

Book Review

Room Acoustics. Sixth edition. Heinrich Kuttruff. CRC Press, Taylor & Francis Group, Boca Raton, London, New York, 2017. ISBN -13: 978-1-4822-6043-4.

Professor Kuttruff's book on room acoustics appeared in the first edition in 1973, and since then it has been a true classic reference for the study of room acoustics. When I wanted to establish a new advanced course on architectural acoustics at the Technical University of Denmark in 1979, it was an obvious choice to use Kuttruff's book for the room acoustical part of the course. The book addresses students and researchers as well as practitioners, who want to understand the mathematical foundation of room acoustics. However, that does not mean that this is a very theoretical book; there are not many equations and only few derivations of formulae. Instead, the mathematical and physical principles are explained and discussed in a way that is easy to follow and understand for the reader with some basic knowledge of acoustics.

The book is divided into ten chapters, like the first edition, but a wealth of new stuff has been added, mainly due to new findings, methods and applications that have appeared over the years. The first chapter '*Some facts on sound waves, sources and hearing*' presents a basis for the following chapters. What I find particularly well in this chapter is the introduction of the Fourier transform, FFT, convolution, cross-correlation, and the transfer function.

Chapters 2 and 3 are entitled '*Reflection and scattering*' and '*Sound waves in a room*', respectively. The fundamental relation between wall impedance and absorption coefficient and the angle dependent absorption of a locally reacting surface are presented. A new section in this edition covers the reflection of spherical waves. The reflection from finite-sized surfaces is explained in terms of Fresnel zones for the special case of a circular surface. However, other shapes like rectangular reflectors are not dealt with, and neither are reflector arrays, although they are often an important part of the acoustical design in auditoria. The section on scattering from irregular surfaces gives a brief introduction to the principles behind periodic and pseudo-stochastic diffusers, and in particular the quadratic residue diffuser. Another new section explains the principle of the '*Finite Element Method*'. The description of the steady state sound field in a room is excellent, and some interesting analogies between the frequency domain and the spatial domain are displayed. I should like to emphasize the elegant explanation of the non-linear decay curves in a room with different damping constants of the modes.

'*Geometrical room acoustics*' is the title of Chapter 4. Among many other things, it explains the Lambert's cosine law for diffuse reflections and discusses the diffusion equation. The next chapter is entitled '*Reverberation and steady-state energy balance*' and at the end of this is a section on the radiosity integral

and its application for analysing the influence of imperfect diffuseness. In Chapter 6 we come to '*Sound absorption and sound absorbers*' and again, this is a very clear and thorough exposition.

In Chapter 7 the difficult topic of '*Subjective room acoustics*' is dealt with. Audibility of single and multiple reflections, the '*Haas effect*' and colouration due to a comb filter are explained. Next follows room acoustical parameters related to clarity and the '*speech transmission index*' STI. The '*rapid speech transmission index*' RASTI is also introduced, although this could have been left out since it is today considered obsolete. Parameters related to spaciousness include both groups of '*apparent source width*' and '*listener envelopment*'. A long section discusses the assessment of concert hall acoustics, and this includes the results from interesting and very recent references. The important use of factor analysis is demonstrated as a means to analyse the correlation between groups of objective and subjective parameters. Finally, and in order to make the discussion complete (as the author says), the ideas of Ando and his suggested four parameters are explained, namely in addition to the reverberation time and the sound pressure level, the more controversial '*initial time delay gap*' and '*interaural cross correlation*' IACC. These four parameters are combined into Ando's '*total subjective preference*' by using some weighting factors. However, the section concludes that the various investigations '*do not combine to form a well-rounded picture of subjective concert hall acoustics*'. Instead, the author expresses the hope that the auralisation techniques will '*help acoustical designers to create concert halls with satisfactory or even excellent listening conditions*'.

Chapter 8 is entitled '*Measuring techniques in room acoustics*'. A little unusual is the definition of the 1/3 octave band filter as covering the frequency interval of 5/4, which is the pure major third in music and in fact a good approximation to the exact definition (a tenth of a decade). After descriptions of loudspeakers and microphones for room acoustical measurements, the principle of measuring the impulse response is explained with emphasis on the techniques using '*maximum length sequences*' (MLS) and sine sweep. Next follows some room acoustic parameters that can be derived from the impulse response, including the echo-criterion by Dietsch and Kraak. The autocorrelation function and its use for detecting colouration is also described. There is an interesting section on directional distribution and diffuseness of a sound field, including descriptions of various measurement devices for this special purpose. The last parts of this chapter deal with measurement of the absorption coefficient of materials and the scattering coefficient of surface structures. The '*Waterhouse effect*' and the related correction factor accounts for the total energy in a room relative to that measured in the central zone. It was originally derived for α , and is usually applied to the measurement of sound power of a source in a room. However, here the '*Waterhouse effect*' appears in a new and unusual connection, namely in the case when a sound absorbing test material covers the entire wall of a reverberation chamber.

Chapter 9 is entitled '*Design considerations and design procedures*' and the contents include prediction of noise level in rooms, handling the direct sound in auditoria, importance of room shape, and design of

appropriate reverberation time. Coupled volumes are dealt with, but here I must admit that I miss the very clear exposition in the first edition of the book; that explained both possibilities of the early decay to be either steeper than the late decay, or starting with a horizontal tangent. In the present edition, only the former case is presented. Today it is generally agreed that good concert halls are either of the shoebox type or of the vineyard type, and the archetypical examples being presented are the Boston Symphony Hall from 1900 (not 1895, one of very few misprints) and the Berlin Philharmony from 1963. The first hall had Wallace C. Sabine as acoustical consultant and was the very first case of using the reverberation time in the design of a new concert hall. The second hall in Berlin was the result of a successful cooperation between a visionary architect and an exceptional acoustician, Lothar Cremer. After this, the use of scale models and the basic principles of computer simulations are presented. The chapter ends with an introduction to auralisation and virtual reality.

The final Chapter 10 deals with '*Electro-acoustical systems in rooms*'. Electrodynamic loudspeakers, horn loudspeakers and line arrays are explained with emphasis on the directivity and the directional factor. Simple approximations are presented for the half-power width of the main lobe in degrees. The required power of loudspeakers in a hall is discussed, and it is explained very clearly, why the low frequencies are often a problem with sound reinforcement systems in a large hall. The section on acoustical feedback is particularly well written with nice illustrations to explain the critical threshold for stability of the system. As a natural continuation follows a derivation of equations for the increase of reverberation due to acoustical feedback. The final two sections are devoted to reverberation enhancement, either with external reverberators or with controlled feedback. Some of the advanced, newer systems like the use of wave front synthesis are explained. In general, the various methods are presented with reference to early, original papers, and the examples of halls with such systems are some of the very first known cases. In a textbook like this, I find it important and very correct to credit the origins of the ideas and the first applications, such as the '*assisted resonance*' that was invented for -, and installed 1964 in the Royal Festival Hall.

The fact that Kuttruff's book '*Room Acoustics*' has appeared in the sixth edition is a clear proof that this a book with many readers and that it is being used. It is an unavoidable reference for any serious work in the field of room acoustics. We, the readers, can only appreciate that it is still being improved and brought up-to-date.

Jens Holger Rindel

Odeon A/S, Scion-DTU, Denmark,

Former professor at the Technical University of Denmark,

E-mail address: jhr@odeon.dk