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Teatro di San Carlo, Naples – Conservation of the Excellent Acoustics in the Oldest Active Opera House in Europe During Restoration and Extension

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ABSTRACT

The theatre "Teatro di San Carlo" in Naples, built in 1737, is the oldest opera house still active in Europe. After a devastating fire in 1816, the theatre has been rebuilt and is being considered, until today, one of the most beautiful semi-classical opera houses in the world. Also, from the acoustic point of view, it is reputed to be one of the best theatres in the world. These excellent characteristics had to be maintained and in no way affected by the extensive restoration and extension works which were carried out during a period of one year and a half, until January 2010. On the contrary, if possible, the acoustics were even to be improved. The restoration of the auditorium in terms of room acoustics, the creation of new rooms above and under the auditorium as well as the installation of an air-conditioning system were, among others, the object of the acoustic project of Müller BBM. The activities carried out as well as the obtained acoustic results are being illustrated in form of objective measurements and subjective comments of the artists and the opera lovers.

INTRODUCTION

The Teatro di San Carlo in Naples is the oldest opera house still in full activity in Europe. It belongs to the jewels of historical theatres and is, by many, considered the most beautiful theatre in the world.

Especially the auditorium – *Sala Tteatrale* – has practically maintained its original state, just as architect Niccolini had rebuilt it in 1817 after the fire disaster. The entire building complex of the Teatro di San Carlo too was conserved in its original state, except for the reconstructions and extensions typical for a theatre, such as the creation of a new foyer.

Until its present restoration, the auditorium was not equipped with a ventilation and air conditioning system, which led to considerable limitations of the working possibilities of the theatre during the summer months in southern Italy Naples. Also, the musicians and artists were constrained to be satisfied with the minimum of rehearsal rooms available in the building complex.

In the context of a tender published in June 2008, a very ambitious program was announced. Ambitious with regards to the amount of rooms planned, very ambitious as far as the time schedule for its realization was concerned, and even extremely ambitious considering that the program established a handling time of only two months for the tender which was to include the complete design by the architects and by all engineers and professionals.

Already in the beginning of August 2008, the tender was published and the winning team, under the management of the company COBAR, was commissioned with the immediate start of the works. Jürgen Reinhold of Müller-BBM was responsible for the acoustic design during the reconstruction phase.

The program involved three working stages, each of which was supposed to last from the end of the theatre season, i.e. beginning of July, until December. In the remaining period of time from January until June, a shortened season was supposed to take place.

Already at the beginning of January 2009, all restoration work in the auditorium was finished and a new foyer zone – *Ridotto* – had been built below the stalls area. The ventilation system had been installed in the auditorium and was neither visible nor audible. The theatre could successfully be opened to the public on January 25th, 2009 for a shortened season; starting with the premiere of Benjamin Britten's *Peter Grimes* under the direction of Maestro Jeffrey Tate and a symphonic concert conducted by Maestro Riccardo Muti.

During the second work phase which started in July 2009, the complete stage was renewed and equipped with new understage and upperstage machinery. The remaining work was completed and the new rehearsal rooms were finished too. On January 27th, 2010, Jeffrey Tate inaugurated the new theatre season with Mozart's *The Clemency of Titus* in the now completely finished theatre.

BASIS AND SCOPE OF THE RESTORATION WORKS

Besides for its beauty, the Teatro di San Carlo was also considered as one of the best theatres in the world as far as acoustics is concerned. Mr. Leo Beranek was among those who judged – based on his survey with a great number of eminent conductors – that the San Carlo is one of the five best opera houses in the world, at a level with such great names as the Teatro Colón of Buenos Aires, the Teatro della Scala in Milan as well as the Semper Opera House in Dresden, whereby the acoustics in the orchestra pit is being judged at a distinctly higher level than the acoustics in the auditorium.

Figure 1. Royal box of the restorated theatre

In consideration of this important inheritance, long before its beginning, the planned restoration work at the San Carlo was the object of animated discussions in the Italian public and press. Headlines like “Stop the restoration plans [...] the acoustics in the San Carlo will be destroyed [...]” were published almost daily in the Italian press. Away from these inauspicious forebodings, in the offices of Müller-BBM in Munich, the formulation of the basic acoustic concept proceeded. The extremely tight time schedule between the end of the competition and the beginning of the construction works made it impossible to carry out measurements of room acoustics in the conditions existing in the auditorium before the restoration. Therefore, today exist only measurements of the pre-existing conditions which have been carried out by the Laboratorio di Acustica Musicale e Architettonica, Venice, a few months before the beginning of the restoration works [1].

