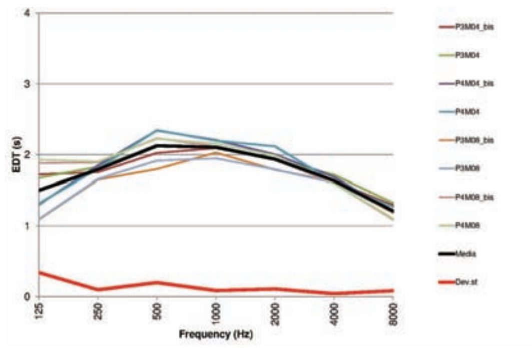
Figure C.4: Reverberation and energy parameters in the audience obtained from measurements performed with balloons (10/09/2015).



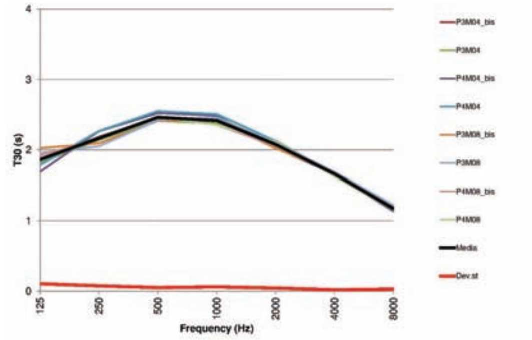
(a) C_{80}



(b) D_{50}

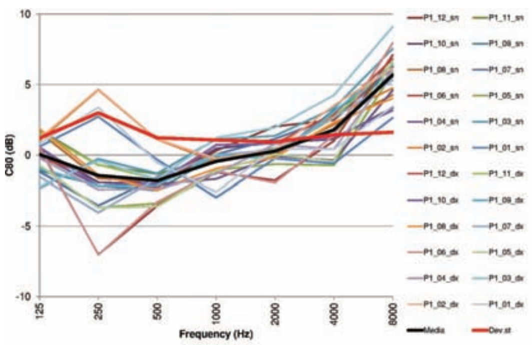


(c) EDT

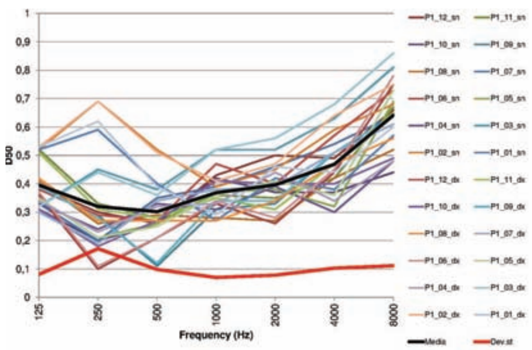


(d) T_{30}

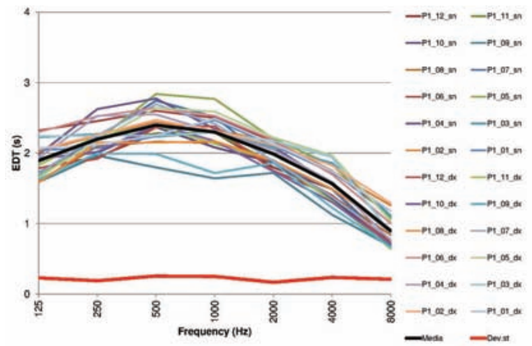
Figure C.5: Reverberation and energy parameters on the stage obtained from measurements performed with balloons (10/09/2015).



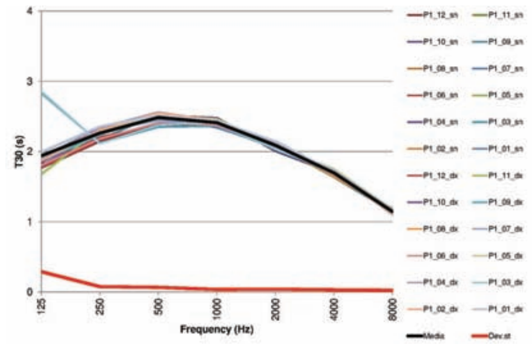
(a) C_{80}



(b) D_{50}

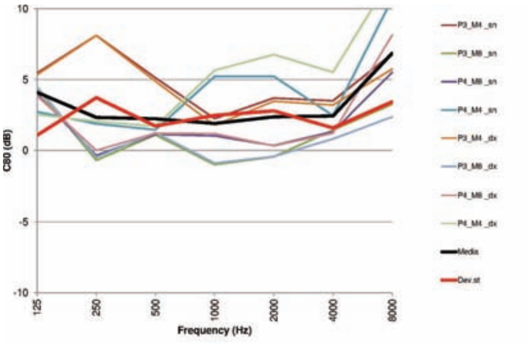


(c) EDT

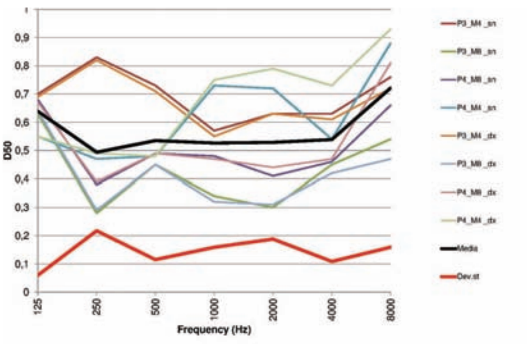


(d) T_{30}

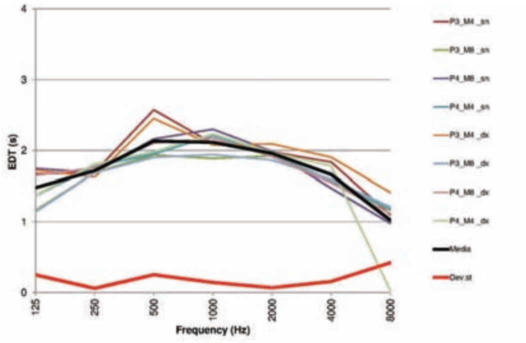
Figure C.6: Reverberation and energy parameters in the audience obtained from measurements performed with balloons and Tascam digital recorder (10/09/2015).



