HOW DEMANDING IS GLOBAL APPROACH TO INDOOR ENVIRONMENTAL QUALITY ASSESSMENT?

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ABSTRACT

The indoor environmental quality of a building is intended as the thermal, visual, acoustic and indoor air quality performances as a whole, which provide health and comfort for occupants.
In architecture, global approach to environmental quality design is necessary. High levels of quality are needed for each aspect, even though design requirements may at times be opposed.
In order to determine opportunities and limits of global approach, problems related to visual and acoustic comfort assessment were examined for a baroque church in Italy. Visual and acoustical comfort parameters were obtained by means of experimental and numerical analyses.
As far as numerical analysis two demanding codes, RAMSETE and LIGHTSCAPE, were used for simulation.
The outcome of this work seems to indicate that global approach is still too demanding to be performed by a professional. The time required, software complexity, lack of simulation data, coupled with the high level of expertise necessary, are the limits for which the integrated environmental analysis comes to be applied only to research ambit.

KEYWORDS

visual comfort, acoustic comfort, indoor environmental quality, LIGHTSCAPE, RAMSETE, simulation

INTRODUCTION

In design bureaux professionals work together to develop an architectural concept from all possible points of view, but at the stage of architectural design the indoor environmental quality aspects are mostly neglected. The reasons for that are the lack of knowledge on comfort theories and predictive design methods, added to the complexity of many commercial calculation code necessary to compare different design choices.
For "indoor environmental quality" of a building is intended the thermal, visual, acoustic and indoor air quality performances as a whole, which provide health and comfort for occupants.
The final design goal is to maximise the environmental quality through appropriate design choices that take into account all the aspects in an integrated way.
"HyperComfort" design tool represents a first step in this direction (Filippi et al 2000). It is an informatic tool for designing and checking environmental comfort. It simulates environmental phenomena occurring in a room, calculates and graphically represents both spatial and temporal profile of comfort indices, in such a way as to integrate different comfort aspects. It is suitable for medium sized simple rooms for which simplified models can be adopted to simulate environmental phenomena. For large rooms like churches, theatres and auditoriums, these algorithms are not appropriate, and more complex calculation models must be applied.

In order to determine opportunities and limits of global approach in a large room, problems related to visual and acoustic comfort assessment were examined for a baroque church in Italy.
The evaluation of environmental comfort in existing buildings requires a preliminary phase, aimed at drawing specification on comfort goals, a field monitoring (experimental analysis) for comfort checking and, if necessary, a simulation phase (numerical analysis) for the comparison of different renovation interventions.

DESCRIPTION OF THE CASE STUDY

The case study is S. Michele parish church built in the 13th-century and restructured in the Baroque era. It preserves traces of the primitive Romanesque-Gothic structure (Figs. 1-2). It is a small church of approximately 24*15*10 m (3600 m^3) made up by three aisles and a line of chapels on the right hand side. All the church surfaces are bright ceiled, except the vaults presenting coloured frescos. Stone columns divide the aisles. The furniture, i.e. the chorus beside the altar, the benches in the broad aisle and the organ balcony at the back of the church, is dark wooden. Light comes into the church from wide coloured windows on the left hand side, while on the other side only fanlights are present. Luminaries with incandescent bulbs hang between the aisles and spots and projectors light up the altar and the ambo.

Figure 1: Picture of the church – Front view.

Figure 2: Picture of the church – Broad aisle.

ENVIRONMENTAL REQUIREMENTS

In this phase the environmental quality design goals are collected. The environmental requirements chosen for acoustic and visual comfort assessment are:

- reverberation time T_{30} for evaluating globally acoustical quality of the church;
- clarity C_{80} for evaluating musical quality;
- average maintained illuminance (E_m) for evaluating visual comfort in artificial light conditions;
- sun light penetration and daylight distribution.

As far as acoustic comfort is concerned the question of optimal reverberation time in a church depends on the character of the service, whether more emphasis is given to organ music and liturgical chants or to the sermon. In the first case longer reverberation times are to be preferred, but in the latter case the reverberation time should certainly not exceed 2 s (Kuttruff 2000). According to specific literature a typical values of optimum reverberation time for religious music in the frequency range 500 – 1000 Hz, for a church of 3600 m^3, is

