ACOUSTICS OF ATRIA: CONTRASTING MEASUREMENT AND MODELING RESULTS

Ardeshir Mahdavi, JinGuk Pak, Josef Lechleitner

Department of Building Physics and Building Ecology
Vienna University of Technology
Vienna, Austria

ABSTRACT

This paper includes the results of empirical measurements in and computational modeling of atria. Five atria with different designs were considered. In each atrium reverberation times and sound distribution patterns were obtained via measurements. Subsequently, the spaces were modeled in a room acoustic simulation application. The comparison of measurement and simulation results support the formulation of recommendations toward a more reliable use of modeling tools for proper acoustical design and analysis of atria.

KEYWORDS

room acoustics, atria, measurement, simulation

INTRODUCTION

Generously dimensioned entrance and transitional areas in general and atria solutions in particular have enjoyed persistent popularity in architecture. There is, however, a certain paucity in the scientific study of the acoustics of such spaces. Only recently more efforts have been made to systematically study the room acoustic features of atria (see, for example, Rosenheinrich and Kornadt 2005).

A number of reasons may be responsible for this circumstance. Atria refer to a class of spaces that are rather vaguely defined, as far as their use patterns are concerned. In many instances, a clear use pattern for such atria is not clearly established at the outset of the design stage. Thus, representational and aesthetic considerations typically guide the respective design solutions and not specific and stringent performance requirements. Moreover, most atria are inherently multi-purpose spaces, thus making it rather difficult to unambiguously specify such performance requirements.

The broad range of options in geometry and material selection represents an additional challenge. As compared to more typical spaces for acoustical performance (concert halls, theater spaces, movie theaters, etc.), there is, in the case of atria, less explicit design guidance and documented experience available. Simulation-based predictions of acoustical performance are in the case of atria especially plagued with uncertainties, not only due to geometry modeling problems, but also because of difficulties in correctly specifying relevant material properties.

To effectively address the above issues, acoustical analysis (measurements and simulation) of existing atria is essential. In this context, the present contribution presents the results of empirical measurements and computational modeling pertaining to atria (or atrium-like spaces) in five buildings in Vienna, Austria (three museum buildings, an educational building, and an office building). These five atria have very different shapes and surface finishes. They represent, thus, a wide variety of possible atria designs.

In each of these five atria, we measured reverberation times and sound level distribution patterns. Subsequently, we modeled these spaces with the aid of a computational tool for room acoustics simulation, using material input data (absorption coefficients) typically available to designers and consultants.

From measurement results, we expect to gain a general impression of the acoustical performance of different atria spaces. Specifically, we would like to examine the acoustical features of these spaces in the light of the kind of activities they are meant to support and accommodate. Moreover, the comparison of measurement and simulation results allows the evaluation of the reliability of acoustical simulation tools as applied to atrium spaces and to possibly formulate recommendations toward a more effective use of such simulation tools for acoustical design support purposes.

APPROACH

Five atrium spaces were selected in five buildings in Vienna, Austria (see figure 1 to 5). General information regarding these atria is provided in Table 1. Schematic plans are given in Figures 6 to 10. Prior to actual measurements of reverberation times and sound distribution patterns, background sound levels were recorded in all five selected atria. Reverberation times were measured in empty (non-occupied) conditions using at least two different loudspeaker positions and 8 microphone positions.

For sound level distribution measurements, one loudspeaker position and a grid of microphone positions were considered (see Figures 6 to 10 for loudspeaker and microphone positions for sound level distribution measurements). In all measurements, the loudspeaker was positioned 1.4 m above the floor. Microphones were located 1.2 m above the floor

The geometry of the atria was modeled in a CAD application (FormZ 2006) using, as the basis, the available architectural plans. The CAD models were exported to (and further augmented) in a commercially available room acoustical simulation and auralization tool (ODEON 2006). This tool provides different computational means for either simplified or detailed room acoustic simulations. For the purposes of the present research, the tool's detailed computational approach was employed, whereby responses from point sources are calculated using a hybrid calculation method: While the early reflections are computed using a combination of image source model and ray-tracing, the late reflections are calculated using a special ray-tracing process that generates secondary sources. These radiate energy localy from the surfaces of the walls. Further details on the algorithms applied in the simulation tool may be find in Christensen 2005.