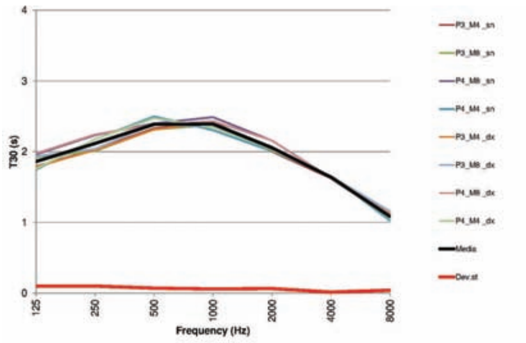
(a) C_{80}



(b) D_{50}

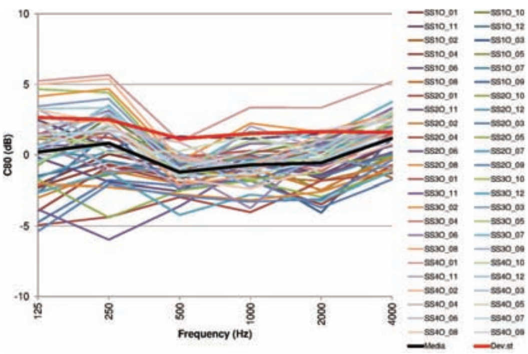


(c) EDT

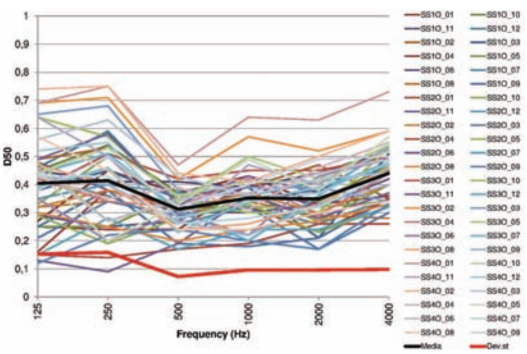


(d) T_{30}

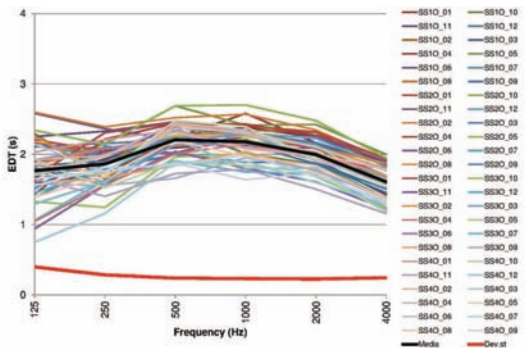
Figure C.7: Reverberation and energy parameters on the stage obtained from measurements performed with balloons and Tascam digital recorder (10/09/2015).



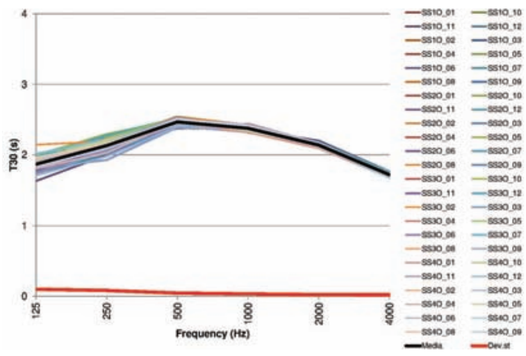
(a) C_{80}



(b) D_{50}

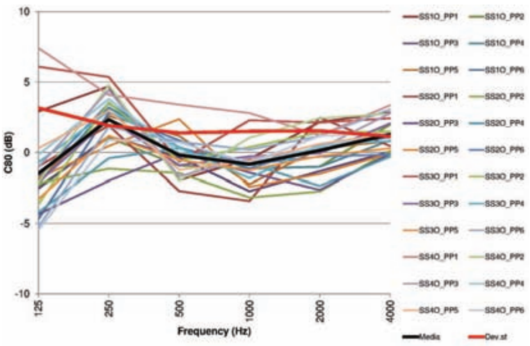


(c) EDT

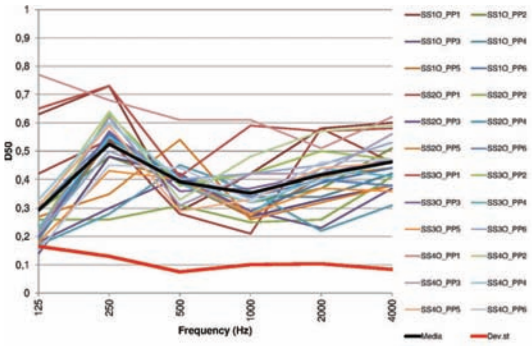


(d) T_{30}

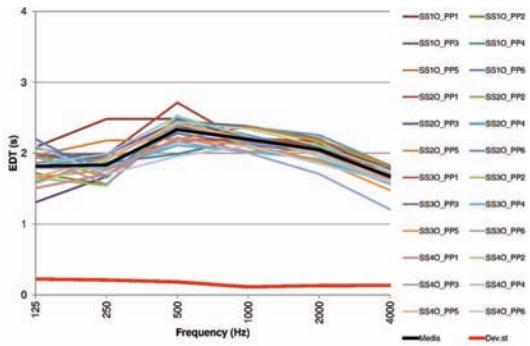
Figure C.8: Reverberation and energy parameters in the audience obtained from measurements performed with omnidirectional source (11/09/2015).