In the course of the restoration, with very few exceptions, the relevant bounding surfaces of the auditorium had to be conserved, which meant that the surfaces were only to be retouched and not visibly altered. The modifications and renovations were limited to the following building components and surfaces which maintained essentially their appearance and were only changed as far as materials were concerned and, wherever possible, were optimized from the acoustic point of view:

- Completely new wood floor construction in the stalls area necessary in order to create a new foyer underneath
- New fabric covering on all surfaces of the boxes
- Padding on the arm-rests on top of the box parapets
- Fabric curtains in front of the entrance doors of the boxes
- Fabric teasers at the open front of the boxes
- Seats in the stalls area maintaining their historical appearance
- New upholstery for the movable chairs in the boxes
- Installation of a ventilation system in the stalls area and in all boxes

The new requirements regarding the technical installations of the building, the regulations regarding fire protection as well as the needs of the theatre to have additional rehearsal rooms made it necessary to include the following rooms in the already existing building structure:

- Big rehearsal hall for stage production and orchestra rehearsals located above the auditorium
- Additional new foyer directly below the auditorium
- New underground rehearsal hall for the orchestra outside the actual theatre complex
- A great number of technical rooms in the basement, next to the orchestra rehearsal hall
- Ventilation plant and pump station directly above the auditorium
- Cooling and heating units mounted on the roof
- New organization of the artists' dressing rooms and backrooms

The upperstage machinery – until that day mainly operated manually – was brought to the highest technical standard requested for a modern theatre. A multitude of electrically operated fly bars and point hoists were mounted in the fly tower. Due to the complete redesign of the stage house, it was also possible to incorporate an understage machinery consisting of four stage lifts.

GENERAL CONSIDERATIONS

The restoration and extension of an historic theatre like the Teatro di San Carlo represents always a big challenge for the specialist in acoustics, especially when the acoustics in the auditorium has been applauded as excellent throughout the world.

Not alone has the restoration work inside the auditorium to be done without affecting prejudicially the acoustic conditions, also the integration of a new ventilation system as well as the creation of new rooms above and below the auditorium has to take place without any negative influence.

A new hall for stage production and orchestra rehearsals directly above the “painting” at the ceiling of the auditorium and a new foyer directly below the stalls area give a clear impression of the fact that – from the point of view of space arrangement as well as of acoustics – there was much more work to be done than just the restoration of the surfaces.

The extensive work in the stage area, mainly the installation of stage lifts and electric fly facilities, as well as the minor

adjustments in the orchestra pit must not be detrimental to the high quality level of the acoustics, appreciated all over the world.

The ambitious goal to conserve and even improve the acoustic quality of the Teatro di San Carlo was reached, as one can conclude from the unanimous comments by the conductors, first among them Maestro Riccardo Muti, and the music critics and orchestra musicians themselves.

The opera spectators in Naples are invited to plunge into the freshly lit-up brightness of the Teatro di San Carlo as well as in the even more vivacious acoustics, now in conditions that are also optimum from the room climate point of view.

Figure 2. View of the restored auditorium

AUDITORIUM

What can be realized in terms of acoustics in the context of the restoration of a building ? Will it be possible to include new rooms close to the auditorium and install an air-conditioning system without negative impact on the acoustics? Will it be possible to prove wrong the inauspicious forebodings of the press before the beginning of the works and to maintain the high acoustic standard, or even improve it further?

Many were the questions that the specialist in charge of the acoustics had to face and they certainly were no questions that could be resolved easily. Properly speaking, restoration means reconstruction: of the basic shape, height of the room, ceiling of the auditorium, boxes, surfaces, orchestra pit, proscenium arch. As a matter of fact, everything is being conserved, especially as far as the geometric layout is concerned, and only the surfaces are being touched up.

