Are classrooms in historical buildings compatible with good acoustics standards?

Luigi Maffei, Gino Iannace and Massimiliano Masullo

Built Environment Control Laboratory Ri.A.S., Second University of Naples, Abazia di S. Lorenzo, 81031 Aversa, Italy
luigi.maffei@unina2.it

Many surveys and researches have underlined that the acoustic characteristics of classrooms are strictly connected to performances of students and to the stress of the teachers during lessons. In standard classrooms sound quality can be easily reached without sound amplification but introducing appropriate sound absorbing/scattering materials at the ceiling and/or at the vertical walls. Nevertheless in historical buildings with vaults or trusses, high walls and many architectural restrictions imposed by district superintendent, it could be very difficult to achieve good acoustics standards with widespread solutions. In this paper the acoustic performances of different classrooms in an historical Monastery actually center of the Faculty of Architecture of the Second University of Naples are analyzed. After these analyses, compatible architectural and acoustic solutions to improve the sound quality were developed and tested in laboratory measurements and then applied in some classrooms to verify the benefits.

1 Introduction

The acoustical characteristics of classrooms are very important to guarantee the verbal communication between teachers and students.

In fact different research studies have connected low students' performance [1,2] and teachers' stress [3] to acoustical parameters in classrooms such as reverberation time, background sound levels and speech transmission indices (RASTI, STI).

These studies have been applied to all primary and secondary school classrooms but also to universities classrooms [4, 5].

All over the world, thanks to many surveys, specific suggestion and regulations have been published [6, 7] by institutional entities in order to control the phenomena and realize better learning environments.

Avoiding sound amplification, the optimal acoustic characteristics of classrooms can been mainly obtained with introduction, preferably at the design stage of the buildings, of absorbing/scattering materials at ceiling and/or at side walls, of good sound insulation partitions and of low noise ventilation and air-conditioning systems. With these design guidelines good results can be obtained with affordable construction costs.

More parameters (e.g. applicability, costs/benefits analysis, design bounds) should be take into account for acoustic renovation of classrooms.

Generally primary and secondary schools have dedicated old or new buildings, while more often academic structures for different reasons (availability, prestige) are hosted in historical buildings. These last buildings are generally protected by National Cultural Heritage Ministry with architectural bounds whose effect is a reduced number of possible acoustic renovation solutions.

All Faculties of the Second University of Naples in Italy are hosted in historical buildings. In particular the Faculty of Architecture, with its offices and classrooms, is sited since 1995 in a 16th century monastery (Abbey of San Lorenzo ad Septimum) of high historical value.

In this paper is presented a survey of the acoustic characteristics of teaching and conference rooms of the Faculty of Architecture and are investigated renovation solutions in order to improve the global acoustic performance.

The proposed renovation solution fulfils the architectural bounds, the optimal room acoustic requirements and the eco-sustainable new strategies in terms of materials.

2 Acoustic survey

To host the Faculty of Architecture between 1995 and 2000 it was necessary to renovate the building under the aegis of national cultural heritage superintendent and it was possible to get 17 rooms classified as "classrooms" and 2 rooms classified as "conference rooms". The renovation did not take into account any acoustical performance of the closed spaces and it was mainly addressed to the reconstruction of the original architectural features. The classrooms present different ceiling typologies (barrel vaults with fanlights, flat roof with iron joints and rough bricks, flat roof constitute by wooden primary and secondary frame, wooden trussed roof, iron trussed roof with painted staves) while walls are covered by painted plaster and floors are marble type.
14 classrooms have a volume less than 1000 m^3; only one (drawing classroom) has a volume higher than 2000 m^3. The classrooms are distributed on three floors and are positioned around the cloister of the monastery away from external traffic noise sources; the furniture is more or less homogeneous (presence of lamps, chairs, desks, blackboards, projector board) except for two rooms that have pad chairs.

Fig.1 Magna Room and detail of the original ceiling.

During last years instructors and students manifested slight complains regarding the intelligibility of the vocal signal during lessons. It was then decided to investigate reasons of the complains with a focused acoustic survey in 8 rooms (T1,T5, P3, P4, P9, S2, S3 and S4) which are representative of the typology of all other classrooms.

In these classrooms the acoustic parameters EDT, T30, STI, RASTI, background noise level and impact sound insulation were measured in different conditions:

a) empty room for reverberation parameters and background noise levels (fan-coils of the heating system on);

b) room partially occupied (50%) for speech intelligibility parameters (fan coils of the heating system on) as suggested by Sato and Bradley [8].

