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## Simulation as a tool for studying the reallocation of a pipe organ in a church

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### ABSTRACT

We have studied the acoustical conditions of the Saint James Basilica in Algemesí (Valencia-Spain) by means of measurements and simulation. The comparison has allowed us to validate the model. We have changed the location of different sound sources (ranks of pipes) to a new place where the organ will be soon reallocated so as to find out the acoustics of the room when this instrument is in the new allocation.

This method could be applied to model the best location for such an instrument as a pipe organ or any other sound source in any big room. This organ is being now installed in the new location and it will be operative in May 2006 (the project is explained in <http://www.orguebasilica.tk>).

### 1 INTRODUCTION

The first church in Algemesí was built in the 13th century. Nowadays, it conforms the Communion Chapel and is communicated with the main Church by three arches.

The new part of the Church is in Baroque style. It was built in the second part of the 16<sup>th</sup> century (between 1550 and 1582) by Doménech Gamieta in collaboration with Joan d'Alacant and Joan Matalí.

The main nave is composed by an apsidal nave and two lateral naves which have been transformed in little chapels. The apsidal nave has an interesting transept with an arch, arch ribs, buttresses and stone-carved pilasters. This building was refurbished at the end of the 18th century (1789) and recovered with stuccoes and gold leaves in 1890 and 1927. The main door is located in the right lateral nave. It is in a Renaissance style with images belonging to a later period placed in ornamental vaulted niches. The bell tower, built in 1703, is placed on the arch of the main entrance. The Saint James Minor Basilica was considered a building of Cultural Interest in the Royal Decree 3028/1979, BOE in 18/01/1980.

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The current organ was built in 1954 to substitute the organ destroyed during the Spanish Civil War. Last year, this organ was refurbished and reinstalled in the Communion Chapel (Capella de la Comunió). It was inaugurated in June, 26<sup>th</sup>, 2006.

The acoustical simulation and analysis of buildings is a very helpful tool for reallocating a refurbished sound source, as it is now our case. Other locations for the pipe source have not been studied, because they would not be realistic for the purpose sought. It could be interesting to find out an optimum location for the organ in the church.<sup>1,9</sup>



Figure 1: Former and current placement of the organ (the second one is refurbished)

In this paper, the work made in a theoretical-practical study of the acoustical conditions in the Saint James Church in Algemesí (Valencia) is presented. The theoretical distribution of several acoustical parameters have also been studied.

## 2 NUMERICAL MODEL OF THE CHURCH

A mathematical model of the building in 3D has been created by using EPIDAURE<sup>®</sup> (a ray-tracing program for room-acoustic simulation)<sup>2</sup>. This model has also been used to predict the acoustical behaviour of the building. This model has been validated by acoustical measurements<sup>1,2</sup>.

The room modelling process consisted in defining all the surfaces which are present in the building. In this case, two sets of plans from two architectural studies have been used: a plan of the floor made in 1985 by Mr Carlos Cebrian and a set of plans with floor and sections made in 2000 by Mrs Marina Sender and Mr Ricardo Perelló. With these plans, the whole building has been modelled including 1,314 surfaces for the whole room-acoustic simulation.

In this model, 6 basic materials for the modelling process for the modelling process. Each one of them has its own absorption coefficient tabulated in octave bands between 125 and 4,000 Hz. Data from the bibliography<sup>4</sup> has been collected. In table 1, the values for the 6 materials have been specified.

Material	Surface(m <sup>2</sup> )	Absorption coefficient ( $\alpha$ )					
		125 Hz	250 Hz	500 Hz	1000Hz	2000 Hz	4000 Hz
Plaster cover	8519.48	0.120	0.100	0.070	0.090	0.070	0.050
Marble	2164.58	0.010	0.010	0.010	0.020	0.020	0.010
Pine Wood	92.76	0.098	0.110	0.061	0.081	0.082	0.110
Timber	525.29	0.100	0.160	0.130	0.100	0.060	0.050
Light felt	180.57	0.020	0.040	0.100	0.210	0.570	0.920
Stone	356.52	0.010	0.012	0.020	0.020	0.023	0.035
Air (dB/100m)		0.037	0.121	0.284	0.504	0.999	2.806