The input data assumptions concerning the absorption coefficient data for surface finishes were based on various sources of information available (architectural documentation, plan documentation, literature, simulation tool's database). To compute the reverberation times and the sound level distribution, virtual loudspeakers were placed in the model in the same location as the real loudspeakers in the course of measurements. Likewise, the location of virtual microphone positions in the model matched those of the real microphones during the measurements. To model the sound source properly, the frequency-dependent sound power level of the loudspeaker used in the measurements was applied in the simulations (see Figure 11).

Figure 1 Atrium space in Albertina

Figure 2 Atrium space in Uniqa tower

Table 1: Summary of the selected atria, their volume, and their main use

ATRIUM (SYMBOL)	BUILDING	VOLUME [m^3]	ATRIUM FUNCTION (TYPICAL USE)	DEFAULT OCCUPANCY (NUMBER OF PEOPLE)
A	Albertina	3393	Presentations, corporation events	150
L	Leopoldmuseum	5060	Press conferences, presentations	300
U	Uniqa Tower	6325	Diverse events, cafe	700
W	Wien Museum Karlsplatz	6680	Diverse events, cafe	150
G	Gregor Mendel Institute	3642	Lobby and discussion space for students	35

Figure 3 Atrium space of Leopoldmuseum

Figure 4 Atrium space of Wienmuseum Karlsplatz

Figure 5 Winter garden in Gregor Mendel Institute

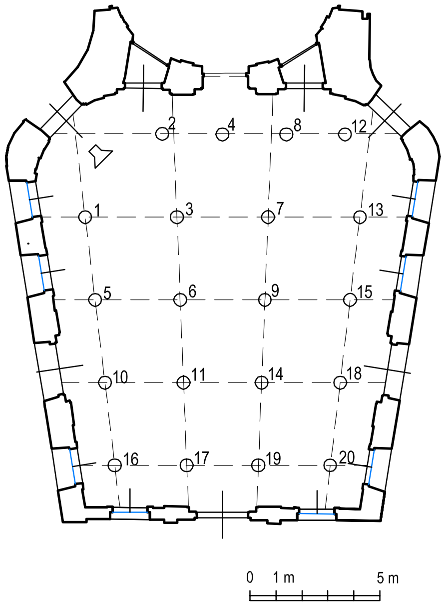