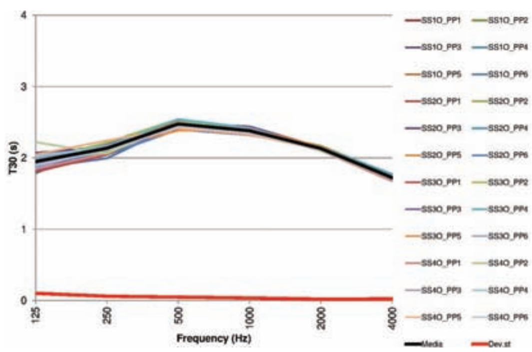
(a) C_{80}



(b) D_{50}

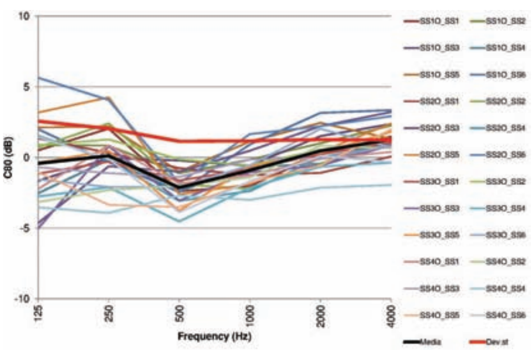


(c) EDT

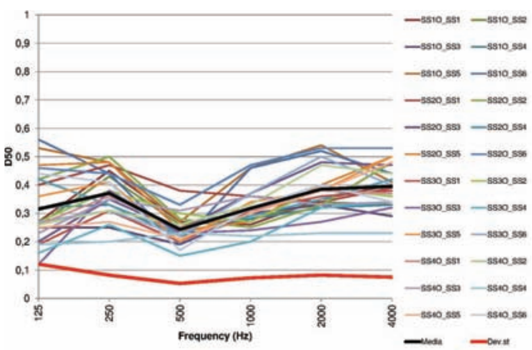


(d) T_{30}

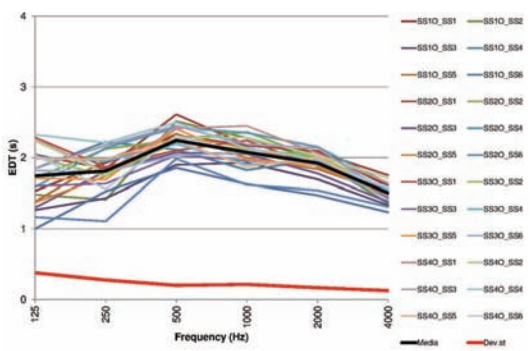
Figure C.9: Reverberation and energy parameters in the first order obtained from measurements performed with omnidirectional source (11/09/2015).



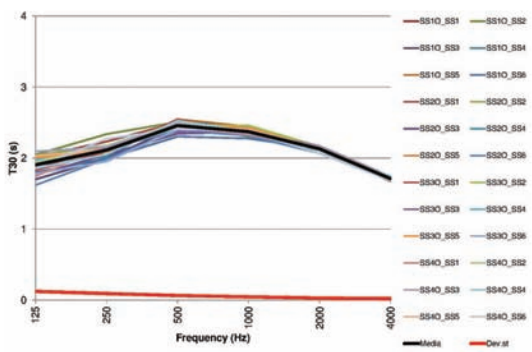
(a) C_{80}



(b) D_{50}

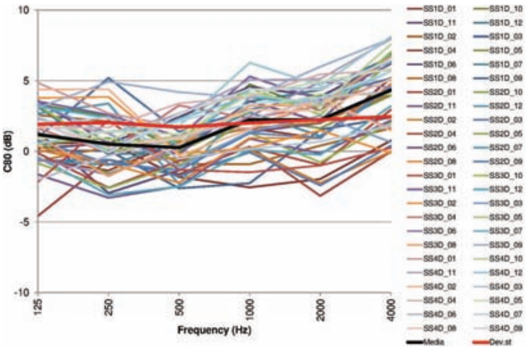


(c) EDT

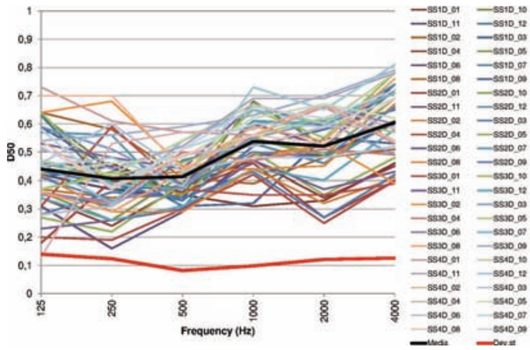


(d) T_{30}

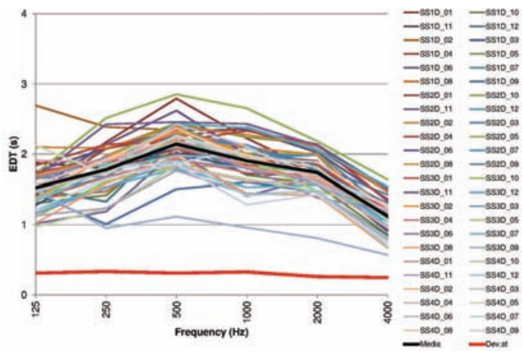
Figure C.10: Reverberation and energy parameters in the second order obtained from measurements performed with omnidirectional source (11/09/2015).



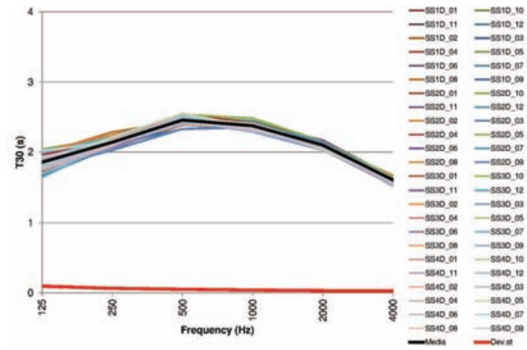
(a) C_{80}



(b) D_{50}

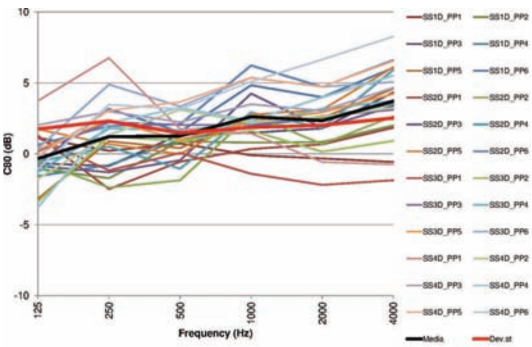


(c) EDT

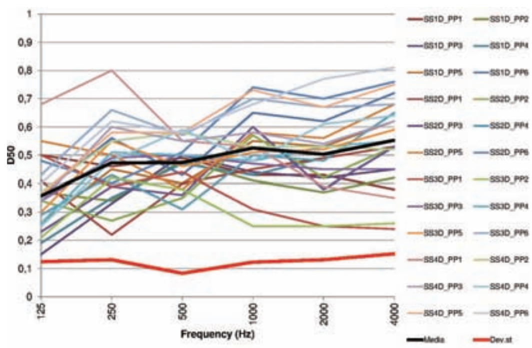


(d) T_{30}

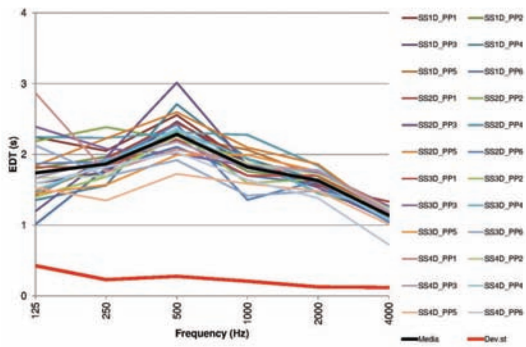
Figure C.11: Reverberation and energy parameters in the audience obtained from measurements performed with directional source (11/09/2015).



