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ACOUSTICS DESIGN OF S.TOMMASO EX-MONASTERY CHURCH

Cinzia Buratti, Irene Costarelli, Lucia Susta

Facoltà di Ingegneria, Dipartimento di Ingegneria Industriale
Università degli Studi di Perugia
Via G. Duranti, 67
06125 Perugia, Italy
cburatti@unipg.it

Abstract

The acoustic properties of a small auditorium are investigated; the auditorium, having a seating capacity of 64, was designed into an ex-monastery now used part as a school, part as a little museum and part as flats. The ex-church monastery ceiling is constituted by two cross vaults, frescoed by an Andrea Pozzo's pupil at the beginning of the XVIII Century. So, the church original volume was chosen for the project of the hall. The room acoustic performances were evaluated using *RAMSETE*, a simulation and forecast acoustic software, and considering two configurations: Concert Hall and Conference Hall.

INTRODUCTION

Umbria region, in Italy, is rich of numerous historical buildings, especially with a religious destination. Some of them are currently employed as faith places; others, after their deconsacration, assume a different destination: auditorium, conference room, etc. In any case the acoustic performances of the room are very important both for language intelligibility and for music listening.

Nevertheless, a correct acoustic design of historical buildings is often difficult due to the shape and dimensions of their surfaces.

In the present paper the acoustic performances of an ex-church situated in Perugia are examined. S. Tommaso ex-conventual area is now used part as a school, part as a little museum and part as flats; the church original volume is divided by two

reinforced-concrete floors built inside it. The ceiling was frescoed by an Andrea Pozzo's pupil at the beginning of the XVIII Century. So, in order to give again visibility to the frescoes and to provide the school of a new conference hall, a little auditorium was designed into S. Tommaso ex-monastery church (fig. 1).

After the auditorium architectural design, the room acoustic performances were evaluated using RAMSETE, a simulation and forecast acoustic software. A comparison between the simulation results and the optimal values of the different acoustic parameters was carried out. Results showed that an acoustic correction was necessary, due to the shape of the ceiling and its cross vaults. So different simulations, corresponding to various solutions of acoustic correction, were carried out: as final configuration the one allowing to reach the acoustic performances required, without modifying the church ceiling, was chosen.

THE ARCHITECTURAL AND STRUCTURE DESIGN

The structure design had to assure frescoes complete visibility and, at the same time, good acoustic parameters in each listening point. The choice was directed towards the planning of tiers for people, carried by a steel structure bound to the ground through hinges (fig. 2).

Tiers structure is disconnected from the church walls because they support even the full weight of the two floors built above the original room ceiling.

In order to avoid architectural barriers and to observe the law about security for public recreation places, the main paths were positioned at the same level (the original level of the church floor).



Fig. 1 – The frescos on the cross vaults and a room virtual representation.

