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Musical Perception within a highly Reverberant Room

Nelia Valverde, Marcos Fernandez, Javier Ariza, Jose Ballesteros and Juan Ruiz

Universidad de Castilla-La Mancha, Campus Universitario, 16071 Cuenca, Spain
nelia.valverde@uclm.es

The listening of the same musical composition generates a unique perception for every listener but, simultaneously, the concrete acoustic conditions of the chosen room have a decisive influence on the perceptions mentioned, so that they can fit in almost completely with its acoustic qualification.
The aim of this study is to determine how the high reverberation of a room influences on the perception of a musical work. Because of this fact, a church with limited volume and high reverberation time has been chosen as the room (San Pedro, Cuenca, Spain) and a musical work has been composed, for voice and electroacoustics, specifically for this church; later on we have proceeded to the recording of the musical composition inside the church using a HATS; and, finally, a survey to a group of professional musicians has been carried out, once they have previously heard the recording with headphones.
The results of the psychoacoustics analysis show that the high reverberation of the church carries a very low intelligibility and a confusing sound of the recording, which coupled with a background noise considered unacceptable drift in a general acoustic perception does not sound very supportive.

1 Introduction

The relations between architecture and acoustics have always been present along the history, and have been determined, in the first place, by the relation between form and function. On the other hand, the sound has been and it is still clearly joined to the rooms receiving it.

In this work, we are trying to relate the architectural space, object of study, in this case the church of San Pedro (Cuenca, Spain), to its acoustic properties; and simultaneously with an artistic intervention through a musical work, composed specifically for the mentioned space. The fact of interpreting in the church a musical work causes two events that interact: on the one hand, the free listening of the composition generates a unique perception for every listener; and on the other hand, the acoustic conditions of the church influence in a decisive way on the perception of the one who carries out the listening.

The listener becomes an essential element of this study. The active listening of the musical composition in the church is an object of analysis, specifically of a psychoacoustic analysis, where we can find the existing interrelationship between both events previously mentioned, paying attention to percentages or statistic information, across a survey, such as the perceptions of a group of professional musicians that hear the recording of the musical composition in the church.

2 Method

2.1 Environment of study

The Church of San Pedro is placed in the highest part of Cuenca. It was constructed a little time after the city was conquered by Alfonso VIII on September 21, 1177 [1].

In the 18th century the church of San Pedro is plundered and inflamed. Later, it was totally renewed, and the manager of this renovation was the architect José Martín de Aldehuela, very influential in the Baroque of Cuenca.

The floor is an octagon in which a circumference is traced, whose perimeter is leaned by pilasters and among they round arches turn round. The copulation of the chapel demonstrates the eight-side shape design of the floor. Nevertheless, in this centralized space, the apse, which is also polygonal, marks a clear axle, to the end of which, the front part of the building is placed. This facade is constituted by the front and the tower, staying that one displaced of the center of the gable-wall. Over the door we can find a small choir.

This circular space, which is crossed by a denticulated cornice widely highlighted, is closed with a dome on drum, whose windows, of mixtilinean shape, highly agree with José Martín's aesthetics. Also the stone chippings, which adorns capitals and harness of hollows, are an ornamental motive used often by this architect.

Also, the front of the building is very illustrative of José Martín's art, with the round arch of trunk of a cone among pilasters and niches on brackets in the sides; the same thing can be said about the overlapping of the cornice that unbows slightly, in whose center the shield of the benefactor of the reconstruction of the church is placed, and of the scrappy decoration that joins the low body with the niche of the high body framed by ionic pilasters, occupied by the image of a Virgin. The door presents in its front San Pedro's symbol, the tiara and the keys.

The last restoration of this church concluded in 1999, and from July 4, 2002 [2], it has been declared "good of cultural interest", with category of monument.

