

EXPLORING THE ROLE OF SIMULATION IN ROOM ACOUSTICAL RETROFIT OF OFFICE SPACES: A CASE STUDY

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ABSTRACT

This paper addresses the use of performance simulation within the framework of a case study pertaining to room acoustics. The target of the study is an existing office area. The study involved acoustical measurements and simulations, as well as interviews with the occupants before and after acoustical improvement measures. The results of the study contribute to the discussion concerning the effectiveness of acoustical simulation applications and the extent of necessary simulation calibration efforts in modeling the acoustical conditions in existing spaces and prediction of the implications of acoustical retrofit measures.

INTRODUCTION

The potential benefits of a simulation-aided approach to building design and retrofit have been widely discussed in the past (see, for example, Hensen and Lamberts 2011). The basic idea is to evaluate design intentions a priori using simulation, such that they can be improved and fine-tuned before realization. Currently, the potential of this simulation-aided design support strategy is not being fully exploited. The reasons are multi-faceted. Thereby, usability and reliability concerns with respect to performance simulation applications may play a role. Hence, it would be useful to collect, discuss, and evaluate actual experiences pertaining to the practical cases of simulation deployment in building design, retrofit, and operation.

In this context, the present contribution circles around the use of performance simulation within the framework of a case study pertaining to room acoustics. The target of the study is an office area within a university, consisting of closed and open spaces for different functions (workstations, seminar, service spaces). Certain indicators of the room acoustical performance of this office area were obtained based on both measurements and simulations. Subsequently, the simulation models were calibrated using the measurement results. The calibrated simulation models facilitated the prediction of the implication of acoustical retrofit measures. Upon the implementation of on such

measure (installation of acoustical absorbers), measurements and simulations were conducted again and the results were compared. Moreover, occupants' subjective evaluation of the acoustical conditions before and after the acoustical retrofit measures were explored as well using appropriate questionnaires.

The results of the case study are relevant in view of a number of questions: How effective are acoustical simulation applications in modeling the existing conditions? What are the likely sources of uncertainty in simulation? What is the extent of the calibration needed? Can a calibrated simulation model reliably predict the implications of retrofit measures? The results allow, in addition, the exploration of possible change in the occupants' subjective evaluations of the acoustical conditions as a consequence of the executed retrofit measures.

APPROACH

The study involved the following steps:

- i)* The existing spaces were documented in view of geometry and material properties. Figure 1 shows a schematic plan of the office area. The study focused on two areas, namely the seminar room (SR) and the open-plan office area (OP). Figures 2 and 3 show the existing conditions in these two areas.
- ii)* Basic acoustical measurements – pertaining to reverberation time and sound distribution – were conducted to capture the existing acoustical conditions.
- iii)* Occupants were interviewed with respect to their perception of the acoustical conditions.
- iv)* Office spaces were modeled in an advanced room acoustics simulation program (ODEON 2009). Note that a documentation of the acoustical room surface properties (absorption coefficients) did not exist. An in-situ measurement of such properties was also not possible. Thus, assumptions were made based on the surface material types (e.g., plaster, glass, wood) and available general absorption coefficient data in literature (e.g., Fasold and Veres 2003) and the simulation application's

database. A summary of these assumptions is given in Table 1.

- v) The simulation model was calibrated using the measurement data. The calibration was based on the comparison of the measured and simulated reverberation times and was realized in terms of virtual surfaces distributed in the office spaces.
- vi) Existing acoustical conditions were compared with applicable criteria.
- vii) Acoustical improvement measures – in this case, additional absorption – were conceived and modeled with the simulation tool. The additional absorption was introduced in the office spaces in terms of panels attached to and suspended from the ceilings, as well as suspended cubical elements. Tables 2 and 3 summarize the sound absorption properties of these elements.
- viii) The acoustical improvement measures were realized. Figures 4 and 5 show the added absorption elements in the course of the acoustical retrofit.
- ix) Post-retrofit measurements and simulations were performed and compared.
- x) Occupants were interviewed again in view of the modified acoustical conditions.
- xi) The results were processed, analyzed, and discussed.