Table 1: Used materials

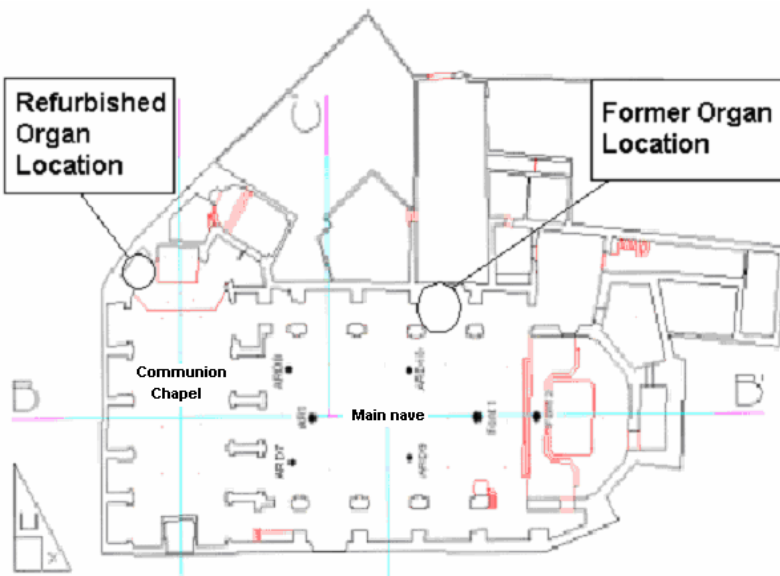


Figure 2a: Plan of the church

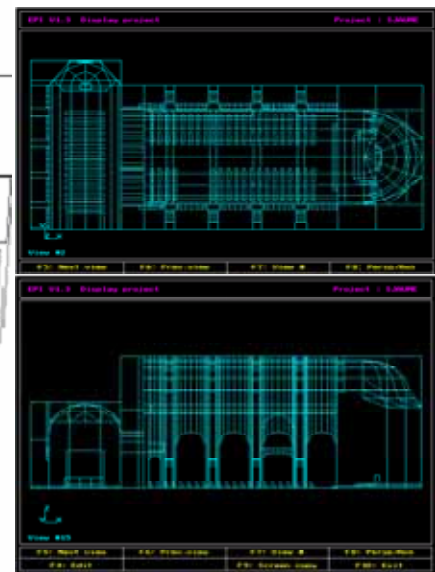


Figure 2b: Model of the church

### 3 MODEL OF THE PIPE ORGAN AS A SET OF SOUND SOURCES

The organ is a very complex instrument. It is composed of ranks and each one is formed of several dozens of pipes in many sizes. In the first model, the pipe organ was considered as a set of sound sources<sup>5</sup> placed in a central line of the current location and separated with the distances represented in table 3. The instrument was further regarded as a unique source placed at the façade of the organ playing a "tutti" (i.e. all the ranks at the same time). In this work, the results for the second case are presented.

In order to get the SPL for the Organ Pipe as a sound source, a digital recording (with a MD) of a cluster was made, separately with 12 set of ranks (see table 2) that had a sufficient spectral width (between C3 and C6). The Leq(A) and Lmax were measured for 10 seconds with a sound meter class 1 (CESVA SC-30). The sound recorded and the sonometric measurement have been done simultaneously in order to compare results.

The measurement has been made with all the ranks (called ‘tutti’), which allowed comparing results in the model with a unique source (‘tutti’) and with a set of 12 sources (each rank as a source located in the Organ location -see figure above- and separated the values represented in table 3)

f (Hz)	Flute 4'	Flute 8'	Clarin 4'	Gamba 8'	Octave 4'	Mixtures
125	96.7	89.0	96.7	98.9	90.6	92.7
250	95.4	97.5	95.4	94.8	95.0	93.3
500	93.5	97.1	93.5	92.6	93.4	94.3
1000	91.3	95.2	91.3	90.8	93.2	93.4
2000	87.0	85.4	87.0	83.7	91.2	92.5
4000	78.4	70.6	78.4	72.5	85.0	87.6
Leq10" (dBA)	82.7	88.0		82.3	84.2	90.2
Lmax	85.8	90.4		83.8	85.9	90.9

f (Hz)	Fifteenth 2'	Trumpet 4 8	Celeste Voice 8/15	Violone 16'	Tutti
125	98.0	96.1	97.7	98.1	93.8
250	96.1	94.9	96.2	96.3	95.1
500	93.0	94.4	93.1	93.3	95.8
1000	90.4	93.3	90.7	90.4	94.3
2000	86.3	88.3	86.6	67.3	92.5
4000	74.6	80.4	74.9	57.3	87.2
Leq10" (dBA)	85.6	88.8	83.4	84.0	94.3
Lmax	86.5	89.7	84.8	85.0	95.6

