Acoustic analysis and identification of smart solutions for the acoustic insulation of a large historical building

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Abstract. The object of the present paper is the acoustic study of Palazzo Borghese, one of the most important buildings of the neoclassical period present in Florence, which occupies the entire block between Via Ghibellina and Via dei Pandolfini. The Palace has been interested by various architectural interventions occurred in different historical periods. In 1437 a series of grandiose works of unification, enlargement and modernization were undertaken by Michelozzo who created a grand palace with a large open loggia much admired at the time. In 1709 a large, still existing, ballroom was built with a stage for the orchestra. The last major renovation was carried out at the beginning of the nineteenth century by Camillo Borghese: on the first floor, the monumental rooms, above all the main hall and the hall of mirrors, stand out for their magnificence, with a great profusion of gilded stuccoes, marble statues, columns, carved chandeliers, paintings. Currently some areas of the building are used for receptions, conferences and events, while others are part of a receptive structure, residences and offices. The contiguity of spaces, characterized by very different acoustic requirements and by the presence of three very silent internal courtyards on which these spaces overlook, led to the emergence of numerous acoustic problems whose solution is made particularly delicate by the historical-artistic constraints present on the building. In order to identify the acoustic criticalities, several campaigns of acoustic measurements have been carried out, both during the reception activities and through the use of a sample source. This investigation allowed to determine the structural weaknesses of the building and to identify the most appropriate technical and smart interventions compatible with the structural constraints and historical-artistic protection of the property.
1. Introduction

This article deals with the acoustic study and the definition of the interventions for the mitigation of acoustic criticalities related to the Palazzo Borghese, one of the most important buildings of the neoclassical period in Florence, which occupies the entire block between Via Ghibellina and Via dei Pandolfini (figures 1 and 2). This block, which occupies a very central position in the city, covers an area of about 2000 square meters (dimensions 50 x 40 m) and consists of four floors above ground at most.

![Figure 1. Top view of Palazzo Borghese in Florence.](image)

This palace has been interested by interventions carried out in different historical periods. In 1437 a series of grandiose works of unification, enlargement and modernisation were undertaken by Michelozzo, who created a grandiose palace with a large open loggia much admired at the time. In 1709 a large ballroom was built with a stage for the orchestra, which still exists today, in line with the grand staircase. The last major renovation was carried out at the beginning of the nineteenth century at the behest of its owner, Camillo Borghese.

![Figure 2. View from Via Ghibellina (on the left) and Via Pandolfini (on the right).](image)

On the first floor, the monumental rooms, above all the main hall and the hall of mirrors (figure 3), are distinguished by their splendour and magnificence, with a great profusion of golden stuccoes, marble statues, columns, carved chandeliers, paintings. This floor is currently used to host events such as receptions, parties, congresses, and in general also very noisy events due to the presence of sound amplification systems located in the main rooms of the palace.

The main acoustic criticality of this monumental complex is caused by the contiguity of spaces characterized by very different acoustic needs (the rooms used for events border with an accommodation facility, residences and offices) and the presence of three very quiet internal courtyards overlooked by these spaces. This situation has led to the emergence of numerous acoustic criticalities, whose solution is made particularly critical by the historical-artistic constraint of the Superintendence present on the building.
Figure 3. Main hall (on the left) and hall of mirrors (on the right) of Palazzo Borghese.

In order to accurately identify the acoustic criticalities, several sound measurement campaigns have been carried out, both during the reception activities and through the use of a sample source. These measurements, together with surveys and punctual analysis on site, made it possible to determine the structural weaknesses of the building and to identify the most appropriate technical interventions compatible with the structural constraints and the historical-artistic protection of the property.

2. Acoustic analysis

An in-depth investigation was carried out into the different environments that characterize the Borghese palace, in order to identify the potentially noisiest environments on which to concentrate acoustic mitigation interventions. In particular, these include: the main hall, the hall of mirrors, the passage rooms between these two halls and the two kitchens. The other rooms of the palace, other than those mentioned above, do not represent an acoustic criticality as they are used only occasionally and without the use of music.

As far as the noise level of the kitchen and the meal regeneration room is concerned, the kitchen overlooking Via dei Pandolfini was found to be more critical than the meal regeneration room, since the windows are kept normally open due to the lack of an air treatment and exchange system. This condition, together with the canyon configuration of the street, determines a high transmission of the noise produced by the kitchen activities (dishes, voices, etc.) along the whole street. The windows are all made of single-glazed wood, and many of them are characterised by poor air-tightness and noise insulation levels.
Figure 4. First floor plan of Palazzo Borghese.