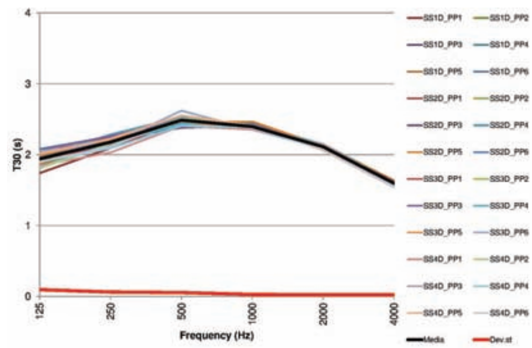
(a) C_{80}



(b) D_{50}

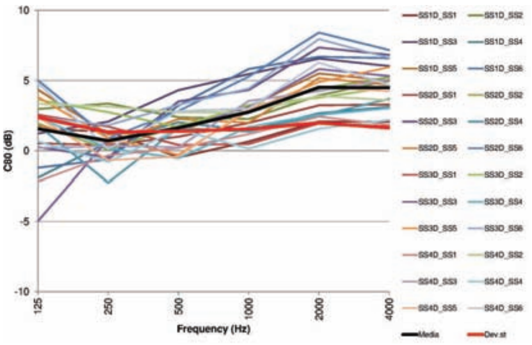


(c) EDT

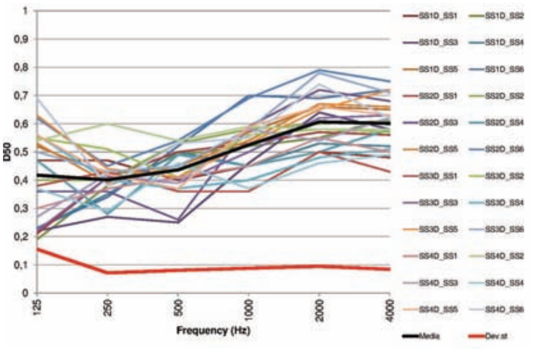


(d) T_{30}

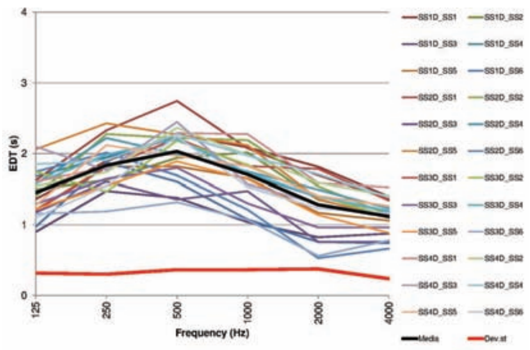
Figure C.12: Reverberation and energy parameters in the first order obtained from measurements performed with directional source (11/09/2015).



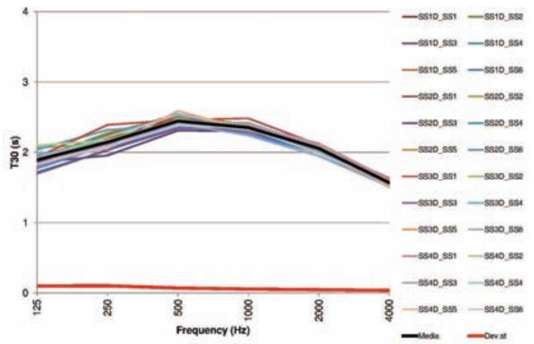
(a) C_{80}



(b) D_{50}



(c) EDT



(d) T_{30}

Figure C.13: Reverberation and energy parameters in the second order obtained from measurements performed with directional source (11/09/2015).

Appendix D

Representation of the results through the use of GIS

The values of the parameters obtained with the acoustic characterization can be represented trough the use of Geographical Information Systems (GIS). In this work, QGIS software has been used to create maps that represent the distribution of the values of the parameters (STI male, STIPA, C_{80}, EDT and T_{30}) in the environment analysed.

First of all, a raster layer representing the audience of the Civic Theatre has been uploaded in QGIS software. A vector layer has been created, made by points in the audience representing where the receivers have been placed *in situ*. The symmetrical points in the audience have been added, to due the symmetry of the Theatre. The values of the parameters (STI male, STIPA, C_{80}, EDT and T_{30}) for each point, and eventually for each frequency, have been included in the attribute table of the layer. Then, the *Inverse Distance Weighting* function of QGIS software has been used to interpolate the values and to obtain the final maps (visible in the figures of this appendix). *Inverse distance weighting* (IDW) is the simplest interpolation method. A neighborhood about the interpolated point is identified and a weighted average is taken of the observation values within this neighborhood. The weights are a decreasing function of distance [31].

Maps of values of C_{80}, EDT and T_{30} obtained with *Inverse Distance Weighting* function have been reported for the frequency bands of 500 Hz, 1000 Hz and 2000 Hz (figures D.1, D.2, D.3 and D.3).

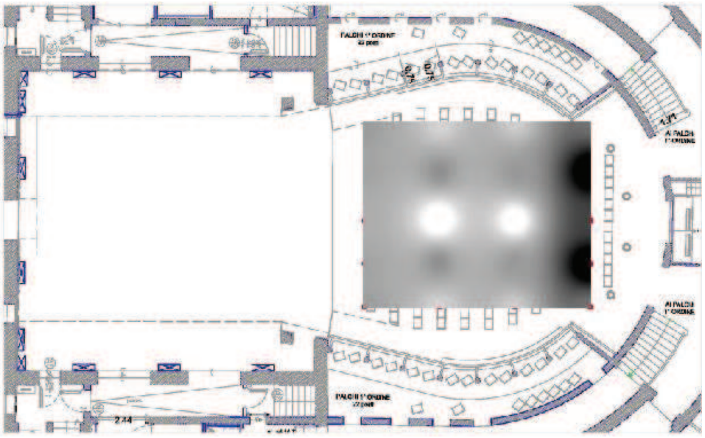
Lower values have been represented in white and higher values have been represented in black. The symmetry has been represented well and it is visible that the measurements have been performed in different points of the audience. The values of the parameters (STI male, C_{80}, EDT and T_{30}) used have been the ones obtained on 11/09/2015 with the omnidirectional source placed in position S1 and the receivers in the audience. The values of STIPA used have been the ones obtained on 11/09/2015 with the Talk Box placed in position S1 and the receivers in the audience. It has to be noticed that, in these representations, the variations of the parameters are very small, because in the audience, and in general in all the Theatre, the results are homogeneous and they don't have large variations. The representations have the aim to highlight where the highest and the lowest values are found for each parameter analysed. In addition, it can be noticed that the same analysis in QGIS software is applicable to any other problem of environmental noise.