RESULTS

As noted in the introduction and approach sections, the present research involved data collection pertaining to reverberation times and sound distribution in the office area as well as subjective evaluations by the office users before and after retrofit measures. For the purposes of the present paper, however, the presentation and discussion of result shall focus on the measured and simulated reverberation times in the seminar space (SR) and the open-plan office area (OP).

Figures 6 and 7 show, for SR and OP respectively, the measured values of the reverberation time together with corresponding non-calibrated simulation results. Note that the calibrated simulation results almost exactly match the measurements are thus not explicitly plotted in Figures 7 and 8.

As these results show, the existing reverberation times were found to be too long for both SR and OP. Hence, it was concluded that the addition of sound absorbing elements could reduce the reverberation times and improve the room acoustics in the office area. Toward this end, acoustical panels were considered for SR, and a combination of acoustical

panels and cubical elements for OP. A reverberation time of around 1.0 s was targeted for the SR (occupied setting). For OP, the targeted reverberation time was around 0.8 s.

Figures 8 and 9 show, for SR and OP respectively, the measured and simulated post-retrofit reverberation time values. To illustrate the effect of calibration, these Figures include both non-calibrated and calibrated simulation results. To consider the effect of occupancy in SR, Figure 10 includes calibrated simulation results for the reverberation time under non-occupied and occupied (20 people) conditions.

Table 1 Summary of assumptions pertaining to the existing sound absorption properties (α) of the office area surfaces (included are also the assumed absorption coefficients of the virtual absorbers deployed for model calibration)

ELEMENT	FREQUENCY [Hz]					
	125	250	500	1000	2000	4000
Floor (wood)	0.04	0.04	0.07	0.06	0.06	0.07
Ceiling (CO)	0.20	0.15	0.10	0.08	0.04	0.02
Ceiling (OP)	0.02	0.02	0.03	0.04	0.05	0.05
Ceiling (SR)	0.02	0.02	0.03	0.04	0.05	0.05
Ex. wall (Brick)	0.02	0.02	0.03	0.04	0.05	0.05
Int. wall- (Brick)	0.02	0.02	0.03	0.04	0.05	0.05
Int. wall (Gyps. boa.)	0.28	0.14	0.09	0.06	0.05	0.01
Window, door (Glass)	0.25	0.15	0.10	0.05	0.03	0.03
Win. frame (Wood)	0.04	0.04	0.05	0.06	0.06	0.06
Door (wood)	0.20	0.12	0.10	0.07	0.05	0.05
Chairs	0.11	0.35	0.53	0.63	0.64	0.57
Virtual absorb. (SR)	0.50	0.42	0.11	0.15	0.15	0.20
Virtual absorb. (OP)	0.68	0.57	0.24	0.31	0.31	0.32

Table 2 Sound absorption (α) of installed panels

ELEMENT	FREQUENCY [Hz]					
	125	250	500	1000	2000	4000
Panels	0.29	0.48	0.97	0.92	0.86	0.89

Table 3 Equivalent absorption area (in m^2) of one cubical element

ELEMENT	FREQUENCY [Hz]					
	125	250	500	1000	2000	4000
Cub. el.	0.60	1.40	1.80	1.80	2.10	1.70