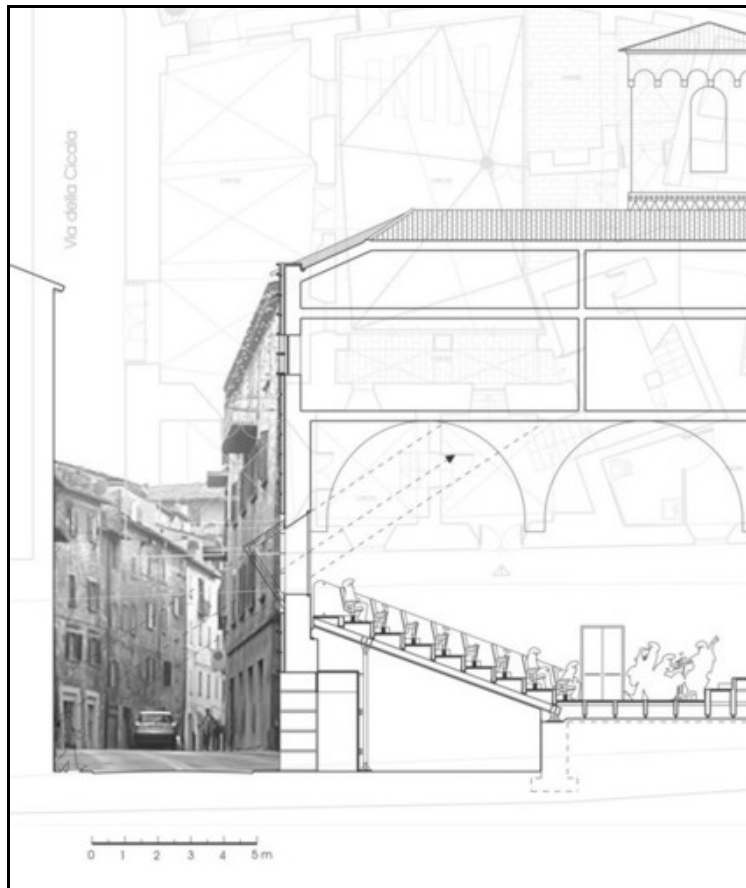


Fig. 2 – Section of the room.

RAMSETE SOFTWARE AND ITS APPLICATION TO THE PROJECT

Ramsete software [1], [2] is an acoustic simulation and forecast model based on geometrical acoustics and on an algorithm tracing separate pyramidal rays.

It has a functional structure divided in several blocks; through *Ramsete CAD* block it's possible to model the room, representing it by plane surfaces. Then it's possible to assign the materials and the acoustic absorption coefficients of each surface; finally the source and the listening sounders could be located into the room. After the model definition, the software, through *Ramsete TRACER* block, starts to trace divergent pyramidal rays, providing different acoustic indicator values; during each tracing process, some parameters must be set:

- ❖ **level:** it's related to the number of pyramidal rays traced by each source; the number of pyramids is 8×2^N , where N is the level value. In our project N = 8 (2048 pyramids);
- ❖ **time:** it's the time of each ray way and it must be larger than the

reverberation time; in our project it is 5 seconds;

- ❖ **time resolution:** it's the time range of the response taken on listening positions; in our case, time resolution is 0,001 seconds (maximum resolution);
- ❖ **humidity and temperature:** the values chosen in the simulations are temperature = 20° C, humidity = 50%;
- ❖ **history:** it's the number of reflections of each ray before stopping. It was set the value -1 because it allows to follow the ray during its way.

After the parameters setting, the simulation starts and at the end of the process a file is provided. The different acoustic indicator values are contained in the file and are read through *Ramsete view* block.

In the project, the following parameters were considered: reverberation time T_{60} , weighed A equivalent pressure level $L_{eq}(A)$, clarity index C_{80} , definition index D_{50} , **STI/RaSTI** indexes.

Unfortunately, the S. Tommaso church volume is currently divided by two reinforced-concrete floors, so acoustic measurements for the model calibration were not possible. The room was modelled and the materials, the same as in the project, were chosen from *Ramsete* database. After a first simulation, the materials in the room were corrected until the acoustic indicators values became good. The process was repeated twice: considering the room as a concert hall and as a conference hall.

Then, for both configurations, the auralization technique was used, in order to reproduce the room psychoacoustic sensation filtering an anechoic signal.

CONCERT HALL CONFIGURATION

Four simulations were carried out in order to improve the concert hall acoustic quality. In the first simulation the design parameters were used (Tab. 1). In the hall surface model a good definition of curve surfaces (especially for the vaults) and of the architectural details was necessary; finally the source and the listening points were positioned in the room model following *International Standard ISO/FDIS 3382* [3] indications. After the simulation, the obtained acoustic parameters were analysed and compared with the Literature optimal values. The optimal reverberation time T_{60} for a concert hall of about 700 m³ was 1,6 seconds at 500 Hz [4]; the variation of T_{60} with the frequency was determined as in [4]. Its optimal range of values vs. the frequencies (125 – 8000 Hz) is reported in fig. 4. The values obtained by the first simulation of the other acoustic parameters, such as C_{80} , D_{50} and RaSTI were acceptable, while T_{60} was higher than the optimal one; in particular it was too much high in the medium, high – frequencies range. So other three simulations were carried out, supposing the introduction of:

- ❖ acoustic plaster over the bottom wall (simulation n. II);
- ❖ moquette on the floor (simulation n. III);
- ❖ presence of people (simulation n. IV).