Figure 6 Albertina atrium

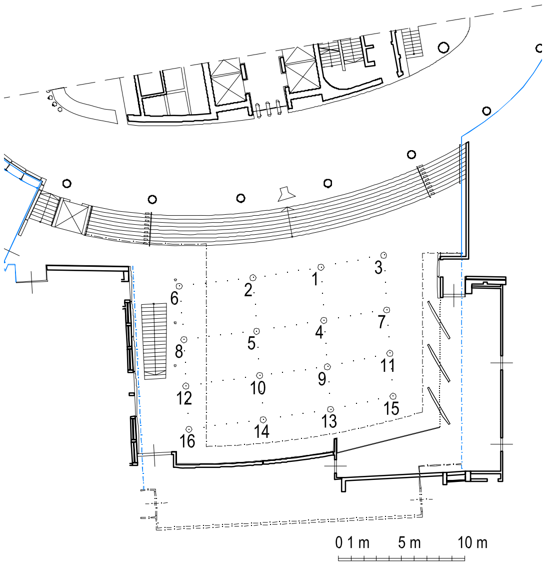

Figure 7 Uniqa Tower atrium

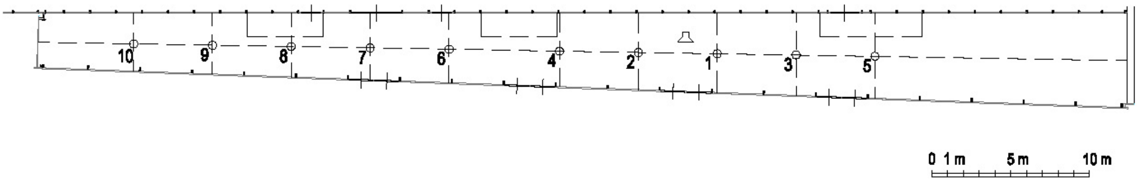

Figure 8 Winter garden in Gregor Mendel Institute

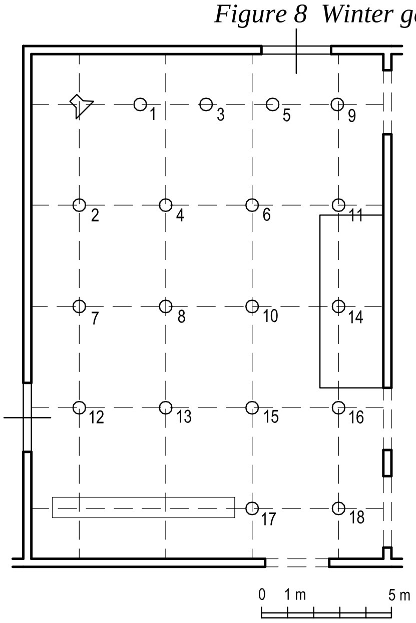

Figure 9 Leopoldmuseum atrium

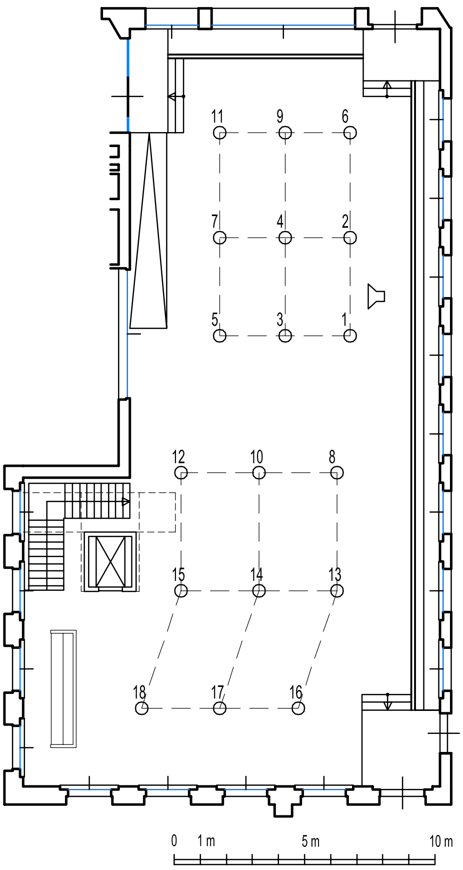

Figure 10 Wienmuseum Karlsplatz

RESULTS

Figure 12 includes the results of the background sound level measurements. These rather high levels are primarily due to *i)* sound transmission from the external environment (particularly in cases where a part of the atrium's enclosure is also a part of the building's envelope); and *ii)* actvities in the atria itself, which, in some cases, act as entrance and circulation spaces.

Figures 13 to 17 depict the frequency-dependent (octave-band) measured and simulated reverberation times (T_{60}) for each atrium in the unoccupied state as well as the simulated reverberation times for a default occupancy scenario (see also the last column of Table 1). Figure 18 illustrates the measured reverberation times in all five atria.

Figures 19 to 23 illustrate the results of sound level measurements (under unoccupied conditions) and the corresponding simulations. The *x*-axis in these Figures marks the microphone positions ordered in accordance to their respective distance from the loudspeaker. Thereby, the numbers correspond to the numbers included in Figures 6 to 10.