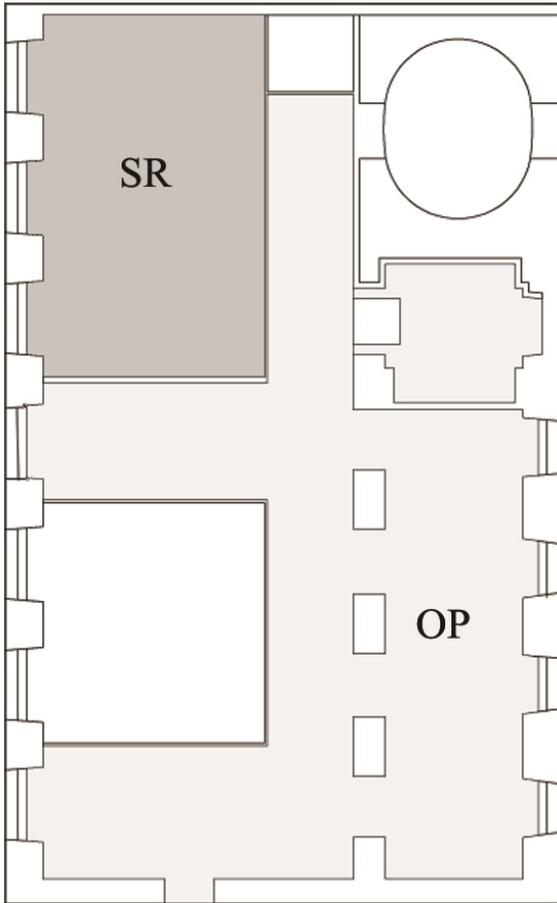


Figure 1 Schematic plan of the office area (SR: seminar room; OP: open-plan office area)



Figure 3 Existing conditions in OP



Figure 4 Added absorption elements in SR



Figure 2 Existing conditions in SR



Figure 5 Added absorption elements in OP

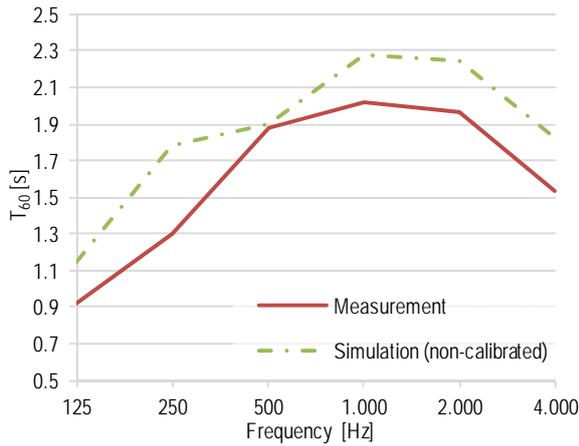


Figure 6 Measured and simulated (non-calibrated) reverberation times in SR (non-occupied)

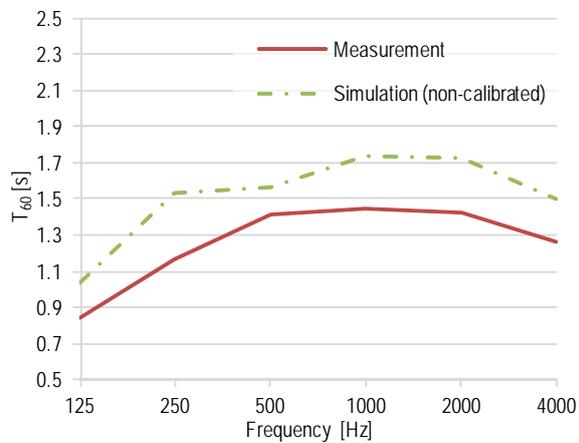


Figure 7 Measured and simulated (non-calibrated) reverberation times in OP (non-occupied)

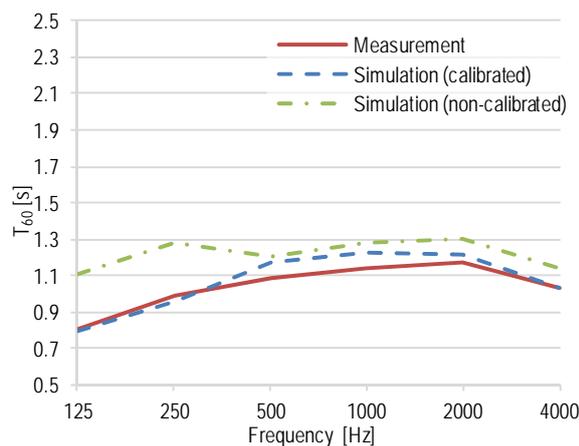


Figure 8 Measured and simulated (non-calibrated and calibrated) post-retrofit reverberation times in SR (non-occupied)