approximately 2.5 s. In addition to an optimum reverberation time in the mid frequencies range, a longer reverberation time at the lower frequencies is highly desirable. This low-frequency reverberation gives fullness of tone to music and body to speech. This increase at 100 Hz can be 1.4 – 1.75 times the reverberation time at 500-1000 Hz (Magrab 1975).
Clarity C_{80} is the comfort parameters used to assess musical quality, while speech quality was neglected, assuming it can be controlled by using electro-acoustic devices. It is an early to late energy ratio for a 0.08 s early sound limit, obtained from measured or calculated impulse response for a given source – receiver pair (ISO 1997). It depends strongly on the location of the sound source and receiver. Optimal values for music are $-4 \leq C_{80} \leq 2$ dB.
As far as visual comfort the main reference is a document about new churches design edited by the Italian Episcopal Conference (C.E.I. 1993).
When the services are taking place higher illuminaces (obtained with daylight or artificial light) should be provided compared to the free prayer visit condition. Moreover a hierarchy is identifiable among the different parts of the church. The altar and the tabernacle should be always lit and the reference illuminance level for the service condition are respectively 300 and 500 lx. With reference to the free prayer visit condition 150 and 300 lx are required. The aisles should be darker so to help congregation meditation and to focus the attention where the action takes place (150 and 20 lx for the two conditions). In other parts of the church (e.g. ambo, baptism fount) light is important for some defined liturgical ceremonies.
As far as light colour, artificial sources with a warm correlated colour temperature should be employed (A.I.D.I. 1999).
Daylight should cover a double role: aesthetic and symbolic. Moreover its contribution should be optimised to the detriment of artificial light use.

EXPERIMENTAL ANALYSIS

An environmental monitoring took place in the church during the winter period of the year 2000, in a time gap in which the church was unoccupied. The aim of the experimental analyses was both to evaluate the existing conditions and to measure parameters useful for the simulation.
As far as acoustical analysis is concerned, reverberation time T_{30}, based on the –5 to –35 dB part of the sound decay, was measured with the interrupted noise method (ISO 1997) using an omni-directional sound power source with a pink noise test signal. Results for two source positions and some microphone positions, combined to give a spatial average value for the church as a whole, are showed in Figure 5.
Optimal conditions are reached at lower frequencies, while at medium-high frequencies measured values don't meet quality standards. Shorter reverberation times at high frequencies could be obtained by means of insertion of porous sound absorbing materials.
As far as lighting analysis is concerned, luminous transmittance and reflectance values and chromatic co-ordinates were measured in order to characterise church surfaces. Moreover daylight illuminances were collected on a rectangular grid inside the church (UNI 1994) and meantime global external illuminance was measured in order to calibrate daylight condition in the simulation.
Artificial illuminances were measured during the night period, turning on all the lamps and turning off urban light located closeness to the church.
In field analysis shows that daylight penetration is relevant due mostly to the wide windows in the left aisle and in artificial light conditions the hierarchy of the illuminances as above defined is identifiable, but artificial light contribution alone does not reach required levels. In fact, as example, altar zone is characterised by 40 lx instead of 300 lx required, and aisle by 18 lx instead of 150 lx.

NUMERICAL ANALYSIS

As far as numerical analysis, two demanding codes, which require a tri-dimensional CAD model as support for the calculation, were used for the simulation. For large environments, such as churches, auditoriums, theatres, etc., use of complex simulation codes is often mandatory because of irregularity of geometry and diverse physical characterisation of room surfaces.

Acoustic performances were investigated by means of RAMSETE, a code for the simulation of sound propagation in large rooms, based on the *Pyramid Tracing* algorithm (Farina 1995). LIGHTSCAPE (AA.VV. 1999) was used to investigate lighting performances. This is a code to simulate light propagation in indoor and outdoor spaces, based on the *Radiosity* algorithm.

The first step in a numerical simulation is the characterisation of room's geometry, surfaces and sources. The results of a calculation will depend on how these input data are approximated.

Concerning room's geometry, two CAD models were created according to the specifications of each code to optimise both accuracy and computational time (see Figures 3 and 4). Both the codes require a closed enclosure, free from warped, duplicated or overlapped planes.

The software systems need proper acoustical and luminous characterisation of surfaces and sources. About material, data can be obtained from literature and catalogues, but it is not always possible to find suitable values, and moreover only a few data of directional and diffusive properties of materials have been published until now. As a consequence a lot of experience is necessary to choose the correct values of these parameters. About source's power and directivity, data can be collect on catalogues or modelled on purpose within the software.

Another aspect to be considered is the calculation setting parameters (i. e. number of rays for acoustical simulation and surfaces subdivision for lighting simulation). The choice of all these parameters determines the computing time, so expertise is needed to optimize them and get good results in a limited time.

The first aim of the simulation phase of an existing building is the calibration of the model so to be able to compare the effectiveness of different renovation interventions. To that purpose acoustical and lighting features were modified in order to fit measured and simulated values.