An omnidirectional loudspeaker (for the reverberation), a small directive loudspeaker (for the intelligibility) and a tapping machine (for the impact sound insulation) were used as sound sources. Classroom impulse-response measurements were performed using the Maximum Length Sequence System Analyzer with a SYMPHONIE 01dB octave band analyzer. Measurement positions were at least six in each classroom.

During measurements the background noise level was generally lower than 52 dB(A) and it was mainly due to the fan-coils of the heating system and to some students' voices in the corridor. No interference was registered for tapping noise from above classrooms as the structure of all floors is massive and the normalized impact sound pressure level is, for all rooms, below 48 dB.
Fig.2 shows the reverberation time (T30) in the octave band between 250 and 4000 Hz for the surveyed classrooms. Except for classroom P9, which is a conference room with pad chairs, the reverberation time is generally higher than values suggested by literature and by national guidelines [6] (0.8-1.3 s). Very high is the reverberation time for the "drawing classroom" T5.

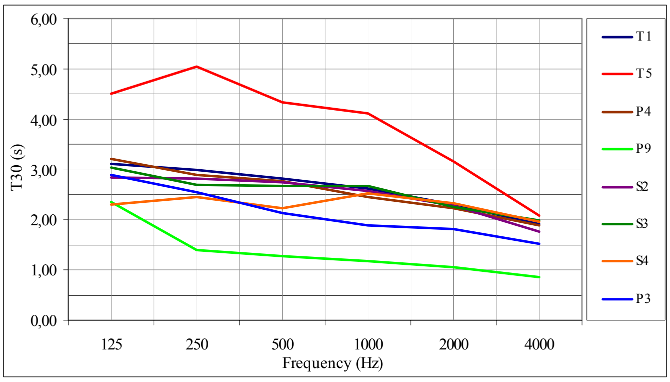

Fig. 2 Reverberation time T30.

Fig.3 shows speech indexes (STI and RASTI) for the surveyed classrooms. According to the reverberation analysis, most classrooms [6] can be classified as "Poor" with regard to the speech intelligibility scale as the RASTI values are included between 0.30-0.45. Only two classrooms (P3 and P9) can be classified "Fair" as RASTI is slightly higher than 0.45.

The overall survey and analysis confirmed complains regarding poor speech intelligibility during lessons in most of the classrooms essentially due to absence of absorbing surfaces and suggested acoustical treatments.

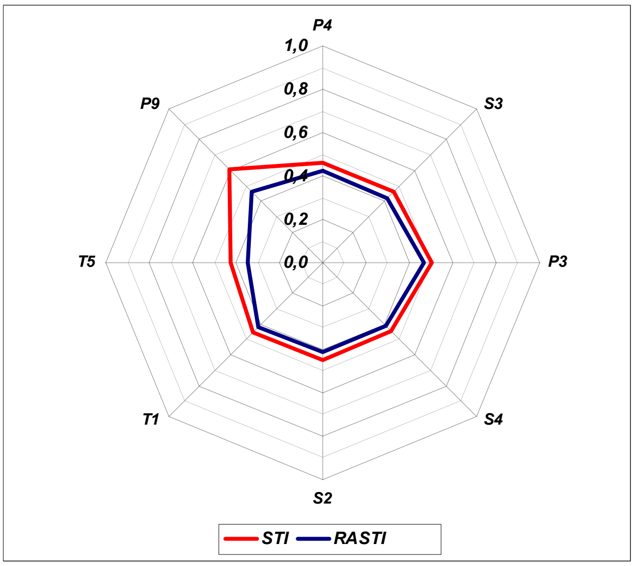

Fig. 3 STI and RASTI.

3 Design of the acoustical treatments

3.1 Solutions

The design stage of the acoustic renovation required coordination with local and national cultural heritage offices.

For the ceiling, classical absorbing solutions such as mineral or glass fiber lay-in panels, shredded wood fiber panels, perforated panels, clouds and baffles, etc. were not realistic as they would cover and make not more visible the main architectural and original features of the rooms (e.g. barrel vaults, truss roof). For the side walls, architects of the cultural heritage offices did not consider possible any solution that could modify definitively the characteristics of the surfaces (e.g. spaced wood slats, acoustic plasters [9]). With all this background, the only affordable solution was limited to movable and temporary furnishing elements such as drapery and absorbent boards. Draperies has disadvantages as they require cleaning and re-fireproofing from time to time. The design of the acoustical treatments had to consider also the sustainability of the materials that could be used.

The final solution was the design of absorbing paintings constituted by a board of a sustainable material of fixed thickness covered by natural fabric and hanged to the side walls with a non-invasive system.

For the absorbing material, four types were considered: hemp (density 40 kg/m^3), kenaf (density 50-100 kg/m^3), shredded wood fiber (density 400 kg/m^3) and cork (density 200 kg/m^3). Linen, juta and silk were considered for the covering natural fabric.