In the Teatro di San Carlo, fortunately many of these basic conditions were already optimal: the classic form of the “Italian style” theatre, i.e. a horseshoe shape with tiers of boxes, a very high room and consequently a favorable volume of 13,500 m³, a completely even, horizontal ceiling which allows to guide the sound reflections in the desired direction and, at last, an ideal proscenium area with an optimal orchestra pit. Therefore, the question was: where could be the starting point for the acoustic specialist?

The installation of the air conditioning plant which provides ventilation for the stalls area, all boxes, the orchestra pit and the stage, in fact, represented a big challenge regarding the maintaining of the outer appearance of the surfaces and of an inaudible background noise level.

The acoustics of the auditorium is indeed very complex and only when all parameters are in absolute harmony, the acoustics inside the auditorium will be perfect.

The following paragraphs describe the most important elements necessary to obtain this result.

Floor in the Stalls Area

In order to allow the creation of a new foyer directly below the auditorium, it was necessary to remove the original wood floor which was supported by several layers of wooden beams. A reinforced concrete slab now creates the necessary acoustic insulation between the auditorium and the foyer. The new floor in the stalls area, as the historic one, is constructed as a solely wooden structure, see. Fig. 3. The empty space underneath is also being used as a plenum in order to bring fresh air to the spectators sitting in the stalls area. The floor in the stalls area represents the only true structural modification of the fixed surfaces in the auditorium. The acoustic specialists took advantage of this variation for their own purposes by increasing the inclination of the stalls area. In this way, the visibility could be improved and, from the acoustic point of view, also the supply of the spectators with direct sound. The original quality of the floor in the stalls area, i.e. its capacity to transmit to the audience the perceptible vibrations when the orchestra plays a *fortissimo*, has been maintained completely. The musical performance is not only being ‘heard’ with the ears, but also being ‘perceived’ by means of vibrations through the legs, with the result of a considerable intensification of the musical experience.

Figure 3. Wooden floor construction in the stalls area

Auditorium Ceiling

The artwork at the ceiling of the auditorium, painted on a very large canvas, has been restored and its fixing at the overlying wooden structure has been improved (see. Fig. 4). Thanks to the restoration of the surface of the painting, its porosity has been reduced and consequently also the absorbing capacity of the ceiling surfaces. The same goes for the additional fixing.

The completely even configuration of the ceiling of the auditorium is excellent from the acoustic point of view and leads to a very uniform distribution of the sound reflections in the area of the stalls and balconies.

Parapets and Decorations

The auditorium is very richly adorned with decorations and structural elements realized in stucco, plaster, wood and pasteboard. All these surfaces contribute to a very important diffusion in the high and medium frequency range, one of the secrets of vivid acoustics. In this manner one produces a very soft timbre of the sound, without strong dominating reflections.

Reverberation Times and Absorbing Surfaces

Horseshoe shaped theatres in 'Italian style' with tiers of boxes are generally considered as dry from the acoustic point of view, i.e. the reverberation times in these theatres are rather short, especially in the range of medium and high frequencies. This characteristic favors a perfect intelligibility, but, at the same time, it is not favorable for the blending of the sound.

The taste of the opera lovers has changed and therefore there is now a tendency to provide the opera houses with considerably longer reverberation times. This tendency is also reflected in the restoration work; in fact, one tries to reduce to a minimum the absorbing surfaces in the auditorium prolonging this way the reverberation time for the benefit of a greater sonority.

Figure 4. Painted canvas of the reconstructed ceiling.

The volume of the room, very large for an opera house with a horseshoe shape, proved to be very useful and already before the restoration work produced in combination with surfaces that were optimized under the acoustic point of view reverberation times longer than those normally found in similar opera houses.

Consequently, the acoustic project work pinpointed to individual surfaces which could be optimized by reducing their sound absorption capacity.

To this purpose, for example, the padding of the arm-rests on top of the parapets of the boxes was reduced to a minimum. A lining of special material was applied on the back of the fabric covering the walls of the boxes, and the distance between the covering and the wall was reduced to a minimum. The fabric covering on the ceilings of the boxes was glued to the base surface and the teasers at the open front of the boxes were lined on the back with sound reflecting material.

The original building of the theatre was already equipped with many optimized surfaces: for example, the crown above the royal box was not made of fabric as it may look like at first glance, but of plaster and pasteboard which are optimal materials since they are sound reflecting. The same can be said of the teasers at the gallery level which have sound reflecting surfaces.