The obtained values of the acoustic indicators were good for all the frequencies. Figure 3 shows the room model and figure 4 the results of the four simulations. The auralization technique was also employed, in order to simulate the acoustic sensation before and after the acoustic corrections.

frequency (Hz):	125	250	500	1000	2000	4000	8000
Smooth plaster	0,02	0,02	0,03	0,04	0,04	0,03	0,02
Varnished wood	0,11	0,12	0,12	0,12	0,1	0,1	0,1
Ordinary glass	0,35	0,25	0,18	0,12	0,07	0,04	0,03
Iron doors	0,01	0,01	0,02	0,02	0,03	0,03	0,03
Pit stall	0,139	0,402	0,432	0,488	0,509	0,439	0,343

Tab. 1 – Acoustic absorption coefficients (first simulation)

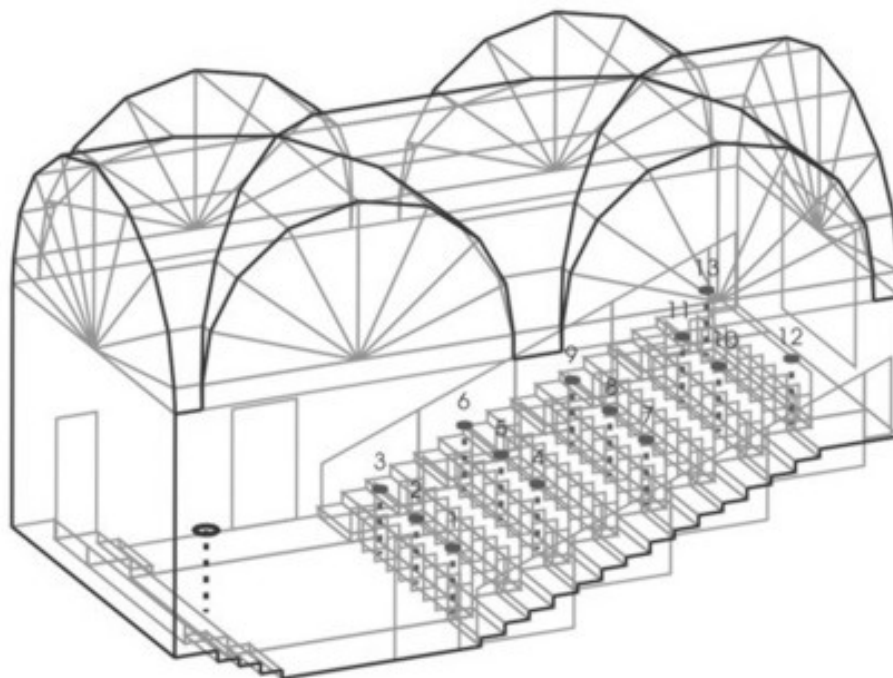


Fig. 3 – Concert hall model

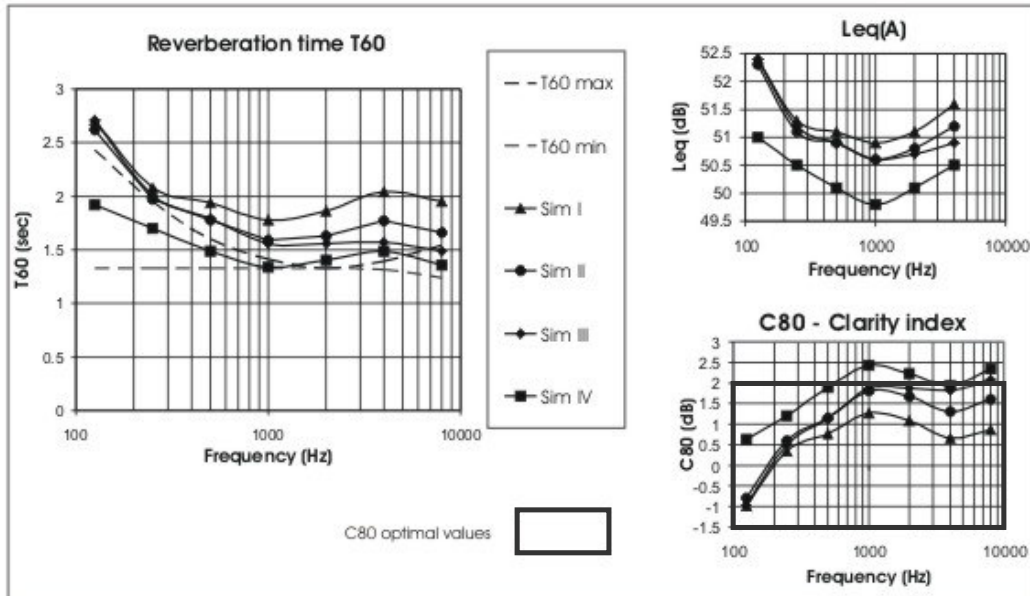


Fig. 4 – Concert hall - final situation: T_{60} , C_{80} , $Leq(A)$

CONFERENCE HALL CONFIGURATION

In the project the room could be used as a conference hall too, so the acoustic simulation was carried out also for a speech configuration. In this case, the optimal reverberation time was 0.8 s. The optimal values of the other acoustic indicators were higher than the concert hall configuration ones.