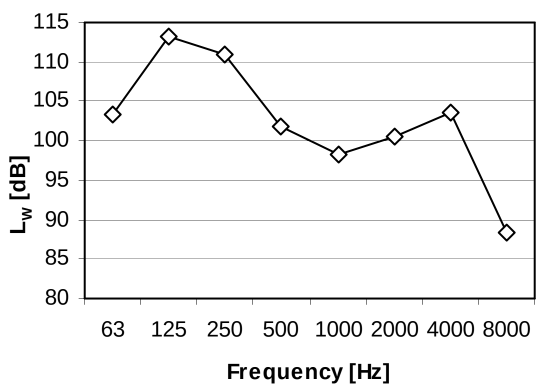

Figure 11 Measured sound power level of sound source used in measurements

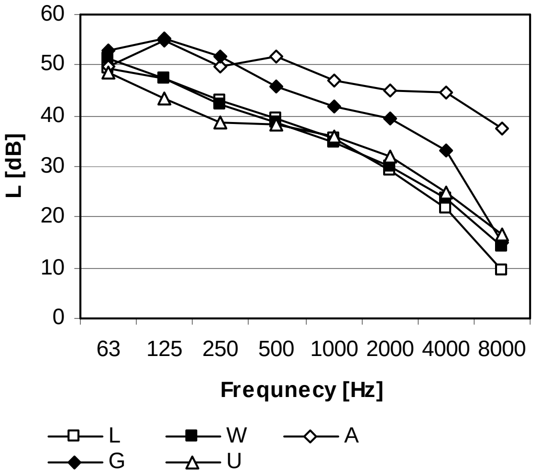

Figure 12 Measured background sound levels in all five atria

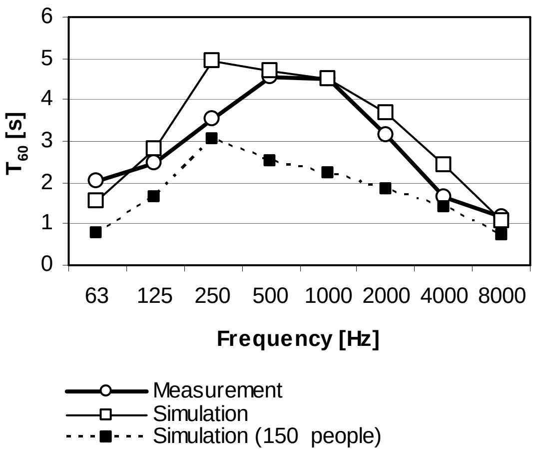

Figure 13 Reverberation times, Albertina

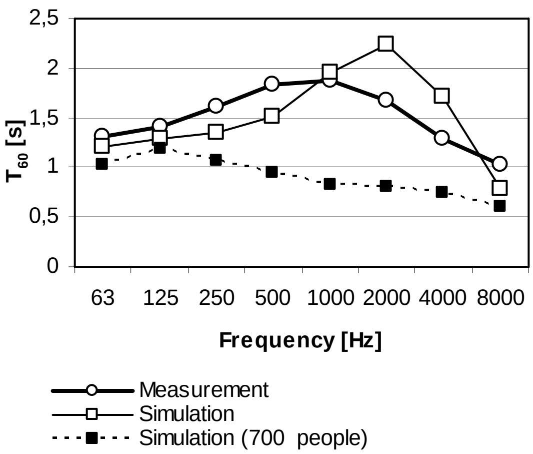

Figure 14 Reverberation times, Uniqa T.

