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ACOUSTIC PROGRAM IN THE COMPETITION FOR THE RECONSTRUCTION OF THE ''LA FENICE'' OPERA HOUSE AFTER THE FIRE OF 29 JANUARY 1996

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This paper describes the acoustic program of the competition opened by the Town Council of Venice for the reconstruction of the "La Fenice" opera house after the fire which destroyed the threatre on 29 January 1996. The experience of the authors in the preparation of this document suggests the need of guidelines which establish a general agreement on the objective parameters and on the procedures to be introduced in the acoustic program of an architecture competition for the construction of a threatre.

1. INTRODUCTION

After the fire which destroyed the "La Fenice" opera house on 29 January 1996, the town Council of Venice decided to proceed with its reconstruction. Following a harsh discussion, the decision to rebuild the threatre "as it was and where it was" was taken. The Perfect of Venice was appointed as the Commissary for the reconstruction of the new "La Fenice" opera house. Very soon he established a work group entrusted with the preparation of the program for the architecture competition. At the end of September 1996 the program was ready and the competition opened: six months were allowed for the invited participants to present their projects. Five architects presented their projects. A panel of judges was established by the Perfect: F. Dal Có, E. Bettanini, D. Commins, A. Di Tommaso and L. Mazzarolli were the nominated members. Daniel Commins had the task of evaluating the acoustic aspects of the projects. The Italian architect Gae Aulenti, with the building company Impregilo S.p.A., won the competition. The construction site was opened in September 1997 and the new theatre was expected to open at the end of September 1999. Unfortunately, an appeal by one of the participant companies has forced the work to stop.

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2. THE ACOUSTIC PROGRAM

An important part of the program of the competition concerns the acoustic requirements of the theatre in order to obtain good acoustic conditions in the building in general and excellent room acoustics in the main hall. As the acoustics of "La Fenice" had been praised since its opening on 16 June 1792, the work group entrusted with the preparation of the acoustic program decided to investigate in detail the project of Gianantonio Selva, the architect who built the "La Fenice" opera house at the end of the 18th century [1].

The program of the architecture competition strongly recommends to build the main hall "as it was" and many drawings and construction details are given to help the architects in this task. The part of the program concerned with acoustics includes the results of some experimental measurements taken by Tronchin [2] in October and November 1995, just two months before the fire: binaural measurements of the impulse response were performed in a large number of positions within the hall according to the ISO standard 3382.

The management of "La Fenice" also stated that the new theatre will be used not only for opera and ballet, but also for concert music; an acoustic chamber was suggested for this task. Specific acoustic requirements are stated for the rehearsals rooms for the orchestra, choir and ballet. One important modification was specified for the main hall; the orchestra pit should be large enough to house at least 90 musicians. Also, the stage should be as large as possible and with modern and highly technological devices.

The acoustic program is subdivided into two general parts: one general and one specific concerning the acoustics of the main hall, of the rehearsals rooms, of the foyer, of the workshops and of heating and ventilating rooms. Of course, most of the acoustic program is devoted to the main hall.

2.1. ACOUSTIC FEATURES

The program asked the acoustic consultants involved in the design to accompany the project with a thorough and detailed report that demonstrated a clear control of the parameters affecting the acoustics in the hall. The report had to provide an estimate of the most important objective parameters currently used to assess the acoustic performance of a hall, such as the reverberation time (T_{60}), the definition index (D), the clarity (C_{80}, C_{50}), the center time (t_s) the lateral efficiency (LE), and the speech transmission index (STI). The estimation of these quantities can be obtained by means of scale models of the Main Hall or by means of suitable mathematical models. It is particularly important to be able to assess the acoustics of the hall by means of a process of "auralization".

It was requested that the report accurately explain the technique used for the estimate: in the case of scale models, a detailed description of the model, the construction methods, the materials, the sound sources and the series of measurements employed had to be provided. In the case of mathematical models, the report had to illustrate the model used to describe the geometry of the hall and the calculation method used to reach the estimate of the previously mentioned acoustic parameters. In particular, all the calculation parameters capable of

TABLE 1

Reference values ranges of objective parameters

T_{60} (occupied)	C_{80} (unoccupied)	D (unoccupied)	T_s (unoccupied)	LF (unoccupied)
$1{\cdot}2 < T_{60} < 1{\cdot}8$ Average 0·5–1 kHz	$-2 < C_{80} < +2$ Average 0.5–1·2 kHz	$< 50\%$ Average 0.5–1 kHz	< 140 ms Average 0.5–1 kHz	$>0{\cdot}2$ Average 0.5–1 KHz

providing an evaluation of the degree of accuracy achieved by the assessment model had to be specified. The report had to give a detailed description of the acoustic features of the materials proposed for the construction and furnishing of the main hall. The acoustic data inserted in the mathematical model had to be suitably documented. Whenever possible, the values of the acoustic absorption coefficients for the proposed material had to be certified; for the seats, it was compulsory to provide the acoustic certification of the level of performance. The methods used for the assembly and installation of linings inside the hall had to be illustrated by means of sketches and/or drawings.