So, in order to obtain a good intelligibility, higher values of C_{80} and D_{50} were necessary; an acoustic diffusion system with very directional diffusers (60° horizontal width, 40° vertical width) was therefore introduced. The acoustic energy was concentrated in the first moments, so C_{80} and D_{50} values were better. Then the equalization by the *Ramsete View* block was realized. It doesn't influence T_{60} , C_{80} and D_{50} values, but it can improve the acoustic pressure level and RASTI values. The RASTI index values were in the range 0,45 – 0,75; so a good intelligibility was found.

The mapping of the values of RaSTI index into the conference hall shows an improvement when compared with the initial situation (Tab. 2): a mean value of 0.59 was found instead of 0.54 of the initial situation.

Finally, also for conference configuration, the auralization technique was used; it showed an intelligibility improvement.

Conference hall configuration: RaSTI

Listening points	1	2	3	4	5	6	7	8	9	10	11	12	13	Room
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Initial situation	0.58	0.57	0.57	0.54	0.53	0.54	0.54	0.52	0.52	0.52	0.52	0.53	0.54	0.54
Final situation	0.63	0.64	0.61	0.62	0.64	0.62	0.60	0.59	0.59	0.55	0.55	0.54	0.55	0.59

Quality class	Very bad	Low	Fair	Good	Very good
RaSTI	< 0.32	0.32 - 0.45	0.45 - 0.60	0.60 - 0.75	> 0.75