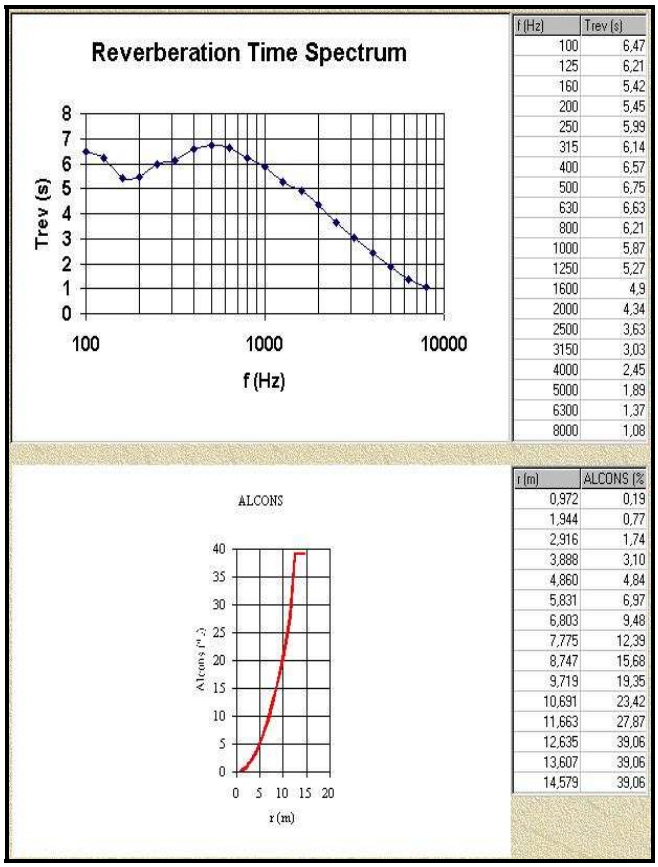
The current use of the church of San Pedro is the celebration of the religious worship and classical music concerts.

Practically all materials that form the interior coatings of the church (painted plaster in walls and roofs, stucco in details of ornamentation, marble and granite on the floor) are reflective, with the exception of the wood (pedestal of the presbytery, rail of the choir, balconies and roof of San Marcos' chapel), but its influence is insufficient due to the fact that it covers a minimal surface; therefore, they should avoid an excessive loss of both, bass and treble sounds, in order to guarantee a good acoustic. But many more factors influence causing an excessive reverberation, such as the form and the volume of the church. These conditions are magnified with the marble floor in the central zone and the dome that crowns the building.

As mentioned above, the church of San Pedro is a construction in a Baroque style, nevertheless the ornamentation turns out to be quite insufficient and does not help to a good diffusion of the sound; also is evident the lack of carpets, curtains or tapestries that would increase the absorption of the sound and, therefore, they would diminish the reverberation.

2.2 Acoustic study

For the acoustic characterization of the church, it is necessary, at least, to measure the reverberation time, supported by the index ALCONS that refers to the intelligibility, the sound pressure level and the background noise level; besides knowing the dimensions, volume and total surface of the room [3,4].



f (Hz)	Trev (s)
100	6,47
125	6,21
160	5,42
200	5,45
250	5,99
315	6,14
400	6,57
500	6,75
630	6,63
800	6,21
1000	5,87
1250	5,27
1600	4,9
2000	4,34
2500	3,63
3150	3,03
4000	2,45
5000	1,89
6300	1,37
8000	1,08

r (m)	ALCONS (%
0,972	0,19
1,944	0,77
2,916	1,74
3,888	3,10
4,860	4,84
5,831	6,97
6,803	9,48
7,775	12,39
8,747	15,68
9,719	19,35
10,691	23,42
11,663	27,87
12,635	39,06
13,607	39,06
14,579	39,06

Figure 1. Reverberation time of the church of San Pedro

Reverberation Time	4.78 s
Sound Pressure Level	95.34 dB
Noise Level	40.64 dB
ALCONS	acceptable up to 7 m

Table 1.Average values of the acoustic parameters of the church of San Pedro

According to the information obtained [5], represented in the figure 1, we appreciate that the reverberation time increases as the point is far away from the source, and that inside the same point this time diminishes as the frequency increases. The table 1 shows that the average reverberation time is 4.78 s, which is a very high value for the volume of this church (7300 m^3) and, evidently, this time is far from the ideal times recommended of less than 2 s [6].

The intelligibility turns out to be good up to 5 m (5%) and acceptable up to 7 m (10%), which is not a good result [7], since the audience area has a higher range (up to 15 m). The problems deriving from this results are constantly stated by the people who attend the celebration of the religious rite.

