Design and analysis of the sound reinforced system for the FIFA world cup 2014 stadium "DUNAS ARENA", in Natal.

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Summary

The FIFA World cup 2014 will involve several different towns in Brazil and in most of them new stadia were designed and realized. Amongst them, one of the most important examples is the Dunas Arena stadium in Natal.

In order to analyze the efficiency and quality of the sound reinforcement system of the stadium, a numerical, 3D model was realized and utilized to determine eventual acoustic and electroacoustic limitations. For this purpose, two different numerical modelling software were considered to improve the credibility of the results. In order to analyse the acoustic quality of the stadium (that might be utilized for pop/rock music concerts) and the global intelligibility, the numerical evaluation comprised the determination of the number, the position, the orientation, the typology and model of the loudspeakers (and of other electroacoustic devices). This optimization was also combined with the global cost of possible acoustic corrections, in order to limit the investment while enhancing the intelligibility.

In this paper, the main aspects of the acoustic design will be presented, together with some results.

PACS 43.55.Jz; 43.55.Ka; 43.55.Fw

1. Introduction

The "Arena das Dunas" or "Dunas Arena" is a football stadium designed by Populous, host the football matches in Natal, for the 2014 FIFA World Cup, which were held in Brazil. The work presented in this paper is focused on the technical development of numerical models and on the analysis of the results of the sound reinforcement system, to be installed in the new football stadium.

In the first part of this article, we introduce the project and describe the design of the "Dunas Arena", focusing in particular on the structural and non-structural elements that are fundamental for the acoustic analysis. Following, we discuss the numerical analysis with two different acoustic design software and present the technical choices that were made during this phase. We then proceed to the analysis of the results on CATT-Acoustic and DDA (Digital Directivity Analysis, By Duran Audio), the two programs that were used to analyze and verify the sound reinforcement system that were planned to be installed in the new football stadium. During this study, it was not possible to experimentally analyze the acoustics and the electroacoustic system on site, because the stadium was still under construction. Therefore, we present the principal steps that were taken to draw the 3D model which has been the base for the acoustic analysis with CATT-Acoustic and DDA. This work has been made in collaboration with InAcoustics studio from Portugal that was commissioned to evaluate the quality of the sound reinforcement system of the stadium, according to FIFA requirements.

Two different solutions will be analysed, since two different reinforcement configurations were presented by the installer. The former was the original design and the latter was the executive design.

2. Analysis of the executive project

The project of the new stadium is based on two different configurations: *before* and *after* 2014 FIFA World Cup matches. This means that the architectural design is going to change after the stadium has hosted the football matches for the 2014 FIFA World Cup. Because of this, a part of the last level of the platforms was designed to be disassembled. This design could limit the construction costs and, even more important, give more versatility to the stadium. The FIFA standard code suggests designing “a new stadium with a capacity of 30000 people, might find it preferable to think in terms of nearer 40000”.

The arena’s design is unique. Its façade and roof are integrated and made up of 20 petal-shaped modules. It is designed to be higher on one of the stadium’s sides, to give the impression that the sand dunes – which are common in the region – are moving. The design also enables more ventilation and light to come into the stadium. The petal-shaped structures of the roof are made of steel trusses, covered with aluminum tiles, with thermal and acoustic insulation. Internally they are coated with a PVC prestressed membrane. The parts are joined by translucent polycarbonate, which allows light to come through.

The three levels are sustained by a system of pillars linked with the longitudinal beams that sustain the platforms. The platforms are also structural elements that for the first ring are one single block, only divided by the tunnel entrance, while the second ring is made up of 20 blocks that follow the two principal symmetry axes of the stadium. Parts of these blocks are removable structural elements because, after the 2014 FIFA World Cup matches, they will be disassembled. Another important element is the roof that is realized in order to protect the platforms. This structural element is based on a truss frame with tubular steel elements. This kind of roof follows the idea of the second ring platforms. It is formed by 20 blocks that follow the two principal symmetry axes that gives a waveform to the roof. The two elements, the roof and the concrete platforms assume a fundamental importance in the acoustic analysis, because these are the principal surfaces where the sound is reflected.

