Summary

This project consists of a proposal of sound reinforcement system on the Ignacio Pinedo Sports Centre, located in the Carlos III University Sports Centre, Getafe. As an important part of the work has been developed a software model of the enclosure that allows to simulate the behaviour of the sound reinforcement system designed.

Generally, enclosures for sport use are spaces with the capacity to accommodate large numbers of people. This offers the possibility of performing many types of events other than sports, such as concerts, exhibitions or congresses.

However, these possibilities are not usually taken into account when designing the enclosure, so that the acoustic conditions within it limit its usefulness. High reverberation times, the appearance of echoes and sound focusing present a problem when designing a sound reinforcement system. Apart from the problems related to the geometry of the enclosure and the materials which it is made of, there is an issue with the background noise generated by the public during competitions, that sometimes could become excessive, especially in large sport halls that host multitudinous sports.

For these reasons, it is very important to model the enclosure using software, in order to simulate the sound reinforcement system designed and to verify its behaviour in an environment similar to the real one.

The descriptive memory of this project is divided into two parts: a more theoretical one, in which the technical particularities of this subject are explained, and a more practical one, approaching both the modelling of the enclosure and the sound reinforcement system design and its simulation.

Regarding the theoretical part, this shall be divided into another three different sections: first, an introduction on the different approaches and description methods in room acoustics. Second, an analysis on the goals that the sound reinforcement system in sport halls has to achieve and, finally, a research on the functioning of line arrays.

First of all, an introduction to the approaches and description methods in room acoustics is included, concretely:

- Statistical room acoustics
- Geometrical room acoustics
- Wave based room acoustics
- Subjective room acoustics

The statistical room acoustics assumes a diffuse sound field within the enclosure. This epigraph contains the definitions of sound absorption coefficient, average absorption, free and reverberant field, critical distance and reverberation time. In addition, some of the approaches formulated by different authors to calculate the reverberation time within an enclosure, namely the Sabine, Eyring, Millington and Sette, and Arau approximations are presented. For each of these contributions,

explanations will be made regarding its correspondence to reality, depending on the geometry of the enclosure and its average absorption.

For its part, geometrical room acoustics assumes the sound propagation in form of energy parcels along straight lines. This theory is based on the hypothesis of specular reflections, that assumes the incident ray and the reflected ray have the same angle to the normal. In this epigraph, the concepts of direct and reflected acoustic rays will be defined, as well as the concept of reverberant time. Furthermore, the graphic representation of Energy-Time Curve (ETC), that measures room decay time graphically, will be shown.

Regarding the wave-based room acoustics, it provides a different way to study the sound field, focusing particularly in the particle vibration process which takes place inside it. Here, every type of room modes will be defined, such as axial modes, tangential modes and oblique modes, as well as the influence the emergence that those modes have in the sound field.

Finally, the last part regarding room acoustics approaches the subjective room acoustics, about how a receiver perceives the sound. The behaviour of the ear when exposed to sound is also analysed in this section. It will feature definitions of concepts like how frequencies stimulate our hearing sensibility, the particularities related to critical bandwidth, frequency masking and the parameters used to measure intelligibility. This parameters are %ALCons (Percentage Articulation Loss of Consonants), STI (Speech Transmission Index) and RASTI (Rapid Speech Transmission Index).

The second theoretical part focuses on sound reinforcement systems on closed sport halls. Here, there will be analysed the acoustic particularities in closed sport halls, such as the requirements that a sound reinforcement system has to fulfil and all its different kinds and practical repercussions.

The section regarding the acoustic particularities of the closed sport halls will gather the main problems that usually pop up while trying to make a suitable sound reinforcement system. Generally, factors like the reflecting surfaces and geometry of the enclosure have noteworthy importance in its acoustic behaviour. Specifically, these two factors could have negative consequences such as high reverberant times, echoes, sound focusing or flutter echoes. Also, in this section there will be analysed the two types of background noise susceptible of emerge from this kind of installation. On one hand, the background noise that emerge from the absence of activity and, on the other, the background noise generated by the public attending a sport event in the enclosure.