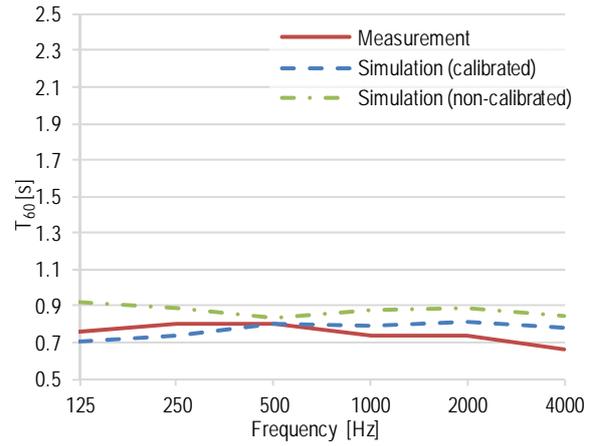


Figure 9 Measured and simulated (non-calibrated and calibrated) post-retrofit reverberation times in OP (non-occupied)

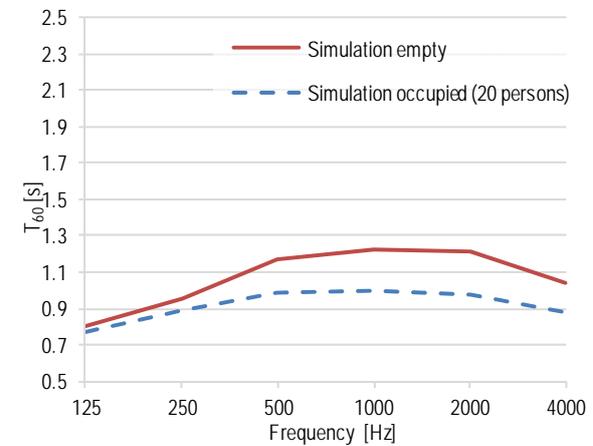


Figure 10 Simulated (calibrated) post-retrofit reverberation times in SR under non-occupied and occupied (20 people) conditions

DISCUSSION AND CONCLUSION

The above results warrant a number of observations and conclusions:

- Simulation results obtained via the non-calibrated simulation model display relatively large errors (see Figures 6 and 7). The errors are most likely due to the uncertainties associated with the assumptions pertaining to the sound absorption coefficients of the room surfaces. As mentioned earlier, a documentation of these coefficients for the existing conditions was not available. Nor was it possible to conduct an in-situ measurement of the absorption coefficients. Default assumptions (based on literature, experience, and simulation application's database) may have thus deviated from the "true" surface properties, leading to the aforementioned errors.

- The calibration process with the virtual absorption elements appears to be quite effective in the trivial sense that, after calibration, simulation results closely match the measurements.
- The calibration process may be also viewed to be effective in a non-trivial sense: There is a relatively good agreement between simulation-based predictions (based on the calibrated model) and measurement results for post-retrofit conditions. This inference is clearly supported by the comparison between the predictions of calibrated and non-calibrated simulation models for the post-retrofit conditions. Predictions based on the non-calibrated model show significantly higher errors than those obtained from the calibrated model (see Figures 8 and 9).

The case study presented suggests thus the calibration of acoustical simulation models of existing spaces via measurement results can provide an effective way to improve the reliability of the simulation-based assessment of the implications of acoustic retrofit measures in buildings. Specifically, measures necessary to achieve the targeted values of the acoustical performance indicator (in this case, the reverberation times) could be realized and tested virtually using the calibrated simulation model, and implemented subsequently in reality.

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