The bad results of reverberation can be due to the type of floor of the church: octogonal in the exterior, circular in the interior and covered by a central dome; what multiplies the focus effects. In addition to this, the edges of the surfaces do not possess an excessive ornamentation, they are practically naked, which causes a minimal absorption of the sound. And the zone destined for the public does not help to reduce the reverberation either, in the moment of the liturgical celebration, or the one destined to the people, when the church does the function of room of concerts, because it is occupied by banks of wood that turn out to be slightly absorbent.

2.3 Musical composition

The musical work has been composed specifically for the church of San Pedro in Cuenca and for this study. Two versions appear: the first version, for voice and organ, as one of the most typical group for churches; the second version, for voice and electroacoustics, as a new experience, as it is not a group so common as the previous one in the music for churches.

The text chosen for the composition is one of the parts of the religious celebration, the Kyrie, and therefore its name and its formal scheme, which is basically a scheme A-B-A inherited from the classic tradition and according to the chosen text.

About the harmonic analysis of the work, though it is not possible to speak of classical harmony, it does have its base in itself. This music is evidently tonal, with an easily recognizable melody and an accompaniment (the organ) developed on the basis of that melody.

In the part of electroacoustics the compositional process differs in several aspects from the other one. From real samples transformed (rain, wind …) and of already synthesized sounds chosen according to the characteristics of the melody and of the text, we proceed to the horizontal and vertical organization of these sounds, always held to the formal structure already explained A-B-A.

After the composition of "Kyrie", in two versions, we proceed to the recording of the work in the church. This recording constitutes the base of the psychoacoustic analysis that is done at the end of this research.

The point of start of the methodology used in these recordings is the utilization of an artificial head with several microphones placed in the input channels of every ear (HATS). The recordings may allow to reproduce, with great precision, the sensation of listening in the point where originally the artificial head was placed [8]. As we reproduce by headphones the recordings carried out in the church (indication that appears at the beginning of the survey), it is possible to study the acoustic of a room without the influence of external acoustic factors.

2.4 Psychoacoustic study

In this psychoacoustic study, a group of professional musicians carry out a survey [9-11], having previously heard the recordings, to finally qualify the chosen room and the musical work based on subjective criteria. In order for these subjective results to be trustworthy, the minimal number of surveys should be 16 [12], but finally the survey is answered by 21 people, which emphasizes the reliability.

The CD that is given to the polled people includes two tracks which correspond to both versions of "Kyrie" recorded in the church:

TRACK 1.- *Kyrie* for voice and organ, psychoacoustic in church (3.44)

TRACK 2.- *Kyrie* for voice and electroacoustics, psychoacoustic in church (4.55)

The survey consists of the following questions [13]:

1. Valuate from one to ten the musical clarity perceived, it is if there appear or not overlappings in the music. The number 1 would correspond to a very confused sound and 10 to a very clear sound.

2. Valuate from one to ten the intelligibility of the text. The number 1 would correspond to a terrible intelligibility and 10 to an excellent one.

3. An alive room is that which has a high reverberation. How do you consider the liveness of the room? Valuate it from one to ten, being number 1 an excessively poor liveness room and 10 an excessively high liveness.

4. How do you perceive the background noise?

5. A room has warmness when wealth is perceived in the deep sounds, smoothness in the music. Valuate the acoustic warmth of the room from one to ten, being 1 an excessively poor warmth and 10 high.

6. Valuate the birghtness of the room from one to ten, it is if the sound is perceived neat and rich in harmonics. The number 1 would correspond to a room with null birghtness and 10 to one with a very high birghtness.

7. The perceived loudness, or sensation of extension of the sound, is high or deficient? Valuate from one to ten, being 1 a very deficient loudness and 10 a very high loudness.

8. About the balance, how do you consider the bass sounds regarding to the treble ones?

9. And what about the voice regarding to the organ and to the electroacoustics?

10. What is your global impression about the acoustic of the room?

11. Describe what type of sonorous scenario does the work suggest you, what sensations or images does it evoke you? (You can attach a drawing).

12. Write the global comments that you consider appropriate.

3 Results

In the table 2 we have a summary of the results corresponding to the questions 1, 2, 3, 5, 6 and 7 for each of the tracks, where the average value and the standard deviation are indicated.