Table 2: SPL vs. frequency classified by ranks and Leq

0,00 m	Façade
0,20 m	Flute 8'
0,40 m	Octave 4'
0,60 m	Violone 16'
0,80 m	Conic Flute 8'
1,00 m	Violone 8'
1,30 m	Plenum (4 rows) - Mixtures
1,70 m	Corridor (40 cm)
1,90 m	Nazard
2,10 m	Sesquialter
2,30 m	Fifteenth 2'
2,50 m	Octaviant Flute 4'
2,70 m	Gamba 8' (narrow)
2,90 m	Corde Nuit (8' round)
3,10 m	Celeste Voice 8/15
3,30 m	Trumpet 8'
3,50 m	Clarin 4'
4,00 m	Corridor (50-55 cm)

Table 3: Ranks for the former organ

Bass	Treble
Flute 8'	Flute 8'
Violone 8'	Violone 8'
Octave 4'	Octave 4'
Twelfth 2' 2/3	Twelfth 2' 2/3
Fifteenth 2'	Fifteenth 2'
Plenum IV 1' 1/3	Plenum IV 1' 1/3
Bass 4'	Clarin 8'
	Travesera 8'
	Flute 4'
	Seventeenth 1' 3/5
Pedaliar	
Contras 16'	
Keyboard coupling	

Table 4: Ranks for the refurbished organ

#### 4 CHARACTERISTICS OF THE SOURCES

The directivity effect of the pipes was considered, setting the radiation values in the front part semi-sphere radiating towards the room<sup>9</sup>. For this, the minimum horizontal limit was set in 180° and the maximum in 360°, and the minimum vertical limit in -90° and the maximum in 90°.

The graphics correspond to the organ simulation as a unique source ('tutti') in the place where is currently allocated. Figures 3a and 3b represent the global SPL distribution and RASTI distribution at the Basilica with the source placed at (32.35, 18.80, 7.00) m (in the main nave of the Basilica), and Figures 4a and 4b correspond to the same parameters with the source placed at (3.40, 23.00, 2.0) m (at the Communion Chapel).

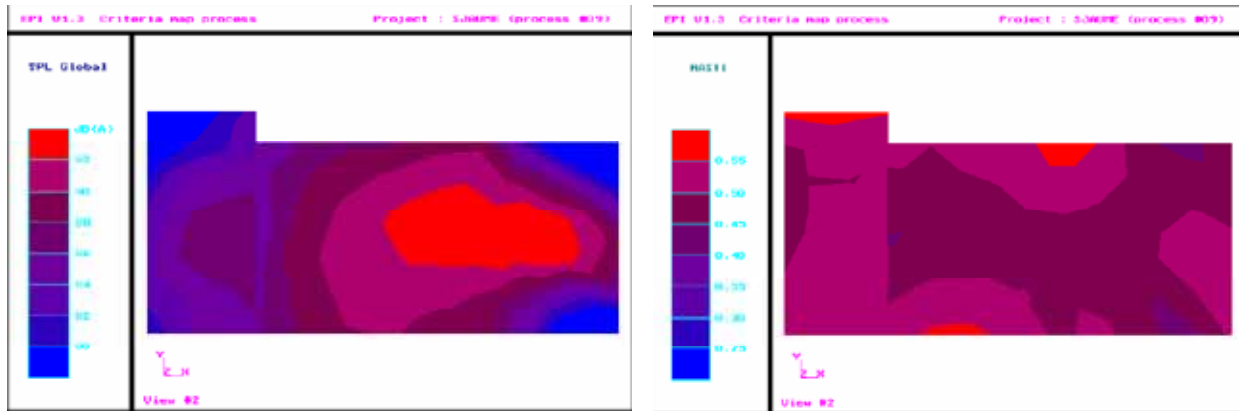


Figure 3: Global SPL (a) and RASTI (b) due to the 'tutti' source at the Basilica.