Six of the fifteen windows overlooking via Ghibellina are equipped with a direct expansion system consisting of an indoor unit and an outdoor unit, the latter takes air through the under-window compartments. The interior and exterior are separated by 20 mm thick MDF panels that are not properly sealed.

The two most critical receivers structurally connected to the noisy environments of the palace have been identified, their exposure to noise is due to their position, in close proximity to the main hall, and to the presence of clear structural point of acoustic insulation weakness.

Given the complexity of the scenario under examination, in order to investigate all possible sound propagation paths, the following types of acoustic measurements were carried out [1-5]:

- simultaneous measurements of sound levels present inside the rooms and at the most impacted receivers points during some events hosted in the different rooms of the palace;
- simultaneous measurements of the sound levels present inside the rooms and at the most impacted receivers points making use of a sample source;
- sound insulation measurements of the horizontal and vertical partitions between Borghese palace rooms and receivers rooms.

A Sound Pressure Level of 64.9 dB(A) was detected at a height of 4 m in Via Ghibellina, on the opposite side of Palazzo Borghese, corresponding to a measured on stage level equal to 90.8 dB(A), determined largely by the noise of the street and not by the activities of the event.

On the opposite side of the main hall in via dei Pandolfini at a height of 4 m, a level of 57.6 dB(A) was detected corresponding to a measured on stage level equal to 91.6 dB(A), analyzing the specific period in which the music was recognizable with respect to background noise.

In Court 1 (see figure 4), several measurements were made using the sample source and during the 6-7/09 event with live music and DJ music. In correspondence with the measurements made with the sample source, it was possible to verify that the main noise propagation takes place from the French window of the meal regeneration room, from the vertical node of the stage wall with the existing masonry of the meal regeneration room and from the semicircular window above the stage structure. The frequency spectra show how the stage walls are characterized by low frequency sound insulation at low frequencies due to their low mass. During an event, acoustic measurements were performed on stage and simultaneously in court 1, in order to investigate the sound levels transmitted at different types of music (live and DJ). The levels measured ranged from a minimum of 57.6 dB(A) with live music (internal level 86.3 dBA) to a maximum of 65 dB(A) with DJ music (internal level 90.8 dB(A). The level measured in the courtyard 1 to 4 m, where most residences overlook, was 68.7, at a stage level of 90.4 dB(A).
The worst condition for receivers facing court 1 is open window (LAeq ≤ 40 dBA). To comply with this condition, it is necessary to reduce the noise transmission to the outside by about 25 dB(A). The main contribution of the levels measured outdoors is due to the high sound levels at low frequencies (60-125 Hz) produced by the subwoofers and the poor insulation of the stage enclosure at these frequencies.

In court 2 the acoustic measurement was made at a height of 1.5 m above the floor of the terrace overlooking the court. Sound levels of about 55.4 dB(A) were detected, corresponding to a level measured on stage in the same time interval of 92 dB(A). From the frequency spectrum analysis, it can be observed that even in this courtyard the transmission of low frequencies coming from the music of the main hall is high and that the worst condition is the one with open windows, to respect the latter it is necessary to reduce the transmission of noise to the outside by about 10-15 dB(A).

Finally, Court 3 was acoustically less critical.

On the basis of the analysis of the plan and the inspections carried out, six measurement scenarios were identified, chosen among those most critical for the structural noise transmission, and the acoustic insulation of the relevant walls and floors bordering the noisiest rooms in the Borghese palace were measured.

Starting from the results of the investigations and acoustic measurements carried out, it can be reasonably assumed that at present an average sound level inside the rooms of the Borghese palace equal to 75-80 dB(A) is able to ensure compliance with the legal limits in all potentially most impacted receivers.

Considering that the activities carried out in the main rooms (main hall, hall of mirrors, kitchens) produce sound levels certainly higher than the ones indicated, as detected in the different measurement sessions, it is necessary to carry out some noise mitigation interventions.

3. Definition of interventions for the mitigation of noise transmission

On the basis of the results of the investigations carried out, a number of interventions ordered according to the extent of the noise criticalities found were identified.

1. Replacement of external windows and doors.
2. Renovation of under-window installations
3. Acoustic improvement of the closure of the technical installations in the mezzanine of the main hall.
4. Improvement of the stratigraphy of the stage wall.
5. Calibration and limitation of the electroacoustic system.
6. Covering of the niche in the hotel room adjacent to the main hall on the second floor.