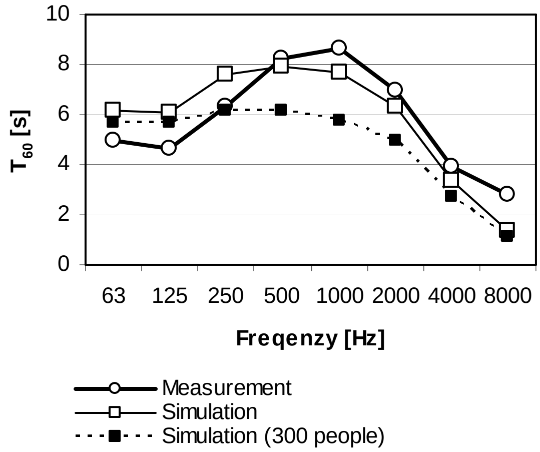

Figure 15 Reverberation times, Leopoldmuseum

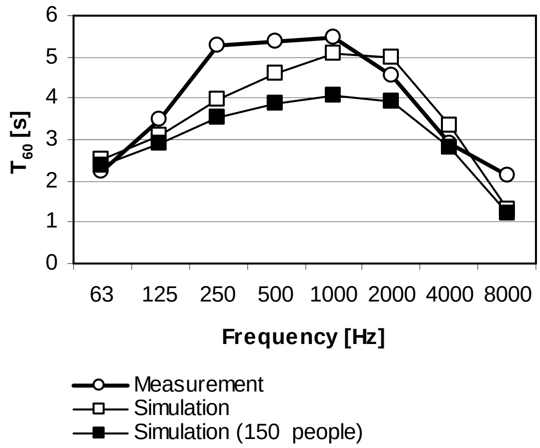

Figure 16 Reverberation times in Wienmuseum Karlsplatz

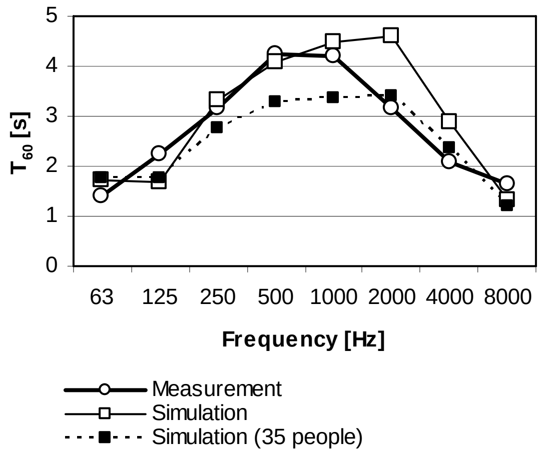

Figure 17 Reverberation times, G. M. I.