The sound reinforcement system under study has been designed by a Brazilian company and it is formed by two different systems: Electro-voice™ (external system) and Bosh loudspeakers (internal system). We focus on the external system, which was the target of verification.

The equipment consists of:

- for all platforms:
    - 10 Clusters with:
      1x EVH1152D/94-FGB Electro-Voice, FULL RANGE;
      2x EVH1152D/96-FGB Electro-Voice, FULL RANGE;
    - 4 Clusters with:
      4x EVH1152D/96-FGB Electro-Voice, BI_AMP;
- for the bottom platforms:
  70x ZX1I-100T Electro-Voice.

This layout represents the executive project, which is the final design, after different ones were presented. In this work the first layout (without the Zx1 sources) and the last one are reported.

3. 3D model analysis

For this analysis it a digital model of the stadium was needed to simulate the acoustic behavior of this space, since the real one was under construction. The software programs used to solve this problem and to make an acoustic and electroacoustic analysis were:

- CATT acoustic v.9;
- DDA acoustic from Duran Audio v.4.1.

It was useful to compare the results from the same model through two different programs, to understand and find the presence of some possible error. These kinds of programs need a 3D model, which is a set of planes with particular characteristics:

- the system must be closed: “*room space*”;
- all planes must be coplanar;
- every plane was set with a single material;
- no intersection between planes should exist in the model.

In this case, the building is a stadium with a very complex geometry. In order to overcome the difficulties on realizing the model, it was decided to utilize an architectural design program to represent and simplify the stadium geometry. The programs used were AutoCAD 2012 (v. F.51.0.0),

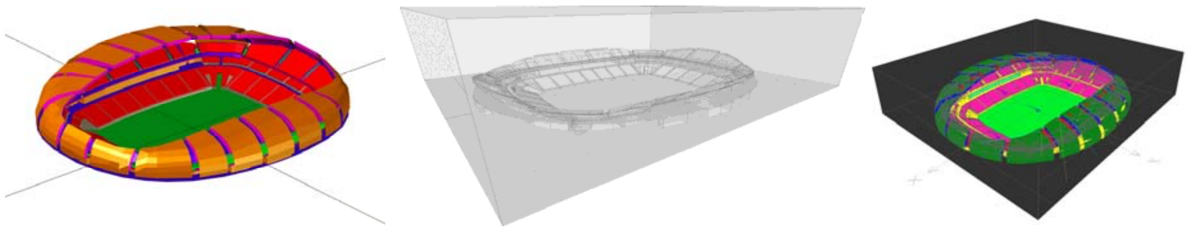

Figure 1. 3D Model in AutoCAD, SketchUP and CATT acoustic.

SketchUP (v. 13.0.3689), and the tool SU^{2}CATT (v. 1.3), to import the model into CATT, and DDA. The professional programs (CATT and DDA) have no limits of the number of surface, but the time of computation is directly linked with its number. As an example, in case of a model having 1000 surfaces, the resolution time (requested for the simulation) is about 10^2 [s]; on the other hand, in case of a 3D model having more than 5000 surfaces, the resolution time becomes roughly 10^5 [s]. Therefore, as normally, the number of surfaces should be limited and optimized, to have a good 3D model and limited computational time, still maintaining a high geometry precision. This compromise was able to satisfy the program requirements and at the same time, to give a sufficiently good representation of the case under study. These kinds of problems are important where it is necessary to represent a curve and not linear geometry. In the Dunas Arena the roof perimeter has a double curvature, and each roof block is a set of curves. Then, the four platforms corner has a curvature, and the external perimeter behind the platforms has an ellipse form. The first choice was approximate to the model in the order of 10^{-2} [m].

However, under the supervision of InAcoustics' engineers, it was decided to prepare a model having about 5000 surfaces in order to have a good 3D model, with enough precision in geometry and low computational time. Thereafter the model was divided into three different files:

- FIRST PLATFORMS RING;
- SECOND PLATFORMS RING;
- ROOF.