The report had to show, with tables and graphs, the predicted values of the required objective parameters in at least 20 positions of the main hall, regularly distributed in the stall and in the boxes. The predictions concerned different configurations of the hall: with and without the audience; with the curtain open and closed. At least two positions of the sources had to be tested: one on the stage and the other in the pit. The investigations concerned the frequencies from the center octave of 125 Hz to the center octave of 4000 Hz. A range of reference values of these objective parameters was also given (see Table 1).

2.2. NOISE AND VIBRATION REQUIREMENTS

High sound and vibration insulation requirements were set for the main hall: the total noise from external and internal sources had to comply with the NC20 curve. Accelerations had to be 70% of the values of the "base response rating". In their design proposal, the architects were required to include a complete description with drawings and sketches, of how the acoustic and vibration requirements would be fulfilled.

2.3. VERIFICATION TESTS

Acoustic surveys inside the hall will be performed at various stages in the progress of the works. Their purpose is to identify any anomalies and/or acoustic defects in good time so that corrective measures can be implemented. A first series of tests will consequently have to be done after the essential construction works, when the hall is still without any furnishings or linings on the walls, in the circles and galleries, and in the stalls. A second series of measurements will be taken once the hall has been completed, but is still without the seats.

The final acoustic test will be performed for at least two configurations of the hall: i.e., (1) with the hall finished, with the seats installed but without an audience; and (2) with the hall finished, with the seats occupied by the audience. In this case the measurements will be performed by measuring the echograms in various positions indicated in the project (at least 20), with sound sources on the stage and in the orchestra pit, with the curtains open and closed, using the method specified in the ISO 3382 international standard. The tests must verify whether the values of the objective acoustic parameters mentioned earlier come within the ranges indicated in Table 1 in at least 80% of the measurement points.

Given the great importance of the aspects relating to the acoustics of the main hall, steps will be taken during the completion of the opera house and at the time of the various scheduled acoustic tests to achieve a non-instrumental "fine-adjustment" of the acoustics with the help of orchestra conductors and musicians (i.e., of the experts) appointed by the Administration. Any solution designed to permit variations in the acoustic response of the main hall during the completion of the interior furnishings in order to achieve this "fine adjustment" will consequently be well received.

During the preliminary measurements and during the tests on the completed hall, with the seats but without the audience, a test will be made on the noise produced by all the plants and by any noise sources outside the hall. In order to pass the test on the noise produced by the plants, which will be carried out according to the international specifications, the noise levels must emerge as being lower than the global values specified by national standards and by the NC20 curve.

Levels of acceleration in the places where the vibration threshold might be exceeded will also be measured.

2.4. ORCHESTRA PIT

The orchestra pit was to be designed with a mobile platform that can be set at various heights up to the height of the stage. With respect to the previous dimensions, the pit had to be extended to make space for a larger orchestra.

The acoustic design of the orchestra pit must take into account various requirements deriving from the need to ensure a perfect balance between the different sections of musical instruments and between the orchestra as a whole and the singers on stage. The walls of the pit must be fitted with variable-acoustics (absorbing and reflecting) panels to enable the adjustment of the acoustic features of the space in the orchestra pit at will. The platform, which is made of wood, must enable an effective transmission of the sound and vibrations between the orchestra and the stalls.

2.5. ACOUSTIC CHAMBER

The acoustic chamber is an essential stage element designed to ensure that the acoustics in the hall and stage can be modified in the event of the theatre being used for symphony and choral music.

The entire system of the acoustic chamber and the main hall must be designed in order for it to become suitable for concert music, i.e., with longer reverberation times and greater early reflections in the hall: the shell must also guarantee a valid balance between the various instrumental sections of the orchestra.

Tests on the acoustic chamber–main hall system will be done by means of echograms in various parts of the stalls, circles, and galleries, with sources in at least three positions within the shell, without audience in the main hall.

2.6. REHEARSAL ROOMS

The design report had to illustrate in detail the materials and the assembly methods used to achieve the expected requirements.

The rehearsal rooms had to be designed in order to obtain the same acoustic situation as in the main hall during a performance. For this purpose, it was advised to arrange for variable-acoustics elements on the walls and, if necessary, on the ceiling so that the response of the room can be adjusted to different needs. The report had to indicate the level of performance expected to be achieved.

The building elements of the rooms used for rehearsals by the choir, the ballet dancers, by the orchestra and for instrumentalists to warm up had to be designed so as to guarantee high levels of sound insulation. In the case of adjacent rehearsal rooms or rooms particularly sensitive to noise, the apparent sound reduction index of the partition walls had to be higher than $R'_w = 57$ dB. The doors of access to the rehearsal rooms had to ensure a high level of sound insulation against airborne noise ($R'_w > 45$ dB).