As regard C_{80}, it can be noticed that higher values have been found in the receiver positions more far to the stage, probably due to the reflections from the boundaries. High values of C_{80} are better for speech listening. As regard EDT, higher values have been found close to the stage, while the behaviour of T_{30} doesn't show a regular trend, even if higher values have been found in the central positions. High values of reverberation times are better for symphonic music listening, while, for speech listening, low values are better. Higher values of speech intelligibility have been found in the positions close to the stage and also in the positions most far from the stage,, probably due to the reflections from the boundaries, especially for STI male. High values of speech transmission index are better for speech listening.

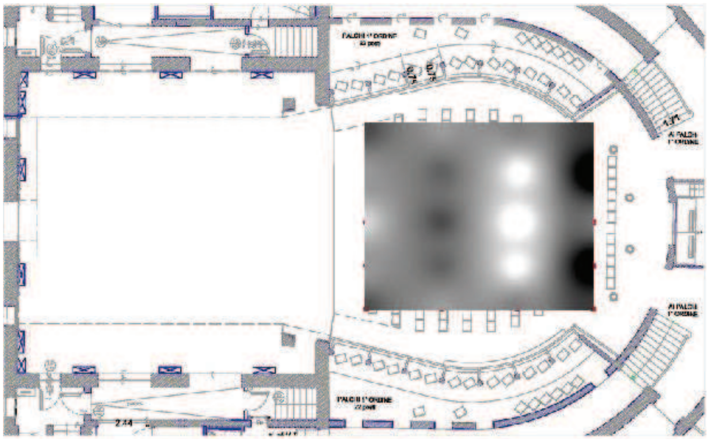
The same analysis can be conducted using the *Triangular interpolation* function of QGIS software. *Triangular Interpolation* (TIN) is a form of vector-based digital geographic data and it is constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. The triangulation satisfies the Delaunay triangle criterion, which ensures that no vertex lies within the interior of any of the circumcircles of the triangles in the network. If the Delaunay criterion is satisfied everywhere on the TIN, the minimum interior angle of all triangles is maximized. Long, thin triangles are avoided as much as possible. TIN preserves all the precision of the input data, simultaneously modelling the values between known points [30].

Maps of values of C_{80}, EDT and T_{30} obtained with *Triangular interpolation* function have been reported for the frequency bands of 500 Hz, 1000 Hz and 2000 Hz (figures D.5, D.6, D.7 and D.7).

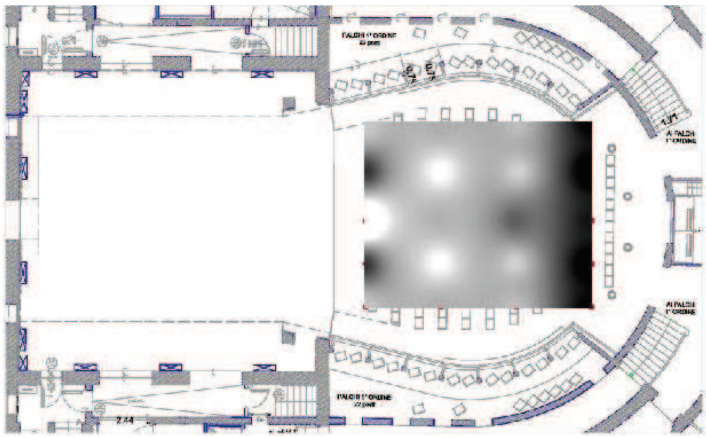
Lower values have been represented in white and higher values have been represented in black. The symmetry hasn't been represented well, so the *Inverse Distance Weighting* function has been preferred.