Hereafter, will try to set the aims we aspire to while installing a sound reinforcement in a closed sport hall, also setting those parameters we want to fulfil to this end, such as word intelligibility, uniform coverage for both terraces and fields and efficient signal to noise ratio.

This second part also displays the three types of sound reinforcement systems susceptible of use in this kind of enclosure. Concretely, a centralized sound reinforcement system, a distributed sound reinforcement system and a combination of a centralized and a distributed system.

Another point featured in this theoretical part is dedicated to the line arrays, and features a brief introduction, a study on the acoustic level addition resulting in a gathering of sound sources, and an epigraph dedicated to the functioning and characteristics in these types of speaker assembling.

Apart from that, the introduction gathers up a brief analysis on the conclusions achieved by Harry Olson, a pioneer in the study of the behaviour of different sound sources when gathered. His importance is unquestionable as his studies form the main basis for line arrays technology.

As the second point in this subject, a study reflecting the acoustic resulting of at least two speakers of the same kind, emitting the same signal. Given that is the same signal and that the speakers have the same features, it is susceptible of a mathematical representation in the form of a coherent addition of acoustic signals, concept which also will be defined. The example object of study will consist in the relation between two point sources. That will ease the analysis of the interaction of several gathered sources emitting coherent signals. This will help obtaining the directivity pattern from a sound sources gathering.

As far as the behaviour and characteristics of line arrays is concerned, these are defined as vertical junctions of sources which perform as a single lineal one. Their main characteristics are two: a coherent addition between the sources that compound that junction and a vertical directivity control. Some of the concepts defined in this epigraph are how to achieve an effective control over the vertical directivity of the lineal source, how to increase the quarter power angle, how to originate a lineal source from several separated sources and how to achieve a coherent addition between them and, finally, the various configurations of the line arrays.

The foregoing paragraphs were intended to sum up the theoretical content of the project. The next part revolves around the modelling of the enclosure object of this project, as well as its sound reinforcement system design and a simulation in order to test the results.

Firstly, the part dedicated to the modelling of the enclosure will feature the stages of the process aimed to take an approach to its eventual final version, in order to make all the required simulations to test it after having designed the sound reinforcement system. Therefore, the characteristics and localization of the enclosure are detailed first and then is its own creation process by means of EASE software.

The enclosure, located in the Carlos III University Sports Centre, Getafe, has a limited capacity of 700 people and it hosts sports competitions of football (only in the form of an internal university league) and basketball and volleyball, between university teams from all over Madrid. Besides, the enclosure hosts rhythmic gymnastics exhibitions.

The use of the EASE software in the modelling process is divided into two parts: the creation of a first version of the model and then make an adjustment, by changing the materials originally assigned, in order to get a more realistic approach.

The creation of the first version of the model required a personal implication, regarding the measurement of the enclosure using a laser meter to obtain its geometric information, since it was not possible to access to the site plans, so a lot of visits were required in order to take the proper measurements of it. Several versions of the model were created, from the one that represented the most basic form of it to the final version, where almost every constructive element is represented, passing through the stages when, progressively, more details were added.

The next step consists in adjusting the model created with the software through the change or edition of the materials initially assigned to the enclosure. Since we don't have any information about them, it takes an initial appraisal to evaluate which one fits in this project. To that end, we must obtain the sound pressure levels on the enclosure by doing an on-site measurement. After that, the results will be compared with the ones obtained from the software by simulation so we can change or edit the materials initially assigned until we get to approach to the results.

The procedure we must follow is this:

1. Defining the measurement points.
2. Obtaining the on-site measurements.
3. Data processing.
4. Adjusting the model by changing the materials.

First of all, it was necessary to define the points from which we would obtain the on-site measurements. Once they were defined, a dodecahedral source was installed in the centre of the enclosure and the sound pressure levels were registered in the 56 previously defined measurement points.

After data processing, the uncertainty in the measurements was calculated in order to establish a margin of which to approximate the measurements obtained with the software.

The adjusting process consisted in simulating the sound pressure levels in the measurement points embedded in the software, all in the same points the on-site measurements were obtained, with a sound source of the same kind and the same sound pressure levels. Once with the simulation results, they were compared with the on-site values and some materials were changed to contrast the values again. This process was repeated until we got to approach the results. At last, a 77.3% of the simulated results were inside the uncertainty margins of the on-site measurements.