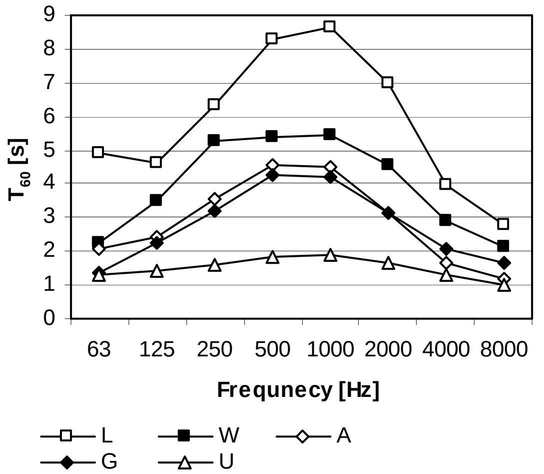

Figure 18 Measured reverberation times in all five atria

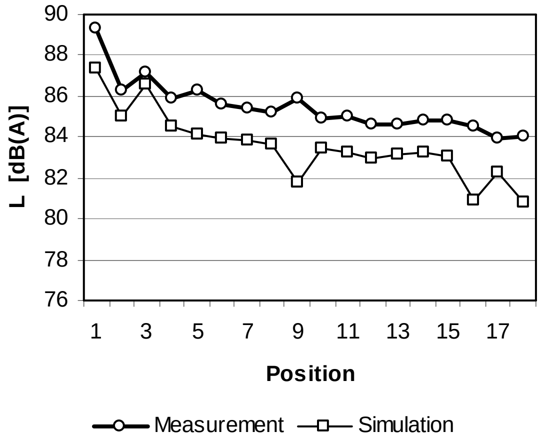

Figure 21 Measured and simulated sound pressure level, Leopoldmuseum

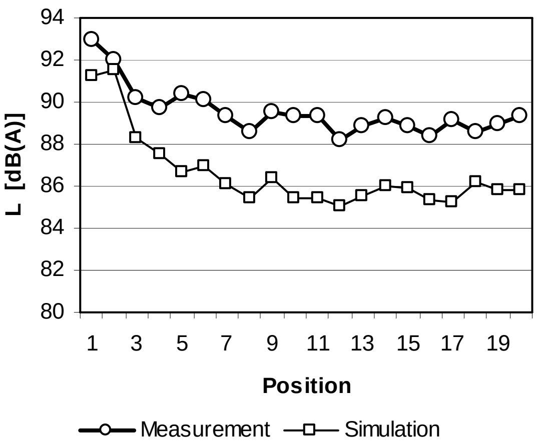

Figure 19 Measured and simulated sound pressure level in various points in Albertina

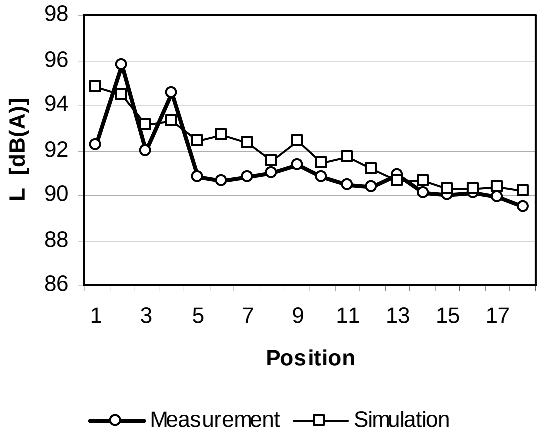

Figure 22 Measured and simulated sound pressure level in various points in Wienmuseum Karlsplatz

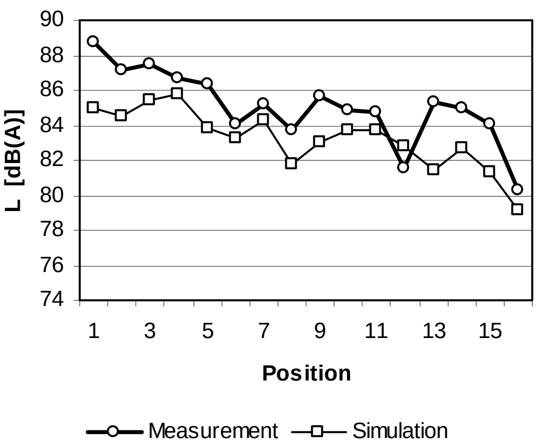

Figure 20 Measured and simulated sound pressure levels, Uniqa Tower

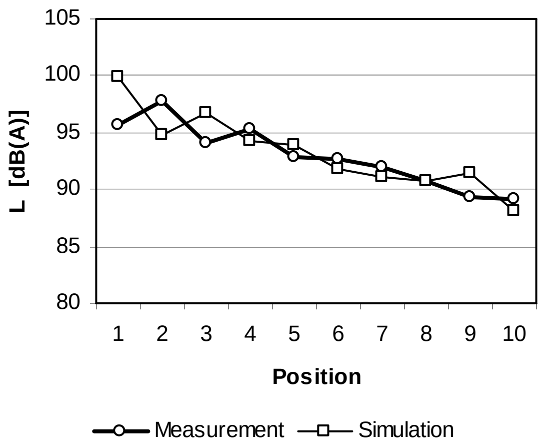

Figure 23 Measured and simulated sound pressure levels, Gregor Mendel Institute

DISCUSSION

The measured reverberation times as depicted in Figures 13 to 17 and as summarized in Figure 18 show considerable variance. As Table 2 demonstrates, these values are, with the exception of Uniqa Tower atrium, rather long, and remain so, even in the occupied state. The relatively large volumes of atria studied, together with their predominantly hard surfaces (particularly glazing) are responsible for the all too long reverberation times in these spaces. Designers must pay more attention to surface treatment specification, so as to achieve the desired architectural characteristics (including aesthetic effects associated with transparent, smooth, and clean surfaces) without compromising the acoustic quality.

