

Table of Contents

1	Introduction	1
1.1	Defining the scope of this work	4
2	Fundamentals and previous work	5
2.1	Theoretical principles behind spatial fluctuations	5
2.1.1	Amplitude distribution due to changes in position	5
2.1.2	The impulse response and other room acoustical quantities	10
2.1.3	Variance of the reverberation time over space	13
2.1.4	Reference to the research question	14
2.2	Acoustical measurements in auditoria	15
2.2.1	Principles and established practice	15
2.2.2	Measurement uncertainty in architectural acoustics	18
2.2.3	Observations in other fields of acoustics	21
2.3	Uncertainties in measurements	23
2.3.1	General metrological terms	23
2.3.2	The guide to the expression of uncertainty in measurement	24
2.4	The perception of sound in auditoria	33
3	General Methodology	37
4	Uncertainty of room impulse response measurements	41
4.1	Introduction	41
4.2	Uncertainty budget for room impulse response measurements	42
4.3	Discussion	45
4.4	Conclusions	45

5	Design of a measurement array	47
5.1	Introduction	47
5.2	Methodology	48
5.2.1	Requirements for the measurement setup	48
5.2.2	Design of a measurement device	52
5.2.3	Acoustical measurements	53
5.2.4	Data analysis	56
5.3	Results	57
5.3.1	Visualization of sound fields	57
5.3.2	Data for the uncertainty discussions	60
5.4	Discussion	60
5.5	Conclusions	62
6	Uncertain input quantities of the measurement function	65
6.1	Introduction	65
6.2	Uncertainty of room acoustical quantities	66
6.2.1	Methodology	66
6.2.2	Results	74
6.3	Uncertainty of the sampling location	82
6.3.1	Introduction	82
6.3.2	Initial methodology	84
6.3.3	Results	87
6.3.4	Revised methodology	88
6.3.5	Results	88
6.4	Discussion	90
6.5	Conclusions	91
7	Measurement function	93
7.1	Introduction	93
7.2	Establishing the measurement function	94
7.2.1	Methodology	94
7.2.2	Results and discussion	99
7.3	Compensating the effect of a finite sampling area	103
7.3.1	Methodology	103
7.3.2	Results and discussion	104
7.4	Reducing the complexity	106
7.4.1	Methodology	106
7.4.2	Results	107
7.5	Discussion	108
7.6	Conclusions	110

8	Validity of the measurement function	111
8.1	Introduction	111
8.2	Methodology	111
8.2.1	Repeatability	112
8.2.2	Reproducibility	112
8.3	Results	117
8.3.1	Repeatability	119
8.3.2	Reproducibility	121
8.4	Discussion	139
8.5	Conclusions	141
9	How accurately must a measurement position be defined?	143
9.1	Introduction	143
9.2	Methodology	144
9.2.1	Establishing the input quantity distribution	145
9.2.2	Implementing the measurement function	147
9.2.3	Determining the measurement uncertainty using Monte Carlo simulations	148
9.3	Results	150
9.3.1	Uncertainty of room acoustical quantities	151
9.3.2	Effect of the auditorium's reverberation	156
9.3.3	Effect of the evaluation interval (time)	159
9.3.4	Effect of the center frequency	162
9.3.5	Effect of the bandwidth	164
9.4	Discussion	166
9.4.1	Uncertainty of broadband measurements	166
9.4.2	Reference to theory	168
9.4.3	Appropriateness of regression models	173
9.4.4	Influence of early reflections	174
9.4.5	Necessity for measurements	175
9.5	Conclusions	175
10	General results	179
10.1	Uncertainty of measured impulse responses	179
10.2	Uncertainty of room acoustical quantities	180
10.3	Uncertainty due to spatial fluctuations	181
11	General Discussion	187
11.1	Uncertainty of measured impulse responses	188
11.2	Uncertainty of room acoustical quantities	189

11.3 Uncertainty due to spatial fluctuations	190
11.4 Critical aspects	191
11.5 Implications	192
12 General conclusions and outlook	195
12.1 General conclusions	195
12.2 Outlook	196
13 Acknowledgements	199
Bibliography	201
A Detailed discussion of uncertainties in room impulse response measurements	215
A.1 Introduction	215
A.2 Formulation stage	215
A.2.1 The output quantity	215
A.2.2 The input quantities	216
A.2.3 The measurement model	219
A.3 Results - Calculation stage	260
A.4 Discussion	263
A.5 Conclusions	265
B Influence of the measurement apparatus on the sound field	267
B.1 Introduction	267
B.2 Analytical approach	268
B.2.1 Methodology	268
B.2.2 Results	270
B.3 Empirical approaches	275
B.3.1 Methodology	275
B.3.2 Results	277
B.4 Discussion	279
B.5 Conclusions	281
C Uncertainty propagation for room acoustical quantities	283
C.1 Energy decay curve	283
C.2 Reverberation times	285
C.3 Clarity	289