Tab. 2 – Conference hall configuration: RaSTI

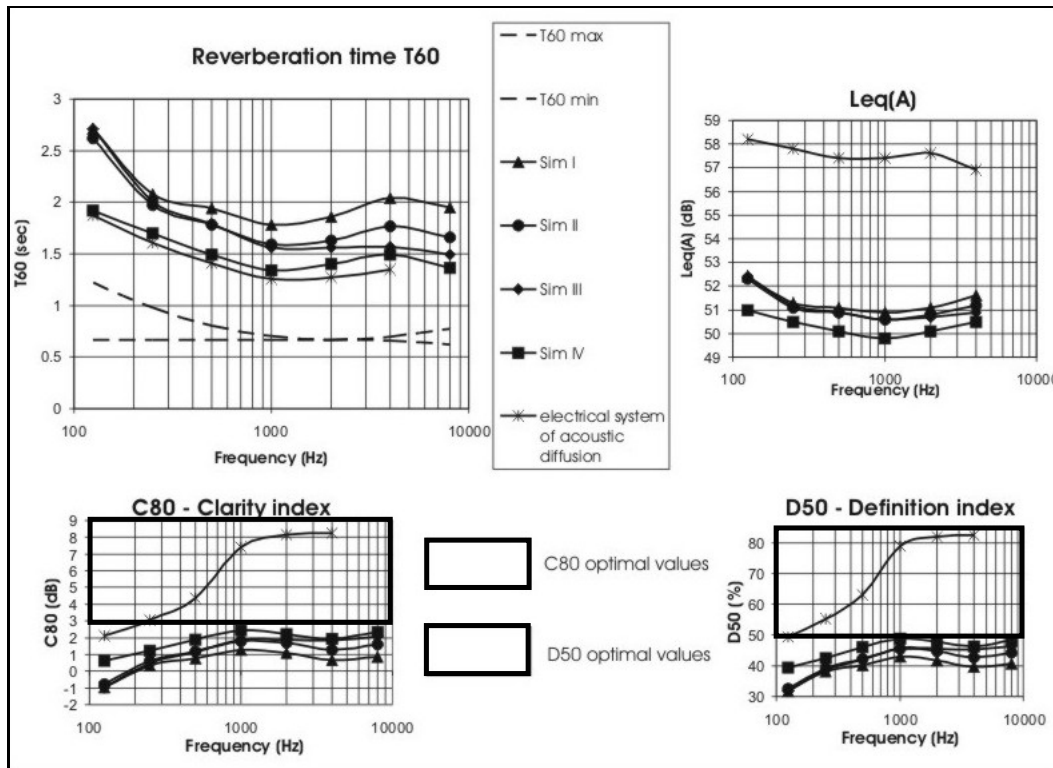


Fig. 5 – Conference hall configuration - final situation: T_{60} , $Leq(A)$, C_{80} , D_{50}

CONCLUSIONS

S. Tommaso ex-monastery is a XV Century building, used part as a school, part as a little museum and part as flats.

The church ceiling is constituted by two cross vaults, frescoed by an Andrea Pozzo's pupil, at the beginning of the XVIII Century.

The design of a little auditorium with tiers for people (64 seats) was studied, to give again visibility to the frescoes and to provide the school of a new great hall. Tiers let the direct sound to reach each listening position and give visibility to the frescoes.

The room acoustic quality was verified using RAMSETE, a simulation and forecast acoustic software, which allows the room modelling through plane surfaces with their acoustic absorption coefficients. An omni-directional source and 13 receiver points were located in the model and then the process was started to trace divergent pyramidal rays and providing different acoustic indicator values. Two different configurations were considered: concert hall and conference hall. The following parameters were calculated: reverberation time T_{60} , weighed A equivalent pressure level $L_{eq}(A)$, clarity index C_{80} , definition index D_{50} , STI/RASTI indexes.

The T_{60} values obtained by the first simulation, related to the initial configuration, were too much high. So sound absorbent materials and presence of people in the room were inserted in the model. The obtained values of the acoustic indicators were in the optimal ranges for the configuration Concert Room. In order to obtain a good intelligibility of the language, higher values of C_{80} and D_{50} were necessary; so an acoustic diffusion system with very directional diffusers was introduced.

Then, for both the configurations, the auralization technique was used. Results showed that, with the solutions proposed, a good acoustic quality of the room could be obtained, both for concert and conference hall.

REFERENCES

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