Furthermore, an important potential for acoustic improvement was inherent in the curtains in front of the doors of the boxes. Due to their extension (in each one of the boxes, the surface covered by curtains amounts to 2–3 m²), these very heavy curtains, highly sound-absorbing, contributed in a determinant way to the total absorption in the auditorium, as well as to the absorption in each single box. Thanks to an appropriate treatment of these fabric curtains it was possible to reduce half their sound absorbing capacity for almost the whole range of frequencies. With this procedure, it was possible to contribute enormously to the increase of the reverberation times.

Seats in the Stalls

The chairs in the stalls had to be renewed completely, but such operation had to be carried out by maintaining their outer appearance which had to be identical to the one of the original chairs. In an auditorium, the chairs play a very important role for the acoustics. The empty chairs, for example during rehearsals, have to provide a sound absorbing effect very similar to that of the occupied seat, like during the performance of the opera. When using chairs with very thick upholstery, the surfaces not covered by the sitting person have to be as sound reflecting as possible. At first, the chairs designed for the Teatro di San Carlo did not have these characteristics and therefore extensive tests were carried out in the laboratory with the existing historical chairs in order to obtain, in close cooperation with the producer of the chairs, the best result possible. At the end, by integrating hard, sound-reflecting surfaces in form of wood inserts and layers of imitation leather it was possible to obtain an optimal acoustic result and a reduction of the additional, unwelcome sound absorption.

Ventilation System for the Auditorium

For acoustic requirements, the ventilation system has to be extremely quiet and, on the other hand, for aesthetic reasons it has to be practically invisible; especially surfaces of historical value must not be damaged in any way. The basic concept which included the introduction of the air into the orchestra seating area through a plenum underneath the wood floor has already been described. As regards the boxes, the incoming air passes through a grid in the ceiling. It was possible to achieve the requested low noise level by keeping the speed of the air flow appropriately low and by choosing the right size of silencers. The air exhaust takes place through openings previously existing in the ceiling as well as alongside sections of the ceiling in the side galleries of the 6th tier – *Loggione* –, without any damage to the historical surfaces.

The orchestra pit too had to be equipped with very light aeration which was realized though air inlets in form of open joints close to the platform, avoiding this way to 'perforate' the flooring. A ventilation system with an air flow similar to the one in the auditorium could have been perceived as drafty and would not have been accepted by the orchestra musicians.

Reverberation Times and Comments

We not only succeeded in conserving the excellent acoustic conditions in the Teatro di San Carlo, but also in prolonging the reverberation times considerably over almost the whole range of frequencies. Fig. 5 compares the reverberation times measured in similar conditions of stage settings, before the beginning and after completion of the restoration works.

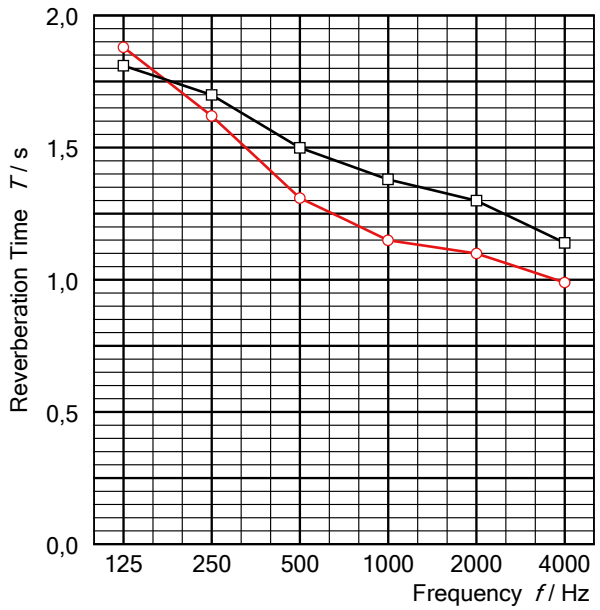

Figure 5. Reverberation times of the auditorium in 2008 before the restoration [1] (red line, circles) and after the restoration (black line, squares) for similar room conditions

The degree of positive reception of the acoustic renewal and improvement of the Teatro di San Carlo was described explicitly by Paulo Isotta in his newspaper article" Il Restauro del San Carlo: "*virtuosismi per l'acustica*", in the Corriere della Sera of January 27th, 2009.