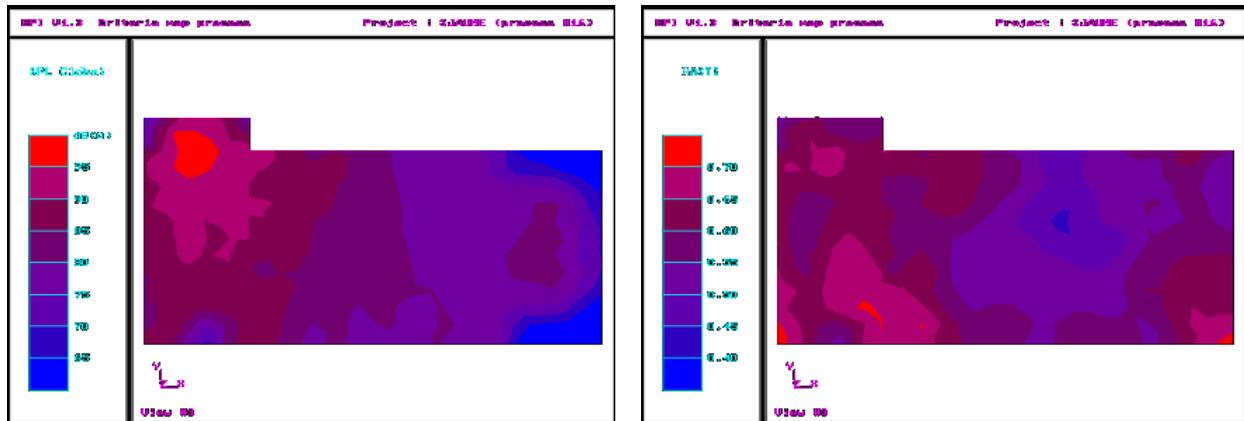


Figure 4: Global SPL (a) and RASTI (b) due to the 'tutti' source at the Communion Chapel.

## 5 DISCUSSION

Table 5 shows several parameters calculated from echograms for four receivers located at a height of 1.5 m in several places in the church (one placed at the Communion Chapel -receiver 6- and three placed at the main nave -receivers 2, 4, 5-).

+ Micro #2 : Receiver # 2 Location : X = 25.00 ; Y = 10.00 ; Z = 1.50							+ Micro #6 : Receiver # 6 Location : X = 7.00 ; Y = 8.00 ; Z = 1.50						
CRITERIA	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	CRITERIA	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
Lp (dB)	79.48	81.08	81.84	78.85	75.23	68.01	Lp (dB)	87.76	89.14	90.09	87.21	84.00	77.40
G (dB)	-20.51	-27.41	-26.25	-27.34	-21.17	-13.58	G (dB)	-12.23	-19.35	-18.00	-18.98	-12.39	-4.19
TR stat. (s)	2.93	3.08	3.83	3.18	3.34	2.68	TR stat. (s)	2.06	2.14	2.68	2.27	2.47	2.19
EDT (s)	2.91	3.02	0.00	3.17	3.36	2.75	EDT (s)	2.15	2.28	2.84	2.40	2.58	2.29
D50 (%)	20.22	20.03	15.40	18.30	18.00	21.98	D50 (%)	17.27	16.56	12.96	15.40	13.05	14.63
C80 (dB)	-3.80	-4.12	-5.43	-4.58	-4.94	-4.08	C80 (dB)	-2.10	-2.68	-4.03	-2.97	-3.27	-2.62
Ts (s)	177.43	180.38	203.43	187.89	194.31	175.73	Ts (s)	155.87	164.76	191.02	170.36	177.78	164.65
TI (-)	0.38	0.38	0.34	0.37	0.36	0.39	TI (-)	0.45	0.43	0.39	0.42	0.42	0.44
STI global = 0.38 Sound level = 83.5 dB(A), (G = -17.9)							STI global = 0.43 Sound level = 91.9 dB(A), (G = -8.6)						