All the interventions designed and synthetically described below, have been defined paying great attention to the historical-artistic constraint of the property, thus preserving the architectural and material characteristics of the elements subject to intervention.

With regard to the first intervention, 18 external windows and doors have been identified to be replaced with windows and doors with high acoustic performance. As can be seen in the figure below, two different types of windows and doors have been selected, respectively characterized by the following minimum acoustic performance certified in the laboratory, in terms of soundproofing power evaluation index, Rw (dB):

- Rw ≥ 44 dB (windows and doors 3, 6, 7, 8, 9, 14, 15, 16).
- Rw ≥ 41 dB (windows 1, 2, 4, 5, 10, 11, 12, 13, 17, 18).
With regard to intervention 2, in the current condition, six of the under-window rooms overlooking Via Ghibellina have been modified in order to place the external and internal air-conditioning machines for the rooms. These elements were realised using simple wooden panels fixed to the walls and are very poor from an acoustic point of view. The project foresees the temporary removal of the air conditioning machines, the demolition and disposal of the wooden panels and the remaking of the closures through the realization of the following elements:

- In the case of deep compartments, fixed side closures with variable depth depending on the specific compartment, made with a single metal frame, 2 plasterboard sheets on both sides and a cavity filled with soundproofing panel.
- Fixed horizontal element placed under the sill made by means of a high density MDF panel 3 cm thick, with underlying soundproofing panel glued and sealed at the edges with butyl tape and silicone.
- Inspectionable vertical door made by means of a 2 cm thick double MDF panel and a 4 cm thick cavity filled with soundproofing material, screwed to a wooden structure. The pipes must pass through the side closures, where present, and must be completely foamed.
With regard to intervention 3, the project plans to improve the tightness of the current plasterboard casing of the technical installations in the main hall by sealing every hole/crack in the casing and grouting all exposed plasterboard sheets. In addition, the existing inspection hatch will be improved by removing the outermost slab and replacing it with a plasterboard slab at least 5 cm larger on each side, in order to create a groove around the entire perimeter on which an acoustic seal will have to be installed.

The acoustic analysis, as well as the information found regarding the stratigraphy of the wall and stage cover, have determined the need to increase the acoustic insulation of these elements in order to contain the noise emissions coming in particular from this area of the main hall. The project (intervention 4) foresees an intervention on the two vertical walls of the stage through the realization of an acoustic counter-wall positioned on the external side. The internal counter-wall, certainly more effective from an acoustic point of view (because it is able to eliminate all possible acoustic bridges by creating an internal envelope independent from the existing structure) was not proposed because on the internal side of the wall there are many fixed elements of furniture, stuccoes and decorations.
Subsequent to the above-mentioned interventions, a calibration will be carried out with consequent limitation of the electroacoustic system, with particular reference to low frequencies. This intervention will make it possible to overcome the criticality of the design solutions due to their low performance at low frequencies due to the limited surface mass that characterizes them (intervention 5).

In the wall of the hotel room on the second floor of the Palace, adjacent to the main hall, there is a niche about 60 cm deep in which a wardrobe has been currently created. Since this element was found to represent an acoustic weakness of the structure, it was proposed to wall it in 12 cm thick plastered solid brick blocks and cover two sides of the cavity with 8 cm thick soundproofing panels (intervention 6).

4. Conclusions

Palazzo Borghese is one of the most important buildings of the neoclassical period in Florence. It has been the object of several interventions carried out in different historical periods respectively by several experts such as Michelozzo and Camillo Borghese.

The main acoustic criticality of this monumental complex is caused by the contiguity of spaces characterized by very different acoustic needs (the rooms used for events border with an accommodation facility, residences and offices) and the presence of three very quiet internal courtyards overlooked by these spaces. This situation has led to the emergence of numerous acoustic criticalities, whose solution is made particularly critical by the historical-artistic constraint of the Superintendence present on the building.

On the basis of the results of the carried out acoustic measurements and investigations, a number of interventions were identified, mainly related to the replacement of external windows and doors, the renovation of under-window installations and the acoustic improvement of the closure of the technical installations in the mezzanine of the main hall.

All the interventions designed and described in the paper have been defined paying great attention to the historical-artistic constraint of the property, thus preserving the architectural and material characteristics of the elements subject to intervention.

References

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