Assuming this case study as a demonstrative one, once calibrated the model, no extra simulations were made aimed to evaluate any retrofit interventions.

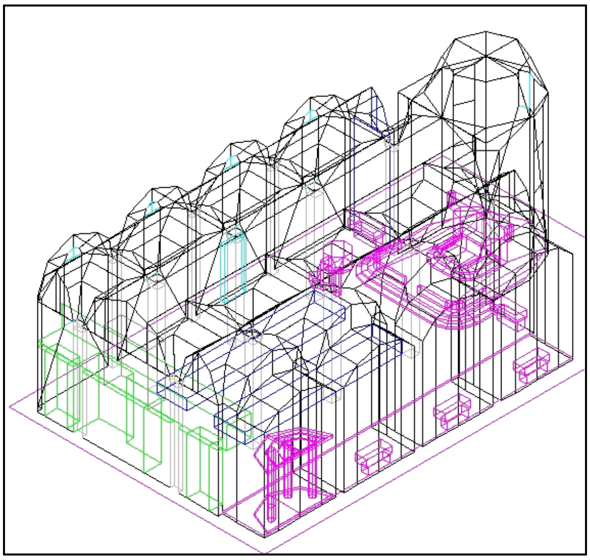

Figure 3: 3D model for acoustical simulation.

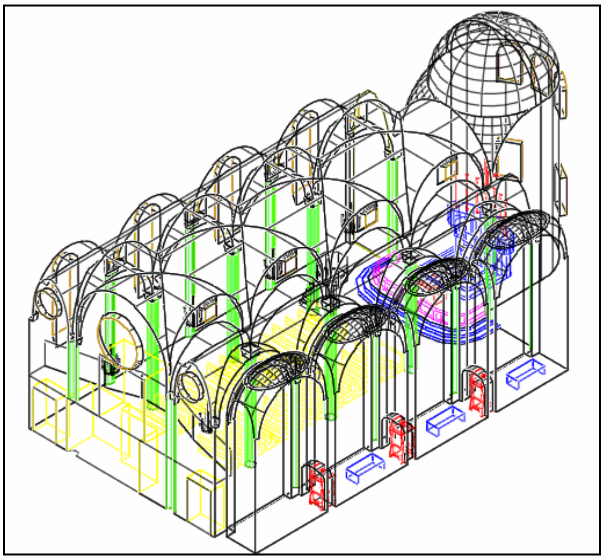

Figure 4: 3D model for lighting simulation.

Acoustical simulation

Concerning the geometrical aspects, modelling a lot of small surfaces to achieve high geometrical fidelity is likely to produce worst than better results. All surfaces are considered to be infinitely large in comparison to the wavelength, so to keep the calculated results accurate, they should be kept reasonably large. What is essential is mimic the character of the room's geometry.
Concerning the surface features, Ramsete takes into account both specular and diffuse reflections, but at first approximation, due to the lack of data, diffuse reflection can be neglected still obtaining good performances (Farina 2000).
As results, it calculates standard acoustical parameters according to ISO 3382 (1997) and creates colour maps of the selected quantities. The parameters cover acoustical aspects like reverberation, clarity of speech and musical quality.
In order to calibrate the model, absorption coefficients of surfaces were defined to fit the measured values of reverberation time. Reverberation time T_{30}, moreover, was the parameter used to evaluate reverberation (see environmental analysis).
With reference to the calibration, a good accordance between measured and calculated values was achieved (see Figure 5). Once calibrated the model, C_{80} values were calculated for musical quality assessment. As it is shown in figure 6 the optimal range is reached for the half part of the church close to the source, while at the back late reverberant energy is prevalent.

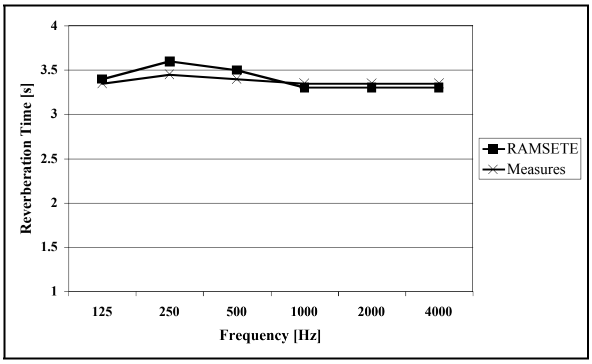

Figure 5: Measured and calculated reverberation time.