(a) 500 Hz

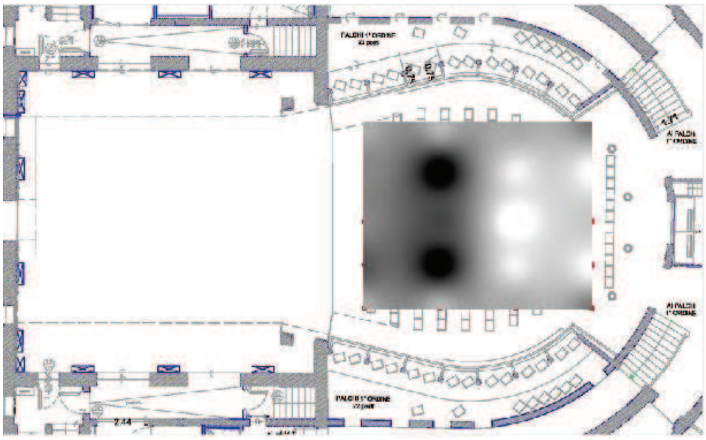


(b) 1000 Hz

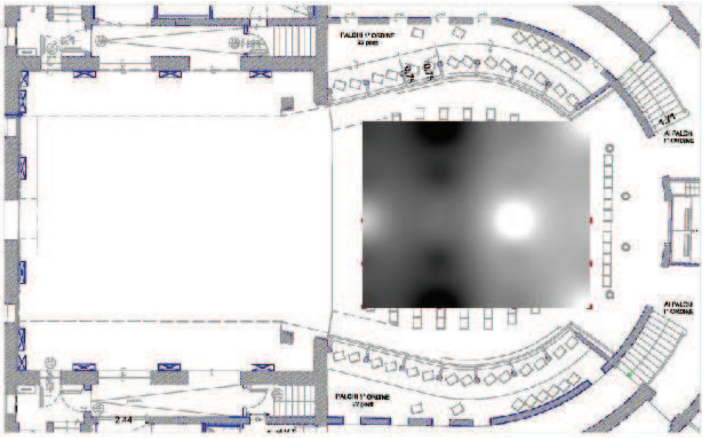


(c) 2000 Hz

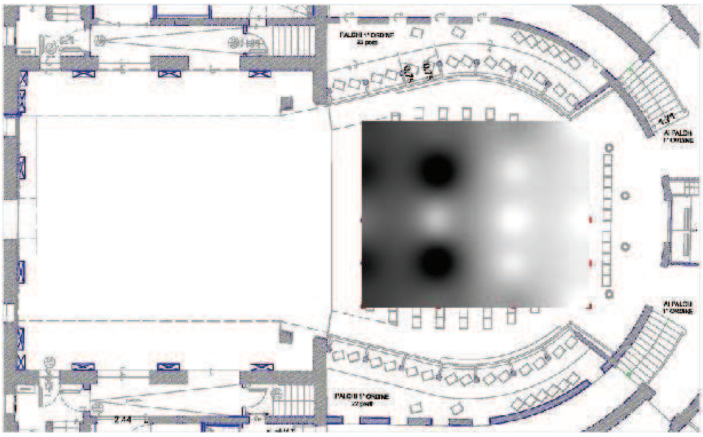
Figure D.1: Distribution of the values of C_{80} in the audience obtained with *Inverse Distance Weighting* function.



(a) 500 Hz

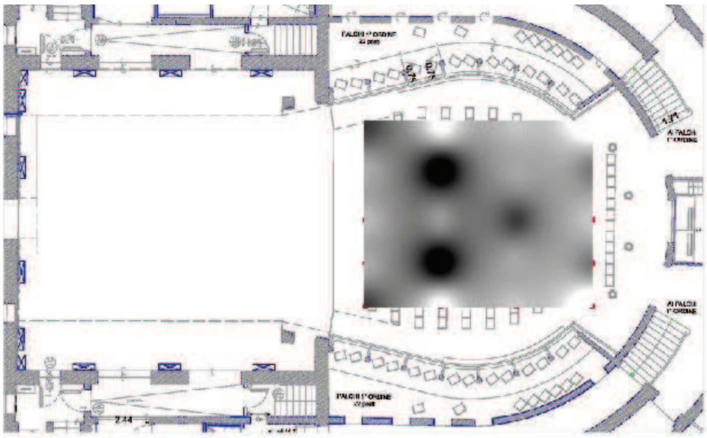


(b) 1000 Hz

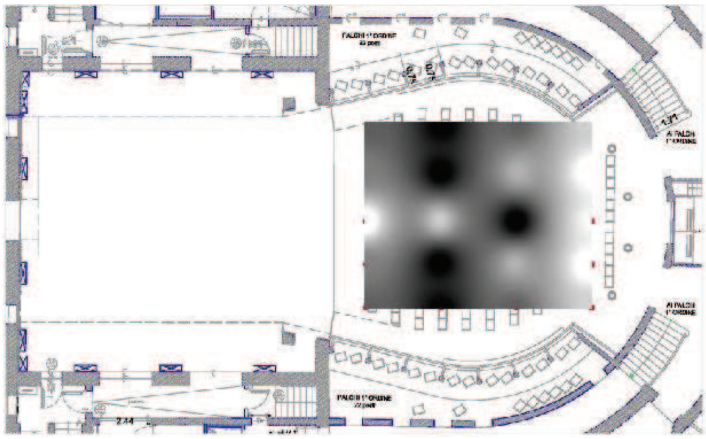


(c) 2000 Hz

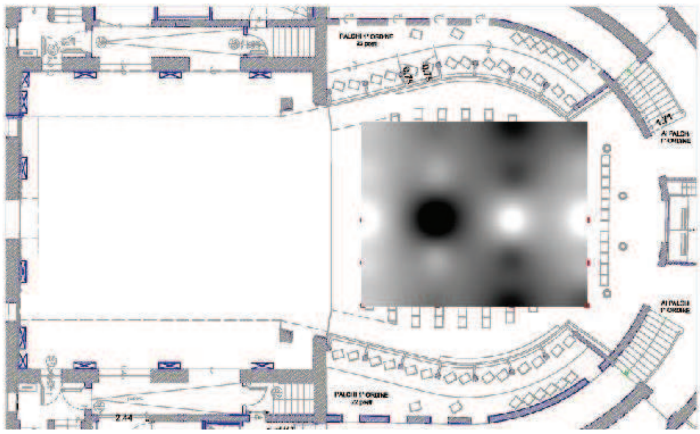
Figure D.2: Distribution of the values of EDT in the audience obtained with *Inverse Distance Weighting* function.



(a) 500 Hz

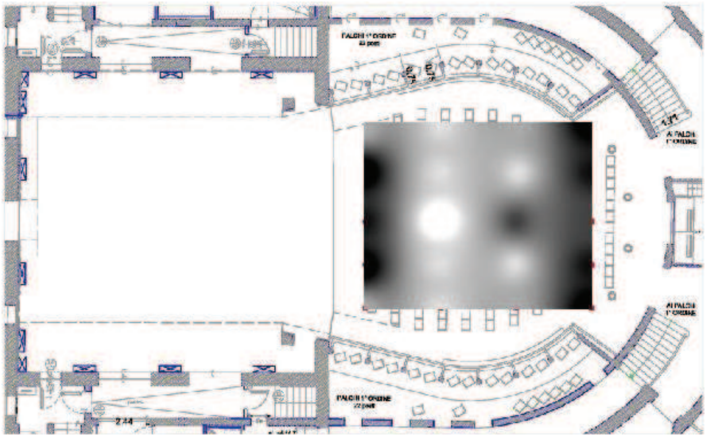


(b) 1000 Hz

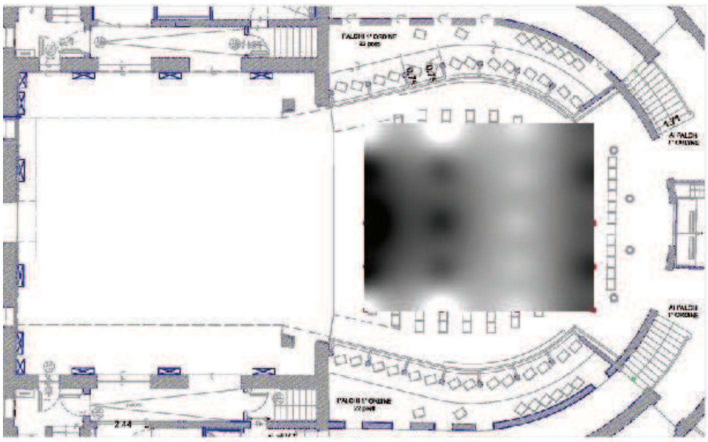


(c) 2000 Hz

Figure D.3: Distribution of the values of T_{30} in the audience obtained with *Inverse Distance Weighting* function.