As Figures 13 to 17 and 19 to 23 as well as Table 2 show, there is a good agreement between measurements and simulations.

In case of reverberation times, the simulation errors occur in different frequency ranges in the five atrium instances and are primarily the result of inaccuracies in modeling the material properties. In most cases, the architectural documentation included neither absorption coefficient values nor information that would help finding such values. Thus, the absorptioncoefficients had to be frequently determined based on values included in general literature.

A major shortcoming in available material information concerns the glazed surfaces. Neither general information in literature, nor manufacturers' specifications sufficiently cover the wide variance in glazing solutions (number and type of layers, influence of element size and frames). Thus, the specification of the acoustical reflection due to glazed surfaces involves a high degree of uncertainty. In this context, more comprehensive information needs to be obtained for the large variety of glazing products applied in contemporary architecture.

Concerning sound level distribution in atria, the corresponding patterns are fairly well predicted by the simulation (see Figures 19 to 23). However, the absolute values of measurement-simulation deviations are somewhat too large in some cases (particularly in case of Albertina atrium and – to a lesser extent – in case of Leopoldmuseum and Uniqa Tower). Errors in material properties assumptions, might have also contributed to these deviations. In case of Albertina, there might have been another specific source of error, namely a temporary artistic installation (a large inflated object floating in the space as visible in Figure 1, which could not be properly captured in the simulation model).

Table 2 Mean reverberation times in seconds (averaged over 125, 500, and 2000 Hz) as measured (unoccupied), simulated (empty and occupied), and recommended (Fasold and Veres 2003)

ATRIUM	A	L	U	W	G
Measured, empty	3,39	6,61	1,65	4,46	3,22
Simulated, empty	3,74	6,71	1,69	4,21	3,46
Simulated, occupied	2,0	5,59	0,98	3,56	2,51
Recommended	1,3	1,4	1,4	1,4	1,2

CONCLUSION

The main findings of the present contribution are as follows:

i) The design of atrium-like spaces appears not to address acoustical requirements explicitly but is frequently guided by representational considerations;

ii) The acoustics of the atria generally do not support the way the spaces are used. With one exception (Uniqa Tower), the reverberation times in the atria we studied are too long;

iii) Acoustical properties of building elements are seldom specified in the architectural documentations;

iv) Despite difficulties in accurately determining the absorption coefficients of surfaces, it was possible to reasonably predict both reverberation times and sound level distribution. The average relative error (and standard deviation) in prediction of reverberation times (integrated over all frequencies and atria) was 2 % (±23 %). The average deviation of measured and simulated sound pressure levels integrated over all points and atria amounted to -1,3 dB (±1,8 dB);

v) To support the design of the acoustical properties of atria, it is important that performance requirements are specified early in design addressing the use patterns expected. Moreover, architectural documentation of buildings in general and atria in particular must include detailed information on the acoustical properties of materials and components applied;

vi) A more comprehensive empirically obtained database of acoustical properties of architectural elements is necessary. Such a database could be incorporated in acoustical simulation tools in order to expedite the simulation and analysis process and thus make it more effective toward design support.

Furture acoustical studies should include an extended number of atria as well as a more comprehensive set of room acoustic quality indicators. Moreover, collaborative efforts involving architects, building performance experts, manufacturers, and software developers are needed to improve and substantiate the acoustical property databases currently embedded in simulation applications for architectural acoustics.

REFERENCES

Christensen, C. L. 2005. ODEON Room Acoustics Program. Version 8.0. User manual. Industrial, Auditorium and Combined Editions.

Fasold W., Veres E. 2003. Schallschutz und Raumakustik in der Praxis. HUSS-MEDIEN GmbH Berlin, Verlag Bauwesen. ISBN 3-345-00801-7.

FormZ 2006. http://www.formz.com.

ODEON 2006. http://www.odeon.dk.

Rosenheinrich H., Kornadt O. 2005. Die Raumakustik in Atrien. Bauphysik 27 (2005) Heft 3. Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Berlin. pp. 145 – 1