+ Micro #4 : Receiver # 4 Location : X = 33.00 ; Y = 10.00 ; Z = 1.50							+ Micro #5 : Receiver # 5 Location : X = 37.00 ; Y = 10.00 ; Z = 1.50						
CRITERIA	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	CRITERIA	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
Lp (dB)	77.33	78.83	79.66	76.56	72.91	65.19	Lp (dB)	77.49	79.13	79.49	76.59	72.30	64.37
G (dB)	-22.67	-29.66	-28.43	-29.63	-23.48	-16.40	G (dB)	-22.50	-29.36	-28.60	-29.60	-24.10	-17.22
TR stat. (s)	3.15	3.37	4.31	3.53	3.78	3.10	TR stat. (s)	4.06	4.01	4.69	4.05	4.11	3.12
EDT (s)	3.49	0.00	0.00	0.00	0.00	3.33	EDT (s)	3.49	3.46	0.00	0.00	0.00	2.94
D50 (%)	17.06	14.22	10.40	13.11	13.30	17.01	D50 (%)	20.82	20.37	16.64	19.23	15.91	17.85
C80 (dB)	-4.88	-5.56	-7.04	-5.95	-6.11	-4.86	C80 (dB)	-4.49	-4.34	-5.36	-4.61	-5.72	-5.02
Ts (s)	213.53	220.12	241.04	224.21	226.10	203.63	Ts (s)	173.18	176.27	192.90	182.03	193.44	178.72
TI (-)	0.32	0.30	0.27	0.30	0.32	0.36	TI (-)	0.38	0.38	0.35	0.37	0.35	0.37
STI global = 0.32 Sound level = 81.2 dB(A), (G = -20.6)							STI global = 0.37 Sound level = 81.0 dB(A), (G = -21.3)						

Table 5: Parameters for several locations

With the verified numerical model, recordings of different ranks of the pipe organ were made in order to simulate the behavior of the room to this source. The behaviour of the room is quite similar, both for the simulation of the organ as a unique sound source inside its cubicle (1m away from the edge of the organ façade) and for the composition of the organ as a set of sources. The value of ray-tracing  $T_R$  is given in the following tables:

Results for the 'tutti' source placed at (3.40, 23.00, 2.0) m (the organ placed at the Communion Chapel) :

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Statistical TR (rays)	2.62	2.73	3.57	2.95	3.27	2.78

When the 'tutti' source was placed at (32.35, 18.80, 7.00) m, which corresponds to the organ placed in the main nave, the results are:

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Statistical TR (rays)	3.11	3.30	4.15	3.30	3.29	2.59

## 6 CONCLUSIONS

In this study the acoustical conditions at the Saint James Minor Basilica have been analysed. Firstly, the conditions were studied theoretically by using the ray-tracing method<sup>2</sup> and practically, by measuring acoustical parameters of the main room following the ISO 3382:1997<sup>8</sup> criteria.

The results of the mathematical model have been quite good compared to the measurements made. This allows verifying the model (with the corresponding distribution of materials) in order to predict the behaviour of the room given different sound sources, as it is in this case (a pipe organ) and to evaluate proposals for later alterations in the indoor structure of the building so as to improve the acoustical conditions of the church.

Several parameters for the organ source in the original position<sup>10</sup> have been compared and the position for the one refurbished. The distributions of these parameters have been studied and the global sound pressure level and RASTI have been represented (see figures 3 and 4).

This model has been developed for EPIDAURE<sup>®</sup> software<sup>2</sup>. Currently, this model is being migrated into CATT<sup>®</sup> software<sup>13,14</sup>, in order to be able to compute more parameters and auralizations. This building has also been measured following several procedures offered by WinMLS<sup>®</sup> software and MLSSA<sup>®</sup>.

The audience has to evaluate the acoustics of the building and the sound source. A poll was developed and is being applied in order to study the subjective response in concerts. This tool was validated in the project BIA2003-09306-C04<sup>7</sup> and can be useful for refurbishment processes and the reallocation of sound sources, as it was found in this study.

The next steps in our work will be to compare the different simulations and measurements methods. It will be also useful to establish a correlation between measurements, simulations and subjective response<sup>11,12</sup>.

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