This expedient permitted to manage the model in a better way, in AutoCAD and SketchUP. Every single file is smaller and lighter than one with the entire geometry. Then, another advantage of this method is to create sub-files[1] in CATT, which are divided from MASTER[2] file. SU^{2}CATT program exports one single file to CATT, without any sub-files. However, if it designs three deferent files it will manage each one in CATT and link them together into a single MASTER file with two sub-MASTER files. The expedient used to link together the different files, was fix the “*GAME PLAN*” in each file, so when it will unite the three files there will be the same reference system.

4. Acoustic design

The acoustic design should follow part of the international FIFA requirements for an international stadium, which should host the matches of the FIFA world cup. These requirements are summarized in the following paragraphs.

Sound reinforcement and acoustics Public address system[3]

It is essential that stadium operators and authorities are capable of communicating with spectators inside and outside the stadium by means of a sufficiently powerful and reliable public address (PA) system. To ensure that adequate speech intelligibility for public address and emergency messages is achieved in the stadium spectator areas, the PA system should be designed to meet the following performance requirements and standards:

- *The system is to achieve STI values (measured using the STI-PA method or calculated from the impulse response) of not less than 0.55 in the fixed spectator seating areas.*

[1] Sub-file is a MASTER file, of CATT.

[2] MASTER is the main file of CATT, it has the set of model points and it links the sub-file together.

[3] From chapter: 6.3 - Communication with the public, (FIFA, 2011).

- *The system shall provide maximum continuous sound levels of not less than 100 dB(A) and peak sound levels of at least 105 dB(A), with deviations in overall direct sound levels across the spectator seating not exceeding +/-3.5 dB(A).*
- *Frequency response as measured in the seating areas shall be at least 120 Hz to 5000 Hz +/-3 dB.*

The system would have to meet the minimum speech intelligibility requirement and exceed the performance requirements for loudness, frequency response, and uniformity.

Table I. 3D model summary.

3D model		
Volume [m^3]	Area [m^2]	Audience [m^2]
4142788.7	309834.3	19504.5
		6.29%

The absorption coefficients were obtained from acoustic library [5-12] to find the proper sound absorption coefficient for each material (absorption and scattering coefficients), and in CATT it set the acoustic properties of each material. The *abs_defs.geo* file is based on the following script, and the model follows the model properties, which derive from the geometry division:

```
;CATT 3D model v4.0

ABS Concrete = <01 01 01 02 02 02> { 255 254 23 }

ABS Game_plane = <02 06 14 37 60 66> { 0 241 44 }

ABS Glass = <18 06 04 03 02 02> { 41 241 133 }

ABS People = <68 75 82 85 86 86> L <30 40 50 60 70 80> { 255 27 170 }

ABS plane_ass = totabs

ABS Steel = <10 10 10 10 10 10>{ 0 136 17 }

ABS Membrane = <10 10 10 10 10 10>{ 0 0 255 }

ABS Polycarbonate = <10 10 10 10 10 10>{ 235 0 17 }
```

Some of the values above were not obtained by measurement or literature but on data supplied by the client. An important aspect of the analysis was the following hypothesis, which permitted to compute the 3D model. In an open space like the "Dunas Arena", wave reflections have a moderate influence on the results, but not fundamental like in a closed space. Moreover, the full computation in CATT, was not easy to be performed on a normal computer. Therefore, the *Direct Sound Pressure* was the parameter evaluated to define the *Total Sound Pressure.*

After the computation of first layout (without Zx1 sources) in CATT it is observed that (in the whole stadium) the level of *Total Sound Pressure* and of the *STI* values are lower than the FIFA requirements. Moreover, the analyses underline that under the second ring there was a "shadow" area; moreover, all the middle platform level was affected by this problem. In fact, the sound waves come from the top and the second platform ring generate a barrier for the bottom platforms. The level of the acoustical parameters (*Total SPL* and *STI*) is less than 30% of the requirement value, so it is necessary to introduce a new sound reinforcement layer. In the executive project the problem was solved by a new layer of 70 sources on the bottom side of the second ring platform.