3.2 Material and system testing

The sound absorbing coefficients of the sustainable materials were measured in laboratory using:

1- a standing wave Kundt tube (for the frequency range 200-2000 Hz)

2- "in situ" two microphones acoustic impedance measurement technique (for the frequency range 500-5000 Hz) [10, 11]

Fig.4 shows the comparison of absorbing coefficients of all tested materials in the frequency range 200-2000 Hz obtained with the Kundt tube. The best results can be achieved with a kenaf panel of density 100 kg/m^3 and 6 cm thickness. Results are in good accordance with previous studies [12].

To check the influence of the covering fabric, the sound absorption coefficient of the system sustainable material + covering fabric has been measured with the "in situ" two microphones technique.
Fig.5 reports, as example, measured values for a hemp panel (6 cm thickness) with covering juta. No significance differences were found covering the panels with other natural fabrics.

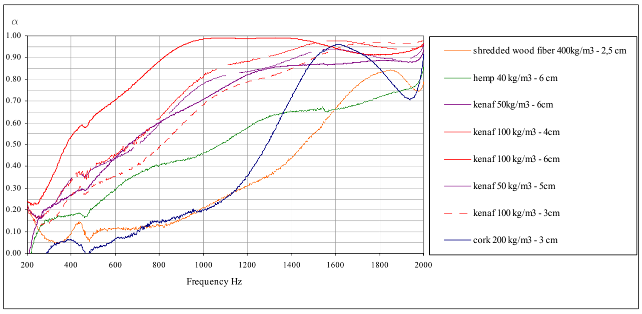

Fig.4 Absorbing coefficient of sustainable materials

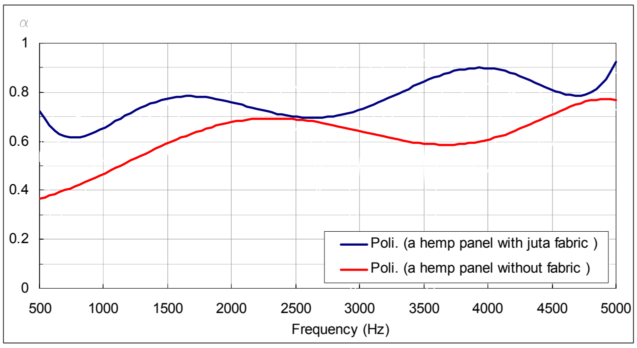

Fig.5 Absorbing coefficient of hemp+ juta.

Fig.6. Kenaf boards.

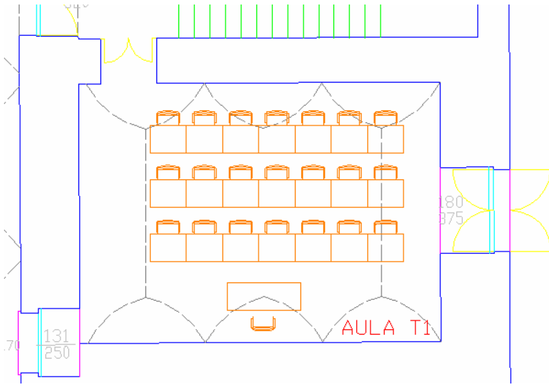

Fig. 7 Classroom T1

4 Pilot project

To test if the acoustical treatments could be successful enough for a large scale renovation, a pilot project was prepared. 15 wood frames of dimension 60 mm x 140 mm were built in laboratory. Each was filled with kenaf panels with thickness 6 cm and covered by stretched juta or linen. Classroom T1, with a area of 40 m^2, average height 5.3 m and 21 students occupancy, was chosen as test room.

Reverberation and speech intelligibility was measured for three conditions: no acoustic treatments, 8 and 15 boards (paintings) corresponding to 6.72 m^2 and 12.6 m^2 of absorbing surface respectively.
Boards were uniformly distributed around the classroom tight to the side walls and during measurements 10 persons (50% of occupancy) were present.

Fig. 8 Classroom T1 with insertion of absorbing boards.

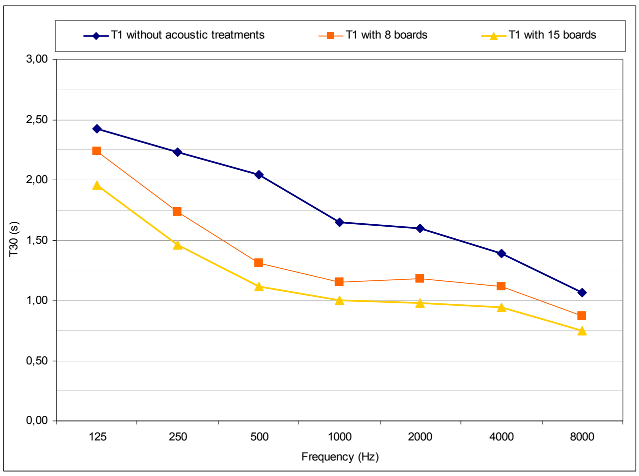

Fig. 9 T30 values in T1 classroom.