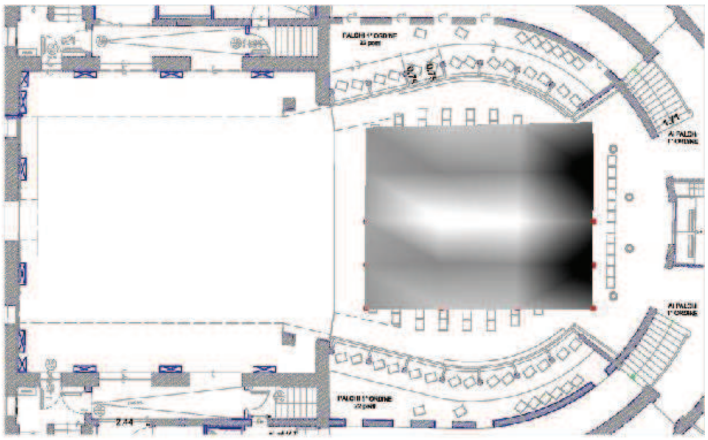


(a) STI male

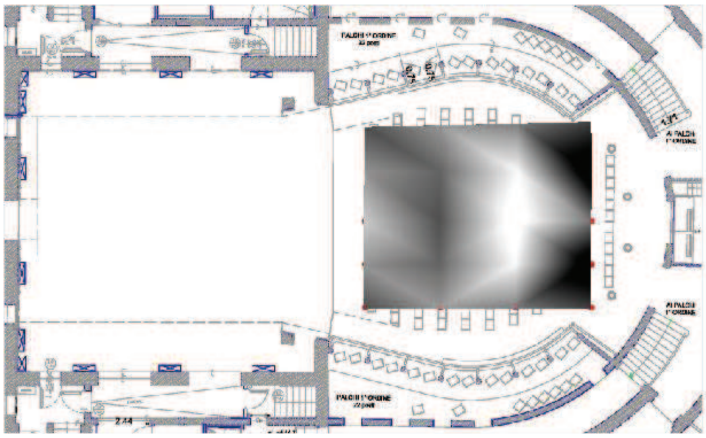


(b) STIPA

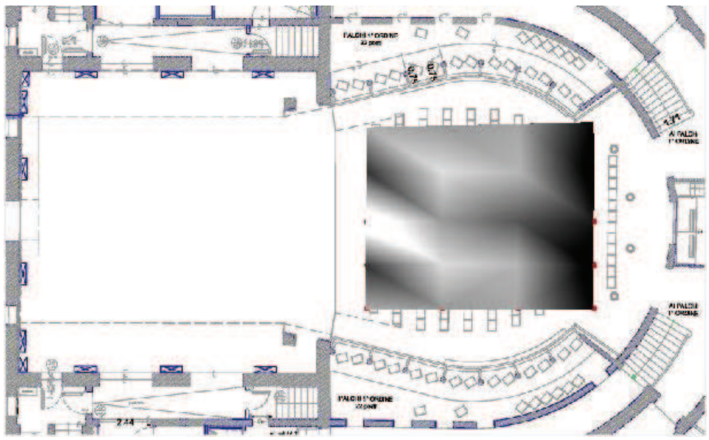
Figure D.4: Distribution of the values of intelligibility parameters in the audience obtained with *Inverse Distance Weighting* function.



(a) 500 Hz

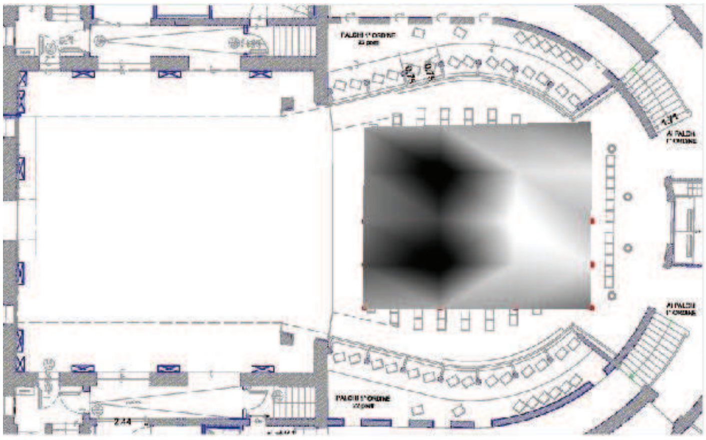


(b) 1000 Hz

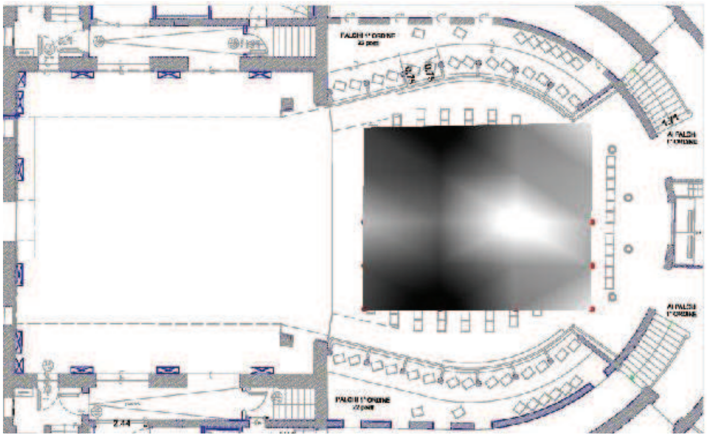


(c) 2000 Hz

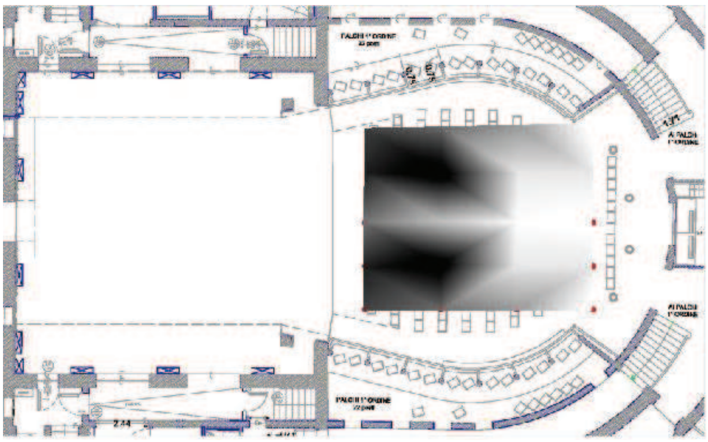
Figure D.5: Distribution of the values of C_{80} in the audience obtained with *Triangular interpolation* function.