As it is shown on *Figure 2* the loudspeakers external layout proposed by the installer of the system was based on 5 clusters for each side (North and South) with 3 Electro-Voice elements for each one (paragraph 2). In CATT and DDA, the 10 cluster (5 for side) are represented by groups A, B, C, D and (2 for side) by the groups E, F, G, and H. The group G is on the North side and group H is on the other. The "gain" level of cluster's element was set with 3 dB less than the maximum value permitted: Gain @ -3dB by maximum value (in this case 27 dB and 20 dB). In the middle platforms ring there are the 70 sources referred before. They have an orientation that follows the position of the platforms, i.e. one every 8 meters.

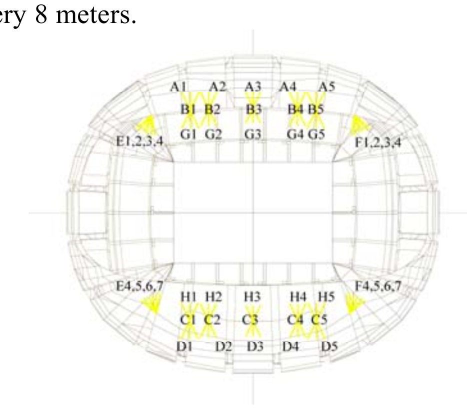

Figure 2. Top sound reinforcement orientation.

4.1. Output CATT

The results from CATT computation show that the FIFA requirements are not fully satisfied.

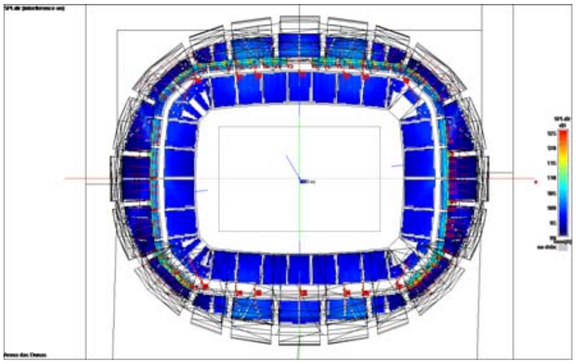

Figure 3. Sound Pressure Level – CATT output.

The *Sound Pressure Level* (*Figure 3*) is lower than the minimum value of FIFA. Moreover, if we observe the percentage ≈80% of the Audience Area it has a value <100dB. At the same time, this value is nearby the lower value (100dB) of FIFA requirements, but it is also important to underline that in this simulation, as in the study presented by the installer the noise of the supporters was not considered, something that is essential when considering STI predictions.

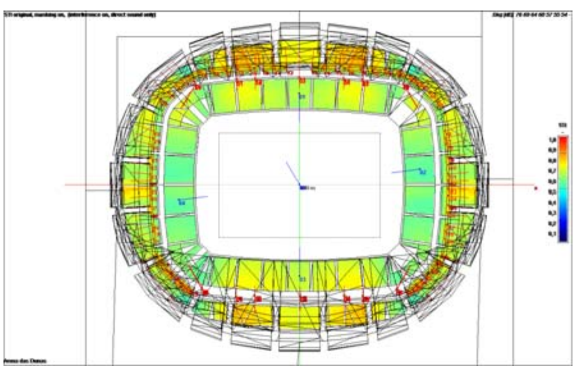

Figure 4. STI – CATT output.

For *STI* values (*Figure 4*), the analysis shows that the FIFA requirements are satisfied, again without the noise of the supporters considered. The average values, and the percentage of the Audience Area with a value < 0.55 is about 3%.

4.2. Output DDA

The model from CATT was imported into DDA and the sources position and orientation was set. In fact, the geometry properties did not change, so the original model did not change but only the method to define the sound reinforcement. The results from DDA computation showed that the FIFA requirements were, again, not fully satisfied.

If we analyze the outputs, the *Sound Pressure Level* (*Figure 5*) resulted lower than the minimum value of FIFA. Moreover, observing the percentage ≈70% of the Audience area, it resulted with a value <100dB. These results underlined that the two programs gave very similar outputs. For *STI* values (*Figure 6*), the analysis showed that the FIFA requirements were satisfied, since, the average values, and the percentage of the Audience Area with a value < 0.55 was ≈3%. As before the noise of the supporters was not considered. Then, the presence of Zx source layer has fixed the shadow areas problem. The percentage of shadow area is 0%.