> I would like to define a genuine miracle the most important part of the restoration, that is the acoustics. The San Carlo is not only the most beautiful theatre in the world, it also belongs to the theatres with worldwide the best acoustics, fact which we owe to the creative genius of Niccolini, because the original auditorium in Rococo style, designed by Medrano in 1735, left much to be desired as far as acoustics were concerned. Now, these acoustics – at the same time distinct and yet smooth; these acoustics – enabling the stereophony of sound mixing as well as blending of the tones right there, where it is necessary; these acoustics that find, by themselves, the balance between the stage and the orchestra pit [...] these acoustics remained unchanged and were even, if this is actually possible, rendered more natural.
>
> I will give an example. I already had experienced the auditory sensation when seated in the stalls area. Therefore I took a seat in a box on the third tier, and precisely a seat in the back of this box. When one sits in the Scala in a box, right next to the parapet, one receives the sound lightly attenuated, in any case, different from the sound that one hears when sitting in the stalls; taking a seat in the centre row of the box, the sound changes again, and if one sits in the very back of the box, the sound is extremely weak. In the box that I had chosen – which, by the way, was a lateral box – the sound had the same sonority and timbre as the sound perceived in the stalls. I changed place, and nothing changed. [...] and sitting in the Loggione, one has the feeling to be seated among the orchestra musicians.

STAGE TOWER

The technical equipment of the stage tower was completely renewed. Thanks to the installation of understage machinery, i.e. stage lifts, as well as of upperstage machinery in the form of point hoists and fly bars, in the future it will be possible to change the stage settings in a much easier and more flexible way. Since the change of the stage settings often is also used as a scenic effect, it was necessary to choose machinery generating very little noise in order to avoid any kind of disturbance.

The installation of a ventilation system (air intake and outtake) inside the stage tower had to meet the most rigorous acoustic requirements. In this case too, the general rule is to be inaudible, since otherwise the spectators in the auditorium would be disturbed.

The construction of the roof was completely renewed. It was necessary to guarantee a high degree of acoustic insulation i.e. R'_w = 60 dB, in order to protect from the noise of air traffic. The take-off direction of the airplanes leaving the airport of the city, at a distance of only about 5 km, leads in most cases over the centre of town and thus directly over the Teatro di San Carlo. The supporting framework of the roof is carried out in wood. On top of this structure, several layers of concrete slabs and insulating material were put, covered by the classic southern Italian tile roofing. This build-up guarantees the requested high acoustic insulation.

IL NUOVO RIDOTTO – THE NEW FOYER BELOW THE AUDITORIUM

A new foyer – *Ridotto* – has been created right below the stalls area of the auditorium. Thanks to the separation realized by means of a solid reinforced concrete slab it was possible to obtain a sufficient acoustic insulation of R'_w > 60 dB for the parallel use of the premises. In order to reduce the noise level during the use of the foyer and at the same time create suitable conditions for performances of chamber music in the *Ridotto*, it was necessary to provide for sound absorbing elements. To this purpose, almost the entire surface of the ceiling has been covered with sound absorbing material. The surface visible for the public is composed of a fabric covering on top of a layer of panels of cellular materials.

The horseshoe shaped walls represent a problem from the acoustic point of view since they lead to local sound focusing and entail a very irregular distribution of the sound reflections. This is the reason why the idea came up to cover a large potion of on these surfaces with sound absorbing paintings (see Fig. 6) which break the regularity of the walls, producing this way a very positive acoustic effect.

The acoustic conditions in the *Nuovo Ridotto* are largely satisfying for the visitors using the premises as a foyer by offering a very pleasant environment as far as acoustic insulation is concerned, as well as for the musicians during the rehearsals or small music events.

Figure 6. New foyer space below the auditorium

LARGE REHEARSAL HALL ABOVE THE AUDITORIUM

With a volume of over 4,500 m³, the new rehearsal hall represents an ideal hall for rehearsals of the orchestra, the chorus as well as stage settings.

Separating slab

The big challenge was to offer the possibility of a contemporaneous use of the auditorium and the rehearsal hall. The requested optimal acoustic separation could be obtained by inserting a reinforced concrete slab – which, obviously, due to the very extended span and the existing historical construction, by no means could be excessively heavy – at a distance of about 2 m above the ceiling painting in the auditorium, in combination with a special plaster floor applied on this slab. As could be observed during the first rehearsals, it is possible to use the two rooms in parallel without limitations of any kind.