The next part of the project is dedicated to describe the sound reinforcement system design process through the EASE Focus software. Due to the particularities of the enclosure, there were designed several sound reinforcement systems for each part of it, depending of their requirements. On the one hand, a line array composed reinforcement for the terraces and also in the field, depending on its purpose (type of sport hosted, i.e.).

For the terraces, the initial aim was to achieve a uniform coverage of ±3 dB for the 500 Hz, 1 kHz, 2 kHz and 4 kHz octave bands and a signal to noise ratio of 25 dB in order to guarantee an efficient intelligibility, because in that part of the enclosure both music and voice would be heard. Several line arrays with different configurations were tested to that end.

The proper epigraph will feature the non-weighted sound pressure levels for the 500 Hz, 1 kHz, 2 kHz y 4 kHz octave bands and the signal to noise ratio for the same ones.

The sound reinforcement systems of the field, as said, were differentiated taking in consideration its different use depending on the sport that is being played.

For example, for the sound reinforcement intended to gymnastics exhibitions, the initial aim was, much like in the terraces case, to achieve a uniform coverage of ±3 dB for the 500 Hz, 1 kHz and 2 kHz and a signal to noise ratio of 25 dB. It is important to achieve a good intelligibility because is very important for the gymnasts to hear both the music and the voices emitted by the speakers.

Moreover, the field is divided into three parts, used to host badminton and volleyball competitions, indifferently. A signal to noise ratio of 25 dB is enough to achieve an efficient intelligibility. Same with football and basketball, despite both sports will need the three parts of the field when hosted.

After pondering the needs of every configuration, it was designed a sound reinforcement for the field with enough versatility to cover all of them.

The last part of the project features some simulations of the sound reinforcement designed with the EASE software in order to test its behaviour, not in the real environment but in a quite similar one. Here, we would obtain the reverberation time values, the total pressure levels and the intelligibility parameters (%ALCons y STI/RASTI). Finally, we must analyse these values to check if the design fulfils the initially required features.

Reverberant time values are obtained through the Sabine and Eyring formulas for each third octave band, as well as for an empty venue and full crowded terraces kind of situations.

Simulations to obtain the total sound pressure levels are made for each of the sound reinforcement types proposed. On one hand, we obtain the results regarding the different configurations of the sound reinforcements corresponding the terraces, while on the other, we obtain the ones corresponding the field. The levels represented in this epigraph correspond the the 500 Hz, 1 kHz, 2 kHz and 4 kHz octave bands.

Finally, we would study the parameters that allow to determine the level of intelligibility you achieve with each sound reinforcement. To that purpose, we need to obtain the %ALCons and STI values for each of them, regarding the zone: terraces or field, depending in this last case on the kind of sport hosted and the total amount of parts used (each one of the three in which is divided, or the complete field).

After obtaining every result needed, we would draw conclusions and expose eventual future projects.

In view of the results, it is possible to guarantee correct intelligibility in all zones of the enclosure, complying with the values established for the parameters %ALCons, STI and signal to noise ratio. A uniform coverage can also be guaranteed for the areas in which such an objective was established, the terraces and the area of the field where the rhythmic gymnastics exhibitions are held. In terms of the reverberation times of the enclosure, it is observed that the results are quite high in the frequency range between the third octave bands of 200 Hz and 2.5 kHz.

As a final part of the work, after the part devoted to theoretical concepts and the part dedicated to the modelling of the enclosure, a chapter is devoted to the analysis of the regulatory framework that would apply in this project and the analysis of the socio-economic environment, in which a detailed budget of the elaboration of this project and its possible economic and social impact is made.

The regulatory framework that applies to this project is mainly related to the limit values of noise exposure. These limits are set by the World Health Organization. In this section are also mentioned the regulations related to obtaining measures in the process of adjustment of the computer model.

In the section devoted to the socio-economic environment, a detailed budget of the cost involved in carrying out this project is shown first. This budget takes into account both the material used and the workforce. This section also analyses the socio-economic impact generated by the development of this project.