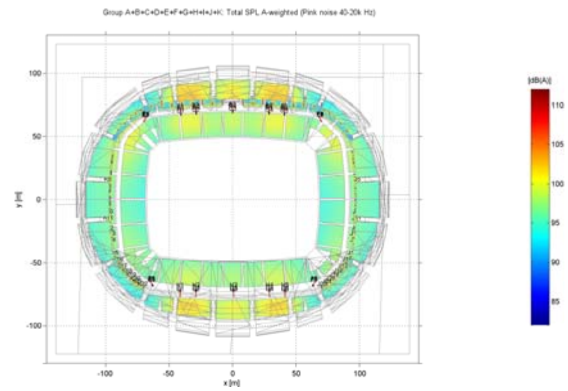

Figure 5. Sound Pressure Level – DDA output.

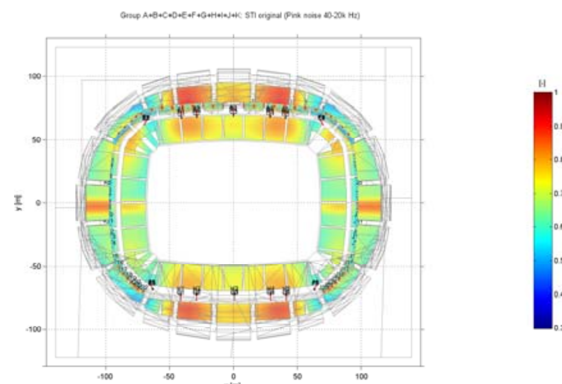

Figure 6. STI – DDA output.

Considering the results, and further simulations that included reflection to a 3rd order, it was possible to conclude that neglecting the reflection effect was a realistic hypothesis. In DDA there is the possibility to visualize the *Direct SPL* and *Total SPL*. The outputs of *Direct SPL* and *Total SPL* underline a very similar behavior of these ones. So, this case the *Direct SPL* was comparable with the *Total SPL*. The approximation is reasonable, but the only way to check this hypothesis is to study the behavior of these parameters with tests in the real stadium.

5. Conclusion

As a concluding remark, the sound requirement was not fully satisfying everywhere in the arena. In both analyses, the "total SPL" results are lower than the interval 100-105 dB, as the FIFA rules impose. In particular, the average is ≈98 dB. However, many areas resulted having a lower value. In particular, these areas were in the East and West platform corner. This phenomenon is clear in the mapping plot of "*Direct SPL*" parameter. Instead, the "*STI*" values satisfy the minimum values given from the FIFA requirements. However, the results did not include the noise of the supporters into the computation, which will influence all the results, in particular the intelligibility. Preliminary simulations on this influence were made and showed a severe degradation of the results. This suggests that the executive layout does not satisfy the FIFA requirements. The two different programs gave very similar results for all the parameters evaluated. This means that the two programs had a similar approach to analyze the sound diffusion in a 3D model, while they have a completely different computation method. CATT-Acoustic has many tools and applications, and never crashed under a full run, because it is very stable, but the time to end the process with a high order of reflections was in the order of months. DDA has a very good processor, but the difficulty is the geometry approach: after importing from CATT, the DDA model had more than 11107 surfaces (in CATT 2497). Another limit of this one is that Matlab (used for the computation in DDA) needs a very large quantity of internal memory in order to resolve the script. In other words, one of the most important problems is the computation of the 3D model. In fact, the choice of a good level of geometric approximation will change the time and the success of the following computation. The 3D model used for the analysis has the correct level of approximation. It was made in order to limit the difference between the real surface and the virtual one under 1 meter. A bigger simplification of the model will provide a loss of too much information and the final results will be very far from the real one. For the final report, Inacoustics studio decided to add a full run in CATT. It was not possible to run the entire 3D model but only a limited sector. This analysis confirmed the DDA output. The partial analysis shows that there is an increase of "*total SPL*", but a decrease of "*STI*" values due to the reflection effect. Therefore, in order to check the results, it is necessary a test in the real stadium, and then a comparison of the results.

Acknowledgement

The Authors thank Mr. Filipe Martins for his fundamental contribution to the 3D computation and modeling in both software.

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