Fig.9 shows a significant reduction of T30 with the introduction of 8 boards (paintings) which cover only 5% of the side wall surfaces. With 15 boards the reverberation time drops to 1 s in the octave frequency bands 500-4000 Hz.
With regard to speech intelligibility (Fig.10), the increase of the parameters STI and RASTI can classify the classroom in the category "fair".

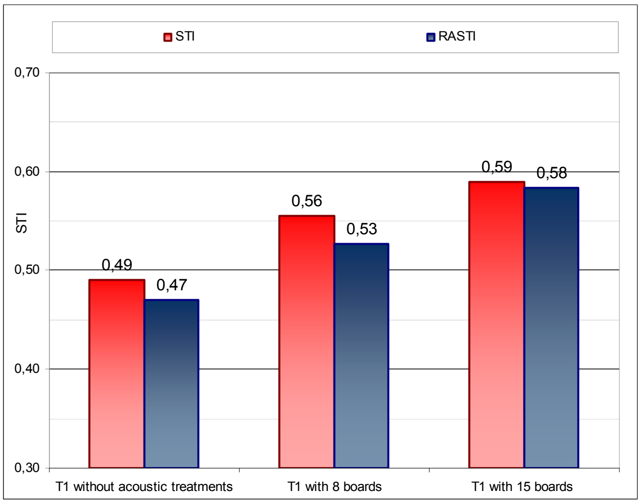

Fig. 10 STI and RASTI values in T1 classroom..

5 Conclusion

Acoustics in university classrooms inside historical buildings can be very "poor" in terms of reverberation and speech intelligibility. This consideration is mainly due to large volumes and lack of absorbing materials because of architectural bounds. Acoustical treatments need to be non invasive and movable. A pilot study has showed that good results can be achieved introducing simple boards built with sustainable materials. The boards can be painted using new textile painting technique which do not alter the porosity of the fabric.

References

[1] S.D. Soli, J.A. Sullivan, "Factors affecting children's speech communication in classrooms", *J. Acoust. Soc. Am.* 101, 3070 (1997).

[2] J.E. Dockrell, B. Shield, "Children's perceptions of their acoustic environment at school and at home", *J. Acoust. Soc. Am.* 115 (6), 2964-2973 (2004).

[3] I. Enmarker, "The effect of road traffic noise on teachers' memory and attention", *Proceedings of Euronoise 2006*, Naples, paper ID-322.

[4] S.M. Kennedy, M. Hodgson, L.D. Edgett, N. Lamb, R. Rempel, "Subjective assessment of listening environments in university classrooms: perceptions of students", *J. Acoust. Soc. Am.* 119 (1), 299-309 (2006).

[5] M. Hodgson, "Case-study evaluations of the acoustical designs of renovated university classrooms", *Applied Acoustics* 65, 69.89 (2004).

[6] M. Vallet, Z. Karabiber, "Some European policies regarding acoustical comfort in educational buildings," *Noise Control Eng. J.* 50, 58-62 (2002).

[7] Acoustic Design of School. A design Guide. *Building Bulletin 93*. ISBN 0 11 271105 7.

[8] H. Sato, J.S. Bradley, Evaluation of acoustical conditions for speech communication in working elementary school classrooms, *J. Acoust. Soc. Am.* 123 (4), 2064-2077 (2008).

[9] F. Pompoli, P. Bonfiglio, Acoustical and physical characterization of a new porous absorbing plaster, *Proceedings of ICA 2007*, Madrid, paper RBA-09-003.

[10] J.F. Allard, B. Sieben, "measurements of acoustic impedance in a free field with two microphones and a spectrum analyzer", *J. Acoust. Soc. Am.* 77(4), 1617-1618 (1985).

[11] G. Iannace, C. Ianniello, L. Maffei, "Misura dell'impedenza acustica specifica normale di una superficie in campo libero mediante sequenze pseudo casuali periodiche", *Rivista Italiana di Acustica*, vol. XVII n. 1, 1-6 (1993).

[12] R. del Rey Termos, J. Alba Fernandez, V. Sanchis, "Proposal a empirical model for absorbent acoustical materials based in kenaf", *Proceedings of ICA 2007*, Madrid, paper PHY-07-012.