		TRACK 1	TRACK 2
QUEST. 1	x average	3.95	2.48
	deviation	1.80	160
QUEST. 2	x average	4.38	3.10
	deviation	2.18	2.36
QUEST. 3	x average	9.10	9.38
	deviation	0.89	0.86
QUEST. 5	x average	6.05	4.33
	deviation	2.44	2.87
QUEST. 6	x average	5.62	5.52
	deviation	2.04	2.84
QUEST. 7	x average	7.86	7.38
	deviation	1.82	2.48

Table 2. Results of the survey: questions 1, 2, 3, 5, 6 and 7, which are valued in a quantitative scale from 1 to 10

In the table 3 the results are shown in percentages corresponding to the questions 4, 8, 9 and 10 for each of the tracks.

		TRACK 1	TRACK 2
QUEST. 4	unadible	4	5
	acceptable	48	19
	intolerable	48	76
QUEST. 8	weak	33	29
	balanced	14	14
	high	53	57
QUEST. 9	weak	52	53
	balanced	24	14
	high	24	33
QUEST. 10	very bad	19	24
	bad	24	33
	mediocre	19	14
	acceptable	19	14
	good	19	10
	very good	0	5
	excellent	0	0

Tabla 3. Results of the survey: questions 4, 8, 9 and 10.

Regarding to the evocations of the sonorous scenario that the work suggests to the polled musicians, corresponding to the question number 11 of the survey, we can emphasize the difference of opinions, sometimes even opposite: spiritual and earthly, tragedy or lament in front of the relaxation and peace.

In general, according to the global comments corresponding to the question number 12 of the survey, we see a very big influence of the electroacoustics in the evoked sensations, since most of them have not untied from their origin the sounds taken from nature (wind, rain, etc.) and later transformed. Also it is evident, in general, the religious influence that has caused the chosen text (Kyrie).

4 Discussion

For analyzing the results we proceed to valuate the global result of the survey for the two tracks included in the CD.

TRACK 1.- Voice and organ, recording carried out in the church

The high reverberation perceived in the church (9.10) determines the low intelligibility (4.38) and clarity of this recording (3.95); in addition, the high perception of the bass sounds compared to the treble ones implies a weaker perception of the voice regarding to the organ. In addition it is added a background noise considered intolerable, which derives into a bad acoustic perception.

TRACK 2.- Voice and electroacoustics, recording carried out in the church

The impression obtained from this recording is very similar to the previous one, with an intolerable background noise, together with a very high reverberation of the room (9.38), which implies a very low intelligibility (3.10) and a bad general acoustic perception.

From this set of valuations, two basic ideas can be extracted. On the one hand, listening to the same musical composition generates a unique perception to each listener but, at once, the evident differences of style between both "Kyrie"'s versions (for voice and organ and for voice and electroacoustics) have determined the perception of the same listener; the version of organ has been related, for example, to a higher intelligibility of the text or a higher acoustic warmness, whereas the version of electroacoustics has been related to more negative values of the same parameters. The electroacoustics, a less known genre, has added difficulty at the moment of specifying the perception. It could be said that "it has disconcerted the listeners a bit". For all of this, the general perception of this version of the composed work has derived into a more confusing acoustic qualification. It could also be emphasized by the fact that, in spite of having subjected a group of professional musicians to the survey, there have been certain differences in the interpretation of the acoustic parameters and, therefore, their subjective interpretation.

On the other hand, the results show that the high reverberation of the church has a decisive influence, among other things, on the perception of intelligibility and clarity of the musical work, generating an overall perception of it rather confusing and very little intelligible. What in turn leads to a general acoustic perception not very supportive, which is confirmed, almost unanimously, by the answers of the polled musicians.

5 Conclusion

From the results, their analysis and discussion, the following conclusions can be obtained:

1. The acoustic quality of the church of San Pedro (Cuenca, Spain) needs to improve very much, at least, from the strictly acoustic point of view.

2. The psychoacoustic analysis reveals the decisive influence of the close relation between the room and the compound work, and also the decisive influence of the acoustic conditions of the church on the perception.

The interpretation of the original musical composition "Kyrie" inside the church of San Pedro in Cuenca (Spain), has caused two events already mentioned initially: the free listening on the part of the listeners, which generates a unique perception for each of them; and the decisive influence of the high reverberation of the church on the music perception of the listeners.

Technical and artistic questions have been present all along, interconnected through a psychoacoustic analysis in a specific room with an original musical work.

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