Roof construction

As already described in relation to the stage tower, also this part of the building has been equipped with a completely new roofing, consisting of several layers which had to satisfy the requirements of a high sound insulation against noise from the outside. The construction is identical to the one of the stage tower. The skylights, placed at the highest point of the roof, are constructed with highly sound insulating window panes so that, also in the rehearsal hall, the noise of passing airplanes can hardly be heard.

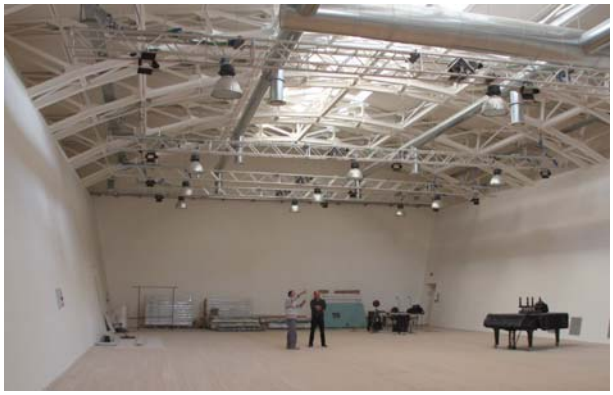

Figure 7. Large rehearsal hall above the auditorium

Room acoustics

The longitudinal walls of the rehearsal hall are slanting, following in this way the slope of the supporting structure. In this way it was possible to avoid the greatly inconvenient parallelism.

An alternately sound absorbing and sound reflecting lining of the ceiling, in combination with large curtain covered surfaces on the face walls reduce the reverberation times to the value necessary for the rehearsals. With its profiles, the visible metal supporting structure contributes to the diffused propagation of the sound.

The wood floor constitutes a good base for all types of rehearsals and serves, at the same time, as efficacious component for the absorption of low frequencies.

On the whole one can say that with this new space above the auditorium, a new rehearsal hall very valuable and usable for many types of activities has been created.

EX-FALEGNAMERIA: THE NEW ORCHESTRA AND CHORUS REHEARSAL HALL

Building acoustics

The former carpentry outside the theatre complex, situated in the basement, has been closed and in the same volume has been created a new rehearsal hall. Since it is in contact with the ground and shielded from the building body of the theatre, only measures regarding the technical rooms that had been integrated in this volume were necessary. This problem could be resolved creating a box-in-box construction, i.e. placing walls on elastic supports inside the rehearsal hall itself and realizing a double layer roof construction.

Figure 8. Orchestra and choir rehearsal room

Room acoustics

With a volume of almost 1,500 m³ the rehearsal hall is a chorus rehearsal hall ideal for not more than 100 chorus members. It also offers sufficient space and good acoustic conditions for orchestra rehearsals with an orchestra of maximum 70 musicians. The ceiling with its ‘hill-shaped’ outline, which presents itself as a concave surface towards the hall, does not represent an ideal surface from the room acoustics point of view and causes a very irregular distribution of sound reflections. For this reason, acoustic reflectors with convex curving which produce the necessary uniform distribution of reflections have been arranged below. The surfaces of the ceiling above these reflectors have mostly been covered with perforated wood panels as to make them sound absorbing.

For the walls, an alternating pattern of sound absorbing and sound reflecting wooden panels was chosen. This makes it possible to obtain sufficiently reduced reverberation times, necessary because of the rather limited volume of the hall. In addition, a high sound diffusivity is being ensured, further reinforced by the folding elements of the walls which can either operate sound absorbing or sound reflecting.

A wood floor has been designed which is placed on supporting joists and this way builds a flooring capable to vibrate. This offers many advantages and also serves for a further acoustic contact between the musicians of the orchestra, above all considering the string instruments such as the contrabass and the cello. This wood covering serves also as a very useful measure for absorbing low frequencies.

Overall, this rehearsal hall represents a valuable addition to the available space in the Teatro di San Carlo.

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[1] Laboratorio di Acustica Musicale e Architettonica Fondazione scuola di San Giorgiom, “Relazione Tecnica misure acustiche”, May 6th, 2008