The L'_{nw} index for assessing the normalized levels of impact noise on floors that separate rehearsal rooms on different floors, one above the other, or that separate rehearsal rooms from rooms that are acoustically "sensitive" (e.g., offices, meeting rooms, etc.) had to be less than 53 dB.

The tests on the acoustic performance of the rehearsal rooms will consist in the measurement of the reverberation times of the rooms. The measurements will be taken according to the methods indicated in the ISO 3382 international standard. The values must be in the vicinity of those measured in the main hall in the positions normally occupied by the members of the orchestra and the choir.

The tests on the performance of the sound insulation against airborne and floor impact noise will be performed according to the ISO 140 international standard, parts 4 and 7.

2.7. APOLLINEAN HALLS (FOYER)

The acoustic requirements for the Apollinean halls can be summarized in the need for an acceptable intelligibility also in the presence of considerable amount of background noise due to a large number of people in conversation. Since the specifications regarding the surfaces of the walls, ceiling and floor were dictated by the specific intention of restoring them as they were before the fire, the only elements on which action could be taken in order to increase the equivalent area of sound absorption were the furnishings (curtains, seats, carpets, etc.) which had to be

as sound-absorbent as possible. The project design report had to provide an estimate of the reverberation times and of the intelligibility levels obtainable in these areas.

The reverberation time will be measured in the empty halls. No particular values are specified.

2.8. OFFICES AND MEETING ROOMS

These rooms had to be suitably treated with sound-absorbent material so as to ensure reverberation times of less than 0·8 s in the frequency range of 500, 1000 and 2000 Hz. In the case of meeting rooms, in addition to the above-mentioned reverberation time, an acceptable intelligibility also had to be guaranteed, as measured by a RASTI index rating of at least 0·6 (RASTI $>$ 0·6) at all points of the room occupied by people.

The sound insulation features of the walls, doors, floors and plant had to be such as to guarantee a noise level inside the offices of not more than 35 dB (A) and a noise level inside the meeting rooms of not more than 30 dB (A).

The tests on the acoustic performance of the offices and meeting rooms will consist in the measurement of the reverberation times, carried out according to the method specified in the ISO 3382 international standard. For the meeting rooms, a test on the degree of intelligibility will also be performed by measuring the RASTI index as per the IEC 258-16.

2.9. UTILITY ROOMS

This term describes rooms containing the various technical plants needed for the opera house to function: electricity transformer substations, cold storage units, compressors, ventilators, heaters, electric motors, circulation pumps, generator sets, etc. No particular acoustic features were required for these areas.

The placement of the utilities and the features of their insulation in terms of noise and vibrations transmitted to all adjacent building elements and plant components had to guarantee insulation levels high enough for airborne and building-transmitted noise to stay within the noise levels indicated in the specifications for all the neighboring rooms, near and far, for which these were specified. Any equipment installed outside the building, such as cold-storage units, chillers, air intakes, etc., had to be insulated in order to avoid disturbing people living in homes near the opera house. As indicated in Vol. 2 "Environmental Impact Report", for these sources of noise it is essential to comply with the specifications of the DPCM 1/3/91 "Maximum limits for exposure to noise indoors and out of doors" (Italian law).

The acoustic test approval procedure will concern particularly testing the noise level in the rooms in the vicinity of these utility rooms for which noise limit values are established. The test will also involve a check on the compliance with the maximum limits and, wherever possible, on the incremental limits established by the aforesaid DPCM 1/3/91 in those positions most exposed to noise produced by plant components situated outside the opera house.

2.10. CONSTRUCTION SITE

Special precautions had to be taken in order to contain as far as possible the acoustic impact of the construction work on adjacent areas. The boundary fencing had to be as high as possible and made of panels ensuring excellent sound-insulation and sound-absorbent features. The machinery used on the building site had to be certified according to the specifications of the following Italian legislation: DL No. 135 of 27/1/92, DL No. 137 of 27/1/92, DL No. 588 of 28/11/87. The choice had to be oriented towards the quietest possible machines. Where feasible, acoustic barriers had to be installed around any particularly noisy fixed or partially fixed plant to reduce the propagation of noise towards residential areas and areas particularly frequented by the inhabitants. The acoustic report had to give a detailed description of all the precautions taken to reduce the acoustic impact on areas around the construction site.

3. COMMENTS AND CONCLUSIONS

Although one architecture competition may be very different from another in relation to the type of building it deals with—for example a new building or a restoration or, like in the case of "La Fenice", a reconstruction—it is believed that there is a need to establish a general agreement on the objective parameters and on the procedure to be introduced into the acoustic program for a competition. This paper is intended as a contribution for the preparation of such a guideline. Moreover, the experience of the "La Fenice" opera house raises the question of a systematic acoustic characterization of the theatres, which should be done according to standarized methods. The acoustics of a theatre is a cultural heritage which must be known and preserved.

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