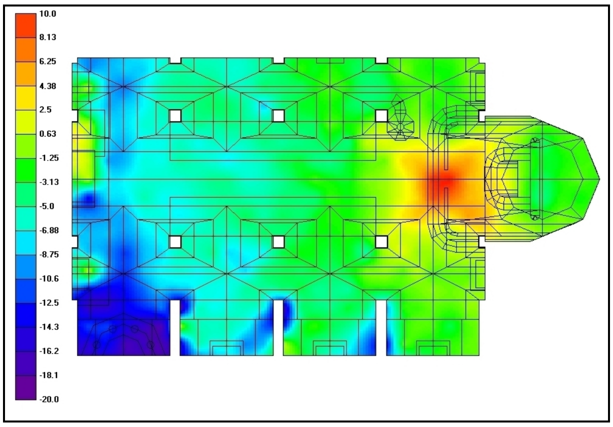

Figure 6: Spatial representation of C_{80}.

Lighting simulation

The simulations dealt with both daylight and artificial light conditions, that were one by one analysed (see Figs. 7-8) and then combined in order to obtain a more realistic situation.
Concerning the geometrical aspects, modelling small details becomes important in order to obtain a realistic rendering. Concerning the surface features, Lightscape takes into account diffuse reflections, and only in a second time specular reflections was considered to obtain realistic rendering.
The main problem in daylight simulation was to identify sky luminance pattern, as it was during measurements, and to identify and characterise the more significant outdoor obstructions. Lightscape allows to investigate daylight dynamics in order to project and emphasise its symbolic and aesthetic value.
As results, it calculates luminance and illuminance on surfaces and produces realistic luminous renderings. The illuminance for daylight condition fit measurements except where sun shines directly the surfaces. In artificial light conditions calculated values quite fit the experimental data, demonstrating how the ambient can appear sombre.

Figure 7: Daylighting simulation.

Figure 8: Artificial lighting simulation.

CONCLUSION

The outcome of this work seems to indicate that global approach is still too demanding to be performed by a professional. The limits are essentially:

- the need of in deep knowledge of environmental comfort theories, regarding comfort indices and measurement procedures;
- in order to obtain a global approach, the need to elaborate different models for different codes and to merge the results;
- the proper use of the complex calculation codes used to evaluate the different comfort aspects, that is strongly affected by user's skill;
- the lack of data needed to execute accurate simulation;
- the long computational time;

Furthermore, the instruments available for global comfort assessment come from different research ambits and are not yet correlated, so it is still hard for a professional to easily elaborate and represent data with an integrated approach. For instance the realisation of a single 3D geometrical model adaptable to different simulation requirements would be desirable. These problems should be faced and solved within the scientific community before the global approach could be applied in professional bureaux.

REFERENCES

AA.VV. (1999). Lightscape release 3.2 - User's guide, USA.

C.E.I. (Conferenza Episcopale Italiana) (1993). *Adeguamento delle chiese secondo la riforma liturgica*, Pastoral Note, Ufficio Liturgico Nazionale, Roma, Italy, February 18th.

A.I.D.I., Associazione Italiana d'Illuminazione. (1999). *Manuale di illuminotecnica*, Tecniche Nuove, Milano, Italy, chapter 4.8.

Farina, A. (1995). RAMSETE – A new Pyramid Tracer for medium and large scale acoustic problems. *Proceedings of Euro-Noise 95*, Lyon, France, March 21st – 23rd.

Farina, A. (2000). Validation of the numerical simulation of the scattered sound field with a geometrical pyramid tracing approach. *Proceedings of ACOUSTICS 2000 - IOA Conference*, Liverpool, U.K., April 17-18th.

Filippi, M., Corrado, V. and Astolfi, A. (2000). Checking of environmental comfort by means of an integrated informatic tool. *Proceedings of International Building Physics Conference*, Eidhoven, The Netherlands, September 18th – 21st.

http://www.lightscape.com

http://www.ramsete.com

ISO (1997). *Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters*, ISO 3382, International Organization for Standardization, Genève, Switzerland.

Kuttruff, H. (2000). *Room Acoustics*, Spon Press, London, U.K.

Magrab, E. B. (1975). *Environmental Noise Control*, John Wiley and Sons, Inc.USA.

Morbelli, G. (2001). Il Calcolatore quale supporto alla conoscenza ed alla valutazione. San Michele Arcangelo di Rivalta Bormida. Degree thesis, Politecnico di Torino, Facoltà di Architettura, Torino, Italy.

UNI (1994). *Illuminotecnica. Illuminazione d'interni con luce artificiale*, UNI 10380, Ente Nazionale Italiano di Unificazione, Milano, Italy.