(a) 500 Hz

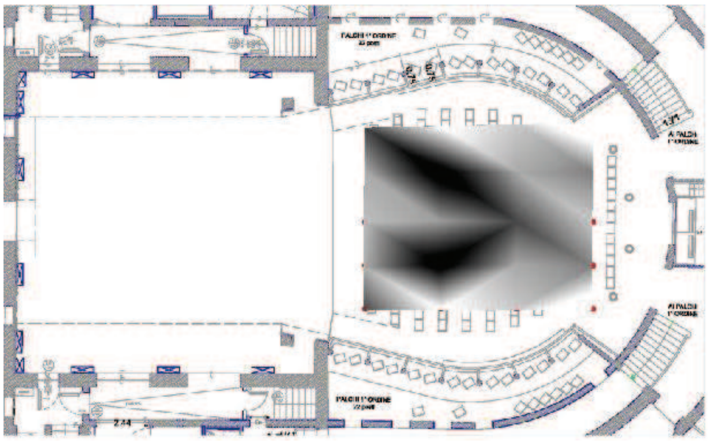


(b) 1000 Hz

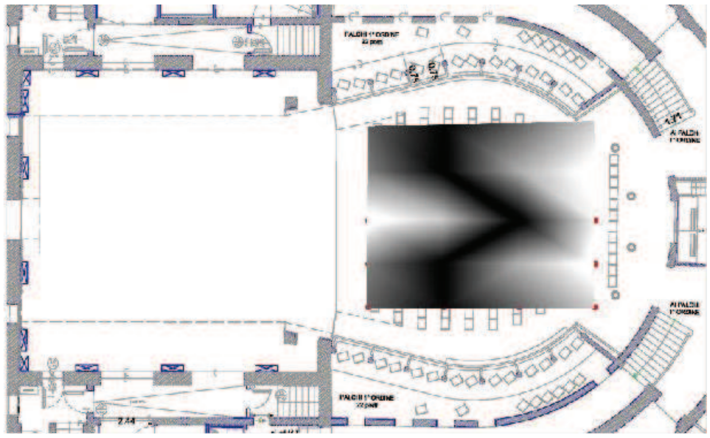


(c) 2000 Hz

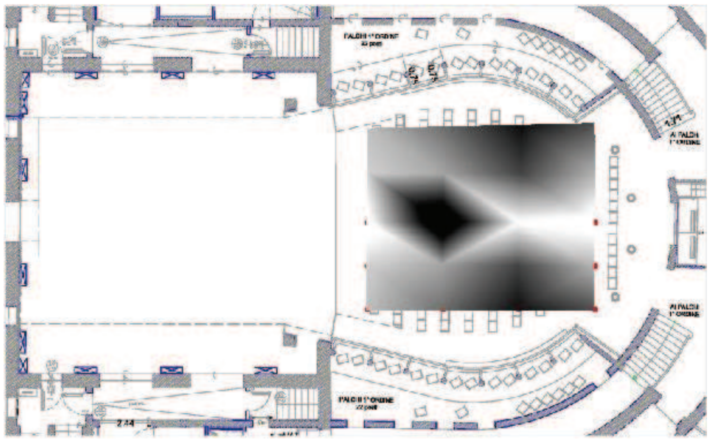
Figure D.6: Distribution of the values of EDT in the audience obtained with *Triangular interpolation* function.



(a) 500 Hz

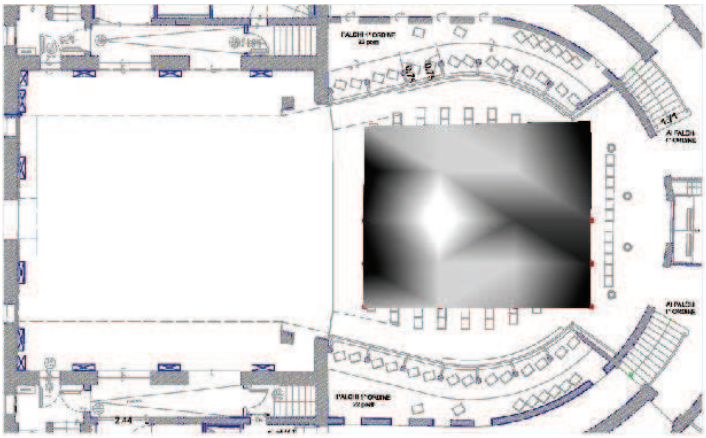


(b) 1000 Hz

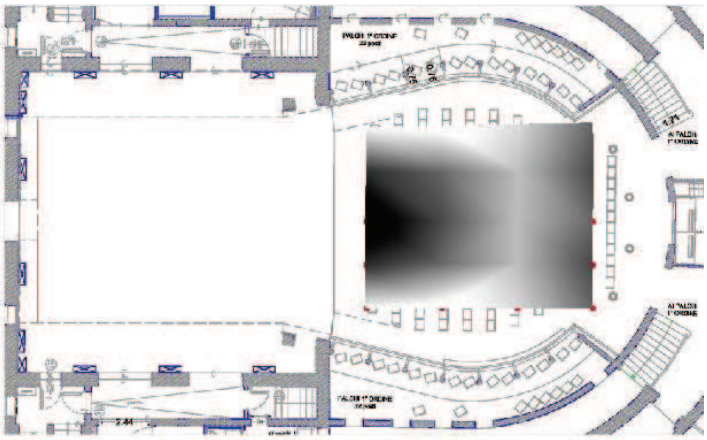


(c) 2000 Hz

Figure D.7: Distribution of the values of T_{30} in the audience obtained with *Triangular interpolation* function.



(a) STI male



(b) STIPA

Figure D.8: Distribution of the values of intelligibility parameters in the audience obtained with *Triangular interpolation* function.

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